University Transportation Research Center - Region 2

Final Report

Evaluation of Public-Private Partnership Contract Types for Roadway Construction, Maintenance, and Rehabilitation

Performing Organization: State University of New York (SUNY)

December 2015

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

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16. Abstract

Public-private partnerships (PPPs) in transportation infrastructure projects refer to contractual agreements formed between a public Agency and a private sector entity to allow for greater private sector participation in project delivery. At the current time, most Agencies do not have a set of straightforward guidelines by which they decide whether to adopt PPP for a given project, and if to adopt one, which type of PPP should be adopted. Before such a decision can be made in an informed manner, the Agency needs to develop and implement a PPP evaluation and decision-support framework that will incorporate the PPP costs and benefits. Such costs and benefits can include the Agency costs and user costs occurred at the time of the project as well as the risk costs borne by the Agency. This study develops a PPP evaluation and decision support framework, supported by an Excel-Based Expert System, which Roadway Agencies can use to decide whether to adopt a PPP
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TECHNICAL SUMMARY

UTRC Project No 49997-42-25 Final report, December 31, 2015

EVALUATION OF PUBLIC-PRIVATE PARTNERSHIP CONTRACT TYPES FOR ROADWAY CONSTRUCTION, MAINTENANCE, AND REHABILITATION

Introduction

Public-private partnerships (PPPs) in transportation infrastructure projects refer to contractual agreements formed between a public Agency and a private sector entity to allow for greater private sector participation in project delivery. At the current time, most Agencies do not have a set of straightforward guidelines by which they decide whether to adopt PPP for a given project, and if to adopt one, which type of PPP should be adopted. Before such a decision can be made in an informed manner, the Agency needs to develop and implement a PPP evaluation and decision-support framework that will incorporate the PPP costs and benefits. Such costs and benefits can include the Agency costs and user costs occurred at the time of the project as well as the risk costs borne by the Agency. This study develops a PPP evaluation and decision support framework, supported by an Excel-Based Expert System, which Roadway Agencies can use to decide whether to adopt a PPP for a given project, and if affirmative, what type of PPP to adopt, such that there is maximum benefit to the Agency.

Findings

In this study several statistical models were estimated for various measures of effectiveness (cost savings, cost overrun, time delays, change orders, asset condition, safety, and operations) by PPP contract type (performance based contracting, incentives/disincentives, lane rentals, warranties, design-build and its derivatives, cost-plus-time, and traditional contracting), and by geographical regions (at the continent, region, country, and US-state levels). These models provided an appropriate context for developing an Excel-based expert system which can be useful for Agencies to select the most beneficial contracting approach for a certain transportation project. The results illustrate that, in cases of the tight schedules and complicated designs, PPP contracting has advantages over traditional contracting approaches. On the basis of the selected evaluation criterion, the best contracting approach that is identified for a given set of project characteristics is found to be heavily influenced by certain project attributes, such as project cost, size, types of constituent activities, and expected duration.

Study Implementation

The study product can be used by highway agency asset managers as a decision-support tool to identify whether to adopt a PPP for a given project, and if affirmative, the specific type of PPP that could yield the greatest net benefits to the agency. Implementing the study product is expected to provide decision-support at highway agencies who continually seek not only to infuse greater transparency and accountability in their investment decisions, but also to provide cost-effective and well-balanced decisions in terms of various criteria (i.e., cost, time, safety, operations, asset condition, etc.).

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CHAPTER 1. INTRODUCTION

1.1 Introduction

This Chapter presents the motivation for investigating the relationship between various Public-private partnership (PPP) approaches on cost, time, safety and management related measures of effectiveness. In addition, the research objectives and scopes are presented.

1.2 Background and Problem Statement

Public-private partnerships (PPPs) in transportation infrastructure projects refer to the contractual agreements formed between a public Agency and a private sector entity to allow for greater private sector participation in project delivery. Traditionally, private sector participation has been limited to separate planning, design, and construction contracts on a fee-for-service basis (based on the public Agency's specifications). Expanding the private sector role allows the public Agencies to tap the private sector's technical, management, and financial resources in ways to achieve certain public Agency objectives, such as greater schedule and cost certainty, supplementation of in-house staff, and access to innovative technology applications, specialized expertise, and private capital.

At the same time, the private partner can expand their business opportunities in return for assuming the new and expanded responsibilities and risks. Hence, PPP contracts typically include incentives that reward private partners for mitigating risk factors.

At the current time, most Agencies do not have a set of straightforward guidelines by which they decide whether to adopt PPP for a given project, and if to adopt one, which type of PPP should be adopted. Before such a decision can be made in an informed manner, the Agency needs to develop and implement a PPP evaluation and decision-support framework that will incorporate the PPP costs and benefits for the different types of highway construction, preservation, or operation. These costs and benefits include the Agency costs and user costs occurred at the time of the project as well as the risk costs borne by the Agency. To that end, this study develops a PPP evaluation and decision support framework, supported by an Excel-Based Expert System, which Roadway Agencies can use to decide whether to adopt a PPP for a given project, and if affirmative, what type of PPP to adopt, such that there is maximum benefit to the Agency.

1.3 Research Objectives

The main objective of this study is to develop a comprehensive methodological framework that provides an appropriate context for transportation Agencies to decide whether to adopt PPP for a given project, and if to adopt one, which type of PPP should be adopted. To that end, 1,074 contracts from USA and abroad are analyzed.

There are two specific objectives in this study. The first objective is to identify the parameters that significantly influence the cost savings, cost overrun, change orders, time delays, and asset, operation and safety conditions. In practice, these Measures of Effectiveness (MOE) are characterized by contract characteristics, activity types, road geometry, pavement condition, and traffic characteristics.

The second objective is to find the most cost effective contract type based on the results of the developed models. To that end, pairwise comparison and Analytic Hierarchy Process (AHP) are used, and an excel-based expert system is developed. The outcome of this system yields the most appropriate PPP type for a specific transportation project.

1.4 Research Scope

The research scope of this study is defined in such a way so that the problem statement is presented in a comprehensive way. The scope of this study can be summarized as follows:

- Coverage: The presented methodological framework has many applications and can be implemented by selecting the most appropriate contract type for various transportation projects related to road construction, maintenance, and rehabilitation. To that end, the presented case study is focusing on seven measures of effectiveness (MOEs):
  - (i) Cost savings;
  - (ii) Cost overrun;
  - (iii) Change orders;
  - (iv) Time delays;
  - (v) Asset (pavement) condition;

- ➢ (vi) Operational condition (level of service); and
- ➢ (vii) Safety condition (accident frequencies).

The first four MOEs are cost-related measures, whereas the remaining three are related to the management, operation, and safety of the roadways. Since, the goals, outcomes and characteristics of each contract type vary across the aforementioned measures of effectiveness, the study is conducted at a PPP contract type basis.

- The analysis period spans over fifteen (15) years, from 1996 to 2011. To that end, only contracts with available and appropriate historical data are considered in the analysis.

1.5 Chapter Summary

This Chapter presented the problem statement, specific objectives, and research scope of this study. The next Chapter will provide fundamental information regarding the investigated PPP approaches and measures of effectiveness.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This Chapter presents the concepts, definitions, and results of conducted studies that are related to popular public-private partnership contracting approaches (cost-plus-time contracts, performance-based contracts, incentives/disincentives contracts, design-build contracts, lane rental contracts, and warranties). Also, this Chapter presents a review of relevant literature, which aims to provide a better understanding of the relationship of the MOEs in relation to the PPP types.

2.2 Concepts and Definition of Public-Private Partnership Contract Types

2.2.1 Performance-Based Contracting

Performance-based contracting (PBC) is one of the recently developed contracting types. Traditional contracting types and PBC have opposite approaches to reach the goals. Final products and results, not the procedure, are quite important under PBC. On one side, the contractor should meet the minimum physical conditions defined in agreement; whereas, traditional contracting is based on the amount of work being measured and paid for on agreed rates for various work items (Anastasopoulos et al., 2008a). During the last few decades, PPP has become more widespread in more than 50 countries worldwide, including several states in the United States and some provinces in Canada (e.g., Texas, Florida, Indiana, British Columbia, Ontario, etc.).

Payments in various types of contracts are usually based on many factors, such as the amount of work, cost, time, etc. However, under PBCs, the payments are based on the performance of the contractors and the contractors are responsible for meeting the defined minimum physical conditions. According to Pakkala (2007), under the PBC model, the contractor should account for the following details:

- Pavement Condition
  - Pavement surface roughness
  - Skid resistance/friction
  - Rutting depth
  - Deflection
  - Texture
- Additional factors
  - Drainage
  - Guardrail
  - Signing
  - Road marking
  - Bridges
  - Etc.

Also under PBCs, the final product is defined for the contractor, and the contractor handles implementing the different phases of the project. Also, the contractor should make a decision about selecting the appropriate materials and devices to be used in the project. To that end, Zietlow (2005) claimed that PBC has the higher risk for the contractor in comparison with the traditional contract types. The risks can be listed as follows:

1- Weakness in construction quality
2- Very bad weather conditions
3- Prognosticating environmental issues
4- Emergencies
5- Etc.

Previous studies also show that PBCs can increase the contractor's benefit in various aspects, especially cost (Anastasopoulos and Labi, 2009; Anastasopoulos et al., 2009a).

One of the significant advantages in PBCs is that the final production is defined in these contracts types. This leads the contractor to focus on the final goal from the beginning of the project and satisfy the outlined requirements listed in the contract. This may cause a reduction in time of the project, which directly influences the cost. The most important component of the PBC is that the contractors have the opportunity to use any new methods and materials to save time and money to meet the final product specifications. Also, if contractors and public Agencies agree on sharing the risks and rewards, the PBC method is more likely to have mutually favorable results.

Paying large amounts of money monthly or annually without paying attention to the growth of the project in that specific duration is one of the major concerns of the PBC model. To that end, some governmental Agencies send their project managers to monitor and measure the project's performance. There is an additional cost occurred for Agencies to send managers to control the performance, which may increase the cost of the project as a whole, which is not desirable.

There are several performance standards for PBCs, of which the most important are listed as follows (Zietlow, 2005; Anastasopoulos, 2007):

(a) The International Roughness Index (IRI), is a measure which presents the roughness of pavement's surface. This can influence the vehicle's operating costs.

(b) A measure which demonstrates the presence, extent, and/or severity of potholes, cracks, and rutting. This index affects the safety and pavement performance.

(c) An index measuring the friction between tires and pavement surface, used to reflect safety aspects.

(d) Retro-reflectivity of road signs and markings, also used to reflect safety aspects.

2.2.2 Cost-Plus-Time

The cost-plus-time contract is a type of contract that considers both the project's time and cost; the contractor must meet both of these parameters as agreed upon by the public Agency and contractor in the bid. Agencies select the best contractor by conducting a bi-criteria optimization on cost and time. *A* is the contractors bid amount, which is calculated by engineers for completing the whole project, and *B* is equal to the road-user cost (cost/day) multiplied by the project's duration (in days). The road-user cost is the summation of standard[1] and additional[2] liquidated damages (State of California Department of Transportation 2002). The Agencies also offer an award on the basis of the mentioned criteria, however, most of the time these two are not the only criteria and other parameters such as safety, quality, social impacts, and other factors play a significant role in delimiting the award (Carpenter et al. 2003; Herbsman et al. 1998).

One of the concerns in cost-plus-time contracts is their potential to increase the initial cost of the project. Sometimes, it is possible to reduce the project duration by acceleration, aggressive management of subcontractors, or using special devices, but using these techniques may increase the initial fee, which may not be desirable by public Agencies. However, under such conditions, the overall cost may decrease (Washington State Department of Transportation 2014).

The Minnesota Department of Transportation has highlighted that, under this model, it takes time for a contractor to provide a reliable project timeline. Also, the cost-plus-time optimization process can completely change by any alteration in the schedule. And contract administration may require more resources.

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[1] "Standard Liquidated Damages is the daily amount of money that state allocate for the field engineering and facility cost." (State of California DOT, 2002)

[2] "Additional Liquidated Damages is the daily additional costs for state and/or public such as road user delay costs, social/economic impacts and many others." (State of California DOT, 2002)

2.2.3 Incentives/Disincentives

Incentives/disincentives contracts provide an option for contractors to get monetary incentives when they finish the project earlier than the agreed-upon deadline. On the other hand, if the contractors delay project completion, penalties are imposed. The penalties for this type of contract derive from road-user cost values to convert time to cost. Cost-plus-time and incentives/disincentives contract types are typically combined (Anastasopoulos et al. 2014; Anastasopoulos et al. 2011a; Anastasopoulos et al 2010a, Anastasopoulos et al. 2010b; Anastasopoulos et al., 2011c; Shr et al. 2004; Carpenter et al. 2003; Segal et al 2003). Among various types of contracts, it is better to select incentives/disincentives contracts for projects that are located in urban areas and have time restrictions, because the incentives encourage the contractor to finish the project ahead of the deadline. The advantages of this type of contract are very similar to the cost-plus-time, because under both approaches, the project's duration can potentially be reduced (NCHRP 2001). Providing an appropriate environment for the contractors to use new methods and devices to accelerate the project is the second advantage of these contracts. This means the contractor can use any innovative and efficient technique to finish the project earlier than or at the deadline (Tanaka et al., 2012).

Although incentives/disincentives contracts have many advantages, there are always some disadvantages that both public Agencies and contractors should consider. The incentives/disincentives contracts usually decrease the competition because these types of contracts typically come with higher financial stakes. Larger companies that have higher budgets have a better chance of being selected for projects using an incentives/disincentives contract (Jaraiedi et al. 1995). The second issue is with respect to determining the contract amount (Jaraiedi et al. 1995).

2.2.4 Design-Build and its Derivatives

Depending on the project size, design-build contracts can be used in low-end design, mid-level design, and mega projects (Carpenter et al. 2003 and the Utah Technology Transfer Center's "Innovative Contracting Best Practices Guide," design; McCullouch et al. 2009; McCullouch and Anastasopoulos, 2009). The low-end design approach is suitable for urgent projects that have little room for innovative design. This method is typically used for the projects that have their issues met, and require process acceleration. Under design-build contracting approaches, the project's life is the primary focus.

The mid-level design projects are appropriate for introducing new and innovative technologies for speeding the project, and are usually related to bridge reconstruction. This type of design-build contracting contains high innovation for both design and construction.

Also under these contracts, mega projects should be divided into smaller projects so that they can still be managed even with limited resources and funding. New and innovative approaches allow public Agencies to use the private sector's resources as a supplement to their strength. Such contracts are usually time-dependent and complex at the same time (Anastasopoulos et al., 2011a). There are several design-build contracting approach derivatives, such as the following:

1- Design-build-operate-maintain (DBOM)

This type of contracting is a form of project financing that gives the private sector a privilege to design, build, operate, and maintain the facility for a predefined period. It is a flexible approach that reduces the risks of outsourcing the project. In this method, the private sector would find the best location and use innovative technologies to speed the construction process and the contractor would try to use the best materials possible so that it can gain benefits in the operating time.

2- Design-build-finance-operate-transfer

In this contracting, public Agencies do not bear any financial risks. The private sector would invest in the project depending on the contract. This approach injects new capital into the government and provides a financial source for other priority projects. In addition, the private sector would be encouraged to complete the project within the agreed-upon time frame and planned budget by using innovative design and new technologies.

3- Design-Build-own-operate

In this type of design-build contracting, ownership of the project usually remains with the public Agency; therefore, the private company receives the future value of the project. This framework is used when the physical life of the project coincides with the contract duration. This method involves a large amount of financing and usually takes a long time for the contractor to get their money back.

2.2.5 Warranties

Warranties are used to ensure that the quality of the product or project is continuously up to predefined standards. If the product does not reach its service life, the contractor replaces it, or takes suitable actions to repair it (Singh et al. 2004). Under warranty contracts, the product's quality is guaranteed by the contractor to provide the desired performance levels of the infrastructure throughout the course of the predetermined warranty period. Thus, the contractor is required to provide regular maintenance for the product after project delivery. This may lead to a decrease in the maintenance costs of the public Agencies due to the assumption of greater responsibility in construction by the contractors. Also, this type of contracting encourages the use of innovative and new technologies by contractors to ultimately increase the life cycle of the project (Anastasopoulos et al. 2011). Note that warranties are the most popular approach among other PPP types for pavement related projects.

A major advantage of warranty contracting is that it is compatible with traditional contracting techniques. Warranty clauses can be added to contracts requiring the contractor to perform all necessary tests to verify material condition and workmanship quality of the project. This could result in public Agencies reducing their need of personnel for inspecting and testing the product during and after construction. Under warranty contracts, higher quality of the end product is more likely than the traditional contracts because both the Agency and the contractor establish threshold levels. The contractor is responsible for repairing or replacing any work that does not meet the requirements of the contract. Furthermore, the contractor is encouraged to use innovative techniques that usually result in improved product quality.

Typically, a one-year warranty clause for contracts is used; while periods lasting longer than one year (most commonly five years), are specified as warranty contracts. Warranty contracts for highway projects, typically have higher contract amounts compared to traditional projects of similar type and scale. However, warranty contracts lead to considerable overall savings (Singh et al. 2006), due to the better quality product they deliver.

Warranty contracts differ in terms of their coverage and duration; performance warranties that require contractors to accept the responsibility of the product performance over the warranty period are usually longer. Conversely, material warranties are short-term.

2.2.6 Lane Rentals

Lane Rental is used to minimize the impacts of a project on the traveling public. It is a method of transferring the roadway user costs to the contractor. The contractor must rent a lane in order to close it. This creates a monetary incentive for the contractor to be innovative and minimize the duration of lane closures.

Lane rentals refer to contracts under which the contractor rents a lane in order to close it and perform roadwork. Payments in lane rental contracts are based on the time to completion. Therefore, the contractors typically prefer to finish the projects as soon as possible, so that they reduce their renting expenses (Herbsman and Glagola 1998). There are three types of lane rentals, as follows (Srinivasan and Harris 1991):

1- Bonus rental charge: In this type, bidding prices and the number of days the contractors need to complete the project are presented by different contractors, and the one with the lowest adjusted bid price is selected by the public Agency for the project. Incentives to the contractor are used when the project is completed ahead of schedule.
2- Continuous site rental: In contrast with the bonus rental charge method, the continuous site rental contract does not contain any incentives or penalties. The public Agency charges the contractor based on the number of days that the contractor rents the site. The lowest bid to do the project is selected by the public Agency.
3- Lane-by-lane rental: This type of lane rental contract was developed in the last decade. Under this method, contractors charge depending on the number of lane closures and number of days needed for completing the project.

2.3 Measures of Effectiveness

2.3.1 Cost Savings / Cost Overrun

Cost is one of the most important factors in every step of a project, and it is always desirable to reduce the project's cost without reducing the quality of the delivered product. To that end, a cost analysis should be conducted for every project to get a sense of which factors can affect the cost. Cost savings and cost overrun analyses are methods that can help administrators to select which contracting type is the most cost efficient for a certain project.

Previous studies demonstrate that cost estimation is one of the most important stages of the decision-making process because it can influence the government's judgment (Nijkamp and Ubbels, 1999). Anastasopoulos et al. (2011; 2014a) captured the effect of contract characteristics (duration, size, cost, etc.) and activity types (pavement repair, guardrail repair, shoulder repair/maintenance, etc.) on cost savings and cost overrun for various PPP approaches. Cost overrun is not unusual. Flyvbjerg et al. (2004) found that 9 out of 10 large transportation infrastructure projects in their study had cost overrun. Ahmed et al. (2003) found that delays on road construction projects are also not uncommon. Other studies investigated influential factors affecting cost overrun and cost savings (Anastasopoulos et al., 2010a; Bhargava et al., 2010; Irfan et al., 2011). For example, Flyvbjerg et al. (2003) found that the duration of a project is one of the major causes of cost overrun. Anastasopoulos et al. (2010c) found that it is more likely to experience cost savings on PBC, or incentives/disincentives contracts, rather than on warranties; and that PBC have the potential to perform better in terms of cost savings (as compared to other PPP contract types) in long duration projects.

2.3.2 Time Delays

Like cost overrun, time delays in project delivery are another major issue. Often, time delays for delivering the project are not solely the contractor's fault, as changing the scope of the project can also lead to time delays (Ambituuni 2011). Moreover, any changes in the scope of the project can also lead to time delays, and can change the entire project's schedule and budget. Other factors that can lead to time delay include improper and insufficient procurement and weak management system (Singh 2009), project complication (Ambituuni 2011), poor technical performance and poor contract management (Frimpong et al. 2003). Interestingly, Bordat (2004) reported that approximately 12 percent of the projects in Indiana Department of Transportation (INDOT) experienced time delays of around 115 days per contract between 1996 and 2001.

There are many parameters that significantly influence times delays, such as project cost characteristics and activity types (Anastasopoulos, 2007). In addition, cost and type of the contracts have the significant effect on the duration of the time delays (Irfan et al., 2011).

2.3.3 Change Orders

Change orders refer to alterations (amount, requirements, and time) in the project's scope that should affect the work of public Agencies, contractors, and engineers. Change orders typically add or remove a portion of work originally outlined in the initial contract. Sometimes these changes may cause the work to be defined as a new project. Similar to cost overrun and time delay, change orders are also very common in construction projects. Various studies are conducted in this area to find the major reasons for change orders and their effects. Serag et al. (2010) focused on some large projects in Florida and found that the timing of change orders was one of the most significant parameters that caused an increase in the contract price. Although change orders often occur in many projects, they can be eliminated or reduced by improving the planning stage and defining an appropriate and detailed scope of the work. There are also several studies related to the influence of change orders on the cost of the project, in which change orders have adverse effect on final cost (Serag et al. 2010; Anastasopoulos et al. 2010b).

2.3.4 Accident Analysis

There have been numerous studies regarding accident analysis, in general, but to the authors' knowledge, none is related to PPPs. Predicting accident frequencies or rates and identifying hot spots can result in improvements in the transportation system and eventually help to reduce accident occurrence and injury-severity. To achieve this goal, finding the best specified model to fit historical data is essential. Past research used many modeling approaches to identify the most influential parameters affecting safety. These parameters are divided into five major groups, namely road geometry (e.g., median width, number of curves, etc.), traffic characteristics (e.g., Average Annual Daily Traffic), pavement condition (e.g., International Roughness Index, Pavement Condition Rating, etc.), weather conditions (e.g., number of rainy days), and human factors (e.g., drinking, driving experience). Various statistical methods are used to model the safety related dependent variables (Accident Frequency, Accident Rate, etc.) based on the type of the data (and the dependent variable). Accident frequencies can be modeled with the Poisson regression (Jones et. al., 1991; Miaou and Lum, 1993), or with the negative binomial model depending on accident frequencies' dispersion (Miaou 1994; Shankar et al., 1995; Poch and Mannering, 1996; El-Basyouny and Sayed, 2006; Lord and Miranda-Moreno, 2008; Kim and Washington, 2006; Malyshkina and Mannering, 2009; Oh et al., 2006); zero-inflated models can also be used when there is a large number of roadway segments (or locations) without accidents observed (Miaou, 1994; Shankar et al., 1997; Lee and Mannering, 2002; Malyshkina and Mannering, 2010).

In the case of accident rate analysis, the tobit model has been shown to be a preferred approach. This model has the advantage of accounting for the left-censored at zero nature of accident data (Anastasopoulos et al., 2008b, 2012f, 2012g).

For accident injury-severity analysis, discrete outcome models are found to be appropriate, such as multinomial logit/probit models (Ulfarsson and Mannering 2004), ordered logit/probit models (Khattak 2001; Russo et al., 2014), and nested logit/probit models (Chang and Mannering 1998).

Some of the aforementioned modeling approaches can be combined using a multivariate modeling approach (Aguero-Valverde and Jovanis, 2008; Ma and Kockelman, 2006; Park and Lord, 2007; Anastasopoulos et al., 2012b; Anwaar et al., 2012). For a detailed discussion of the modeling approaches mentioned earlier, see Mannering and Bhat (2014).

Usually, some of the information needed for modeling is not available or up to date, which may cause unobserved heterogeneity issues in the modeling process. To account for such unobserved heterogeneity, random parameters modeling has proven to provide superior statistical fit and forecasting accuracy (Anastasopoulos and Mannering, 2009, 2011, 2014, 2015; El-Basyouny and Sayed, 2009; Ukkusuri et al., 2011; Venktaraman et al., 2011; Anastasopoulos et al., 2012a). A feature of random parameters modeling is that it allows the effect of the estimated parameters to vary across the observations, thus also improving the model's explanatory power (typically, a random parameters model will yield a larger number of statistically significant explanatory parameters, as compared to its fixed parameters counterpart).

For the accident analysis in this study, influential factors (e.g., traffic characteristics, road geometrics, pavement condition, etc.) affecting accident frequencies before, during, and after construction, maintenance and rehabilitation and under the various PPP types, are investigated. To the authors' knowledge, this is a first time such accident analysis is conducted at this level, by PPP type.

2.3.5 Operations Analysis

Operation in the network is usually defined by the macroscopic conditions of the traffic in each road, which include flow, speed, and density. The relationship between these variables strictly depends on the characteristics of the roadway. Flow is defined as the total number of vehicles per time unit and density as the total number of vehicles per size unit; speed is related to these two variables. Estimating any pair of these variables is enough to derive the third one.

A number of empirical models has been proposed to approximate the relationship between these three parameters. One of the popular methods is the Greenberg model, which defines a logarithmic relationship between speed and density (Gazis, 2002). Another is the Underwood model, which is exponentially derived (Underwood, 1961). Van Aerde (1995) developed another method that consists of two sections; the first one showing the relationship between the key parameters of the traffic, and the second indicating the effects of other parameters, such as weather and day of the week, on these critical parameters. Kerner and Rehborn (1996) developed a model under which the driving behavior of the road-user may vary in different traffic conditions. Recently, two-regime models, such as the triangular model, were developed (Gazis, 2002; Wang et al., 2011).

Furthermore, there are numerous studies that investigated the influential parameters on AADT and the Level of Service (LOS). For example, Mohamad et al. (2014) studied the relationship of the AADT in relation to population, state highway mileage, and per capita income. Several other studies (Xia et al., 1999; Zhao and Chung, 2001) have also identified parameters that are significantly influencing the AADT, such as population, location type (rural/urban), accessibility to other roads, and total arterial mileage, road functional class, and number of lanes.

In this study, the road segment density is expressed as level of service, and is analyzed in order to identify factors that are affecting it (e.g., asset condition, work zone characteristics, traffic characteristics, road geometrics, etc.) by PPP type. Since the level of service has an ordinal nature, and it cannot take negative values, ordered probit/logit models are appropriate and used (see Anastasopoulos et al., 2012c). Note that, to the authors' knowledge, this is a first attempt to identify influential factors affecting LOS by PPP contract types.

2.3.6 Asset (Pavement) Condition Analysis

Many studies have explored pavement design and other pavement management related issues (Scheinberg and Anastasopoulos, 2010; Warith et al., 2014, 2015). However, very few studies have been conducted to investigate the effect of PPP approaches on asset (pavement) condition (Anastasopoulos, 2007, 2009; Anastasopoulos et al., 2012e). Stankevich et al. (2009) found that condition of road assets under PBCs improved, as the number of roads which were in poor condition reduced after a PBC.

Many highway Agencies acknowledge that using warranty or performance-based contracting (PBC) would result in improving the asset's condition after the implementation of the project (Anastasopoulos et al., 2011a; Liquated, 2004). Anastasopoulos et al. (2013, 2014b) looked more deeply into asset (pavement) management and found that a hybrid approach (a combination of PPP and in-house practices) has the potential to result in superior and more cost-effective end results for the Agency, as compared to an all-in-house or all-PPP inclusive approach.

2.4 Chapter Summary

This Chapter reviewed the various PPP approaches (cost-plus-time, performance-based contracting, warranties, incentives/disincentives, lane rentals, design-build and their derivatives), and measures of effectiveness (cost savings, cost overrun, time delays, change orders, operational conditions, asset conditions, and safety conditions) used in the literature. The next Chapter presents an overview of the methodological framework.

CHAPTER 3. METHODOLOGICAL FRAMEWORK

3.1 Introduction

This Chapter presents the methodological framework – including an overview of the study approach and analysis steps – of this study.

3.2 Overview of the Study Approach

This study identifies and quantifies the various Agency cost components, user cost components, and the common risks and rewards that can be expected from each PPP type or project type, and identifies influential factors for each component through rigorous statistical methodologies. To that end, the following typical PPP types are explored:

(i) Performance-based contracting (private sector operations and maintenance on a performance basis);

(ii) Cost-plus-Time contracting (private sector program management for a fee and/or with program costs and schedule);

(iii) Incentives/disincentives (structured to encourage the contractor to finish the project earlier than the time indicated in the original bid document);

(iv) Design-Build-Operate-Maintenance (contractors use this method to minimize the possible risks of the project and also reduce the delivery schedule by overlapping the both construction and design phases of the project);

(v) Warranties (the contractor is liable for product defects or failure, and is responsible that the product meets certain pre-agreed performance standards); and

(vi) Lane-rentals (used to accelerate the completion of a preservation project by charging the contractor with a fee for occupying lanes or shoulders throughout the project duration).

The goal is to establish a decision-support methodology to help Roadway Agencies decide which project types and project sizes are most appropriate for each type of procurement package. The decision-support methodology is based on an elaborative evaluation – through advanced statistical modeling – of the aforementioned PPP types by procurement package, in terms of cost savings (cost comparison between PPP type and in-house practices or traditional outsourcing), cost overrun, time delay, change orders, safety and operations before, during, and after construction and preservation work (work-zone and non-work-zone related). Figure 3.1 presents an overview of the proposed framework.

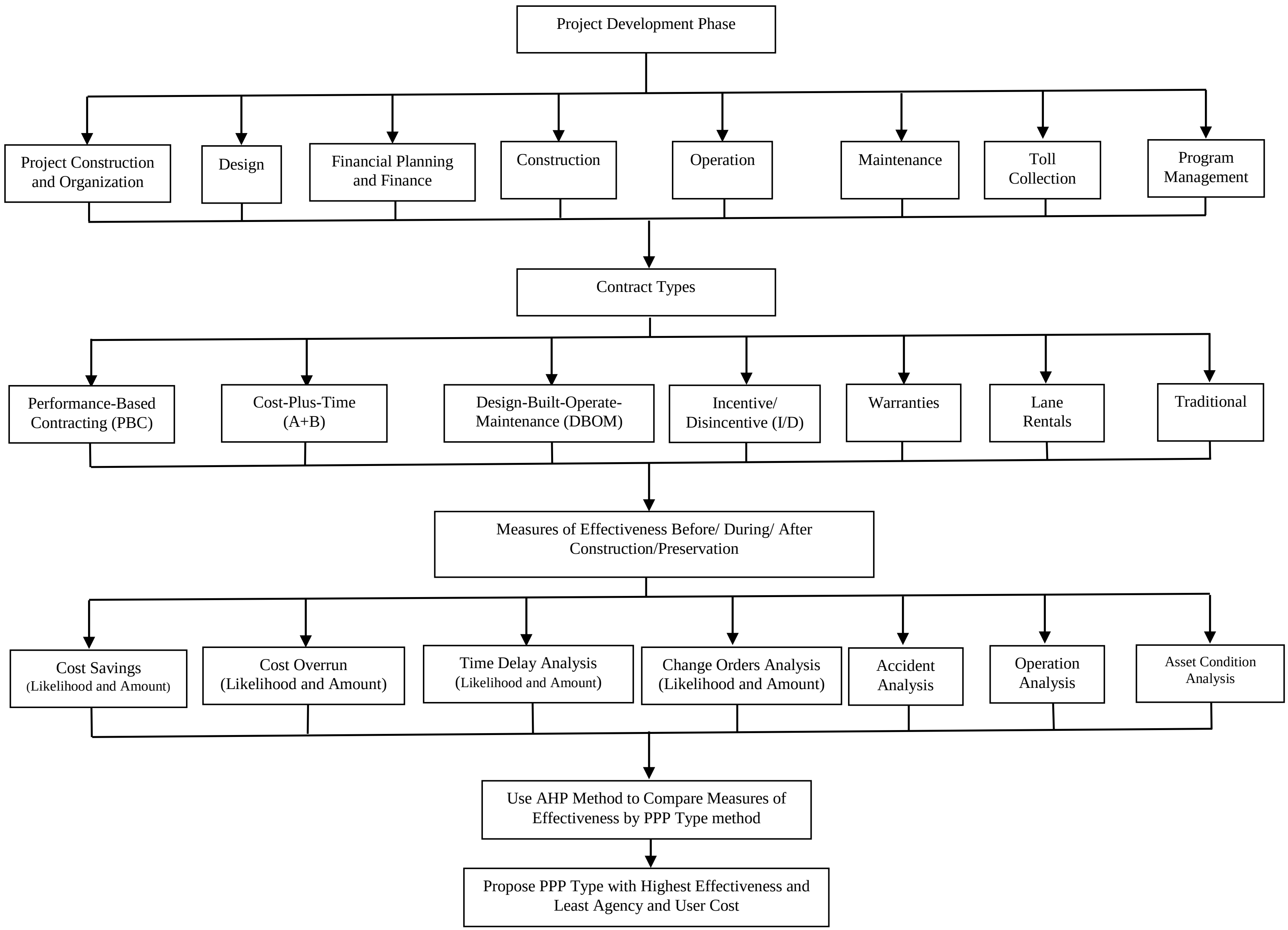

Figure 3.1 Overview of the Decision-Support Framework

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3.3 Analysis Steps

The analysis procedure is presented in Figure 3.2, and can be summarized as follows:

- STEP 1. This step includes gathering data and performing a preliminary analysis to obtain some insights regarding the data at hand.
- STEP 2. This step includes the development of rigorous statistical models for the amount and occurrence likelihood of cost savings, cost overrun, time delays, and change orders, and for the asset (pavement), operational and safety condition.
- STEP 3. Using the estimated models from step 2, in this step a PPP evaluation and decision support framework is developed. The framework uses pairwise comparison and analytical hierarchy process, and aims at helping decision makers make an informed decision regarding whether to adopt a PPP for a given project, and if affirmative, what type of PPP to adopt, such that there is maximum benefit to the Agency. (An excel-based application is developed, which uses the user's input – both in terms of project and contract characteristics, and in terms of relative significance of each measure of effectiveness – and the statistical models and pairwise comparison, to predict the values corresponding to each measure of effectiveness and each PPP type.)
- STEP 4. The process yields the most effective PPP type given the information provided by the user. In other words, the recommended contract type by this expert system has higher benefits in terms of cost, time, safety, level of service, and asset condition in comparison with the remaining competing PPP approaches.

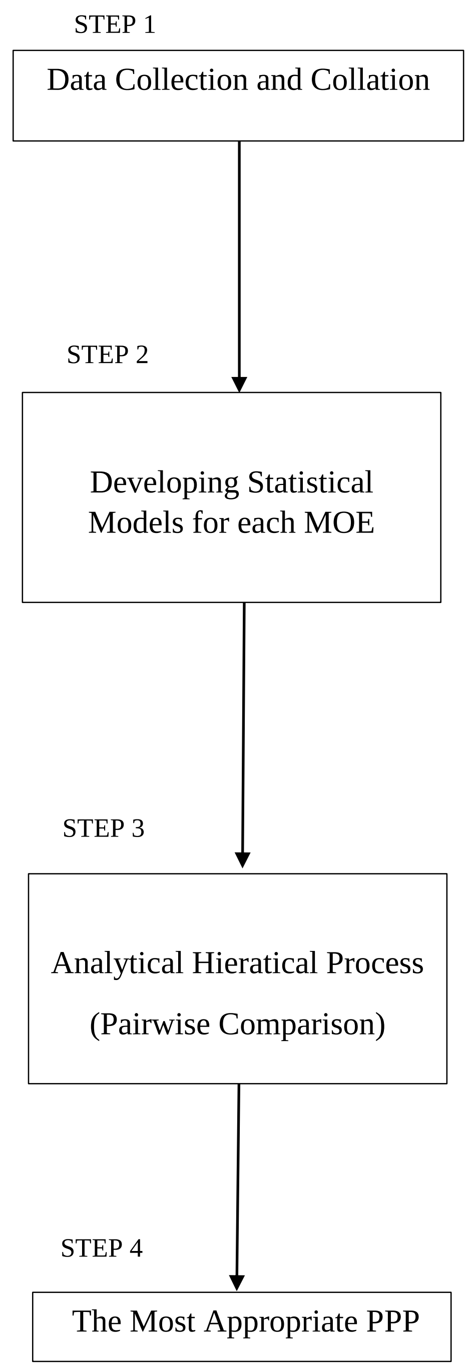

Figure 3.2 Analysis Steps

3.4 Chapter Summary

This Chapter presented the methodological framework and an overview of approach, including the specific analysis steps. The next Chapter describes the collected data.

CHAPTER 4. METHODOLOGY

4.1 Introduction

This Chapter presents an overview of the methodologies used for the statistical modeling of the measures of effectiveness. Linear regression is used to model cost savings/cost overrun percentages (see Anastasopoulos et al., 2015); count data models are used to model change orders and accident frequencies; seemingly unrelated regression equations are used to model pavement condition; hazard-based duration models are used to model time delay; and binary probit/logit models are used to model the likelihood of cost savings, cost overrun, change orders and time delays occurrence.

4.2 Cost Savings and Cost Overrun Analysis

The related cost measures of effectiveness include the cost savings and cost overrun:

$$\%CS_{ki} = 100 \times [(CB_{ki} - CA_{ki})/CB_{ki}], \text{ and} \quad (4.1)$$

$$\%CO_{ki} = 100 \times [(C_{Fki} - C_{WBki})/C_{WBki} \quad (4.2)$$

where, %CS is the percent cost savings of the project i of the PPP contracting approach k under consideration, CB is the cost of the contract with the base contracting approach, CA is the cost of an identical contract with the PPP contracting approach, and %CO is the percent cost overrun of the project i of the PPP contracting approach k under consideration, relative to the corresponding winning bid cost, C_{WB}, of the project, and C_F is the actual final as-built cost after the project is complete and delivered. Positive values for Equations 3 and 4 indicate that cost savings and cost overrun occur, respectively; whereas, negative values indicate the opposite (i.e., no cost savings, and cost-underruns, respectively).

The amount of cost savings and cost overrun can be calculated as a percentage using Equations 4.1 and 4.2, respectively, to provide a comparable measure of cost savings and cost overrun for projects of different sizes. Such variables are continuous in nature, taking positive or negative values depending on whether the PPP yielded positive or negative cost savings or cost overrun, respectively. Linear regression is used to model the relationship between the continuous dependent variables and the independent variables:

$$\%CS_{ki} = \beta_{ki} + \beta_{CS} X_{CSki} + \varepsilon_{ki} \quad (4.3)$$

$$\%CO_{ki} = \beta_{ki} + \beta_{CO} X_{COki} + \varepsilon_{ki} \quad (4.4)$$

where $\%CO_{ki}$ $\%CS_{ki}$ are the dependent variables (as defined in Equations 4.1 and 4.2, respectively) and are a function of the constant terms, β_{ki}, and a constant, β_{CS} and β_{CO}, respectively, times the values $X_{CSki}$and X_{COki} of independent variables X for observation i (i = 1, 2,…, n) in PPP approach k, plus the disturbance terms, ε.

4.3 Time Delay Analysis

Given that a project time delay has occurred, the length of the delay can be statistically modeled as duration data using hazard-based modeling methods. In the case of project delays, the hazard-based approach allows to focus on the conditional probability of a project delay ending at some time *t* given that the delay has lasted until time *t*. To formulate an estimable model, the hazard function is written as:

$$h(t) = f(t)/[1 - F(t)] \quad (4.5)$$

where, $F(t)$ and $f(t)$ are the cumulative distribution function and the density function of project time delay, respectively. This hazard function gives the rate at which the project time delays are ending at time *t*, given that they have lasted up to time *t*. To account for the effect of explanatory variables in hazard models, a proportional hazards approach is used where the explanatory variables act multiplicatively on some underlying (or baseline) hazard function such that:

$$h_n(t|X) = h_0(t)\exp(-\beta X_n),, \quad (4.6)$$

where, Xn is a vector of explanatory variables, β is a vector of estimable parameters, and $h_0(t)$ is the baseline hazard that denotes the hazard when all elements of the explanatory variables' vector are zero. In estimating Equation 4.6, a common approach is to consider various parametric forms of the underlying hazard function. The most widely used parametric forms include the exponential, Weibull, and log-logistic models, and these are explored (Anastasopoulos et al., 2009c, 2012a, 2012b, 2012d).

4.4 Change Orders Analysis

The frequency of change orders can be viewed as count-data (non-negative integers). Such data are generally modeled using Poisson regression or its derivatives, the negative binomial and zero-inflated models (Anastasopoulos et al., 2009b). In the basic Poisson model, the probability, $P(n_i)$, of contract *i* having n_i change orders is,

$$P(n_i) = EXP\ (-\lambda_i)\lambda_i^n / n_i! \qquad (4.7)$$

where λ_i is the Poisson parameter for contract i, which is contract i's expected number of change orders, $E[n_i]$. Poisson regression specifies the Poisson parameter λ_i as a function of explanatory variables by typically using a log-linear function $\lambda_i = EXP(\beta X_i)$ where Xi is a vector of explanatory variables and β is a vector of computable parameters. Depending on the data, a Poisson model may not always be appropriate because the Poisson distribution restricts the mean and variance to be equal ($E[n_i] = VAR[n_i]$). If this equality does not hold, the estimated parameter vector will be biased. To account for this possibility, a negative binomial model can be derived by rewriting $\lambda_i = EXP(\beta X_i)$ to $\lambda_i = EXP(\beta X_i + \varepsilon_i)$, where $EXP(\varepsilon_i)$ is a Gamma-distributed error term with mean 1 and variance α.

Zero-inflated models can be explored, to account for the possibility that change orders are generated from two distinct processes: a normal count state (when change orders occur according to a count process such as the Poisson or negative binomial) and a zero-count state (when change orders do not occur). The zero-inflated Poisson (ZIP) model assumes that the change orders for contract i is,

$$n_i = 0 \text{ with probability } p_i + (1 - p_i)EXP(-\lambda_i) \qquad (4.8)$$

$$n_i = n \text{ with probability } (1 - p_i)EXP(-\lambda_i)\lambda_i^n / n!\,, n = 1,2,3\ ...$$

where p_i is the probability of being in the zero-change order state and *n* is the number of change orders.

The zero-inflated negative binomial (ZINB) regression model follows a similar formulation with,

$$n_i = 0 \text{ with probability } p_i + (1 - p_i)\ [1/\alpha/(1/\alpha + \lambda_i)]^{1/\alpha} \qquad (4.9)$$

$$n_i = n \text{ with probability } (1 - p_i)\left[\frac{\Gamma(1/\alpha + n)u_i^{\frac{1}{\alpha}}(1 - u_i)^n}{\Gamma(1/\alpha)n!}\right], n = 1,2,3 \ldots$$

where $u_i = 1/\alpha/(1/\alpha + \lambda_i)$, Γ denotes the gamma distribution, and all other terms are as previously defined. And to statistically determine the appropriate count model (Poisson, negative binomial, ZIP or ZINB), the Vuong-statistic is used (see Vuong, 1989). This statistic is calculated as follows (for each observation i):

$$m_i = LN[\frac{f_1(y_i|X_i)}{f_2(y_i|X_i)}] \qquad (4.10)$$

where, $f_1(y_i|X_i)$ is the probability density function of model 1, and $f_2(y_i|X_i)$ is the probability density function of model 2. This method is used to test the no nested hypothesis for zero-inflated model 1 versus model 2:

$$V = \sqrt{n}[(\frac{1}{n})\sum_{i-1}^{n} m_i]/\sqrt{\left(\frac{1}{n}\right)\sum_{i=1}^{n}(m_i - \bar{m})^2} = \sqrt{n}(\bar{m})/S_m \qquad (4.11)$$

where, $\bar{m}$ is the mean $(\left(\frac{1}{n}\right)\sum_{i=1}^{n} m_i)$, S_m is standard deviation, and n is a sample size. Vuong's value is asymptotically standard normally distributed. Note that if |V| is less than $V_{critical}$, the test can to choose one model over the other one. Larger positive values for V in comparison with $V_{critical}$ demonstrates that model 1 is better than model 2. Whereas, larger negative values for V in comparison of $V_{critical}$ shows that model 2 is the better choice than model 1. Table 5.1 presents the decision guidelines of this test.

Table 4.1 Vuong's statistics decision guidelines

		t-statistic of the NB over dispersion parameter α	
		< |1.96|	> |1.96|
Vuong statistic for ZINB(f1(.)) and NB(f2(.)) comparison	< |1.96|	ZIP or Poisson as alternative to NB	NB***
	> 1.96	ZIP**	ZINB*

*ZINB stands for Zero-inflated Negative Binomial
**ZIP stands for Zero-inflated Poisson
***NB stands for Negative Binomial

4.5 Likelihood of Cost and Time Discrepancies' Occurrence

The likelihood of the cost savings, cost overrun, change orders, and time delays are also investigated (note that different factors may affect the likelihood and the amount of such phenomena), with possible explanatory parameters being contract characteristics (duration, size, cost, etc.), and road assets/activities included in the contract.

One possible approach to estimate the probability of two discrete outcomes (as in the above cases) is through the use of discrete outcome models for categorical variables (binary as in the presented case where there are only two outcomes, 0 or 1). To that end, binary probit models are considered. The binary probit model can be defined as:

$$P_{ki}(D) = \Phi[(\beta_D X_{Dki} - \beta_{ND} X_{NDki})/\sigma \qquad (4.12)$$

where $P_{ki}(D)$ is the probability of observation i in PPP approach k having a discrepancy, D, with D representing the cost savings, cost overrun, time delay, and change orders, Φ(.) is the standardized cumulative normal distribution, X_D and X_{ND} are vectors of factors affecting the probabilities for the discrepancy or no discrepancy outcomes, D and ND, respectively, and σ is a scaling parameter that determines the discrete outcomes and is typically set to one. For estimating the parameter vector β, standard maximum likelihood methods are used (see Washington et al., 2011).

4.6 Operations (Level of Service) Analysis

The operation of a roadway can be measured using the Level of Service (LOS). The LOS typically measures the density levels (or time delays at intersections), and takes values from A through F, with A representing perfect traffic conditions, and F a complete gridlock. Given that the six possible LOS outcomes are in an ordinal scale, ordered probability models are appropriate. The ordered probit model is derived by defining the ordinal data y for each observation; for example (Washington et al., 2011),

$$y_i = \beta' X_{ik} + \varepsilon_{ik}\,, \quad y_{ik} = j \text{ if } \mu_{j-1} < y_{ik} < \mu_j\,, j = 0, \dots . J\,, \tag{4.13}$$

where, y corresponds to integer ordering of LOS (e.g., A, B, C, D, E, and F) for each roadway segment, i, treated by PPP approach, k, β are vectors of estimable parameters, X are vectors of explanatory variables, μ are threshold parameters that define y, j are the integer ordered LOS, and ε are random error terms that are assumed to be normally distributed with zero mean and variance equal to one. The ordered probit model with ordered selection joint probability for y = j, is then defined as,

$$P(y_i = j \mid X_{ik}) = \Phi(\mu_j - \beta' X_{ik}) - \Phi(\mu_{j-1} - \beta' X_{ik})\,, \tag{4.14}$$

where, Φ is the standard normal cumulative distribution function.

With respect to the signs of the estimated parameters, a positive sign indicates an increase in the probability of the worst LOS outcome (F) and a decrease in the probability of the best LOS outcome (A). In contrast, a negative sign indicates a decrease in the probability of the worst LOS outcome (F) and an increase in the probability of the best LOS outcome (A).

4.7 Asset (Pavement) Condition Analysis

For the asset condition, various condition indicators (e.g., pavement roughness, rutting depth, pavement condition rating) are studied (under each PPP type) to identify their influential factors (e.g., traffic characteristics, weather, etc.). To that end, a Seemingly Unrelated Regression Equations (SURE) approach is used, to account for the cross-equation error correlation typically encountered in performance modeling of multiple condition indicators (see Prozzi and Hong, 2008; Anastasopoulos et al., 2012b):

$$CI_1 = \beta_1 Z_1 + \alpha_1 X_1 + \zeta_1$$

$$CI_2 = \beta_2 Z_2 + \alpha_2 X_2 + \zeta_2$$

$$CI_3 = \beta_3 Z_3 + \alpha_3 X_3 + \zeta_3 \qquad (4.15)$$

where, CI_1, CI_2, and CI_3 are the measured condition indicators, *Z* are vectors of pavement section and pavement condition characteristics, X are vectors of other influential factors affecting the pavement condition, the β and α are vectors of estimable parameters, and the ζ represent a set of excluded variables that, in conjunction with the included explanatory parameters, are sufficient to determine the dependent variables.

4.8 Accident Analysis

Finally, for the accident analysis, influential factors (e.g., traffic characteristics, road geometrics, pavement condition, etc.) affecting accident frequencies on locations before, during, and after construction or preservation (under the various PPP types) are studied. The count data modeling framework discussed within the context of the change orders frequency analysis above (i.e., Equations 4.7-4.11) are used.

4.9 Random Parameters Modeling

For all the statistical models, the possibility that the effect of the explanatory parameters varies across the observations due to unobserved heterogeneity or other data limitations, is explored through the use of random parameters, by letting,

$$\beta_n = \beta + \omega_n \tag{4.16}$$

where, $\boldsymbol{\beta}_n$ is a vector of estimable parameters and $\boldsymbol{\omega}_n$ is a vector randomly distributed terms (for example, normally distributed terms with mean zero and variance σ^2). With random parameters modeling, unobserved factors are accounted for, and the models' statistical fit and forecasting accuracy are expected to improve.

4.10 Chapter Summary

This Chapter presented the statistical modeling approaches used to model the measures of effectiveness, such as the cost savings, cost overrun, change orders, time delays, level of service, pavement condition, and accident frequencies. The next Chapter presents information regarding the data collection and collation, along with descriptive statistics for key variables.

CHAPTER 5. DATA COLLECTION AND COLLATION

5.1 Introduction

This Chapter presents the data used in this study, and provides descriptive statistics of available variables in the dataset.

5.2 Data Collection and Collation

This study uses cost- and project-specific nationwide data available from previously conducted studies in the broad area of PPP cost effectiveness (Anastasopoulos et al., 2009a, 2010, and 2011). The available data include 1,074 contracts (performance-based contracting, cost-plus-time contracting, incentives/disincentives, design-build and its derivatives, warranties, and lane-rentals) that were let or completed in the United States and abroad (in countries in Africa, Asia, Europe, North and South America, and the Pacific) between 1996 and 2011. More specifically, 737 contracts were implemented in North America (645 in the USA, and 92 in Canada), and 337 in the rest of the world. Out of the 645 USA-based contracts, 104 were from Texas, 138 from Virginia, 195 from Indiana, 45 from Minnesota, 91 from Florida, 33 from Washington D.C., and 39 from Alaska.

The data were collected and collated from the World Bank Resource Guide, FHWA, G. Zietlow's PBC website, the British Columbia, Republic of Serbia and Tanzania National Road Agencies, and from other resources (Porter, 2002; Segal et al., 2003; Zietlow, 2004; Zietlow, 2005; Stankevich et al., 2005; Pakkala, 2005; Robinson et al., 2006; FHWA, 2007). Also, data were collected from the following transportation Agencies with the help of many officials: Indiana, Minnesota, Florida, Virginia, Texas, Washington D.C., and Alaska.

5.3 Data Description

The data include information about the origin of the contract (continent, country, region, etc.), type of the contract (the nine PPP contract types discussed above), contract characteristics (duration, size, coordinates of the road segment or intersection, etc.), assets/activities contained in the project scope (specific construction, maintenance, rehabilitation, preservation, and asset management activities), and cost-related information (final cost, in-house cost, engineer's estimate of the cost, cost savings, cost overrun, time delay, change orders, number of bids, highest bid, etc.).

This dataset also contains information about the weather condition (proportion of rainy and snowy days), road geometry (inside and outside shoulder width, presence of median, median width, drainage system, number of horizontal and vertical curves and number of lanes), pavement condition (mean and standard deviation of International Roughness Index, mean and standard deviation of Pavement Condition Rating, and mean and standard deviation of Rutting depth), and traffic characteristics (Average Annual Daily

Traffic, and Truck percentage). The summary of the descriptive statistics of the data is presented in Table 4.1.

The data used in this study can be summarized as follows:

(a) Specific origin of the contracts:

- (i) Continent/Region (Africa, Asia, Europe, Latin America, Middle East, North America, Pacific)
- (ii) Country (Argentina, Australia, Brazil, Burkina Faso, Cambodia, Canada, Cape Verde, Chad, Columbia, Congo, Denmark, Egypt, Estonia, Guatemala, Honduras, India, Lithuania, Madagascar, Nepal, New Zealand, Paraguay, Peru, Philippines, Serbia, South Africa, Sweden, Tanzania, Thailand, UK, Uruguay, USA, Yemen, Zambia)
- (iii) State or Provinces (Alberta, British Columbia, Florida, Minnesota, New South Wales, Ontario, Portsmouth, Queensland, Tasmania, Texas, Victoria, Virginia, Washington D.C. Western Australia, Indiana, Alaska).

(b) Type of contract (contracting method):

- (i) Cost-Plus-time (A+B Bidding)
- (ii) Design-Build-Operate-Maintain (DBOM)
- (iii) Incentives/Disincentives
- (iv) Lane Rentals
- (v) Warranties
- (vi) Performance-Based Contract

(vii) Traditional

(c) Contract characteristics

(i) Duration of the contract (years)

(ii) Extension of the contracts (years)

(iii) Size of the outsourced road segments incorporated in the contract (Lane-Miles)

(iv) Highway/ Non-highway

(v) Rural/ Urban

(vi) Number of Activities included in the contract

(d) Specific road Assets/activities incorporated in the contract:

(i) Bridge-tunnel repair/maintenance/management

(ii) Crack sealing or pothole repair

(iii) Culvert/ditches/gutters/drainage repair/maintenance/replacement

(iv) Emergency facilities maintenance/response

(v) Guardrail repair/maintenance

(vi) Illumination repair/maintenance

(vii) Landscape repair/ maintenance

(viii) Litter removal

(ix) Electrical/cable system repair/maintenance

(x) Mowing

(xi) Pavement repair/maintenance/treatment

(xii) Rest areas

(xiii) Shoulder repair/maintenance

(xiv) Traffic signs and signals

(xv) Vegetation/tree control/maintenance/removal

(xvi) All services[3].

(e) Contracts' cost and time characteristics

(i) Final cost of the contract (final cost of the outsourced contract)

(ii) Cost Savings

(iii) Cost Overrun

(iv) Number of bids for the outsourced contract

(v) Highest bid for the outsourced contract

(vi) Difference between the awarded and highest bids

(vii) Time Delays

(f) Other useful information

(i) Number of change orders

(ii) Level of Service

(iii) Average and mean of International Roughness Index, Pavement Rating Condition, and Rutting Depth

(iv) AADT

(v) Truck percentages

(vi) Presence of Median

(vii) Presence of inside/outside shoulders

(viii) Median and shoulder width

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[3] Often all road assets and activities are incorporated in the contract (usually in PBCs); instead of outsourcing road assets and activities, road sections are contracted out.

(ix) Presence of horizontal and vertical curves

(x) Number of Lanes[4]

5.4 Descriptive Statistics

In this section, an overview of the available dataset is provided to provide a better and insight into the collected data.

Figure 5.1 shows the origin of the contracts. For example, 69 percent of the data are collected from various states and provinces of the United States and Canada. The other 31 percent of the data is collected from other regions (e.g., Pacific, Africa, Asia, Europe and Latin America). Note that there are only three contracts from the Middle East in this dataset.

For the contracts from North America, Figure 5.2 presents their spread in the USA and Canada. Indiana, Virginia, Texas and Florida have the highest percentage of PPP contracts in North America. Canada Provinces represent 12 percent of all North America contracts.

Figure 5.3 demonstrates how various contract types are spread around the world. For example, the traditional contracting approach is the most common contract in this dataset and design-build and its derivatives are the most popular PPP contract types in comparison with the other approaches. Warranties and PBCs represent about 16 and 13 percent of all contracts, respectively.

[4] For additional information about the sources and websites. see Anastasopoulos (2007).

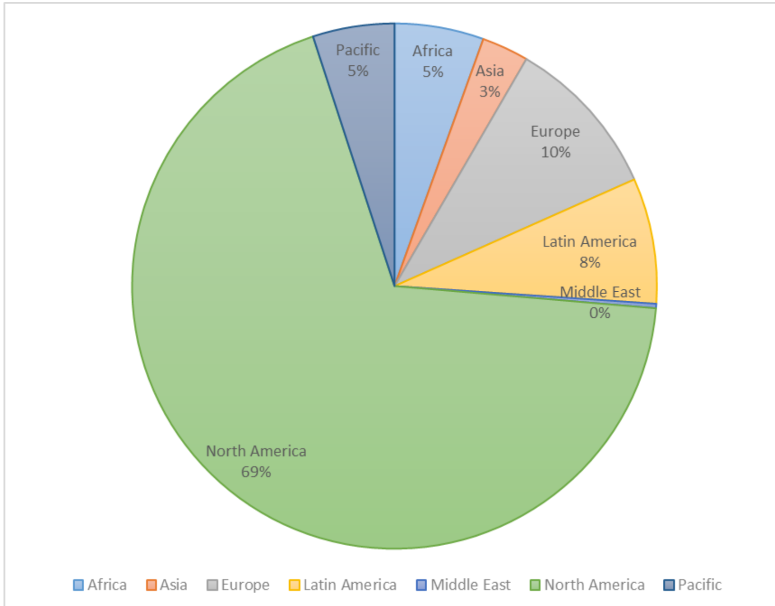

Figure 5.1 PPP contract distribution in each Continent/Region

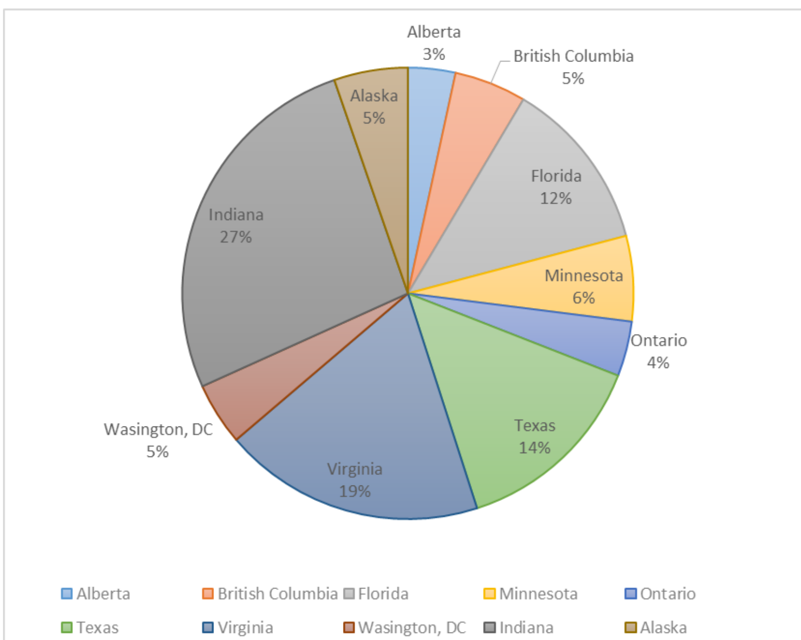

Figure 5.2 PPP contract distribution in USA States and Canadian Provinces

There are 645 contracts in the USA, and Figure 5.4 presents the percentage of each contract type in this country. Figure 5.4 demonstrates that USA follows a similar pattern of all around the world. In this case, the traditional approach is still the most common contracting type in the USA. Design-build and its derivatives, Warranties, and PBCs are also popular methods in the United States.

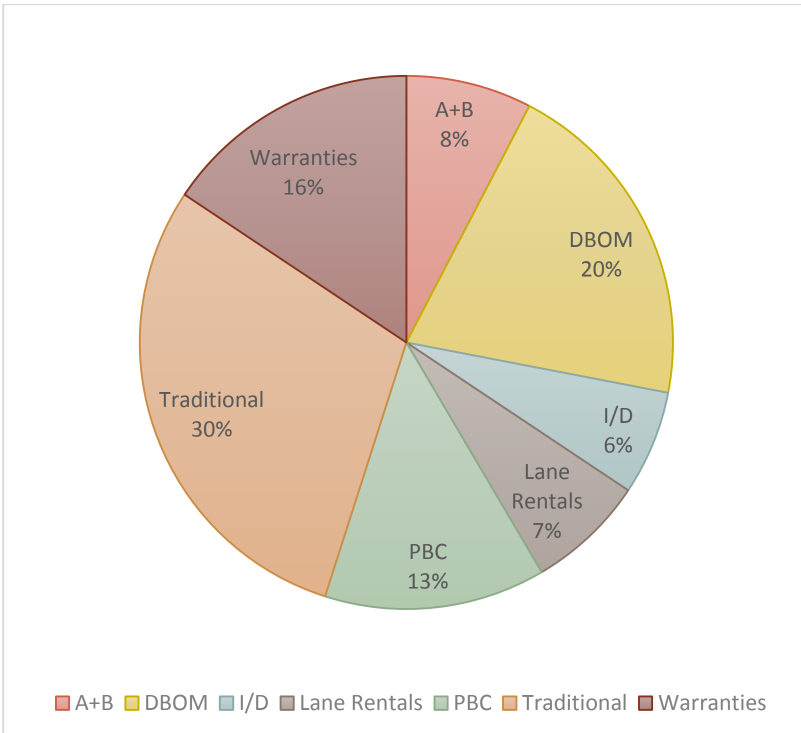

Figure 5.3 Distribution of PPP contract types in all around the world

Figure 5.5 presents the distribution of the contract types by USA states. The traditional contracting approach is the most common contract type in Florida, Texas, Virginia, and Alaska, given the specific dataset. The data show that the second most common contracting approach is DBOMs. There are no available incentives/disincentives contracts in Florida, Washington D.C., and Alaska. In addition, there are no available warranty contracts in Florida, Texas, Washington D.C., and Alaska.

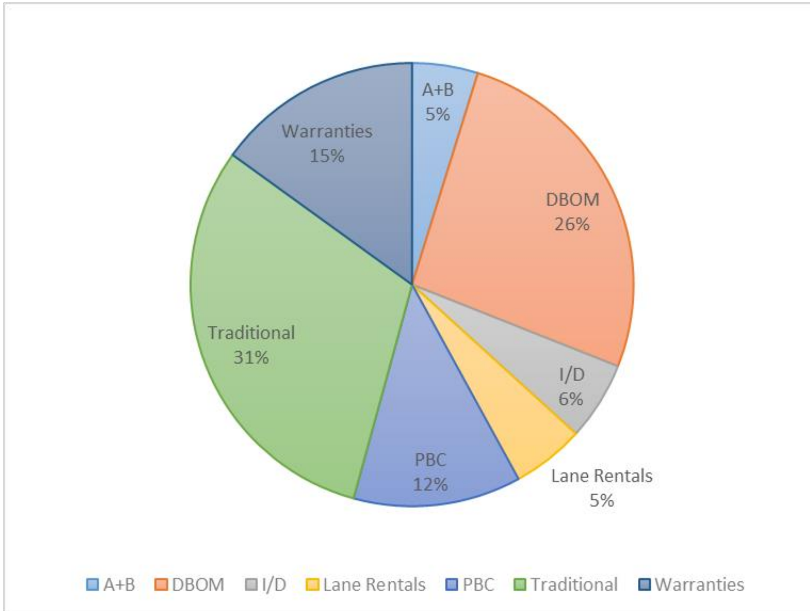

Figure 5.4 Distribution of contract types in USA

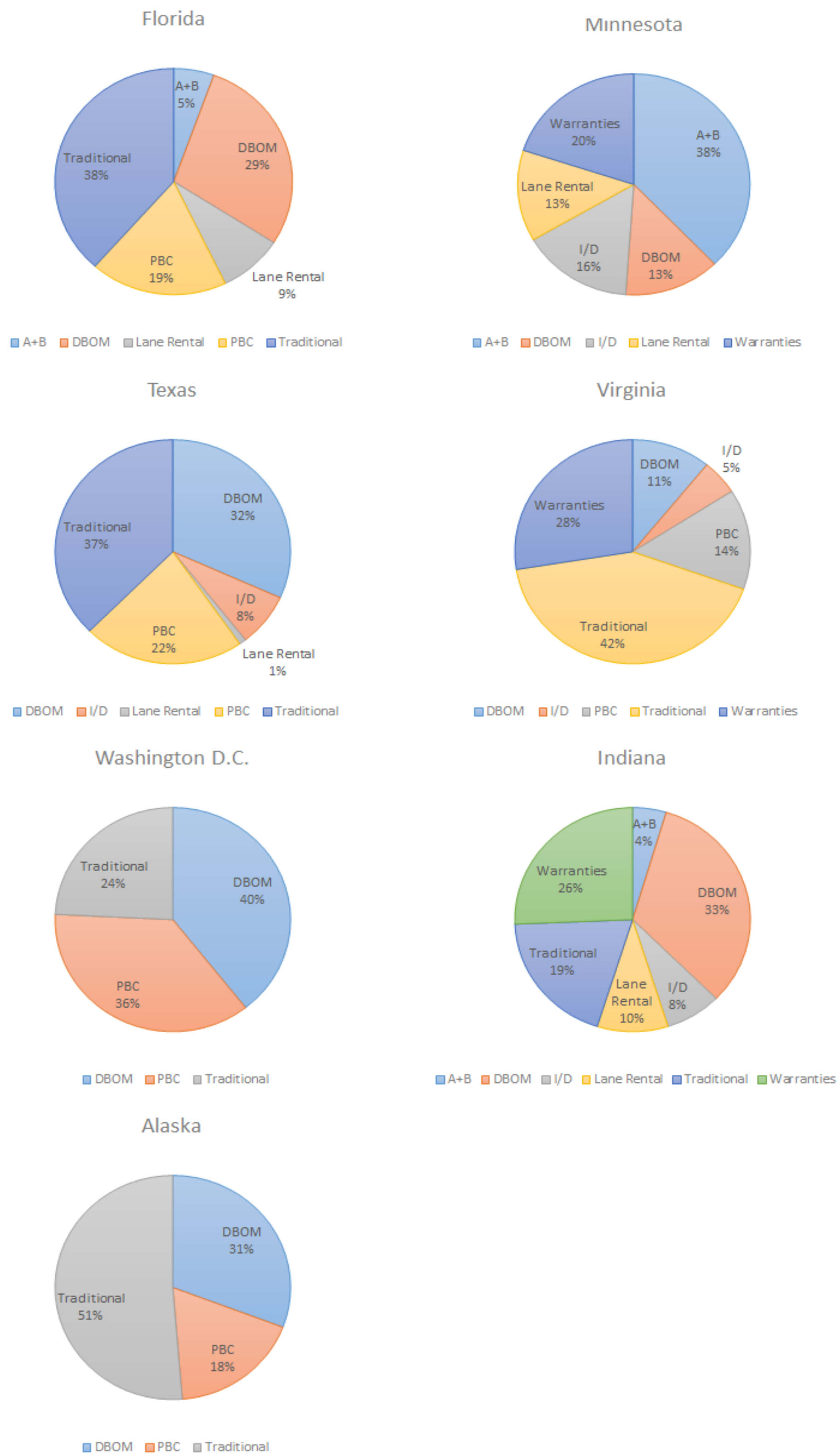

Figure 5.5 Contract types popularity in each State

Figure 5.6 presents the density of contract duration. It is shown that most of the contracts' duration is less than 6 years, and about 30 percent of the contracts have 5 to 6 years duration.

Figure 5.7 shows the contract duration in the USA. It is shown that about 44 percent of the contracts have a duration of 5 to 7 years.

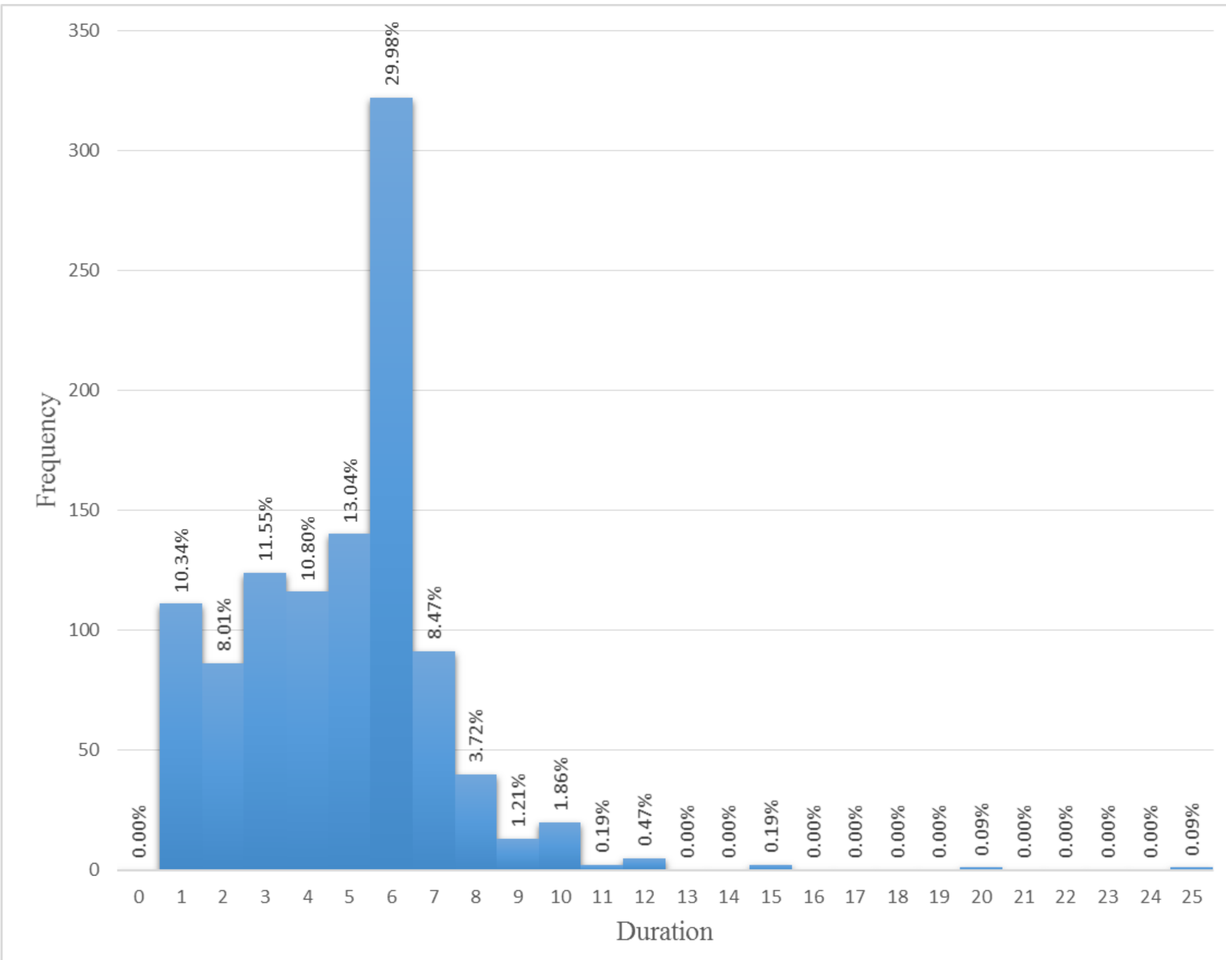

Figure 5.6 Frequency of project duration (in years) (All Regions)

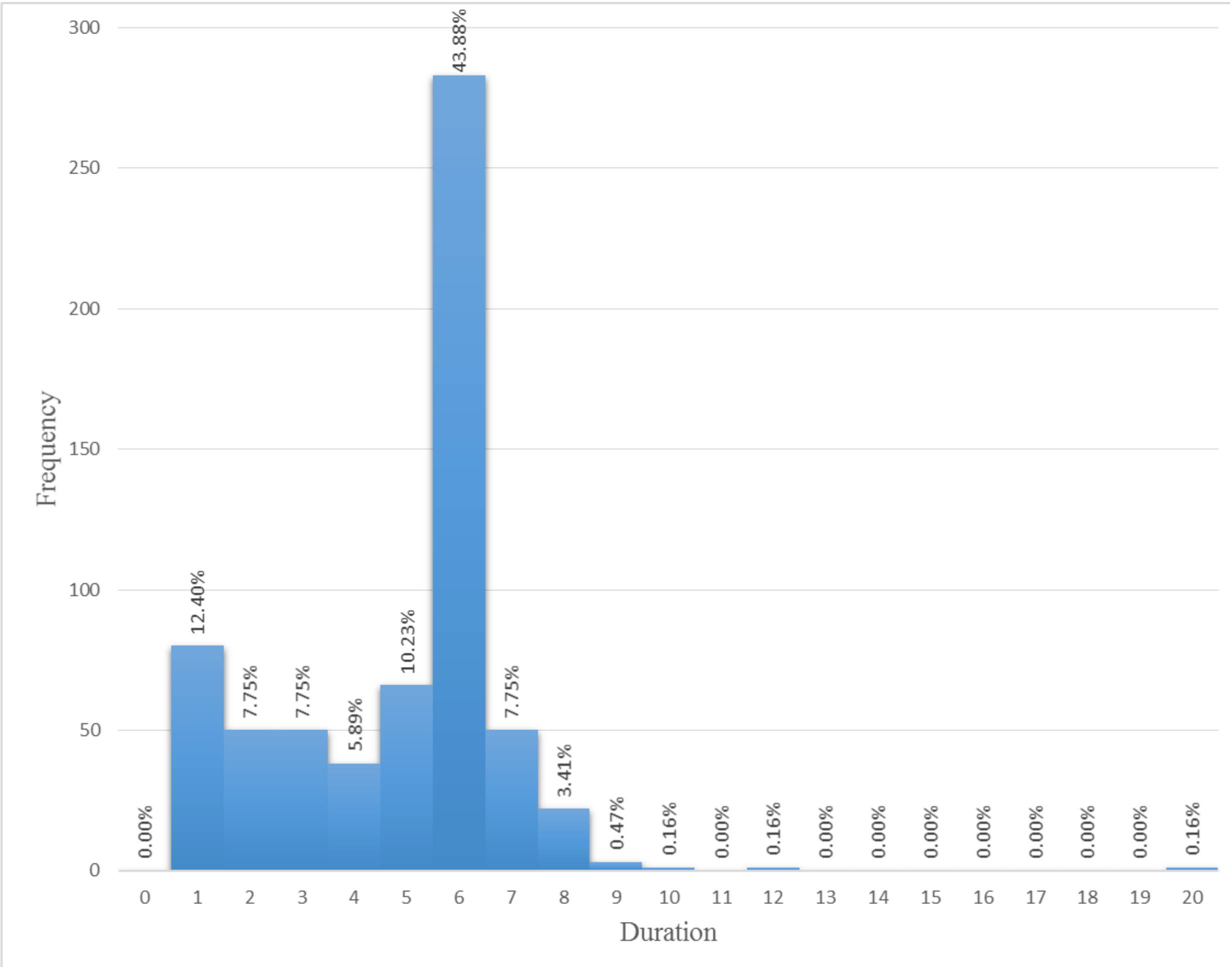

Figure 5.7 Frequency of project duration (in years) (the USA Data)

Figure 5.8 presents the average duration of the project in the USA states. The longer contract durations are observed in Alaska, Virginia, and Washington D.C.

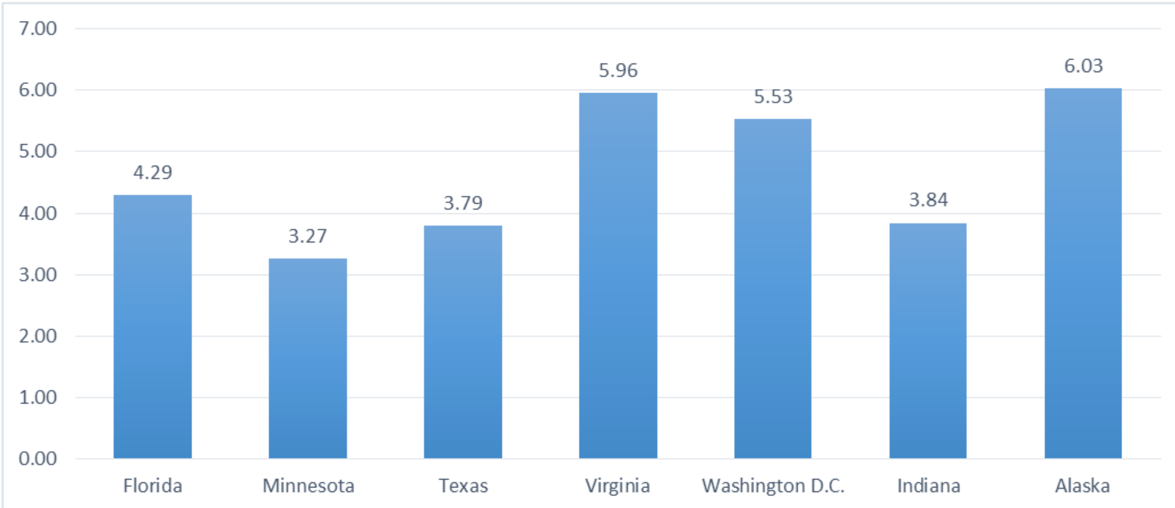

Figure 5.8 Average duration (in years) of the project in the USA states

Figure 5.9 presents the average contract duration by contract type in the USA. It is shown that design-build and its derivatives and PBCs last the longest.

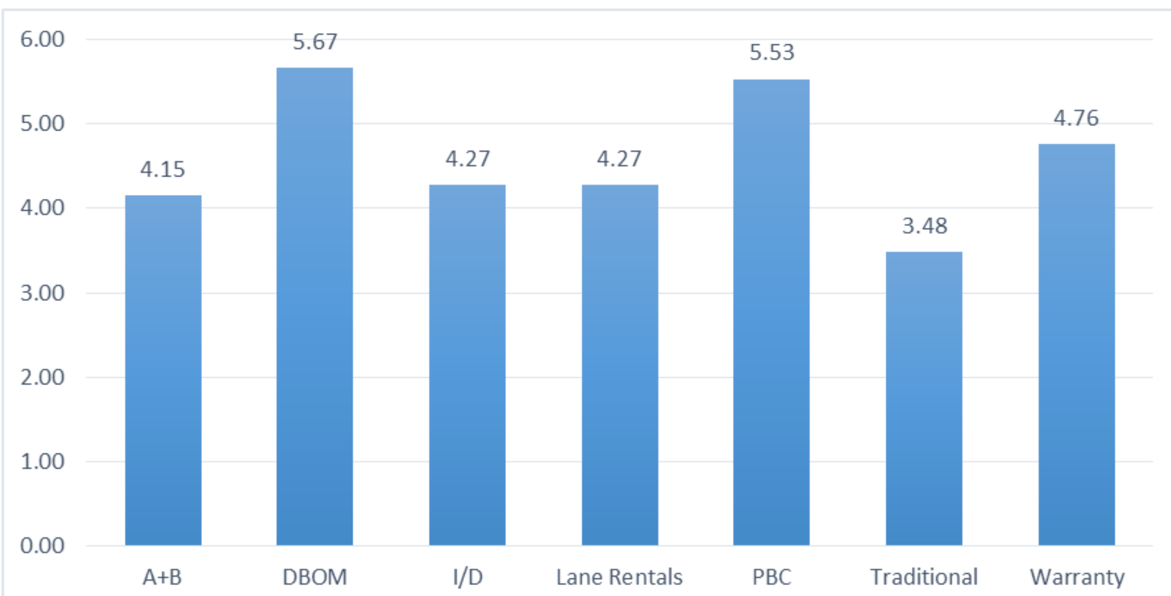

Figure 5.9 Average duration (in years) by each contract type in the USA

As far as the size of the contract is concerned, Figure 5.10 shows that about 71 percent of the contracts have less than 100 lane-miles size. Note that 96 percent of the contracts have less than 500 lane-miles.

Figure 5.11 presents the contract size for USA contracts, where it is shown that about 79 percent of the contracts are less than 100 lane-miles long.

Figure 5.12 presents the average size of the contracts by contract type in the USA. It is shown that PBCs have the greatest average size (in lane-miles).

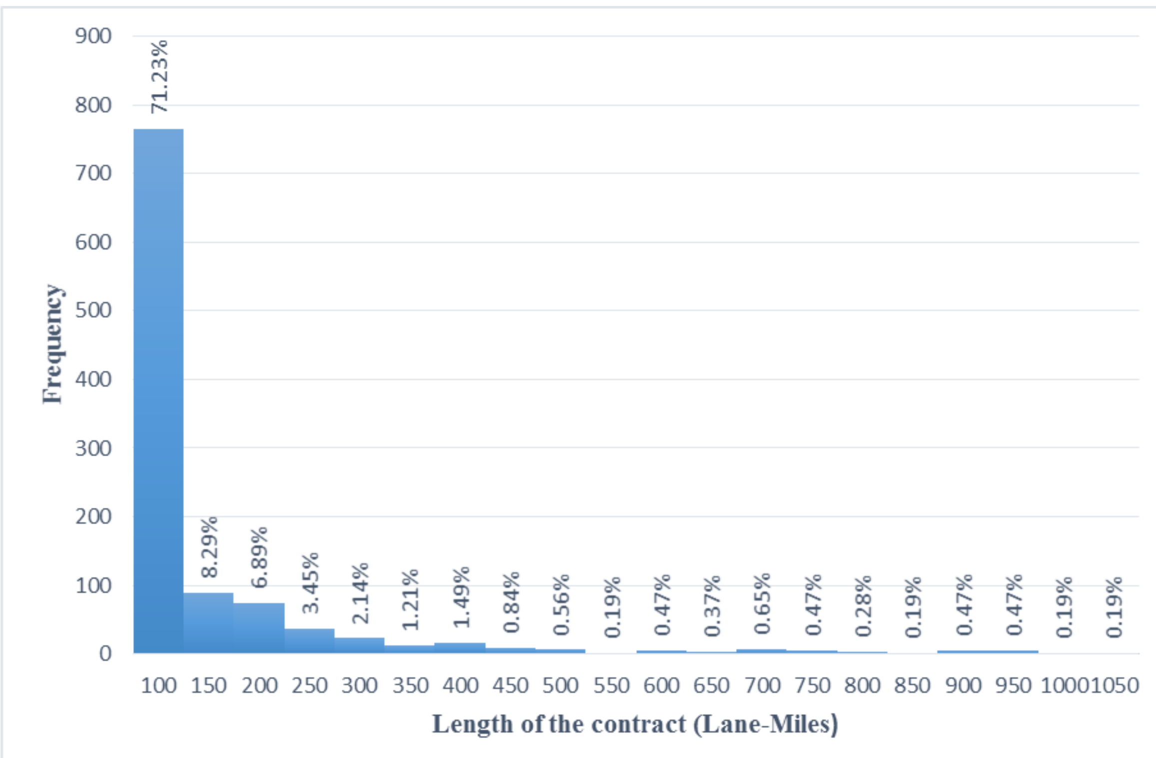

Figure 5.10 Contract size (in lane miles)

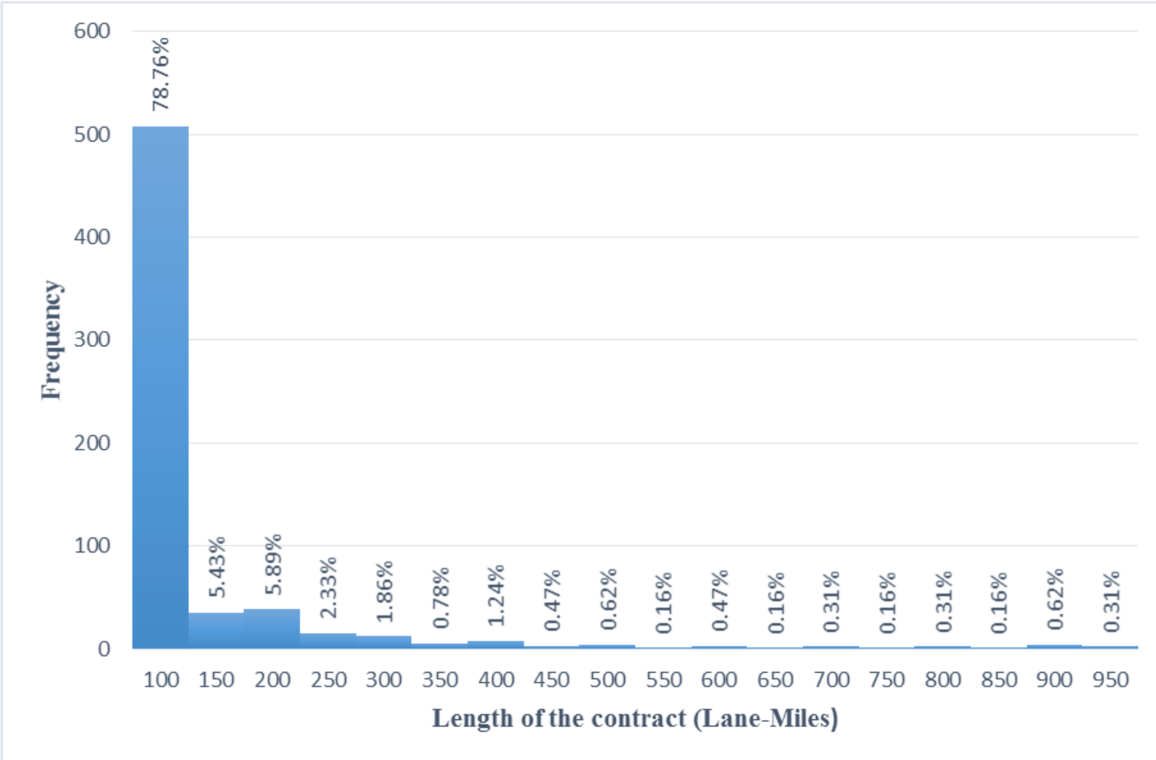

Figure 5.11 Size (in lane-miles) of the contract frequency (USA Data)

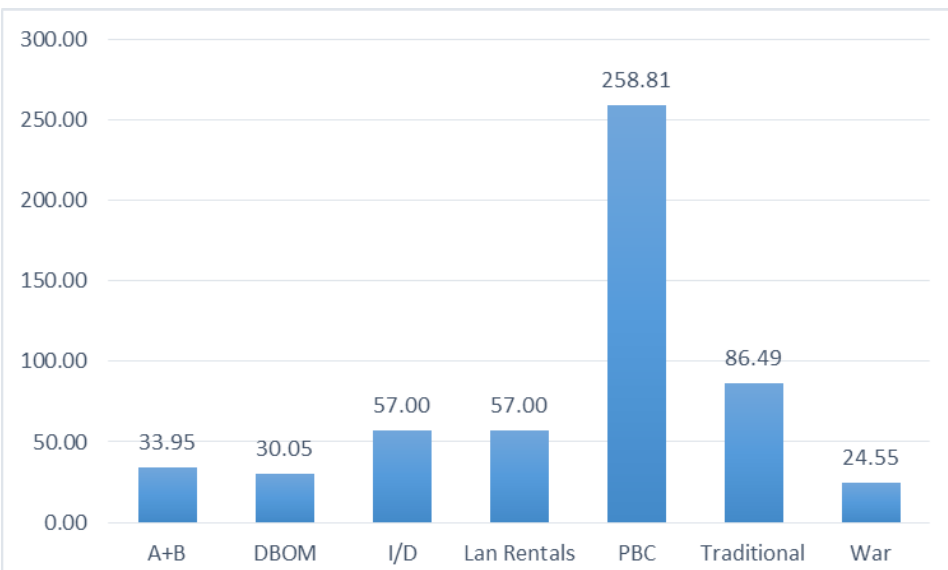

Figure 5.12 Average size (in lane-miles) of the contracts by contract types (USA Data)

Figure 5.13 presents the average size of the contract by US States. Contracts in Florida, Texas, and Washington D.C. have the largest contracts (in lane-miles) among all other states.

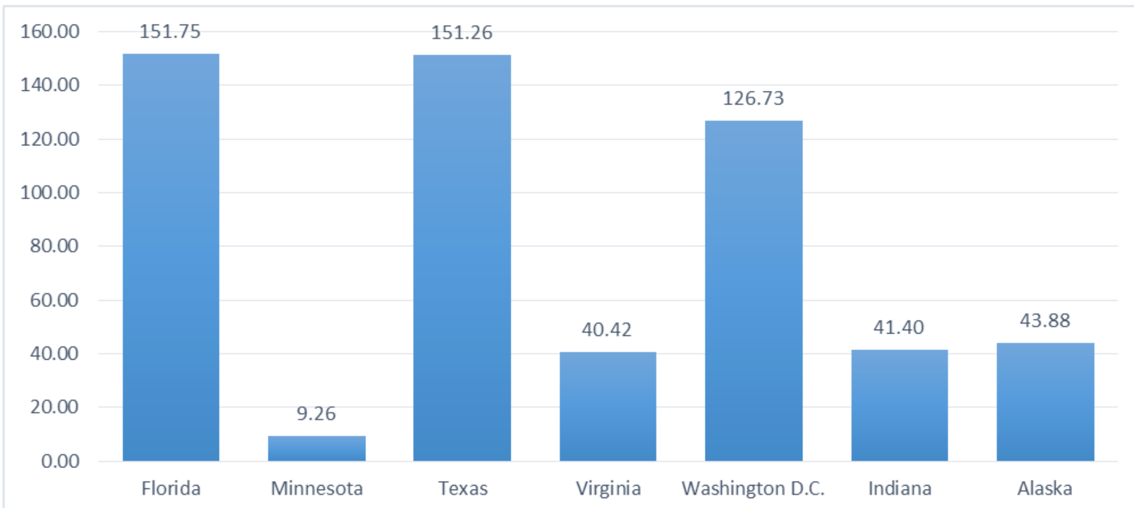

Figure 5.13 Average Size (in lane-miles) of the Contract by States

Table 5.1 Summary of the Descriptive Statistics

Variables	Rest of the World	United States							
	Mean (Std. Dev.)	Mean (Std. Dev.)	A+B Mean (Std. Dev.)	DBOM Mean (Std. Dev.)	I/D Mean (Std. Dev.)	Lane Rental Mean (Std. Dev.)	PBC Mean (Std. Dev.)	Traditional Mean (Std. Dev.)	Warranty Mean (Std. Dev.)
Duration of the contract (in years)	4.486 (2.407)	4.528 (2.203)	4.151 (1.531)	5.667 (0.852)	4.273 (1.547)	2.614 (0.529)	5.532 (1.573)	3.478 (2.500)	4.761 (2.816)
Size of the contract (in lane-miles)	102.222 (164.177)	76.746 (142.530)	33.948 (40.335)	30.053 (31.679)	57.004 (58.848)	38.516 (33.160)	258.808 (270.234)	86.485 (123.411)	24.549 (80.171)
Number of Assets	2.059	2.025	2.581	1.627	1.730	2.382	1.544	2.278	2.402
Cost of the contract (in $1M)	36.961 (59.790)	21.858 (36.552)	9.587 (9.669)	27.715 (28.926)	19.332 (20.994)	11.255 (9.167)	60.103 (63.314)	7.008 (19.287)	19.419 (37.930)
Cost saving (percent)	4.400 (0.117)	0.031 (0.118)	0.099 (0.092)	0.000 (0.0532)	0.146 (0.083)	0.085 (0.053)	0.069 (0.084)	0.019 (0.156)	-0.003 (0.123)
Cost of contract award (in $1M)	36.207 (66.026)	20.731 (35.009)	10.766 (13.316)	25.143 (25.243)	19.465 (19.171)	10.338 (9.224)	63.307 (65.834)	6.346 (16.223)	15.041 (27.684)
Cost overrun (in $100K)	7.539 (187.599)	11.273 (97.093)	-11.789 (57.439)	25.727 (76.208)	-1.329 (67.129)	9.171 (21.529)	-32.047 (157.454)	6.622 (69.799)	43.782 (129.601)
Cost overrun (percent)	13.400 (0.328)	0.154 (0.362)	0.034 (0.302)	0.126 (0.223)	0.007 (0.234)	0.126 (0.178)	-0.031 (0.159)	0.236 (0.530)	0.291 (0.243)
Time Delay (percent)	0.248 (0.349)	0.274 (0.330)	-0.195 (0.285)	0.496 (0.046)	-0.181 (0.220)	0.256 (0.087)	-0.183 (0.294)	0.355 (0.252)	0.427 (0.180)
Number of change orders	4.468	4.040	0.871	3.888	2.216	3.706	4.418	4.242	5.412
Truck percentage	16.100 (0.117)	0.150 (0.113)	0.157 (0.117)	0.149 (0.108)	0.169 (0.143)	0.148 (0.074)	0.136 (0.096)	0.147 (0.114)	0.162 (0.126)
Average AADT (in 1000 veh/day)	15.928 (18.873)	12.909 (16.778)	12.754 (20.281)	12.581 (16.066)	21.664 (28.960)	7.497 (5.254)	18.206 (18.496)	12.181 (15.564)	9.260 (11.790)
Average of International Roughness Index (inches)	108.956 (37.579)	108.633 (41.278)	114.856 (35.428)	114.859 (45.852)	95.016 (28.960)	103.363 (35.607)	106.411 (30.552)	106.860 (39.148)	108.266 (50.320)

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Table 5.1 Summary of the Descriptive Statistics (Continued)

Variables	Rest of the World	United States							
	Mean (Std. Dev.)	Mean (Std. Dev.)	A+B Mean (Std. Dev.)	DBOM Mean (Std. Dev.)	I/D Mean (Std. Dev.)	Lane Rental Mean (Std. Dev.)	PBC Mean (Std. Dev.)	Traditional Mean (Std. Dev.)	Warranty Mean (Std. Dev.)
Standard Deviation of International Roughness Index (inches)	26.288 (21.599)	25.716 (23.331)	28.345 (19.479)	28.052 (35.559)	21.977 (28.428)	25.636 (17.336)	24.103 (14.130)	24.379 (16.238)	26.302 (20.846)
Average of Pavement Condition Rating	88.131 (4.235)	88.293 (4.598)	87.313 (3.987)	87.653 (4.270)	89.689 (4.079)	88.412 (4.743)	88.149 (4.113)	88.609 (4.449)	88.621 (5.877)
Standard Deviation of Pavement Condition Rating	7.844 (3.067)	7.652 (3.039)	9.111 (3.053)	7.707 (3.078)	7.040 (2.088)	8.0186 (3.287)	8.068 (2.918)	7.528 (3.017)	7.110 (2.947)
Average of Rutting Depth (inches/mile)	0.161 (0.066)	0.160 (0.073)	0.169 (0.062)	0.172 (0.076)	0.138 (0.060)	0.154 (0.062)	0.155 (0.059)	0.154 (0.068)	0.161 (0.094)
Standard Deviation of Rutting Depth (inches/mile)	0.057 (0.044)	0.0565 (0.046)	0.042 (0.027)	0.059 (0.041)	0.051 (0.033)	0.051 (0.029)	0.056 (0.043)	0.059 (0.054)	0.056 (0.049)
Number of accidents	14.661	12.915	14.323	13.899	8.432	9.000	15.139	14.258	9.278
Number of lanes	2.145	2.098	2.161	2.207	1.919	2.147	2.228	1.995	2.041
Median width (in feet)	26.391 (41.527)	23.76279 (40.468)	20.452 (26.867)	31.787 (46.354)	13.892 (23.310)	31.529 (45.791)	24.228 (41.761)	21.283 (38.359)	16.567 (34.626)
Interior shoulder width (in feet)	6.861 (4.586)	6.676 (4.543)	6.839 (3.975)	7.003 (4.771)	5.986 (4.481)	6.618 (4.987)	6.101 (4.282)	6.810 (4.512)	6.532 (4.494)
Outside shoulder width (in feet)	9.412 (4.620)	9.437 (4.588)	9.300 (5.068)	9.286 (4.958)	9.308 (4.470)	8.241 (4.610)	9.222 (4.332)	9.776 (4.439)	9.695 (4.334)
Level of Service (LOS)	3.407	3.214	3.290	3.213	3.405	3.441	3.696	3.172	2.732
Number of Observations	1074	645	31	169	37	34	79	198	97

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5.5 Chapter Summary

This Chapter provided an overview of the data used in this study. The next Chapter presents the model estimation results along with a discussion of the major findings.

CHAPTER 6. ANALYSIS RESULTS

6.1 Introduction

This Chapter presents the model estimation results of the statistical models presented in Chapter 4.

6.2 Cost Savings and Cost Overrun Model Estimation Results

The subsequent Chapters summarize the cost saving and cost overrun model estimation results.

6.2.1 Cost Savings Percentage Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.1 to 6.11.[5] The results can be summarized as follows:

- The project's size, in terms of segment size measured in lane-miles, is found to affect the percent of cost savings. Contracts with high project size (with longer roadway segments) have higher cost savings, as opposed to shorter projects (shorter

[5] Actual vs. Predicted values for some of the models are presented in Appendix B.

- roadway segments). On many occasions, project size has variable effect on cost savings by PPP type. For example, the percentage of cost savings increases in 72 percent of cost-plus-time (random parameter with Normal distribution), 68 percent of PBC (random parameter with Normal distribution), design-build and its derivatives, I/D and warranties while the size of the contract decreases. Previously, Anastasopolous et al. (2010) found that it is more likely for contracts with less than 10 lane-miles in size to have higher cost savings.
- Contracts with duration more than 2 years decrease cost savings for warranties, traditional, design-build and its derivatives, and cost-plus-time contracts.
- Cost savings percentage is also affected by the number of assets. Having 3 or more number of assets in the projects generally reduce the percentage of cost savings, and increase the percentage of loss. This result is in line with previous studies (Anastasopolous et al., 2010).
- The results show that, when the cost of the contact is higher than $11.5M in design-build contracts, the percentage of cost saving increases. However, under the lane rental approach the effect of the cost on contracts with higher than $600K is negative on the cost savings percentage. This is intuitive, as lane rental contracts are appropriate for smaller projects; therefore, high-cost projects contracted under lane rentals can result in loss. Past work also shows that contracts with higher costs are less likely to experience change orders, cost overrun and loss (Anastasopoulos et al. 2010).

- Several activities are found to increase the percentage of cost savings (pavement repair, maintenance and treatment under design-build contracting; culvert, ditches, gutters, drainage repair, maintenance and replacement, or mowing, vegetation, tree control, maintenance and removal under lane rentals and PBCs). On the other hand a number of activities are found to generally reduce cost savings (culvert, ditches, gutters drainage repair, maintenance, and replacement or guardrail repair, for incentives/disincentives contracts; mowing and litter removal for warranty contracts; rest areas and electrical cable system repair, and maintenance for PBCs). The results are intuitive considering the nature of the activities and contract types. For example, a PBC including only rest area maintenance is anticipated to result in lower cost savings, considering the comprehensive nature of PBC (typically, long-term and comprehensive PBCs result in significant life-cycle cost savings), and the low intensity work required for the rest area work.
- The factors that their effect varies across the observations are also presented in Tables 6.1 to 6.11, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant

Table 6.1 Descriptive Statistics of Cost Savings Percentage Models

Variables	Mean	Std. Dev	Min.	Max.
Region Indicator (1 if Europe, 0 otherwise) [Full Model]	0.100	-	0	1
Region Indicator (1 if North America, 0 otherwise) [Full Model]	0.686	-	0	1
Region Indicator (1 if Pacific, 0 otherwise) [Full Model]	0.050	-	0	1
State Indicator (1 if Minnesota, 0 otherwise) [Full Model]	0.042	-	0	1
State Indicator (1 if Minnesota, 0 otherwise) [USA Model]	0.070	-	0	1
State Indicator (1 if Virginia, 0 otherwise) [Full Model]	0.128	-	0	1
Contract Type				
Contract Indicator (1 if A+B, 0 otherwise) [Full Model]	0.076	-	0	1
Contract Indicator (1 if Design-Build, 0 otherwise) [USA Model]	0.262	-	0	1
Contract Indicator (1 if Lane Rental, 0 otherwise) [Full Model]	0.072	-	0	1
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [Full Model]	0.134	-	0	1
Contract Indicator (1 if Traditional, 0 otherwise) [USA Model]	0.307	-	0	1
Contract Indicator (1 if Warranty, 0 otherwise) [Full Model]	0.156	-	0	1
Contract Indicator (1 if Warranty, 0 otherwise) [USA Model]	0.150	-	0	1
Contract Characteristics				
Bid range indicator (1 if less than 7150000 $, 0 otherwise) [Full Model]	0.790	-	0	1
Bid range indicator (1 if less than 7150000 $, 0 otherwise) [USA Model]	0.916	-	0	1
Cost of contract indicator (1 if 0.5 years and less, 0 otherwise) [PBC]	0.481	-	0	1
Cost of contract indicator (1 if greater than $11.5M , 0 otherwise) [DBOM]	0.858	-	0	1
Cost of contract indicator (1 if higher than $0.6 M, 0 otherwise) [Lane Rental]	0.882	-	0	1
Duration of contract indicator (1 if between 5.2 and 6 years, 0 otherwise) [A+B]	0.194	-	0	1
Duration of contract indicator (1 if greater than 4 years, 0 otherwise) [DBOM]	0.959	-	0	1
Duration of contract indicator (1 if greater than 6 years, 0 otherwise) [Warranties]	0.062	-	0	1
Duration of contract indicator (1if less than 2, 0 otherwise) [Traditional]	0.409	-	0	1
Duration/Extension of contract indicator (1 if less than 3 years extension or 6.5 year or less duration, 0 otherwise) [Full Model]	0.916	-	0	1
Inverse of the Cost of the Contract [Full Model]	0.132	0.751	0	20
Inverse of the Cost of the Contract Award (in 100k $) [USA Model]	0.000	0.001	.4D-06	0.007
Inverse of the Cost of the Contract Award [Full Model]	0.000	0	0	0.007

Table 6.1 Descriptive Statistics of Cost Savings Percentage Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Inverse of the squared of size of contract (in lane-miles) [I/D]	82.483	413.962	0.001	2500
Size of contract indicator (1 if less than 120 lane-miles, 0 otherwise) [PBC]	0.392	-	0	1
Size of the contract (1 if greater than 160 Lane-Miles, 0 otherwise) [USA Model]	0.149	-	0	1
Size of the contract (1 if less than 18 Lane-Miles, 0 otherwise) [A+B]	0.581	-	0	1
Size of the contract indicator (in 1000th of lane-miles) [DBOM]	0.030	0.032	0	0.25
Size of the contract indicator(1 if greater than 180 Lane-Miles, 0 otherwise) [Full Model]	0.152	-	0	1
Natural Logarithm of square of size of contract (in lane-miles) [Warranties]	4.936	7.772	0.001	38.53
Number of Assets indicator (1 if 3 or less assets, 0 otherwise) [Warranties]	0.825	-	0	1
Number of Assets indicator (1 if less than 2, 0 otherwise) [PBC]	0.595	-	0	1
Number of Assets indicator (1 if equal to 2, 0 otherwise) [A+B]	0.387	-	0	1
Number of Assets indicator (1 if equal to 2, 0 otherwise) [I/D]	0.351	-	0	1
Number of Assets indicator (1 if less than 2, 0 otherwise) [Traditional]	0.662	-	0	1
Number of Assets indicator (1 if less than 2, 0 otherwise) [USA Model]	0.605	-	0	1
Number of Bids indicator (1 if greater than 3, 0 otherwise) [USA Model]	0.236	-	0	1
Road Geometry and Pavement Condition and Traffic Characteristics				
Average Annual Daily Traffic indicator(1 if less than 9000, 0 otherwise) [USA Model]	0.611	-	0	1
Highway indicator (1 if highway, 0 otherwise) [Traditional]	0.813	-	0	1
Inside shoulder width (1 if less than 10 feet, 0 otherwise) [USA Model]	0.724	-	0	1
Median Width (1 if between 50 feet to 80 feet, 0 otherwise) [USA Model]	0.070	-	0	1
Outside shoulder width (1 if greater than 12.1 feet, 0 otherwise) [Full Model]	0.328	-	0	1
Percent of Combination Trucks [Full Model]	0.161	0.117	0	0.65
Road type indicator (1 if urban, 0 otherwise) [Traditional]	0.808	-	0	1
Standard Deviation of IRI (1 if between 11 and 39 inches per mile, 0 otherwise) [USA Model]	0.705	-	0	1
Standard Deviation of IRI (1 if less than 4 inches per mile, 0 otherwise) [Full Model]	0.077	-	0	1
Standard Deviation of PCR (1 if less than 1, 0 otherwise) [Full Model]	0.060	-	0	1
Standard Deviation of Rutting Depth (1 if less than 0.02 inches,0 otherwise) [USA Model]	0.611	-	0	1

Table 6.1 Descriptive Statistics of Cost Savings Percentage Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Asset Type				
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement or mowing or vegetation/ tree control/ maintenance/ removal , 0 otherwise) [PBC]	0.127	-	0	1
Asset type indicator (1 if Culvert/ Ditches/ Gutters/Drainage repair/ maintenance/ replacement or Guardrail repair/ maintenance, 0 otherwise) [Lane Rental]	0.118	-	0	1
Asset type indicator (1 if electrical/ cable system repair/maintenance or rest areas, 0 otherwise) [PBC]	0.089	-	0	1
Asset type indicator (1 if illumination repair/ maintenance, 0 otherwise) [Warranties]	0.072	-	0	1
Asset type indicator (1 if landscape repair/ maintenance, 0 otherwise) [Warranties]	0.072	-	0	1
Asset type indicator (1 if litter removal or mowing, 0 otherwise) [Warranties]	0.062	-	0	1
Asset type indicator (1 if Mowing, 0 otherwise) [Traditional]	0.086	-	0	1
Asset type indicator (1 if Pavement repair/ maintenance/treatment, 0 otherwise) [DBOM]	0.136	-	0	1
Weather Condition				
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.12, 0 otherwise) [USA Model]	0.938	-	0	1
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.25, 0 otherwise) [Full Model]	0.556	-	0	1
Weather indicator (1 if the proportion of snowy days to total days of contract is greater than 0.08, 0 otherwise) [Full Model]	0.160	-	0	1
Weather indicator (1 if the proportion of snowy days to total days of contract is greater than 0.08, 0 otherwise) [USA Model]	0.098	-	0	1

Table 6.2 Cost savings percentage (OLS) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Region Indicator (1 if Pacific, 0 otherwise)	4.214	5.020	0.000
Region Indicator (1 if Europe, 0 otherwise)	17.221	20.060	0.000
Region Indicator (1 if North America, 0 otherwise)	2.723	5.640	0.000
Standard deviation of parameter density function	8.954	56.730	0.000
State Indicator (1 if Virginia, 0 otherwise)	3.364	6.250	0.000
Standard deviation of parameter density function	6.091	14.530	0.000
State Indicator (1 if Minnesota, 0 otherwise)	4.125	4.600	0.000
Standard deviation of parameter density function	8.327	10.590	0.000
Contract Type			
Contract Indicator (1 if Lane Rental, 0 otherwise)	8.428	9.980	0.000
Contract Indicator (1 if Performance-Based Contract, 0 otherwise)	6.354	12.400	0.000
Contract Indicator (1 if Warranty, 0 otherwise)	-8.375	-19.020	0.000
Contract Indicator (1 if A+B, 0 otherwise)	8.280	10.030	0.000
Contract Characteristics			
Inverse of the Cost of the Contract Award	3605.010	7.640	0.000
Inverse of the Cost of the Contract	0.793	2.510	0.012
Bid range (1 if less than 7150000 $, 0 otherwise)	-2.790	-5.480	0.000
Size of the contract (1 if greater than 180 Lane-Miles, 0 otherwise)	-1.133	-2.340	0.019
Standard deviation of parameter density function	*7.777*	*22.730*	*0.000*
Duration/Extension of contract indicator (1 if less than 3 years extension or 6.5 year or less duration, 0 otherwise)	1.200	2.320	0.020
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of IRI (1 if less than 4 inches per mile, 0 otherwise)	-4.384	-2.170	0.030
Standard Deviation of PCR (1 if less than 1, 0 otherwise)	9.079	2.360	0.018
Outside shoulder width (1 if greater than 12.1 feet, 0 otherwise)	-1.441	-4.170	0.000
Percent of Combination Trucks	6.897	5.010	0.000
Standard deviation of parameter density function	9.504	13.230	0.000
Weather Condition			
Weather indicator (1 if the proportion of snowy days to total days of contract is greater than 0.08, 0 otherwise)	-1.307	-2.570	0.010
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.25, 0 otherwise)	-1.097	-2.940	0.003
Model Summary			
Number of Observations	1074		
R-Squared	0.895		
Adjusted R-Squared	0.892		

Table 6.3 Cost savings percentage (OLS) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-29.905	-4.280	0.000
Standard deviation of parameter density function	1.323	16.110	0.000
State Indicator (1 if Minnesota, 0 otherwise)	5.892	8.380	0.000
Contract Type			
Contract Indicator (1 if Traditional, 0 otherwise)	-7.027	-14.330	0.000
Standard deviation of parameter density function	8.544	29.140	0.000
Contract Indicator (1 if Warranty, 0 otherwise)	-8.387	-16.250	0.000
Contract Indicator (1 if Design-Build, 0 otherwise)	-8.245	-15.320	0.000
Contract Characteristics			
Inverse of the Cost of the Contract Award (in 100k Dollars)	7.097	18.990	0.000
Standard deviation of parameter density function	12.183	30.560	0.000
Number of Assets indicator (1 if less than 2, 0 otherwise)	1.815	4.880	0.000
Number of Bids indicator (1 if greater than 3, 0 otherwise)	0.858	2.070	0.038
Bid range indicator (1 if less than 7150000 $, 0 otherwise)	-8.130	-12.470	0.000
Size of the contract (1 if greater than 160 Lane-Miles, 0 otherwise)	-8.412	-16.680	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of IRI (1 if between 11 and 39 inches per mile, 0 otherwise)	-0.867	-2.250	0.024
Standard Deviation of Rutting Depth (1 if less than 0.02 inches, 0 otherwise)	-0.982	-2.060	0.040
Inside shoulder width (1 if less than 10 feet, 0 otherwise)	-1.001	-2.610	0.009
Standard deviation of parameter density function	2.908	30.510	0.000
Median Width (1 if between 50 feet to 80 feet, 0 otherwise)	-9.477	-14.820	0.000
Standard deviation of parameter density function	20.277	32.440	0.000
Average Annual Daily Traffic indicator (1 if less than 9000, 0 otherwise)	-0.637	-1.750	0.081
Weather Condition			
Weather indicator (1 if the proportion of snowy days to total days of contract is greater than 0.08, 0 otherwise)	-3.840	-6.290	0.000
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.012, 0 otherwise)	46.679	6.720	0.000
Model Summary			
Number of Observations	645		
R-Squared	0.948		
Adjusted R-Squared	0.946		

Table 6.4 Cost savings percentage (OLS) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	0.433	3.060	0.002
Contract Characteristics			
Size of the contract (1 if less than 18 Lane-Miles, 0 otherwise)	0.478	2.700	0.007
Standard deviation of parameter density function	0.831	8.300	0.000
Duration of contract indicator (1 if between 5.2 and 6 years, 0 otherwise)	0.587	2.290	0.022
Number of Assets indicator (1 if equal to 2, 0 otherwise)	0.406	1.840	0.007
Model Summary			
Number of Observations	31		
R-Squared	0.857		
Adjusted R-Squared	0.820		

Table 6.5 Cost savings percentage (OLS) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Size of the contract (in 1000th of lane-miles)	-25.503	-6.330	0.000
Standard deviation of parameter density function	10.198	5.160	0.000
Duration of contract indicator (1 if greater than 4 years, 0 otherwise)	-0.645	-1.870	0.062
Cost of contract (1 if greater than $11.5M , 0 otherwise)	2.070	5.400	0.000
Assets Type			
Asset type indicator (1 if Pavement repair/ maintenance/ treatment, 0 otherwise)	29.229	2.405	0.016
Model Summary			
Number of Observations	169		
R-Squared	0.841		
Adjusted R-Squared	0.834		

Table 6.6 Cost savings percentage (OLS) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	17.865	23.260	0.000
Standard deviation of parameter density function	5.813	9.580	0.000
Contract Characteristics			
Number of Assets indicator (1 if equal to 2, 0 otherwise)	-8.035	-6.560	0.000
Inverse of square of size of contract (in lane-miles)	-0.007	-3.970	0.000
Model Summary			
Number of Observations	37		
R-Squared	0.948		
Adjusted R-Squared	0.939		

Table 6.7 Cost savings percentage (OLS) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	13.095	29.470	0.000
Contract Information			
Cost of contract indicator (1 if higher than $0.6 M, 0 otherwise)	-4.316	-3.750	0.000
Assets Type			
Asset type indicator (1 if Culvert/ Ditches/ Gutters/ Drainage repair/ maintenance/ replacement or Guardrail repair/ maintenance, 0 otherwise)	-6.163	-4.010	0.000
Standard deviation of parameter density function	11.973	9.830	0.000
Model Summary			
Number of Observations	34		
R-Squared	0.838		
Adjusted R-Squared	0.809		

Table 6.8 Cost savings percentage (OLS) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Size of contract indicator (1 if less than 120 lane-miles, 0 otherwise)	5.648	7.000	0.000
Standard deviation of parameter density function	12.286	15.770	0.000
Cost of contract indicator (1 if 0.5 years and less, 0 otherwise)	4.710	5.430	0.000
Number of Assets (1 if less than 2, 0 otherwise)	4.203	6.540	0.000
Standard deviation of parameter density function	4.420	9.350	0.000
Assets Types			
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement or mowing or vegetation/ tree control/ maintenance/ removal , 0 otherwise)	7.013	5.310	0.000
Asset type indicator (1 if electrical/ cable system repair/ maintenance or rest areas, 0 otherwise)	-16.361	-9.280	0.000
Model Summary			
Number of Observations	79		
R-Squared	0.930		
Adjusted R-Squared	0.922		

Table 6.9 Cost savings percentage (OLS) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Number of assets indicator (1 if less than 2, 0 otherwise)	9.807	5.100	0.000
Duration of the contract (1if less than 2, 0 otherwise)	7.246	5.260	0.000
Road Geometry			
Highway indicator (1 if highway, 0 otherwise)	-4.583	-2.260	0.024
Standard deviation of parameter density function	6.278	12.350	0.000
Road type indicator (1 if urban, 0 otherwise)	-4.471	-3.070	0.002
Standard deviation of parameter density function	2.319	6.190	0.000
Assets type			
Asset type indicator (1 if Mowing, 0 otherwise)	-7.859	-2.880	0.004
Standard deviation of parameter density function	6.393	2.820	0.005
Model Summary			
Number of Observations	198		
R-Squared	0.755		
Adjusted R-Squared	0.743		

Table 6.10 Cost savings percentage (OLS) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Duration of contract indicator (1 if greater than 6 years, 0 otherwise)	-25.296	-7.830	0.000
Standard deviation of parameter density function	24.154	7.920	0.000
Natural Logarithm of square of size of contract (in lane-miles)	-0.313	-4.360	0.000
Number of assets (1 if 3 or less assets, 0 otherwise)	3.251	3.530	0.000
Standard deviation of parameter density function	0.916	2.290	0.022
Assets Type			
Asset type indicator (1 if landscape repair/ maintenance, 0 otherwise)	-9.654	-2.180	0.029
Asset type indicator (1 if illumination repair/ maintenance, 0 otherwise)	-7.762	-2.170	0.030
Standard deviation of parameter density function	6.134	2.010	0.044
Asset type indicator (1 if litter removal or mowing, 0 otherwise)	21.666	4.060	0.000
Standard deviation of parameter density function	14.462	4.340	0.000
Model Summary			
Number of Observations	97		
R-Squared	0.760		
Adjusted R-Squared	0.744		

Table 6.11 Summary of Cost Savings Results

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Region Indicator (1 if Europe, 0 otherwise) [Full Model]	↑								
Region Indicator (1 if North America, 0 otherwise) [Full Model]	(↑)								
Region Indicator (1 if Pacific, 0 otherwise) [Full Model]	↑								
State Indicator (1 if Minnesota, 0 otherwise) [Full Model]	(↑)								
State Indicator (1 if Minnesota, 0 otherwise) [USA Model]		↑							
State Indicator (1 if Virginia, 0 otherwise) [Full Model]	(↑)								
Contract Type									
Contract Indicator (1 if A+B, 0 otherwise) [Full Model]	↑								
Contract Indicator (1 if Design-Build, 0 otherwise) [USA Model]		↓							
Contract Indicator (1 if Lane Rental, 0 otherwise) [Full Model]	↑								
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [Full Model]	↑								
Contract Indicator (1 if Traditional, 0 otherwise) [USA Model]		(↓)							
Contract Indicator (1 if Warranty, 0 otherwise) [Full Model]	↓								
Contract Indicator (1 if Warranty, 0 otherwise) [USA Model]		↓							
Contract Characteristics									
Bid range indicator (1 if less than 7150000 $, 0 otherwise) [Full Model]	↓								
Bid range indicator (1 if less than 7150000 $, 0 otherwise) [USA Model]		↓							
Cost of contract indicator (1 if 0.5 years and less, 0 otherwise) [PBC]							↑		
Cost of contract indicator (1 if greater than $11.5M , 0 otherwise) [DBOM]				↑					
Cost of contract indicator (1 if higher than $0.6 M, 0 otherwise) [Lane Rental]						↓			
Duration of contract indicator (1 if between 5.2 and 6 years, 0 otherwise) [A+B]			↑						
Duration of contract indicator (1 if greater than 4 years, 0 otherwise) [DBOM]				↓					

Table 6.11 Summary of Cost Savings Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Duration of contract indicator (1 if greater than 6 years, 0 otherwise) [Warranties]									(↓)
Duration of contract indicator (1if less than 2, 0 otherwise) [Traditional]								↑	
Duration/Extension of contract indicator (1 if less than 3 years extension or 6.5 year or less duration, 0 otherwise) [Full Model]	↑								
Inverse of the Cost of the Contract [Full Model]	↑								
Inverse of the Cost of the Contract Award (in 100k $) [US Model]		(↑)							
Inverse of the Cost of the Contract Award [Full Model]	↑								
Inverse of the squared of size of contract (in lane-miles) [I/D]					↓				
Size of contract indicator (1 if less than 120 lane-miles, 0 otherwise) [PBC]							(↑)		
Size of the contract (1 if greater than 160 Lane-Miles, 0 otherwise) [USA Model]		↓							
Size of the contract (1 if less than 18 Lane-Miles, 0 otherwise) [A+B]			(↑)						
Size of the contract indicator (in 1000th of lane-miles) [DBOM]				(↓)					
Size of the contract indicator(1 if greater than 180 Lane-Miles, 0 otherwise) [Full Model]	(↓)								
Natural Logarithm of square of size of contract (in lane-miles) [Warranties]									↓
Number of Assets indicator (1 if 3 or less assets, 0 otherwise) [Warranties]									(↑)
Number of Assets indicator (1 if equal to 2, 0 otherwise) [A+B]			↑						
Number of Assets indicator (1 if equal to 2, 0 otherwise) [I/D]					↓				
Number of Assets indicator (1 if less than 2, 0 otherwise) [PBC]							(↑)		
Number of Assets indicator (1 if less than 2, 0 otherwise) [Traditional]								↑	
Number of Assets indicator (1 if less than 2, 0 otherwise) [USA Model]		↑							
Number of Bids indicator (1 if greater than 3, 0 otherwise) [USA Model]		↑							

Table 6.11 Summary of Cost Savings Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Road Geometry and Pavement Condition and Traffic Characteristics									
Average Annual Daily Traffic indicator(1 if less than 9000, 0 otherwise) [USA Model]		↓							
Highway indicator (1 if highway, 0 otherwise) [Traditional]								(↓)	
Inside shoulder width (1 if less than 10 feet, 0 otherwise) [USA Model]		(↓)							
Median Width (1 if between 50 feet to 80 feet, 0 otherwise) [USA Model]		(↓)							
Outside shoulder width (1 if greater than 12.1 feet, 0 otherwise) [Full Model]	↓								
Percent of Combination Trucks [Full Model]	(↑)								
Road type indicator (1 if urban, 0 otherwise) [Traditional]								(↓)	
Standard Deviation of IRI (1 if between 11 and 39 inches per mile, 0 otherwise) [USA Model]		↓							
Standard Deviation of IRI (1 if less than 4 inches per mile, 0 otherwise) [Full Model]	↓								
Standard Deviation of PCR (1 if less than 1, 0 otherwise) [Full Model]	↑								
Standard Deviation of Rutting Depth (1 if less than 0.02 inches,0 otherwise) [USA Model]		↓							
Asset Type									
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement or mowing or vegetation/ tree control/ maintenance/ removal , 0 otherwise) [PBC]							(↑)		
Asset type indicator (1 if culvert/ ditches/ gutters/drainage repair/ maintenance/ replacement or guardrail repair/ maintenance, 0 otherwise) [Lane Rental]						(↓)			
Asset type indicator (1 if electrical/ cable system repair/maintenance or rest areas, 0 otherwise) [PBC]							↓		
Asset type indicator (1 if illumination repair/ maintenance, 0 otherwise) [Warranties]									(↓)
Asset type indicator (1 if landscape repair/ maintenance, 0 otherwise) [Warranties]									↓
Asset type indicator (1 if litter removal or mowing, 0 otherwise) [Warranties]									(↑)

Table 6.11 Summary of Cost Savings Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Asset type indicator (1 if Mowing, 0 otherwise) [Traditional]								(↓)	
Asset type indicator (1 if Pavement repair/ maintenance/treatment, 0 otherwise) [DBOM]				↑					
Weather Condition									
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.12, 0 otherwise) [USA Model]		↑							
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.25, 0 otherwise) [Full Model]	↓								
Weather indicator (1 if the proportion of snowy days to total days of contract is greater than 0.08, 0 otherwise) [Full Model]	↓								
Weather indicator (1 if the proportion of snowy days to total days of contract is greater than 0.08, 0 otherwise) [USA Model]		↓							

6.2.2 Cost Savings Likelihood Model Estimation Results

Descriptive statistics and model estimation results (along with goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.12 to 6.22. The results can be summarized as follows:

- The cost savings likelihood model under warranties demonstrates that this contract type in Virginia decreases the likelihood of cost savings occurrence. Similar results are found for contracts under design-build in Minnesota. On the other hand, it is likely to have cost savings under design-build in Indiana.
- The likelihood of cost savings occurrence under design-build, incentives/disincentives, and warranties decreases, when the duration of the contracts increases. However, the lane rentals model shows opposite results (when the duration of the contract increases, the likelihood of cost savings occurrence increases). This is an interesting finding, illustrating that these types of contracts are also appropriate for short term projects.
- Larger projects, in terms of size (in lane-miles), have lower likelihood to experience loss (for design-build, PBC, and traditional contracts). This finding is in-line with previous studies (Anastasopoulos et al., 2010). For warranties, it is found that projects with less than 30 lane-miles have a higher likelihood to have cost savings.
- The cost of the project can play a significant role on the likelihood of cost savings occurrence. Under PBC, if contract cost exceeds $110M, the likelihood of cost savings occurrence decreases. This finding is also in line with past work (Anastasopoulos et al. 2010).

- Higher contract costs under warranties (greater than $70M) and design-build contracts (greater than $4M), are associated with higher cost savings occurrence likelihood. This result is also in line with previous studies (Anastasopoulos et al. 2010).
- Contracts with less than 2 activity types during the projects under PBCs and design-build contracts, are more likely to have cost savings. This finding captures the effect of possibly smaller projects consisting of very few activities, which are typically less prone to cost and time discrepancies.
- Interestingly, mowing in traditional contracts reduces the likelihood of cost savings occurrence. This is an indication that mowing may favor outsourcing under a PPP option, in terms of cost savings. Anastasopoulos et al. (2010d) suggest that PBC may be viable contract type for this activity.
- Cost-plus-time contracts are not typically selected for pavement maintenance or rehabilitation. Therefore, including such activities under this contracting approach can cause a reduction in cost savings occurrence likelihood. The most popular contract types for this activity type are warranties and PBCs.
- Illumination repair and maintenance under warranty contracts is intuitively found to increase the likelihood of cost savings occurrence.
- The factors, the effect of which varies across the observations, are also presented in Tables 6.12 to 6.22, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.12 Descriptive Statistics of Cost Savings Likelihood Models

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Region Indicator (1 if Latin America, 0 otherwise) [Full Model]	0.077	-	0	1
State indicator (1 if Indiana, 0 otherwise) [DBOM]	0.379	-	0	1
State Indicator (1 if Minnesota, 0 otherwise) [DBOM]	0.063	-	0	1
State indicator(1 if Virginia, 0 otherwise) [Warranty]	0.392	-	0	1
Contract Type				
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [USA Model]	0.122	-	0	1
Contract Indicator (1 if Traditional 0 otherwise) [Full Model]	0.294	-	0	1
Contract Characteristics				
100^{th} of Size of the contract	0.301	0.317	0.002	2.498
100^{th} of the Size of the contract (in lane-miles) [PBC]	2.588	2.702	0.001	9.24
Bid Range (in $1M) [Full Model]	5.085	15.058	0	286
Bid range Indicator (1 if greater than 4000000 $, 0 otherwise) [USA Model]	0.153	-	0	1
Cost of the contract (1 if greater than $70 M, 0 otherwise) [Warranty]	0.082	-	0	1
Cost of the contract (1 if greater than $110 M, 0 otherwise) [PBC]	0.228	-	0	1
Cost of the contract (1 if greater than $4 M, 0 otherwise) [DBOM]	0.929	-	0	1
Cost of the contract (in $1M) [Traditional]	7.008	19.287	0.01	181.719
Cost of the contract award (in $1M) [Full Model]	36.207	66.026	0.014	1197.081
Duration of the contract indicator (1if between 2 and 6 years, 0 otherwise) [Warranty]	0.886	-	0	1
Duration of contract (in years) [Lane Rental]	2.614	-	1.62	3.75
Duration of the contract (1 if less than 6 years, 0 otherwise) [I/D]	0.903	-	0	1
Duration of the contract indicator (1 if greater than 5 years, 0 otherwise) [DBOM]	0.805	-	0	1
Inverse of square root of the highest bid (in $1M) [Full Model]	0.531	0.783	0.029	8.233
Size of the contract indicator(1 if less than 3.5 years, 0 otherwise) [Traditional]	0.753	-	0	1
Size of the contract indicator(1 if less than 30 lane-miles, 0 otherwise) [Warranty]	0.907	-	0	1
Number of asset (1 if less than 2, 0 otherwise) [PBC]	0.595	-	0	1
Number of Asset Indicator (1 if equals to 1, 0 otherwise) [US Model]	0.526	-	0	1
Number of assets (1 if equal to 2, 0 otherwise) [Full Model]	0.178	-	0	1
Number of assets (1 if equal to 3, 0 otherwise) [A+B]	0.129	-	0	1
Number of assets (1 if less than 2, 0 otherwise) [DBOM]	0.692	-	0	1
Road Geometry and Pavement Condition and Traffic Characteristics				
Average AADT (1 if greater than 42000, 0 otherwise) [USA Model]	0.09	-	0	1
Average Annual Daily Traffic (1 if greater than 38000, 0 otherwise) [Full Model]	0.189	-	0	1
Drainage System Indicator (1 if poorly drained, 0 otherwise) [USA Model]	0.197	-	0	1

Table 6.12 Descriptive Statistics of Cost Savings Likelihood Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Highway Indicator (1 if highway, 0 otherwise)[USA Model]	0.829	-	0	1
Number of Horizontal Curve Indicator (1 if greater than 5, 0 otherwise) [USA Model]	0.622	-	0	1
Number of Vertical curves per segment size (1 if more than 5, 0 otherwise) [Full Model]	0.733	-	0	1
Asset Type				
Asset Type indicator (1 if All Service, 0 otherwise) [Full Model]	0.084	-	0	1
Asset Type Indicator (1 if All Services, 0 otherwise) [USA Model]	0.079	-	0	1
Asset Type indicator (1 if illumination repair/ maintenance, 0 otherwise) [Traditional]	0.081	-	0	1
Asset Type indicator (1 if Mowing, 0 otherwise) [Full Model]	0.056	-	0	1
Asset Type indicator (1 if mowing, 0 otherwise) [Traditional]	0.086	-	0	1
Asset type indicator (1 if other assets, 0 otherwise) [DBOM]	0.124	-	0	1
Asset Type Indicator (1 if Pavement Repair/Maintenance/Treatment, 0 otherwise) [A+B]	0.161	-	0	1
Asset type indicator (1 if traffic signs and signals, 0 otherwise) [Lane Rental]	0.088	-	0	1
Weather Condition				
Proportion of snowy days to total days of contract (1 if no snowy days, 0 otherwise) [Full Model]	0.313	-	0	1
Weather indicator (1 if the proportion of rainy days to total days of contract is less than 0.36, 0 otherwise) [USA Model]	0.115	-	0	1

Table 6.13 Cost savings likelihood (Logit) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Region Indicator (1 if Latin America, 0 otherwise)	-1.237	-4.130	0.000
Standard deviation of parameter density function	2.690	5.270	0.000
Contract Type			
Contract Indicator (1 if Traditional 0 otherwise)	-1.487	-10.740	0.000
Contract Characteristics			
Cost of the Contract Award (in $1M)	0.006	2.920	0.004
Inverse of square root of the highest bid (in $1M)	0.675	8.860	0.000
Bid Range (in $1M)	-0.126	5.840	0.000
Number of Assets (1 if equal to 2, 0 otherwise)	-0.501	-3.240	0.001
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Vertical curves per segment size (1 if more than 5, 0 otherwise)	0.789	6.620	0.000
Average Annual Daily Traffic (1 if greater than 38000, 0 otherwise)	-0.864	-5.240	0.000
Standard deviation of parameter density function	0.863	4.320	0.000
Asset Type			
Asset Type indicator (1 if Mowing, 0 otherwise)	-0.926	-3.620	0.000
Asset Type indicator (1 if All Service, 0 otherwise)	0.698	2.530	0.011
Weather Condition			
Proportion of snowy days to total days of contract (1 if no snowy days, 0 otherwise)	-0.446	-2.890	0.004
Model Summary			
Number of Observations	1074		
Log likelihood at Zero	-698.028		
Log Likelihood at convergence	-516.017		

Table 6.14 Cost savings likelihood (Logit) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Type			
Contract Indicator (1 if Performance-Based Contract, 0 otherwise)	0.836	2.710	0.007
Contract Characteristics			
Number of Asset Indicator (1 if equals to 1, 0 otherwise)	0.675	4.410	0.000
Bid range Indicator (1 if greater than 4000000 $, 0 otherwise)	1.326	5.030	0.000
Asset Type			
Asset Type Indicator (1 if All Services, 0 otherwise)	2.127	4.400	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Highway Indicator (1 if highway, 0 otherwise)	-0.610	-4.160	0.000
Number of Horizontal Curve Indicator (1 if greater than 5, 0 otherwise)	0.801	5.880	0.000
Drainage System Indicator (1 if poorly drained, 0 otherwise)	0.702	2.960	0.003
Standard deviation of parameter density function	1.903	5.120	0.000
Average AADT (1 if greater than 42000, 0 otherwise)	-1.088	-4.150	0.000
Weather Condition			
Weather indicator (1 if the proportion of rainy days to total days of contract is less than 0.36, 0 otherwise)	-0.973	-4.290	0.000
Standard deviation of parameter density function	0.603	1.990	0.046
Model Summary			
Number of Observations	645		
Log likelihood at Zero	-409.855		
Log likelihood at Convergence	-324.839		

Table 6.15 Cost savings likelihood (Logit) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.246	3.11	0.002
Contract Characteristics			
Number of Assets (1 if equal to 3, 0 otherwise)	-2.754	-1.92	0.055
Asset Type			
Asset Type Indicator (1 if Pavement Repair/Maintenance/Treatment, 0 otherwise)	-2.324	-1.660	0.096
Model Summary			
Number of Observations	31		
Log-likelihood in convergence	-8.457		
Restricted Log likelihood	-11.921		

Table 6.16 Cost savings likelihood (Logit) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
State Indicator (1 if Minnesota, 0 otherwise)	-6.570	-2.610	0.009
State indicator (1 if Indiana, 0 otherwise)	8.700	1.780	0.076
Contract Characteristics			
Duration of Contract Indicator (1 if greater than 5 years, 0 otherwise)	-6.679	-3.030	0.003
100th of Size of the Contract	13.828	2.250	0.025
Standard deviation of parameter density function	8.400	1.750	0.079
Cost of the Contract (1 if greater than $4 M, 0 otherwise)	4.390	3.020	0.003
Standard deviation of parameter density function	3.127	2.720	0.007
Number of Assets (1 if less than 2, 0 otherwise)	4.982	2.560	0.011
Assets Type			
Asset type indicator (1 if other assets, 0 otherwise)	5.419	1.780	0.075
Model Summary			
Number of Observations	169		
Log likelihood at Zero	-69.053		
Log likelihood at Convergence	-36.759		

Table 6.17 Cost savings likelihood (Logit) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Duration of contract (1 if less than 6 years, 0 otherwise)	2.079	3.920	0.000
Model Summary			
Number of Observations	37		
Log-likelihood in convergence	-13.251		
Restricted Log likelihood	-24.191		

Table 6.18 Cost savings likelihood (Logit) model (USA contracts): Lane Rental

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Duration of contract (in years)	1.954	2.420	0.016
Assets Type			
Asset type indicator(1if traffic signs and signals, 0 otherwise)	-4.294	-1.770	0.077
Model Summary			
Number of Observations	37		
Log-likelihood in convergence	-3.222		
Restricted Log likelihood	-23.044		

Table 6.19 Cost savings likelihood (Logit) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
100th of the Size of the contract (in lane-miles)	0.718	4.150	0.000
Cost of the contract (1 if greater than $110 M, 0 otherwise)	-2.418	-2.130	0.033
Number of asset (1 if less than 2, 0 otherwise)	2.335	2.020	0.043
Standard deviation of parameter density function	3.150	2.300	0.022
Model Summary			
Number of Observations	79		
Log likelihood at Zero	-35.325		
Log likelihood at Convergence	-29.061		

Table 6.20 Cost savings likelihood (Logit) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	2.683	4.410	0.000
Standard deviation of parameter density function	4.376	5.520	0.000
Contract Characteristics			
Duration of the Contract (1 if less than 3.5 years, 0 otherwise)	-0.999	-2.080	0.038
Cost of contract (in $1M)	-1.689	-4.000	0.000
Asset Type			
Asset Type (1 if illumination repair/ maintenance, 0 otherwise)	2.675	2.290	0.022
Standard deviation of parameter density function	5.525	2.840	0.005
Asset Type (1 if mowing, 0 otherwise)	-4.530	-3.540	0.000
Model Summary			
Number of Observations	198		
Log likelihood at Zero	-136.879		
Log likelihood at Convergence	-97.146		

Table 6.21 Cost savings likelihood (Logit) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
State indicator(1 if Virginia, 0 otherwise)	-4.410	-3.370	0.001
Contract Characteristics			
Size of the contract (1 if less than 30 lane-miles, 0 otherwise)	1.401	1.650	0.097
Standard deviation of parameter density function	5.898	3.760	0.000
Duration of the contract (1 if between 2 and 6 years, 0 otherwise)	-1.470	-1.960	0.050
Cost of the contract (1 if greater than $70 M, 0 otherwise)	4.012	2.590	0.010
Model Summary			
Number of Observations	97		
Log-likelihood in convergence	-55.711		
Restricted Log likelihood	-62.833		

Table 6.22 Summary of Cost Savings Likelihood Results

Variables	**Full Model**	**USA Model**	**A+B [USA**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Region Indicator (1 if Latin America, 0 otherwise) [Full Model]	(↓)								
State indicator (1 if Indiana, 0 otherwise) [DBOM]				↓					
State Indicator (1 if Minnesota, 0 otherwise) [DBOM]				↑					
State indicator(1 if Virginia, 0 otherwise) [Warranty]									↓
Contract Type									
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [USA Model]		↑							
Contract Indicator (1 if Traditional 0 otherwise) [Full Model]	↓								
Contract Characteristics									
100th of Size of the contract [DBOM]				(↑)					
100th of the Size of the contract (in lane-miles) [PBC]							↑		
Bid Range (in $1M) [Full Model]	↓								
Bid range Indicator (1 if greater than 4000000 $, 0 otherwise) [USA Model]		↑							
Cost of the contract (1 if greater than $70 M, 0 otherwise) [Warranty]									↑
Cost of the contract (1 if greater than $110 M, 0 otherwise) [PBC]							↓		
Cost of the contract (1 if greater than $4 M, 0 otherwise) [DBOM]				(↑)					
Cost of the contract (in $1M) [Traditional]								↓	
Cost of the contract award (in $1M) [Full Model]	↑								
Duration of the contract indicator (1 if between 2 and 6 years, 0 otherwise) [Warranty]									↓
Duration of contract (in years) [Lane Rental]						↑		↓	
Duration of the contract (1 if less than 6 years, 0 otherwise) [I/D]					↑				
Duration of the contract indicator (1 if greater than 5 years, 0 otherwise) [DBOM]				↓					
Inverse of square root of the highest bid (in $1M) [Full Model]	↑								
Size of the contract indicator (1 if less than 3.5 years, 0 otherwise) [Traditional]									
Size of the contract indicator(1 if less than 30 lane-miles, 0 otherwise) [Warranty]									(↑)
Number of asset (1 if less than 2, 0 otherwise) [PBC]							(↑)		
Number of Asset Indicator (1 if equals to 1, 0 otherwise) [USA Model]		↑							
Number of assets (1 if equal to 2, 0 otherwise) [Full Model]	↓								
Number of assets (1 if equal to 3, 0 otherwise) [A+B]			↓						

Table 6.22 Summary of Cost Savings Likelihood Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Number of assets (1 if less than 2, 0 otherwise) [DBOM]				↑					
Road Geometry and Pavement Condition and Traffic Characteristics									
Average AADT (1 if greater than 42000, 0 otherwise) [USA Model]		↓							
Average Annual Daily Traffic (1 if greater than 38000, 0 otherwise) [Full Model]	(↓)								
Drainage System Indicator (1 if poorly drained, 0 otherwise) [USA Model]		(↓)							
Highway Indicator (1 if highway, 0 otherwise)[USA Model]		↓							
Number of Horizontal Curve Indicator (1 if greater than 5, 0 otherwise) [USA Model]		↑							
Number of Vertical curves per segment size (1 if more than 5, 0 otherwise) [Full Model]	↑								
Asset Type									
Asset Type indicator (1 if All Service, 0 otherwise) [Full Model]	↓								
Asset Type Indicator (1 if All Services, 0 otherwise) [USA Model]		↑							
Asset Type indicator (1 if illumination repair/ maintenance, 0 otherwise) [Traditional]								(↑)	
Asset Type indicator (1 if mowing, 0 otherwise) [Full Model]	↑								
Asset Type indicator (1 if mowing, 0 otherwise) [Traditional]								↓	
Asset type indicator (1 if other assets, 0 otherwise) [DBOM]				↑					
Asset Type Indicator (1 if Pavement Repair/Maintenance/Treatment, 0 otherwise) [A+B]			↓						
Asset type indicator (1 if traffic signs and signals, 0 otherwise) [Lane Rental]						↓			
Weather Condition									
Proportion of snowy days to total days of contract (1 if no snowy days, 0 otherwise) [Full Model]	↓								
Weather indicator (1 if the proportion of rainy days to total days of contract is less than 0.36, 0 otherwise) [USA Model]		(↓)							

6.2.3 Cost Overrun Percentage Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.23 to 6.33. The results can be summarized as follows:

- The effect of size of the project varies across the various PPP types. As an example, in 86 percent of cases (random parameter with normal distribution), by increasing the size in cost-plus-time contracts, the cost overrun percentage decreases. However, under warranty this parameter has opposite effect; this means that under 70 percent of warranty contracts (random parameters with normal distribution), by increasing the size of the contract, the cost overrun percentage increases. Based on the sign and magnitude of this variable, it is possible to say which PPP contracting approach is more appropriate for large projects in terms of cost overrun.
- Under PBCs, which are commonly preferred for large transportation projects, by increasing the size of the project (greater than 100 lane-miles), the cost overrun decreases.
- The results show that if the project is under incentives/disincentives or PBC, in 88 percent and 65 percent of contracts (both random parameters with Normal distribution) with shorter duration, cost overrun percentages increase, respectively. However, the results are different for lane rentals (65 percent of contracts as a random parameter with Normal distribution), traditional (82 percent of contracts as a random parameter with Normal distribution) and warranties (78 percent of contracts as a random parameter with Normal distribution); in other words, by

increasing the duration of the contract under these PPP types the cost overrun increases. The nature of incentives/disincentives and PBC contracts provide an appropriate context for public Agencies to encourage contractors to finish long projects before the deadline, in return to various monetary incentives.

- At least one construction, rehabilitation, treatment and preservation activity in cost-plus-time and Traditional contracts result in cost overrun in 88 percent and 91 percent of these contracts, respectively (both normally distributed random parameters). In contrast, under design-build and its derivatives, less than 3 activities included in the contract will increase the cost overrun. Note that the type of assets can highly affect the sign of this variable. This can capture the fact that design-build and its derivatives are more flexible with a high number of activities.
- The cost of the contract, as one of the critical parameters, has significant effect on cost overrun. In 72 percent of PBC contracts and 93 percent of cost-plus-time contracts (both random parameters with Normal distribution), cost increases will result in cost overrun increases; however, for incentives/disincentives, cost increases will result in cost overrun reductions.
- Different asset type activities have various effects on the cost overrun percentage. In most of the PPP contract types, except warranties that focus on pavement repair, maintenance, treatment and crack/pothole sealing and repair, the cost overrun intuitively increases. Warranty contracts are widely used for the pavement repair, maintenance and treatment activities; therefore, it was anticipated to see the reduction of cost overrun in this type of PPP. Interestingly, bridge and tunnel repair/maintenance and management – activities that are both expensive and

comprehensive – decrease the cost overrun. In such large projects, contractors will typically overbid, to account for minor change orders or other factors that can result in cost overrun. On the contrary, contractors may seldom underestimate smaller activities (e.g., electrical cable and system maintenance, guardrail repair and maintenance, landscapes, and illuminations repair and maintenance, to name a few), and bid lower amounts to get the award. Although, these activities are generally inexpensive (considering other comprehensive activities), the results show that the cost overrun percentage increases under various PPP types.

- The factors, the effect of which varies across the observations, are also presented in Tables 6.23 to 6.33, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.23 Descriptive Statistics of Cost Overrun Percentage Models

• Variables	Mean	Std. Dev	Min.	Max.
Contract Type				
Contract Indicator (1 if A+B, 0 otherwise) [Full Model]	0.076	-	0	1
Contract Indicator (1 if A+B, 0 otherwise) [USA Model]	0.048	-	0	1
Contract Indicator (1 if I/D, 0 otherwise) [Full Model]	0.063	-	0	1
Contract Indicator (1 if I/D, 0 otherwise) [USA Model]	0.057	-	0	1
Contract Indicator (1 if PBC 0 otherwise) [Full Model]	0.134	-	0	1
Contract Indicator (1 if PBC 0 otherwise) [USA Model]	0.122	-	0	1
Contract Indicator (1 if Warranty 0 otherwise) [USA Model]	0.15	-	0	1
Contract Indicator (1 if Warranty, 0 otherwise) [Full Model]	0.156	-	0	1
Contract Characteristics				
Award of contract Indicator (1 if less than $ 30M dollars, 0 otherwise) [Full Model]	0.642	-	0	1
Bid range (1 if greater than $ 5M, 0 otherwise) [USA Model]	0.876	-	0	1
Bid range indicator (1 if less than $ 5M , 0 otherwise) [Full Model]	0.721	-	0	1
Contract Award Indicator (1if $ 30M, 0 otherwise) [USA Model]	0.792	-	0	1
Cost of the contract (in $1M) [DBOM]	27.72	28.926	0.556	238
Cost of the contract (in $1M) [PBC]	60.1	63.314	0.048	228
Duration of contract (1 if greater than 4 years, 0 otherwise) [PBC]	0.823	-	0	1
Duration of the contract (1 if greater than 1.5 years, 0 otherwise) [Lane Rental]	0.918	-	0	1
Duration of the contract (in years) [Traditional]	3.478	2.5	0.16	7.92
Duration of the contract (in years) [Warranty]	4.761	2.816	0.27	20
Extension of contract indicator (1 if between 0.5 and 3.5 years, 0 otherwise) [USA Model]	0.332	-	0	1
Extension of contract indicator (1 if between 3.2 to 6 years, 0 otherwise) [Full Model]	0.721	-	0	1
Inverse of the Cost of the Contract (in $100K) [Full Model]	0.132	0.751	0.001	20
Inverse of the Cost of the Contract (per 100k Dollars) [I/D]	0.597	3.28	0.001	20
Inverse of the Cost of the Contract [USA Model]	0.205	0.946	0.004	20
Inverse of the Duration of the contract [I/D]	0.277	0.127	0.158	0.5
Size of the contract (1 if between 10 and 20 Lane-Miles, 0 otherwise) [DBOM]	0.183	-	0	1
Size of the contract (1 if between 10 and 20 lane-miles, 0 otherwise) [USA Model]	0.112	-	0	1
Size of the contract (1 if greater than 100 lane-miles, 0 otherwise) [PBC]	0.62	-	0	1
Size of the contract (in lane-miles) [A+B]	33.95	40.336	1.16	146
Natural Logarithm of size of the contract (in lane-miles) [Warranty]	1.081	1.951	-3.219	6.21
Number of assets (1 if equal to one, 0 otherwise) [Traditional]	0.657	-	0	1
Number of assets (1 if less than 3, 0 otherwise) [DBOM]	0.828	-	0	1
Number of assets indicator (1 if equal to 3, 0 otherwise) [A+B]	0.129	-	0	1
Number of assets indicator (1 if greater than 5, 0 otherwise) [USA Model]	0.068	-	0	1
Number of Bids (1 if 2 or 3, 0 otherwise) [Full Model]	0.632	-	0	1

Table 6.23 Descriptive Statistics of Cost Overrun Percentage Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Road Geometry and Pavement Condition and Traffic Characteristics				
Average Annual Daily Traffic Indicator (1 if 10500 or less, 0 otherwise) [USA Model]	0.64	-	0	1
Average Annual Daily Traffic Indicator (1 if less than 10000, 0 otherwise) [Full Model]	0.574	-	0	1
Highway Indicator (1 if highway, 0 otherwise) [DBOM]	0.846	-	0	1
Inside Shoulder width (1 if between 8.25 and 13.2 feet, 0 otherwise) [Full Model]	0.307	-	0	1
Number of lanes indicator (1 if 2, 0 otherwise) [Full Model]	0.745	-	0	1
Outside Shoulder Width (1 if between 8.3 and 10.75 feet, 0 otherwise) [Full Model]	0.151	-	0	1
Outside shoulder width (1 if greater than 12.1 feet, 0 otherwise) [USA Model]	0.143	-	0	1
Percent of Combination Trucks (1 if greater than 5%, 0 otherwise) [Full Model]	0.851	-	0	1
Standard Deviation of IRI (1 if less than 54, 0 otherwise) [Full Model]	0.926	-	0	1
Assets Type				
Asset type indicator (1 if bridge- tunnel repair/ maintenance/management or culvert/ ditches/ gutters/ drainage repair/maintenance/ replacement, 0 otherwise) [DBOM]	0.172	-	0	1
Asset type indicator (1 if bridge- tunnel/ repair/maintenance/ management, 0 otherwise) [I/D]	0.135	-	0	1
Asset type indicator (1 if crack/ pothole sealing/ repair or emergency facilities maintenance and repair, 0 otherwise) [Warranty]	0.093	-	0	1
Asset type indicator (1 if electrical/ cable system repair/maintenance, 0 otherwise) [Traditional]	0.237	-	0	1
Asset type indicator (1 if Emergency facilities maintenance/response or illumination repair/ maintenance or electrical/ cable system repair/ rehabilitation/ treatment, 0 otherwise) [PBC]	0.152	-	0	1
Asset type indicator (1 if guardrail or illumination Repair/Maintenance, 0 otherwise) [Lane Rental]	0.147	-	0	1
Asset type indicator (1 if Guardrail Repair/Maintenance, 0 otherwise) [Traditional]	0.126	-	0	1
Asset type indicator (1 if landscape, 0 otherwise) [Lane Rental]	0.118	-	0	1
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [A+B]	0.161	-	0	1
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [DBOM]	0.136	-	0	1
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [Warranty]	0.289	-	0	1
Asset type indicator (1 if Traffic signs and signals, 0 otherwise) [USA Model]	0.147	-	0	1
Weather Condition				
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.18 and 0.44, 0 otherwise) [Full Model]	0.829	-	0	1
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.18 and 0.44, 0 otherwise) [USA Model]	0.902	-	0	1
Weather indicator (1 if the proportion of snowy days to total days of contract Is greater than 0.075 , 0 otherwise) [USA Model]	0.262	-	0	1

Table 6.24 Cost overrun percentage (OLS) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Region Indicator (1 if Brazil, 0 otherwise)	27.290	4.550	0.000
Contract Type			
Contract Indicator (1 if A+B, 0 otherwise)	-13.683	-6.580	0.000
Contract Indicator (1 if I/D, 0 otherwise)	-13.826	-5.620	0.000
Contract Indicator (1 if PBC 0 otherwise)	-10.543	-5.650	0.000
Contract Indicator (1 if Warranty, 0 otherwise)	17.892	11.810	0.000
Contract Characteristics			
Award of contract Indicator (1 if less than $ 30M dollars, 0 otherwise)	10.863	7.120	0.000
Inverse of the Cost of the Contract (in $100K)	-3.789	-3.670	0.000
Bid range indicator(1 if less than $ 5M , 0 otherwise)	-6.503	-4.220	0.000
Extension of contract indicator (1 if between 3.2 to 6 years, 0 otherwise)	-2.894	-1.840	0.065
Number of Bids (1 if 2 or 3, 0 otherwise)	2.348	2.180	0.029
Standard deviation of parameter density function	5.822	16.900	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of IRI (1 if less than 54, 0 otherwise)	4.524	2.800	0.005
Outside Shoulder Width (1 if between 8.3 and 10.75 feet, 0 otherwise)	6.450	4.360	0.000
Inside Shoulder width (1 if between 8.25 and 13.2 feet, 0 otherwise)	4.194	3.690	0.000
Standard deviation of parameter density function	6.287	6.900	0.000
Number of lanes indicator (1 if 2, 0 otherwise)	2.000	1.730	0.083
Standard deviation of parameter density function	3.309	5.460	0.000
Average Annual Daily Traffic Indicator (1 if less than 10000, 0 otherwise)	2.675	2.450	0.014
Percent of Combination Trucks (1 if greater than 5%, 0 otherwise)	-5.146	-3.890	0.000
Standard deviation of parameter density function	2.131	3.650	0.000
Weather Condition			
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.18 and 0.44, 0 otherwise)	10.616	8.530	0.000
Standard deviation of parameter density function	14.336	36.030	0.000
Model Summary			
Number of Observations	1074		
R-Squared	0.791		
Adjusted R-Squared	0.788		

Table 6.25 Cost overrun percentage (OLS) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Type			
Contract Indicator (1 if A+B, 0 otherwise)	-15.890	-6.050	0.000
Contract Indicator (1 if I/D, 0 otherwise)	-11.630	-4.340	0.000
Contract Indicator (1 if PBC 0 otherwise)	-10.734	-5.380	0.000
Contract Indicator (1 if Warranty 0 otherwise)	14.118	8.320	0.000
Contract Characteristics			
Size of contract Indicator (1if between 10 and 20 lane-miles, 0 otherwise)	5.012	2.600	0.009
Inverse of the Cost of the Contract	-3.746	-4.920	0.000
Highest bid range (1 if greater than $ 5M, 0 otherwise)	-6.785	-3.780	0.000
Extension of contract indicator (1 if between 0.5 and 3.5 years , 0 otherwise)	2.418	1.930	0.054
Standard deviation of parameter density function	3.295	3.370	0.001
Number of Assets indicator (1 if greater than 5, 0 otherwise)	-6.013	-2.670	0.008
Standard deviation of parameter density function	10.059	4.690	0.000
Contract Award Indicator (1if $ 30M, 0 otherwise)	10.288	6.060	0.000
Standard deviation of parameter density function	10.678	17.980	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Asset type Indicator (1 if Traffic signs and signals, 0 otherwise)	-5.785	-3.610	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Outside shoulder width(1 if greater than 12.1 feet, 0 otherwise)	7.743	4.730	0.000
Average Annual Daily Traffic (1 if 10500 or less, 0 otherwise)	4.357	3.620	0.000
Weather Condition			
Weather indicator (1 if the proportion of snowy days to total days of contract Is greater than 0.075 , 0 otherwise)	4.116	3.120	0.002
Standard deviation of parameter density function	15.631	16.040	0.000
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.18 and 0.44, 0 otherwise)	15.553	11.040	0.000
Standard deviation of parameter density function	17.978	62.340	0.000
Model Summary			
Number of Observations	645		
R-Squared	0.870		
Adjusted R-Squared	0.867		

Table 6.26 Cost overrun percentage (OLS) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Size of the contract (in lane-miles)	-0.158	-2.61	0.009
Standard deviation of parameter density function	0.146	2.100	0.356
Number of Assets indicator (1 if equal to 3, 0 otherwise)	26.442	2.550	0.011
Standard deviation of parameter density function	22.671	2.55	0.011
Assets Type			
Asset type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise)	30.452	3.74	0.000
Standard deviation of parameter density function	31.269	3.51	0.000
Model Summary			
Number of Observations	31		
R-Squared	0.753		
Adjusted R-Squared	0.726		

Table 6.27 Cost overrun percentage (OLS) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Cost of the contract (in $1M)	0.151	4.690	0.000
Standard deviation of parameter density function	0.103	3.950	0.000
Size of the contract (1 if between 10 and 20 Lane-Miles, 0 otherwise)	10.005	3.420	0.001
Number of assets (1 if less than 3, 0 otherwise)	-23.758	-5.440	0.000
Standard deviation of parameter density function	5.457	4.900	0.000
Road Geometry			
Highway Indicator (1 if highway, 0 otherwise)	31.117	7.380	0.000
Standard deviation of parameter density function	13.219	13.290	0.000
Assets Type			
Asset type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise)	13.365	4.39	0.000
Standard deviation of parameter density function	28.060	11.14	0.000
Asset type indicator (1 if bridge- tunnel repair/ maintenance/ management or culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise)	-10.225	-3.500	0.000
Model Summary			
Number of Observations	169		
R-Squared	0.836		
Adjusted R-Squared	0.825		

Table 6.28 Cost overrun percentage (OLS) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-10.878	-4.330	0.000
Contract Characteristics			
Inverse of the Cost of the Contract (per 100k Dollars)	-4.353	-8.990	0.000
Inverse of the Duration of the contract	54.231	6.81	0.000
Standard deviation of parameter density function	45.573	15.890	0.000
Assets Type			
Asset type indicator (1 if bridge- tunnel/ repair/ maintenance/ management, 0 otherwise)	-14.229	-4.290	0.000
Model Summary			
Number of Observations	37		
R-Squared	0.825		
Adjusted R-Squared	0.796		

Table 6.29 Cost overrun percentage (OLS) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Duration of the contract (1 if greater than 1.5 years, 0 otherwise)	9.280	6.060	0.000
Standard deviation of parameter density function	8.263	8.39	0.000
Asset Types			
Asset Type Indicator (1 if guardrail or illumination Repair/ Maintenance, 0 otherwise)	63.718	5.47	0.000
Asset Type Indicator (1 if landscape, 0 otherwise)	-51.913	-4.240	0.000
Standard deviation of parameter density function	14.162	3.060	0.002
Model Summary			
Number of Observations	34		
R-Squared	0.897		
Adjusted R-Squared	0.879		

Table 6.30 Cost overrun percentage (OLS) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Cost of the contract (in $1M)	0.027	1.95	0.051
Standard deviation of parameter density function	0.046	5.170	0.000
Duration of contract (1 if greater than 4 years, 0 otherwise)	-5.459	-5.510	0.000
Standard deviation of parameter density function	13.535	15.410	0.000
Size of the contract (1 if greater than 100 lane-miles, 0 otherwise)	-4.053	-1.273	0.006
Assets Type			
Asset type indicator (1 if Emergency facilities maintenance/ response or illumination repair/ maintenance or electrical/ cable system repair/ rehabilitation/ treatment, 0 otherwise)	13.093	5.96	0.000
Model Summary			
Number of Observations	79		
R-Squared	0.945		
Adjusted R-Squared	0.939		

Table 6.31 Cost overrun percentage (OLS) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Duration of the contract (in years)	2.966	3.280	0.001
Standard deviation of parameter density function	3.271	13.210	0.000
Number of assets (1 if equal to one, 0 otherwise)	7.824	1.670	0.094
Standard deviation of parameter density function	5.852	4.670	0.000
Asset Types			
Asset Type Indicator (1 if electrical/ cable system repair/ maintenance, 0 otherwise)	35.270	8.76	0.000
Standard deviation of parameter density function	81.915	28.71	0.000
Asset Type Indicator (1 if Guardrail Repair/Maintenance, 0 otherwise)	11.745	2.010	0.044
Model Summary			
Number of Observations	198		
R-Squared	0.853		
Adjusted R-Squared	0.847		

Table 6.32 Cost overrun amount (OLS) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	21.792	6.190	0.000
Contract Characteristics			
Natural Logarithm of size of the contract (in lane-miles)	1.702	1.770	0.077
Standard deviation of parameter density function	3.258	6.400	0.000
Duration of the contract (in years)	1.273	2.090	0.037
Standard deviation of parameter density function	1.676	5.160	0.000
Assets Type			
Asset type indicator (1 if crack/ pothole sealing/ repair or emergency facilities maintenance and repair, 0 otherwise)	12.712	20.030	0.043
Standard deviation of parameter density function	16.842	2.960	0.003
Asset type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise)	-8.165	-2.090	0.037
Model Summary			
Number of Observations	97		
R-Squared	0.730		
Adjusted R-Squared	0.705		

Table 6.33 Summary of Cost Overrun Percentage Results

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Contract Type									
Contract Indicator (1 if A+B, 0 otherwise) [Full Model]	↓								
Contract Indicator (1 if A+B, 0 otherwise) [USA Model]		↓							
Contract Indicator (1 if I/D, 0 otherwise) [Full Model]	↓								
Contract Indicator (1 if I/D, 0 otherwise) [USA Model]		↓							
Contract Indicator (1 if PBC, 0 otherwise) [Full Model]	↓								
Contract Indicator (1 if PBC, 0 otherwise) [USA Model]		↓							
Contract Indicator (1 if Warranty 0 otherwise) [USA Model]		↑							
Contract Indicator (1 if Warranty, 0 otherwise) [Full Model]	↑								
Contract Characteristics									
Award of contract Indicator (1 if less than $ 30M dollars, 0 otherwise) [Full Model]	↑								
Bid range (1 if greater than $ 5M, 0 otherwise) [USA Model]		(↑)							
Bid range indicator (1 if less than $ 5M , 0 otherwise) [Full Model]	↓								
Contract Award Indicator (1if $ 30M, 0 otherwise) [USA Model]		(↑)							
Cost of the contract (in $1M) [DBOM]				(↑)					
Cost of the contract (in $1M) [PBC]							(↑)		
Duration of contract (1 if greater than 4 years, 0 otherwise) [PBC]							(↓)		
Duration of the contract (1 if greater than 1.5 years, 0 otherwise) [Lane Rental]						(↑)			
Duration of the contract (in years) [Traditional]								(↑)	
Duration of the contract (in years) [Warranty]									(↑)
Extension of contract indicator (1 if between 0.5 and 3.5 years, 0 otherwise) [USA Model]		(↑)							
Extension of contract indicator (1 if between 3.2 to 6 years, 0 otherwise) [Full Model]	↓								
Inverse of the Cost of the Contract (in $100K) [Full Model]	↓								
Inverse of the Cost of the Contract (per 100k Dollars) [I/D]					↓				
Inverse of the Cost of the Contract [USA Model]		↓							
Inverse of the Duration of the contract [I/D]					(↑)				

Table 6.33 Summary of Cost Overrun Percentage Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Size of the contract (1 if between 10 and 20 Lane-Miles, 0 otherwise) [DBOM]				↑					
Size of the contract (1 if between 10 and 20 lane-miles, 0 otherwise) [USA Model]		↑							
Size of the contract (1 if greater than 100 lane-miles, 0 otherwise) [PBC]							↓		
Size of the contract (in lane-miles) [A+B]			(↓)						
Natural Logarithm of size of the contract (in lane-miles) [Warranty]									(↑)
Number of assets (1 if equal to one, 0 otherwise) [Traditional]								(↑)	
Number of assets (1 if less than 3, 0 otherwise) [DBOM]				(↓)					
Number of assets indicator (1 if equal to 3, 0 otherwise) [A+B]			(↑)						
Number of assets indicator (1 if greater than 5, 0 otherwise) [USA Model]		(↑)							
Number of Bids (1 if 2 or 3, 0 otherwise) [Full Model]	(↑)								
Road Geometry and Pavement Condition and Traffic Characteristics									
Average Annual Daily Traffic Indicator (1 if 10500 or less, 0 otherwise) [USA Model]		↑							
Average Annual Daily Traffic Indicator (1 if less than 10000, 0 otherwise) [Full Model]	↑								
Highway Indicator (1 if highway, 0 otherwise) [DBOM]				(↑)					
Inside Shoulder width (1 if between 8.25 and 13.2 feet, 0 otherwise) [Full Model]	(↑)								
Number of lanes indicator (1 if 2, 0 otherwise) [Full Model]	(↑)								
Outside Shoulder Width (1 if between 8.3 and 10.75 feet, 0 otherwise) [Full Model]	↑								
Outside shoulder width (1 if greater than 12.1 feet, 0 otherwise) [USA Model]		↑							
Percent of Combination Trucks (1 if greater than 5%, 0 otherwise) [Full Model]	(↓)								
Standard Deviation of IRI (1 if less than 54, 0 otherwise) [Full Model]	↑								
Assets Type									
Asset type indicator (1 if bridge- tunnel repair/ maintenance/management or culvert/ ditches/ gutters/ drainage repair/maintenance/ replacement, 0 otherwise) [DBOM]				↓					

Table 6.33 Summary of Cost Overrun Percentage Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Asset type indicator (1 if bridge- tunnel/ repair/maintenance/ management, 0 otherwise) [I/D]					↓				
Asset type indicator (1 if crack/ pothole sealing/ repair or emergency facilities maintenance and repair, 0 otherwise) [Warranty]									(↑)
Asset Type Indicator (1 if electrical/ cable system repair/maintenance, 0 otherwise) [Traditional]								(↑)	
Asset type indicator (1 if Emergency facilities maintenance/response or illumination repair/ maintenance or electrical/ cable system repair/ rehabilitation/ treatment, 0 otherwise) [PBC]							↑		
Asset Type Indicator (1 if guardrail or illumination Repair/Maintenance, 0 otherwise) [Lane Rental]						↑			
Asset Type Indicator (1 if Guardrail Repair/Maintenance, 0 otherwise) [Traditional]								↑	
Asset Type Indicator (1 if landscape, 0 otherwise) [Lane Rental]						(↓)			
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [A+B]			(↑)						
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [DBOM]				(↑)					
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [Warranty]									↓
Asset type Indicator (1 if Traffic signs and signals, 0 otherwise) [USA Model]		↓							
Weather Condition									
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.18 and 0.44, 0 otherwise) [Full Model]	(↑)								
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.18 and 0.44, 0 otherwise) [USA Model]		(↑)							
Weather indicator (1 if the proportion of snowy days to total days of contract Is greater than 0.075 , 0 otherwise) [USA Model]		(↑)							

6.2.4 Cost Overrun Likelihood Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.34 to 6.43. The results can be summarized as follows:

- Projects with less than $11M final cost are found to increase the cost overrun likelihood for cost-plus-time and Traditional contracts. However, model results for design-build contracts are found to reduce the cost overrun likelihood.
- For design-build, incentives/disincentives, and lane rental contracts, contracts with shorter size (in terms of lane-miles) are more likely to have cost overrun. For PBCs, in 70 percent of contracts (random parameters with Normal distribution) that have less than 185 lane-miles size, the likelihood of cost overrun occurrence decreases.
- Pavement and guardrail repair, maintenance and treatment activities, in 80 percent of cases (random parameter with Normal distribution) increase the likelihood of cost overrun occurrence for cost-plus-time and design-build contracts. In addition, other activity types, such as bridge-tunnel repair, maintenance and management, general maintenance, repair and rehabilitation, in most of PPP approaches, are found to increase the likelihood of cost overrun occurrence.
- In 73 percent of contracts in urban areas for design-build contracts (random parameter with Normal distribution), cost overrun occurrence is less likely.

- Interestingly, all warranty contracts had a higher cost overrun likelihood when compared to the other PPP contracting approaches.
- The factors, the effect of which varies across the observations, are also presented in Tables 6.34 to 6.43, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.34 Descriptive Statistics of Cost Overrun Likelihood Models

• **Variables**	**Mean**	**Std. Dev**	**Min.**	**Max.**
Region Indicator (1 if USA, 0 otherwise) [Full Model]	0.601	-	0	1
State Indicator (1 if Minnesota, Indiana or Virginia, 0 otherwise) [Full Model]	0.352	-	0	1
State Indicator (1 if Minnesota, Indiana or Virginia, 0 otherwise) [USA Model]	0.586	-	0	1
Contract Type				
Contract Indicator (1 if A+B or I/D, 0 otherwise) [USA Model]	0.105	-	0	1
Contract Indicator (1 if A+B, 0 otherwise) [Full Model]	0.076	-	0	1
Contract Indicator (1 if I/D, 0 otherwise) [Full Model]	0.063	-	0	1
Contract Indicator (1 if PBC, 0 otherwise) [Full Model]	0.134	-	0	1
Contract Indicator (1 if PBC, 0 otherwise) [USA Model]	0.122	-	0	1
Contract Characteristics				
Cost Award of Contract (1 if greater than $ 30M, 0 otherwise) [Full Model]	0.358	-	0	1
Cost Award of Contract (1 if greater than $ 90M, 0 otherwise) [USA Model]	0.05	-	0	1
Cost of the contract (1 if greater than $ 69M, 0 otherwise) [USA Model]	0.071	-	0	1
Cost of the contract (1 if greater than $11M, 0 otherwise) [Traditional]	0.167	-	0	1
Cost of the contract (1 if less than $11M, 0 otherwise) [DBOM]	0.142	-	0	1
Cost of the contract (in $1M) [A+B]	9.587	9.669	0.304	35.2
Duration of the contract (1 if 3.5 years or more and 6 years or less, 0 otherwise) [Full Model]	0.499	-	0	1
Duration of the contract (1 if less than 3.5 years, 0 otherwise) [USA Model]	0.291	-	0	1
Extension of contract (1 if between 2.9 and 4 years, 0 otherwise) [Full Model]	0.077	-	0	1
Inverse of the Size of the Contract [USA Model]	0.902	3.144	0.001	50
Inverse of the Square Root of Size of the Contract [I/D]	0.779	1.435	0.077	7.07
Size of Contract Indicator (1 if less than 50 lane-miles, 0 otherwise) [DBOM]	0.763	-	0	1
Size of the contract (1 if less than 185 lane-miles, 0 otherwise) [PBC]	0.532	-	0	1
Size/Duration of the contract (1 if duration is greater than 2.5 years and size is less than 40 lane-miles, 0 otherwise) [Lane Rental]	0.824	-	0	1
Number of assets (1 if equal to one, 0 otherwise) [Lane Rental]	0.559	-	0	1
Number of assets (1 if equal to two, 0 otherwise) [I/D]	0.351	-	0	1
Number of assets (1 if greater than 0, 0 otherwise) [PBC]	0.797	-	0	1
Number of assets (1 if less than 2, 0 otherwise) [Traditional]	0.662	-	0	1
One 10000th of the Square Root of the Contract Cost [Full Model]	0.482	0.371	0.007	3.03
Asset Type				
Asset Type Indicator (1 if Bridge-Tunnel Repair/Maintenance/ Management or general maintenance/repair/rehabilitation/treatment or guardrail repair/maintenance, 0 otherwise) [Traditional]	0.515	-	0	1

Table 6.34 Descriptive Statistics of Cost Overrun Likelihood Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Asset Type Indicator (1 if emergency facilities maintenance/response or management or landscape repair/maintenance or electrical/ cable system repair/ maintenance,0 otherwise) [PBC]	0.19	-	0	1
Asset type Indicator (1 if General repair/maintenance/rehabilitation/treatment, 0 otherwise) [Lane Rental]	0.618	-	0	1
Asset Type Indicator (1 if guardrail repair/maintenance or pavement repair/maintenance/treatment or rest areas, 0 otherwise) [A+B]	0.516	-	0	1
Asset Type Indicator (1 if illumination repair/maintenance or landscape repair/maintenance or pavement repair/maintenance/treatment or traffic signs and signals or vegetation/tree control/maintenance/removal, 0 otherwise) [DBOM]	0.343	-	0	1
Asset Type Indicator (1 if Litter Removal or Shoulder Repair/Maintenance, 0 otherwise) [Full Model]	0.128	-	0	1
Asset Type Indicator (1 if Litter Removal or Shoulder Repair/Maintenance, 0 otherwise) [USA Model]	0.130	-	0	1
Asset Type Indicator (1 if Rest Areas, 0 otherwise) [DBOM]	0.095	-	0	1
Road Geometry and Pavement Condition and Traffic Characteristics				
Average AADT (1 if greater than 3,900 and 15,200, 0 otherwise) [USA Model]	0.282	-	0	1
One 10000th of the Squared of the Median Width [USA Model]	0.22	0.456	0	2.02
Road type indicator (1 if Urban, 0 otherwise) [DBOM]	0.828	-	0	1
Road type indicator (1 if Urban, 0 otherwise) [Traditional]	0.808	-	0	1
Standard Deviation of IRI (1 if greater than 11 inches per mile, 0 otherwise) [Full Model]	0.848	-	0	1
Standard Deviation of IRI (1 if greater than 11, 0 otherwise) [USA Model]	0.848	-	0	1
Weather Condition				
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.3 and 0.4, 0 otherwise) [Full Model]	0.246	-	0	1
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.3 and 0.4, 0 otherwise) [USA Model]	0.211	-	0	1

Table 6.35 Cost overrun likelihood (Probit) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	0.503	2.14	0.033
Region Indicator (1 if USA, 0 otherwise)	-0.544	-2.96	0.003
State Indicator (1 if Minnesota, Indiana or Virginia, 0 otherwise)	0.888	5.47	0.000
Contract Type			
Contract Indicator (1 if A+B, 0 otherwise)	-1.804	-8.23	0.000
Contract Indicator (1 if I/D, 0 otherwise)	-1.578	-6.74	0.000
Contract Indicator (1 if PBC, 0 otherwise)	-3.051	-8.08	0.000
Standard deviation of parameter density function	7.081	8.67	0.000
Contract Characteristics			
Duration of Contract (1 if 3.5 years or more and 6 years or less, 0 otherwise)	-0.58	-4.35	0.000
Extension of Contract (1 if between 2.9 and 4 years, 0 otherwise)	0.504	1.95	0.052
One 10000th of the Square Root of the Contract Cost	2.298	5.89	0.000
Standard deviation of parameter density function	2.409	12.77	0.000
Cost Award of Contract (1 if greater than $ 30M, 0 otherwise)	-2.498	-8.76	0.000
Asset Type			
Asset Type Indicator (1 if Litter Removal or Shoulder Repair/ Maintenance, 0 otherwise)	-0.596	-3.26	0.001
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of IRI (1 if greater than 11 inches per mile, 0 otherwise)	0.568	3.45	0.001
Weather Condition			
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.3 and 0.4, 0 otherwise)	3.327	7.86	0.000
Standard deviation of parameter density function	3.529	9.16	0.000
Model Summary			
Number of Observations	1074		
Log likelihood at Zero	-677.208		
Log likelihood at Convergence	-583.068		

Table 6.36 Cost overrun likelihood (Probit) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
State Indicator (1 if Minnesota, Indiana or Virginia, 0 otherwise)	0.438	3.84	0.000
Contract Type			
Contract Indicator (1 if A+B or I/D, 0 otherwise)	-0.87	-4.68	0.000
Contract Indicator (1 if PBC, 0 otherwise)	-1.115	-5.73	0.000
Contract Characteristics			
Cost of the Project (1 if greater than $ 69M, 0 otherwise)	1.429	2.39	0.017
Cost Award of Contract (1 if greater than $ 90M, 0 otherwise)	1.429	2.39	0.017
Duration of Contract (1 if less than 3.5 years, 0 otherwise)	0.26	1.99	0.047
Inverse of the Size of the Contract	0.044	1.65	0.099
Asset Type			
Asset Type Indicator (1 if Litter Removal or Shoulder Repair/ Maintenance, 0 otherwise)	-0.487	-2.79	0.005
Road Geometry and Pavement Condition and Traffic Characteristics			
One 10000th of the Squared of the Median Width	-0.321	-2.47	0.014
Standard Deviation of IRI (1 if greater than 11, 0 otherwise)	0.484	4.50	0.000
Average AADT (1 if greater than 3,900 and 15,200, 0 otherwise)	1.632	4.67	0.000
Standard deviation of parameter density function	1.879	5.73	0.000
Weather Condition			
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.3 and 0.4, 0 otherwise)	0.259	1.81	0.07
Model Summary			
Number of Observations	645		
Log likelihood at Zero	-396.928		
Log likelihood at Convergence	-348.865		

Table 6.37 Cost overrun likelihood (Probit) model (USA contracts): A+B

Variables	Coefficient	*t*-stat	*P*-value
Contract Characteristics			
Cost of the Contract (in $1M)	-0.088	-1.950	0.051
Asset Type			
Asset Type Indicator (1 if guardrail repair/maintenance or pavement repair/maintenance/treatment or rest areas, 0 otherwise)	1.443	1.980	0.048
Standard deviation of parameter density function	1.156	2.060	0.039
Model Summary			
Number of Observations	31		
Log likelihood at Zero	-21.342		
Log likelihood at Convergence	-18.664		

Table 6.38 Cost overrun likelihood (Probit) model (USA contracts): DBOM

Variables	Coefficient	*t*-stat	*P*-value
Contract Characteristics			
Cost of the contract (1 if less than $11M, 0 otherwise)	-1.334	-3.060	0.002
Size of Contract Indicator (1 if less than 50 lane-miles, 0 otherwise)	0.460	1.760	0.078
Asset Type			
Asset Type (1 if illumination repair/maintenance or landscape repair/maintenance or pavement repair/maintenance/ treatment or traffic signs and signals or vegetation/tree control/maintenance/removal, 0 otherwise)	1.188	2.850	0.004
Standard deviation of parameter density function	4.377	3.400	0.001
Asset Type (1 if Rest Areas, 0 otherwise)	-1.546	-2.910	0.004
Road Geometry			
Road type indicator (1 if Urban, 0 otherwise)	0.506	2.200	0.028
Model Summary			
Number of Observations	169		
Log likelihood at Zero	-102.636		
Log likelihood at Convergence	-91.810		

Table 6.39 Cost overrun likelihood (Probit) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	17.865	-2.46	0.014
Contract Characteristics			
Inverse of the Square Root of Size of the Contract	0.811	2.81	0.005
Number of assets (1 if equal to two, 0 otherwise)	-8.035	2.850	0.004
Model Summary			
Number of Observations	37		
Log likelihood at Zero	-24.98		
Log likelihood at Convergence	-10.93		

Table 6.40 Cost overrun likelihood (Probit) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Size/Duration of the contract (1 if duration is greater than 2.5 years and size is less than 40 lane-miles, 0 otherwise)	3.510	-2.480	0.013
Number of assets (1 if equal to one, 0 otherwise)	-2.955	-2.040	0.041
Asset Type			
Asset type Indicator (1 if General repair/maintenance/rehabilitation/treatment, 0 otherwise)	2.073	1.870	0.062
Model Summary			
Number of Observations	34		
Log likelihood at Zero	-15.844		
Log likelihood at Convergence	-11.286		

Table 6.41 Cost overrun likelihood (Probit) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Size of the contract (1 if less than 185 lane-miles, 0 otherwise)	-6.024	-2.070	0.038
Standard deviation of parameter density function	11.639	2.590	0.010
Number of Assets (1 if greater than 0, 0 otherwise)	-3.834	-2.560	0.010
Standard deviation of parameter density function	2.460	2.550	0.011
Asset Type			
Asset Type Indicator (1 if emergency facilities maintenance/response or management or landscape repair/ maintenance or electrical/ cable system repair/ maintenance, 0 otherwise)	3.882	2.420	0.015
Model Summary			
Number of Observations	79		
Log likelihood at Zero	-52.915		
Log likelihood at Convergence	-33.635		

Table 6.42 Cost overrun likelihood (Probit) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Cost of the contract (1 if greater than $11M, 0 otherwise)	-1.840	-4.090	0.000
Number of assets (1 if less than 2, 0 otherwise)	0.945	3.840	0.000
Asset Type			
Asset Type (1 if Bridge-Tunnel Repair/Maintenance/ Management or general maintenance/repair/rehabilitation/ treatment or guardrail repair/maintenance, 0 otherwise)	1.144	3.770	0.000
Road Geometry			
Road type indicator (1 if Urban, 0 otherwise)	-1.530	-2.210	0.0270
Standard deviation of parameter density function	2.460	2.550	0.011
Model Summary			
Number of Observations	198		
Log likelihood at Zero	-122.276		
Log likelihood at Convergence	-91.809		

Table 6.43 Summary of Cost Overrun Likelihood Results

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]
Region Indicator (1 if USA, 0 otherwise) [Full Model]	↓							
State Indicator (1 if Minnesota, Indiana or Virginia, 0 otherwise) [Full Model]	↑							
State Indicator (1 if Minnesota, Indiana or Virginia, 0 otherwise) [USA Model]		↑						
Contract Type								
Contract Indicator (1 if A+B or I/D, 0 otherwise) [USA Model]		↓						
Contract Indicator (1 if A+B, 0 otherwise) [Full Model]	↓							
Contract Indicator (1 if I/D, 0 otherwise) [Full Model]	↓							
Contract Indicator (1 if PBC, 0 otherwise) [Full Model]	(↑)							
Contract Indicator (1 if PBC, 0 otherwise) [USA Model]		↓						
Contract Characteristics								
Cost Award of Contract (1 if greater than $ 30M, 0 otherwise) [Full Model]	↓							
Cost Award of Contract (1 if greater than $ 90M, 0 otherwise) [USA Model]		↑						
Cost of the contract (1 if greater than $ 69M, 0 otherwise) [USA Model]		↑						
Cost of the contract (1 if greater than $11M, 0 otherwise) [Traditional]								↓
Cost of the contract (1 if less than $11M, 0 otherwise) [DBOM]				↓				
Cost of the contract (in $1M) [A+B]			↓					
Duration of the contract (1 if 3.5 years or more and 6 years or less, 0 otherwise) [Full Model]	↓							
Duration of the contract (1 if less than 3.5 years, 0 otherwise) [USA Model]		↑						
Extension of contract (1 if between 2.9 and 4 years, 0 otherwise) [Full Model]	↑							
Inverse of the Size of the Contract [USA Model]		↑						
Inverse of the Square Root of Size of the Contract [I/D]					↑			
Size of Contract Indicator (1 if less than 50 lane-miles, 0 otherwise) [DBOM]				↑				
Size of the contract (1 if less than 185 lane-miles, 0 otherwise) [PBC]							(↓)	
Size/Duration of the contract (1 if duration is greater than 2.5 years and size is less than 40 lane-miles, 0 otherwise) [Lane Rental]						↑		
Number of assets (1 if equal to one, 0 otherwise) [Lane Rental]						↓		
Number of assets (1 if equal to two, 0 otherwise) [I/D]					↓			
Number of assets (1 if greater than 0, 0 otherwise) [PBC]							(↓)	
Number of assets (1 if less than 2, 0 otherwise) [Traditional]								↑

Table 6.43 Summary of Cost Overrun Likelihood Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]
One 10000th of the Square Root of the Contract Cost [Full Model]	(↑)							
Asset Type								
Asset Type Indicator (1 if Bridge-Tunnel Repair /Maintenance Management or general maintenance/ repair/rehabilitation/treatment or guardrail repair/ maintenance, 0 otherwise) [Traditional]								↑
Asset Type Indicator (1 if emergency facilities maintenance/response or management or landscape repair/maintenance or electrical/ cable system repair/ maintenance,0 otherwise) [PBC]							↑	
Asset type Indicator (1 if General repair/maintenance/ rehabilitation/treatment, 0 otherwise) [Lane Rental]						↑		
Asset Type Indicator (1 if guardrail repair/maintenance or pavement repair/maintenance/treatment or rest areas, 0 otherwise) [A+B]			(↑)					
Asset Type Indicator (1 if illumination repair/maintenance or landscape repair/maintenance or pavement repair/ maintenance/treatment or traffic signs and signals or vegetation/tree control/maintenance/removal, 0 otherwise) [DBOM]				(↑)				
Asset Type Indicator (1 if Litter Removal or Shoulder Repair/Maintenance, 0 otherwise) [Full Model]	↓							
Asset Type Indicator (1 if Litter Removal or Shoulder Repair/Maintenance, 0 otherwise) [USA Model]		↓						
Asset Type Indicator (1 if Rest Areas, 0 otherwise) [DBOM]				↓				
Road Geometry and Pavement Condition and Traffic Characteristics								
Average AADT (1 if greater than 3,900 and 15,200, 0 otherwise) [USA Model]		(↑)						
One 10000th of the Squared of the Median Width [USA Model]		↓						
Road type indicator (1 if Urban, 0 otherwise) [DBOM]				↑				
Road type indicator (1 if Urban, 0 otherwise) [Traditional]								(↓)
Standard Deviation of IRI (1 if greater than 11 inches per mile, 0 otherwise) [Full Model]	↑							
Standard Deviation of IRI (1 if greater than 11, 0 otherwise) [USA Model]		↑						
Weather Condition								
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.3 and 0.4, 0 otherwise) [Full Model]	(↑)							
Weather indicator (1 if the proportion of rainy days to total days of contract is between 0.3 and 0.4, 0 otherwise) [USA Model]		↑						

6.3 Change Orders Model Estimation Results

Transportation projects are frequently not completed within the original scope of work (Anastasopoulos et al. 2010). Change orders are generally caused by a number of reasons such as design errors, unexpected weather conditions, and so on. There are several parameters that may increase the number or likelihood of change orders. The estimated statistical methods present the possible influential factors on both likelihood and number of change orders.

Anastasopoulos et al. (2010) has found that duration, contract cost, and various activity types can play a significant role on the number of change orders.

6.3.1 Change Orders Frequency Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.44 to 6.54. The results can be summarized as follows:

- Projects in Minnesota under cost-plus-time are found to have a higher number of change orders.
- Change orders frequency increases when the project duration exceeds 5.5 years.
- Under cost-plus-time and incentives/disincentives, in 93 percent of the contracts (random parameter with Normal distribution), increasing the size results in a significant reduction in change orders frequency; however, under design build, PBC and Traditional contracts, increases in project size (in lane-miles), increases

the change orders frequency. For cost-plus-time and incentives/disincentives contracts, the contractors are paid based on the delivery date of the project (whether contractors meet the deadline or not). It is, therefore, expected that the contractors will prevent any change orders occurrence. On the other hand, for design build, PBC, and Traditional contracts, it is not uncommon to observe change orders.

- Bridge-tunnel, guardrail, pavement and general repair and maintenance, are found to increase change orders frequency for PPP contracts. However, assets related to repair, maintenance and treatment of the electrical-cable system, illumination, landscape, traffic signs and signals, are found to decrease change orders frequency.
- The factors, the effect of which varies across the observations, are also presented in Tables 6.44 to 6.54, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.44 Descriptive Statistics of Change Orders Frequency Models

• Variables	Mean	Std. Dev	Min.	Max.
Region indicator (1 Europe, 0 otherwise) [Full Model]	0.1	-	0	1
Region indicator (1 if Asia, 0 otherwise) [Full Model]	0.062	-	0	1
Region indicator (1 if Canada, 0 otherwise) [Full Model]	0.086	-	0	1
Region indicator (1 if United States, 0 otherwise) [Full Model]	0.6	-	0	1
State Indicator (1 if Minnesota, 0 otherwise) [A+B]	0.548	-	0	1
Contract Types				
Contract indicator (1 if DBOM, 0 otherwise) [Full Model]	0.076	-	0	1
Contract indicator (1 if A+B, 0 otherwise) [Full Model]	0.204	-	0	1
Contract Indicator (1 if A+B, 0 otherwise) [USA Model]	0.048	-	0	1
Contract Indicator (1 if incentives/disincentives, 0 otherwise) [USA Model]	0.057	-	0	1
Contract Indicator (1 if Warranty, 0 otherwise) [USA Model]	0.15	-	0	1
Contract Characteristics				
Bid range (1 if less than $6M, 0 otherwise) [Full Model]	0.762	-	0	1
Cost of the contract indicator (1 if greater than $100M, 0 otherwise) [Traditional]	0.061	-	0	1
Duration of the contract (1 if greater than 3.5 years, 0 otherwise) [Full Model]	0.338	-	0	1
Duration of the contract indicator (1 if 5.8 years or less , 0 otherwise) [A+B]	0.806	-	0	1
Duration of the contract indicator (1 if greater than 2 years, 0 otherwise) [Traditional]	0.571	-	0	1
Duration of the contract indicator (1 if greater than 5, 0 otherwise) [DBOM]	0.805	-	0	1
Duration of the contract indicator (1 if more than 2.5 years, 0 otherwise) [I/D]	0.784	-	0	1
Duration/Extension of contract indicator (1 if 5.5 years or less duration of contract or 2 years and less extension of the contract, 0 otherwise) [USA Model]	0.349	-	0	1
Extension of contract (1 if less than 3 years, 0 otherwise) [Full Model]	0.729	-	0	1
Highest bid amount (1if less than $60M, 0 otherwise) [Full Model]	0.789	-	0	1
Highest bid indicator (1 if less than $ 60M, 0 otherwise) [USA Model]	0.907	-	0	1
Inverse of the cost of project (in10K dollars) [Full Model]	0.013	0.075	0.108D-4	2
Inverse of the cost of the contract (per $10K) [USA Model]	0.02	0.095	.420D-04	2
Size of contract indicator (in lane-miles) [A+B]	33.95	40.336	1.16	146
Size of the contract indicator (1 if greater than 130 Lane-Miles, 0 otherwise) [I/D]	0.162	-	0	1
Size of the contract indicator (1 if higher than 36 Lane-Miles, 0 otherwise) [DBOM]	0.675	-	0	1

Table 6.44 Descriptive Statistics of Change Orders Frequency Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Size of the contract indicator (1 if less than 80 Lane-Miles, 0 otherwise) [USA Model]	0.749	-	0	1
Size of the contract indicator (1 if greater than 300 lane-miles, 0 otherwise)	0.08	-	0	1
Size of the Contract indicator (1 if less than 100 lane-miles, 0 otherwise) [PBC]	0.38	-	0	1
Size of the contract indicator (1 if less than 80 Lane-Miles, 0 otherwise) [Traditional]	0.662	-	0	1
Number of bids indicator (1 if higher than 4, 0 otherwise) [USA Model]	0.113	-	0	1
Number of bids indicator (1 if less than 3, 0 otherwise) [Full Model]	0.231	-	0	1
Number of the assets indicator (1 if greater than 0 and less than 6, 0 otherwise) [Lane Rental]	0.824	-	0	1
Number of the assets indicator (1 if greater than 3, 0 otherwise) [Full Model]	0.155	-	0	1
Number of the assets indicator (1 if greater than 3, 0 otherwise) [USA Model]	0.155	-	0	1
Activity Types				
Asset type indicator (1 if Bridge-Tunnel Repair/ Maintenance/Management , 0 otherwise) [Traditional]	0.222	-	0	1
Asset type indicator (1 if General Maintenance/ Repair/Rehabilitation/ Treatment , 0 otherwise) [Traditional]	0.323	-	0	1
Asset type indicator (1 if Shoulder Repair/ Maintenance , 0 otherwise) [Traditional]	0.106	-	0	1
Asset type indicator (1 if Traffic Signs and Signals , 0 otherwise) [Traditional]	0.202	-	0	1
Asset type indicator (1 if all services, 0 otherwise) [DBOM]	0.142	-	0	1
Asset type indicator (1 if all services, 0 otherwise) [Full Model]	0.084	-	0	1
Asset Type indicator (1 if all services, 0 otherwise) [PBC]	0.203	-	0	1
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management or illumination repair/ maintenance, 0 otherwise) [DBOM]	0.112	-	0	1
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management, 0 otherwise) [Warranty]	0.278	-	0	1
Asset type indicator (1 if electrical cable system repair/maintenance, 0 otherwise) [Full Model]	0.175	-	0	1
Asset type indicator (1 if electrical/ cable system repair/maintenance, 0 otherwise) [Warranty]	0.289	-	0	1
Asset type indicator (1 if Electrical/Cable System Repair/Maintenance, 0 otherwise) [Lane Rental]	0.441	-	0	1

Table 6.44 Descriptive Statistics of Change Orders Frequency Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Asset type indicator (1 if General maintenance/ repair/rehabilitation/ treatment, 0 otherwise) [DBOM]	0.201	-	0	1
Asset type indicator (1 if general maintenance/repair/rehabilitation/ treatment, 0 otherwise) [Warranty].	0.381	-	0	1
Asset Type indicator (1 if guardrail repair/ maintenance, 0 otherwise) [PBC]	0.165	-	0	1
Asset type indicator (1 if guardrail repair/ maintenance, 0 otherwise)[DBOM]	0.225	-	0	1
Asset type indicator (1 if Guardrail Repair/Maintenance or illumination repair/ maintenance or landscape repair/ maintenance, 0 otherwise) [Warranty]	0.165	-	0	1
Asset type indicator (1 if Guardrail repair/maintenance, 0 otherwise) [Full Model]	0.128	-	0	1
Asset Type indicator (1 if illumination repair/ maintenance, 0 otherwise) [PBC]	0.063	-	0	1
Asset type indicator (1 if Illumination Repair/Maintenance , 0 otherwise) [Traditional]	0.081	-	0	1
Asset type indicator (1 if illumination repair/maintenance, 0 otherwise) [Full Model]	0.057	-	0	1
Asset type indicator (1 if Landscape Repair/ Maintenance , 0 otherwise) [Traditional]	0.056	-	0	1
Asset type indicator (1 if landscape repair/maintenance, 0 otherwise) [Full Model]	0.05	-	0	1
Asset type indicator (1 if litter removal, 0 otherwise) [Full Model]	0.059	-	0	1
Asset type indicator (1 if Management, 0 otherwise) [Full Model]	0.045	-	0	
Asset Type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise) [PBC]	0.139	-	0	1
Asset type indicator (1 if Pavement Repair/ Maintenance/Treatment , 0 otherwise) [Traditional]	0.101	-	0	1
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [DBOM]	0.136	-	0	1
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [Warranty]	0.289	-	0	1
Asset type indicator (1 if rest area, 0 otherwise) [Full Model]	0.116	-	0	1
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise) [PBC]	0.101	-	0	1
Asset type indicator (1 if traffic signs and signals, 0 otherwise) [Full Model]	0.133	-	0	1
Asset type indicator (1 if traffic signs and signals, 0 otherwise) [Warranty]	0.062	-	0	1
Asset type indicator (1 if vegetation/tree control/maintenance/removal, 0 otherwise) [Full Model]	0.048	-	0	1

Table 6.44 Descriptive Statistics of Change Orders Frequency Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Road Geometry and Pavement Condition and Traffic Characteristics				
Annual Average Daily Traffic (1 if less than 5000, 0 otherwise) [USA Model]	0.533	-	0	1
Junction Indicator (1 if no junction, 0 otherwise) [USA Model]	0.22	-	0	1
Vertical curve Indicator (1 if greater than 5 curves, 0 otherwise) [USA Model]	0.611	-	0	1
Weather Condition				
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.35, 0 otherwise) [Full Model]	0.229	-	0	1
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.35, 0 otherwise) [Full Model]	0.04	0.049	0	0.28
Weather indicator (1 if the proportion of rainy days to total days of contract is higher than 0.37, 0 otherwise) [USA Model]	0.129	-	0	1
Weather indicator (1 if the proportion of Snowy days to total days of contract is higher than 0.07, 0 otherwise) [USA Model]	0.42	-	0	1

Table 6.45 Change orders frequency (Poisson) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Region indicator (1 if United States, 0 otherwise)	0.549	10.560	0.000
Region indicator (1 if Canada, 0 otherwise)	0.282	2.650	0.008
Region indicator (1 Europe, 0 otherwise)	1.078	10.450	0.000
Region indicator (1 if Asia, 0 otherwise)	0.478	2.960	0.003
Contract Types			
Contract indicator (1 if A+B, 0 otherwise)	-0.517	-6.630	0.000
Contract indicator (1 if DBOM, 0 otherwise)	0.347	5.43	0.000
Contract Characteristics			
Duration of Contract (1 if greater than 3.5 years, 0 otherwise)	-0.130	-2.590	0.009
Extension of contract (1 if less than 3 years, 0 otherwise)	0.098	2.390	0.017
Size of the Contract (1 if greater than 300 lane-miles, 0 otherwise)	0.660	7.890	0.000
Number of assets (1 if greater than 3, 0 otherwise)	0.768	9.130	0.000
Square Root of the Cost of the Project (in10K dollars)	-2.068	-2.680	0.007
Number of bids (1 if less than 3, 0 otherwise)	0.175	2.610	0.009
Highest bid amount (1if less than $60M, 0 otherwise)	0.239	3.53	0.000
Bid range (1 if less than $6M, 0 otherwise)	0.457	6.47	0.000
Activity Types			
Asset type indicator (1 if all services, 0 otherwise)	0.189	1.99	0.047
Asset type indicator (1 if Management, 0 otherwise)	1.123	14.930	0.000
Asset type indicator (1 if Guardrail repair/maintenance, 0 otherwise)	-0.587	-6.120	0.000
Asset type indicator (1 if illumination repair/maintenance, 0 otherwise)	-0.304	-2.03	0.043
Asset type indicator (1 if landscape repair/maintenance, 0 otherwise)	-0.627	-3.070	0.002
Asset type indicator (1 if litter removal, 0 otherwise)	-1.310	-10.570	0.000
Asset type indicator (1 if electrical cable system repair/ maintenance, 0 otherwise)	-0.265	-2.720	0.007
Asset type indicator (1 if rest area, 0 otherwise)	-0.259	-2.310	0.021
Asset type indicator (1 if traffic signs and signals, 0 otherwise)	-0.551	-6.640	0.000
Asset type indicator (1 if vegetation/tree control/ maintenance/ removal, 0 otherwise)	-0.605	-3.390	0.001
Weather Condition			
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.35, 0 otherwise)	0.465	9.150	0.000
Weather indicator (proportion of snowy days to total days of contract)	1.606	2.350	0.019
Model Summary			
Dispersion Parameter (α)	0.232	12.91	0.000
Number of Observations	1074		
Log likelihood at Zero	-2737.870		
Log likelihood at Convergence	-2545.900		

Table 6.46 Change orders frequency (Poisson) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	2.081	19.960	0.000
Contract Type			
Contract Indicator (1 if A+B, 0 otherwise)	-1.376	-10.880	0.000
Contract Indicator (1 if incentives/disincentives, 0 otherwise)	-0.651	-6.050	0.000
Contract Indicator (1 if Warranty, 0 otherwise)	0.126	2.170	0.030
Contract Characteristics			
Duration/Extension of contract indicator (1 if 5.5 years or less duration of contract or 2 years and less extension of the contract, 0 otherwise)	-0.355	-6.100	0.000
Size of the contract (1 if less than 80 Lane-Miles, 0 otherwise)	-0.404	-6.410	0.000
Number of assets indicator (1 if greater than 3, 0 otherwise)	0.192	3.000	0.003
Inverse of cost of contract (per $10K)	-1.298	-2.080	0.038
Number of bids indicator (1 if higher than 4, 0 otherwise)	-0.189	-2.620	0.009
Standard deviation of parameter density function			
Highest bid indicator(1 if less than $ 60M, 0 otherwise)	-0.391	-5.790	0.000
Road Geometry			
Junction Indicator (1 if no junction, 0 otherwise)	0.251	3.200	0.001
Vertical curve Indicator (1 if greater than 5 curves, 0 otherwise)	-0.270	-3.590	0.000
Weather Condition			
Weather indicator (1 if the proportion of Snowy days to total days of contract is higher than 0.07, 0 otherwise)	0.132	2.450	0.014
Weather indicator (1 if the proportion of rainy days to total days of contract is higher than 0.37, 0 otherwise)	0.254	3.800	0.000
Traffic Characteristics			
Annual Average Daily Traffic (1 if less than 5000, 0 otherwise)	0.161	2.990	0.003
Model Summary			
Number of Observations	645		
log-likelihood at convergence	-1347.585		
Restricted log-likelihood	-1593.528		

Table 6.47 Change orders frequency (Poisson) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
State Indicator(1 if Minnesota, 0 otherwise)	1.642	4.430	0.000
Contract Characteristics			
Duration of contract indicator (1 if 5.8 years or less , 0 otherwise)	-0.813	-1.850	0.064
Size of contract indicator (in lane-miles)	-0.178	-3.270	0.001
Standard deviation of parameter density function	0.121	4.100	0.000
Model Summary			
Number of Observations	31		
log-likelihood at convergence	-26.474		
Restricted log-likelihood	-50.755		

Table 6.48 Change orders frequency (Poisson) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Duration of contract indicator (1 if greater than 5, 0 otherwise)	0.445	4.100	0.000
Size of the contract (1 if higher than 36 Lane-Miles, 0 otherwise)	0.295	2.620	0.009
Asset Type			
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management or illumination repair/ maintenance, 0 otherwise)	0.457	3.940	0.000
Asset type indicator (1 if guardrail repair/ maintenance, 0 otherwise)	0.643	4.380	0.000
Asset type indicator(1 if pavement repair/ maintenance/ treatment, 0 otherwise)	1.292	9.720	0.000
Asset type indicator (1 if General maintenance/ repair/ rehabilitation/treatment, 0 otherwise)	0.503	4.750	0.000
Standard deviation of parameter density function	0.446	5.500	0.000
Asset type indicator (1 if all services, 0 otherwise)	0.902	4.260	0.000
Model Summary			
Number of Observations	169		
log-likelihood at convergence	-317.596		
Restricted log-likelihood	-372.015		

Table 6.49 Change orders frequency (Poisson) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	0.916	3.670	0.000
Contract Characteristics			
Duration of contract indicator (1 if more than 2.5 years, 0 otherwise)	-0.524	-1.860	0.063
Standard deviation of parameter density function	0.566	4.120	0.000
Size of the contract (1 if greater than 130 Lane-Miles, 0 otherwise)	0.847	2.710	0.007
Model Summary			
Number of Observations	37		
log-likelihood at convergence	-60.216		
Restricted log-likelihood	-74.396		

Table 6.50 Change orders frequency (Poisson) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	0.861	2.580	0.010
Contract Characteristics			
Number of assets indicator (1 if greater than 0 and less than 6, 0 otherwise)	0.752	2.250	0.024
Asset Type			
Asset type indicator (1 if Electrical/Cable System Repair/ Maintenance, 0 otherwise)	-0.585	-2.930	0.003
Model Summary			
Number of Observations	34		
log-likelihood at convergence	-64.432		
Restricted log-likelihood	-73.984		

Table 6.51 Change orders frequency (Poisson) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	1.565	12.460	0.000
Contract Characteristics			
Size of the Contract (1 if less than 100 lane-miles, 0 otherwise)	-0.743	-3.650	0.000
Asset Types			
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise)	-1.977	-3.550	0.000
Standard deviation of parameter density function	1.650	3.330	0.001
Asset Type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise)	0.730	3.260	0.001
Asset Type indicator (1 if all services, 0 otherwise)	0.545	2.640	0.008
Asset Type indicator (1 if guardrail repair/ maintenance, 0 otherwise)	-1.112	-3.540	0.000
Standard deviation of parameter density function	0.669	2.440	0.015
Asset Type indicator (1 if illumination repair/ maintenance, 0 otherwise)	-1.862	-2.230	0.026
Standard deviation of parameter density function	2.538	3.060	0.002
Model Summary			
Number of Observations	79		
Log likelihood at Convergence	-151.850		
Restricted Log likelihood	-234.420		

Table 6.52 Change orders frequency (Poisson) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	0.994	9.380	0.000
Contract Characteristics			
Duration of the contract (1 if greater than 2 years, 0 otherwise)	0.424	4.810	0.000
Size of the contract (1 if less than 80 Lane-Miles, 0 otherwise)	-0.234	-3.060	0.002
Cost of the Contract (1 if greater than $100M, 0 otherwise)	0.495	2.100	0.036
Assets Type			
Asset type indicator (1 if Bridge-Tunnel Repair/ Maintenance/ Management , 0 otherwise)	0.668	7.930	0.000
Asset type indicator (1 if General Maintenance/ Repair/ Rehabilitation/ Treatment , 0 otherwise)	0.389	4.230	0.000
Asset type indicator (1 if Illumination Repair/Maintenance , 0 otherwise)	-0.616	-2.460	0.014
Asset type indicator (1 if Landscape Repair/ Maintenance , 0 otherwise)	-0.712	-2.110	0.035
Asset type indicator (1 Pavement Repair/ Maintenance/ Treatment , 0 otherwise)	0.586	5.710	0.000
Asset type indicator (1 Shoulder Repair/ Maintenance , 0 otherwise)	0.289	2.650	0.008
Asset type indicator (1 if Traffic Signs and Signals , 0 otherwise)	-0.309	-2.530	0.011
Model Summary			
Number of Observations	198		
Log likelihood at Convergence	-340.764		
Restricted Log likelihood	-455.756		

Table 6.53 Change orders frequency (Poisson) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	1.449	15.380	0.000
Asset Type			
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management, 0 otherwise)	0.512	5.070	0.000
Asset type indicator (1 if general maintenance/ repair/ rehabilitation/ treatment, 0 otherwise)	0.242	2.540	0.011
Asset type indicator (1 if Guardrail Repair/Maintenance or illumination repair/ maintenance or landscape repair/ maintenance, 0 otherwise)	-0.613	-3.790	0.000
Asset type indicator (1 if electrical/ cable system repair/ maintenance, 0 otherwise)	-0.296	-2.390	0.017
Asset type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise)	0.436	4.300	0.000
Asset type indicator (1 if traffic signs and signals, 0 otherwise)	-0.569	-1.840	0.065
Model Summary			
Number of Observations	97		
log-likelihood at convergence	-185.505		
Restricted log-likelihood	-233.418		

Table 6.54 Summary of Change Orders Frequency Results

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Region indicator (1 Europe, 0 otherwise) [Full Model]	↑								
Region indicator (1 if Asia, 0 otherwise) [Full Model]	↑								
Region indicator (1 if Canada, 0 otherwise) [Full Model]	↑								
Region indicator (1 if United States, 0 otherwise) [Full Model]	↑								
State Indicator (1 if Minnesota, 0 otherwise) [A+B]			↑						
Contract Types									
Contract indicator (1 if A+B, 0 otherwise) [Full Model]	↓								
Contract Indicator (1 if A+B, 0 otherwise) [USA Model]		↓							
Contract indicator (1 if DBOM, 0 otherwise) [Full Model]	↑								
Contract Indicator (1 if incentives/disincentives, 0 otherwise) [USA Model]		↓							
Contract Indicator (1 if Warranty, 0 otherwise) [USA Model]		↑							
Contract Characteristics									
Bid range (1 if less than $6M, 0 otherwise) [Full Model]	↑								
Cost of the contract indicator (1 if greater than $100M, 0 otherwise) [Traditional]								↑	
Duration of the contract (1 if greater than 3.5 years, 0 otherwise) [Full Model]	↓								
Duration of the contract indicator (1 if 5.8 years or less , 0 otherwise) [A+B]			↓						
Duration of the contract indicator (1 if greater than 2 years, 0 otherwise) [Traditional]								↑	
Duration of the contract indicator (1 if greater than 5, 0 otherwise) [DBOM]				↑					
Duration of the contract indicator (1 if more than 2.5 years, 0 otherwise) [I/D]					(↓)				
Duration/Extension of contract indicator (1 if 5.5 years or less duration of contract or 2 years and less extension of the contract, 0 otherwise) [USA Model]		↓							
Extension of contract (1 if less than 3 years, 0 otherwise) [Full Model]	↑								
Highest bid amount (1if less than $60M, 0 otherwise) [Full Model]	↑								
Highest bid indicator (1 if less than $ 60M, 0 otherwise) [USA Model]		↓							
Inverse of the cost of project (in10K dollars) [Full Model]									
Inverse of the cost of the contract (per $10K) [USA Model]		↓							
Size of contract indicator (in lane-miles) [A+B]			(↓)						

Table 6.54 Summary of Change Orders Frequency Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Size of the contract indicator (1 if greater than 130 Lane-Miles, 0 otherwise) [I/D]					↑				
Size of the contract indicator (1 if higher than 36 Lane-Miles, 0 otherwise) [DBOM]				↑					
Size of the contract indicator (1 if less than 80 Lane-Miles, 0 otherwise) [USA Model]		↓							
Size of the contract indicator (1 if greater than 300 lane-miles, 0 otherwise)	↑								
Size of the Contract indicator (1 if less than 100 lane-miles, 0 otherwise) [PBC]							↓		
Size of the contract indicator (1 if less than 80 Lane-Miles, 0 otherwise) [Traditional]								↓	
Number of bids indicator (1 if higher than 4, 0 otherwise) [USA Model]		↓							
Number of bids indicator (1 if less than 3, 0 otherwise) [Full Model]	↑								
Number of the assets indicator (1 if greater than 0 and less than 6, 0 otherwise) [Lane Rental]						↑			
Number of the assets indicator (1 if greater than 3, 0 otherwise) [Full Model]	↑								
Number of the assets indicator (1 if greater than 3, 0 otherwise) [USA Model]		↑							
Activity Types									
Asset type indicator (1 if Bridge-Tunnel Repair/ Maintenance/Management , 0 otherwise) [Traditional]								↑	
Asset type indicator (1 if General Maintenance/ Repair/Rehabilitation/ Treatment , 0 otherwise) [Traditional]								↑	
Asset type indicator (1 if Shoulder Repair/ Maintenance , 0 otherwise) [Traditional]								↑	
Asset type indicator (1 if Traffic Signs and Signals , 0 otherwise) [Traditional]								↓	
Asset type indicator (1 if all services, 0 otherwise) [DBOM]				↑					
Asset type indicator (1 if all services, 0 otherwise) [Full Model]	↑								
Asset Type indicator (1 if all services, 0 otherwise) [PBC]							↑		
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management or illumination repair/ maintenance, 0 otherwise) [DBOM]				↑					

Table 6.54 Summary of Change Orders Frequency Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management, 0 otherwise) [Warranty]									↑
Asset type indicator (1 if electrical cable system repair/maintenance, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if electrical/ cable system repair/maintenance, 0 otherwise) [Warranty]									↓
Asset type indicator (1 if Electrical/Cable System Repair/Maintenance, 0 otherwise) [Lane Rental]						↓			
Asset type indicator (1 if General maintenance/ repair/rehabilitation/ treatment, 0 otherwise) [DBOM]				(↑)					
Asset type indicator (1 if general maintenance/repair/rehabilitation/ treatment, 0 otherwise) [Warranty].									↑
Asset Type indicator (1 if guardrail repair/ maintenance, 0 otherwise) [PBC]							(↓)		
Asset type indicator (1 if guardrail repair/ maintenance, 0 otherwise)[DBOM]				↑					
Asset type indicator (1 if Guardrail Repair/Maintenance or illumination repair/ maintenance or landscape repair/ maintenance, 0 otherwise) [Warranty]									↓
Asset type indicator (1 if Guardrail repair/maintenance, 0 otherwise) [Full Model]	↓								
Asset Type indicator (1 if illumination repair/ maintenance, 0 otherwise) [PBC]							(↓)		
Asset type indicator (1 if Illumination Repair/Maintenance , 0 otherwise) [Traditional]								↓	
Asset type indicator (1 if illumination repair/maintenance, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if Landscape Repair/ Maintenance , 0 otherwise) [Traditional]								↓	
Asset type indicator (1 if landscape repair/maintenance, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if litter removal, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if Management, 0 otherwise) [Full Model]	↑								
Asset Type indicator (1 if pavement repair/ maintenance/ treatment, 0 otherwise) [PBC]							↑		
Asset type indicator (1 if Pavement Repair/ Maintenance/Treatment , 0 otherwise) [Traditional]								↑	

Table 6.54 Summary of Change Orders Frequency Results (Continued)

Variables	Full Model	US Model	A+B [US]	DBOM [US]	I/D [US]	Lane Rental [US]	PBC [US]	Traditional [US]	Warranty [US]
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [DBOM]				↑					
Asset type indicator (1 if pavement repair/ maintenance/treatment, 0 otherwise) [Warranty]									↓
Asset type indicator (1 if rest area, 0 otherwise) [Full Model]	↓								
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise) [PBC]							(↓)		
Asset type indicator (1 if traffic signs and signals, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if traffic signs and signals, 0 otherwise) [Warranty]									↓
Asset type indicator (1 if vegetation/tree control/maintenance/removal, 0 otherwise) [Full Model]	↓								
Road Geometry and Pavement Condition and Traffic Characteristics									
Annual Average Daily Traffic (1 if less than 5000, 0 otherwise) [USA Model]		↑							
Junction Indicator (1 if no junction, 0 otherwise) [USA Model]		↑							
Vertical curve Indicator (1 if greater than 5 curves, 0 otherwise) [USA Model]		↓							
Weather Condition									
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.35, 0 otherwise) [Full Model]	↑								
Weather indicator (1 if the proportion of rainy days to total days of contract is greater than 0.35, 0 otherwise) [Full Model]	↑								
Weather indicator (1 if the proportion of rainy days to total days of contract is higher than 0.37, 0 otherwise) [USA Model]		↑							
Weather indicator (1 if the proportion of Snowy days to total days of contract is higher than 0.07, 0 otherwise) [USA Model]		↑							

6.3.2 Change Orders Likelihood Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in tables 6.54 to 6.64. The results can be summarized as follows:

- Because of the unique characteristics of each PPP approach, the project size (measured in lane-miles) can have various effects for each PPP contract type. Larger sized cost-plus-time, design build, and warranty contracts are found to reduce the likelihood of change orders occurrence. While, for the remaining of the PPP types, larger sized contracts are found to increase the likelihood of change orders occurrence.
- In a similar fashion, the likelihood of change orders occurrence increases with the project's cost (as the cost increase, the likelihood of change orders occurrence also increases).
- Longer projects in term of duration (in years) increase the likelihood of change orders occurrence for all PPP contract types.
- Activities such as illumination maintenance and repair, litter removal, vegetation or tree control, maintenance and removal, traffic signs and signals, guardrail repair, and maintenance and rest areas, decrease the likelihood of change orders occurrence for incentives/disincentives, Lane Rentals, Traditional, and Warranty contracts. On the other hand, activities such as bridge-tunnel repair, maintenance and management, pavement repair, maintenance and treatment, culvert, ditches

gutter and drainage system repair, maintenance, increase the likelihood of change orders occurrence for cost-plus-time and PBC contracts.

- The factors, the effect of which varies across the observations, are also presented in Tables 6.54 to 6.64, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.55 Descriptive Statistics of Change Orders Likelihood Models

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Region Indicator (1 if North America, 0 otherwise) [Full Model]	0.686	-	0	1
Contract Type				
Contract Indicator (1 if A+B or ID, 0 otherwise) [Full Model]	0.14	-	0	1
Contract Indicator (1 if A+B or ID, 0 otherwise) [USA Model]	0.122	-	0	1
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [Full Model]	0.134	-	0	1
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [USA Model]	0.105	-	0	1
Contract Information				
Cost of the contract (1 if greater than $ 12M, 0 otherwise) [A+B]	0.29	-	0	1
Cost of the contract (1 if less than $ 25M, 0 otherwise) [DBOM]	0.609	-	0	1
Cost of the contract (in $100M) [Lane Rental]	0.113	0.092	0	0.355
Cost of the contract (in $100M) [PBC]	0.601	0.633	0	2.279
Duration of the contract (1 if greater than 3.5 years, 0 otherwise) [Warranty]	0.701	-	0	1
Duration of the contract (1 if greater than 3.8 years, 0 otherwise) [I/D]	0.622	-	0	1
Duration of the contract (1 if less than 4 years, 0 otherwise) [PBC]	0.152	-	0	1
Duration of the contract (in years) [Lane Rental]	2.614	0.529	1.62	3.75
Duration of the contract (years) [DBOM]	5.667	0.852	3	8.1
Duration of the contract (years) [Full Model]	4.486	2,407	0.02	25
Duration of the contract (years) [USA Model]	4.528	2.203	0.16	20
Extension of the Contract (years) [Full Model]	1.714	2.344	0	11.66
Extension of the Contract (years) [USA Model]	1.505	2.203	0	11.66
Inverse of the Cost of the contract (in $100k) [Traditional]	0.429	0.873	0	10
Inverse of the Cost of the contract Award (in $1M) [USA Model]	2.014	5.138	0	69.502
Size of the contract (1 if greater than 120 lane-miles, 0 otherwise) [PBC]	0.608	-	0	1
Size of the contract (1 if less than 30 lane-miles, 0 otherwise) [Warranty]	0.907	-	0	1
Size of the contract (in lane-miles) [A+B]	33.948	40.336	1.16	146.1
Size of the contract (in lane-miles) [DBOM]	30.053	31.679	0.23	249.79
Size of the contract (in lane-miles) [I/D]	57.004	58.848	0.02	170
Size of the contract (Lane-Miles) [Full Model]	102.222	164.177	0.02	1037.7
Size of the contract (Lane-Miles) [USA Model]	76.746	142.53	0.02	924.01
Number of assets (1 if equal to two, 0 otherwise) [I/D]	0.351	-	0	1
Number of assets (1 if greater than 2, 0 otherwise) [Traditional]	0.258	-	0	1
Number of assets (1 if greater than 3, 0 otherwise) [Full Model]	0.155	-	0	1
Number of bids (1 if 2 or 3, 0 otherwise) [Full Model]	0.632	-	0	1
Number of bids (1 if 2 or 3, 0 otherwise) [USA Model]	0.597	-	0	1

Table 6.55 Descriptive Statistics of Change Orders Likelihood Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Road Geometry and Pavement Condition and Traffic Characteristics				
Average Annual Daily Traffic (1 if less than 13000, 0 otherwise) [USA Model]	0.687	-	0	1
Drainage system Indicator (1 if well drained or moderately well drained,0 otherwise) [USA Model]	0.912	-	0	1
Median width (1 if greater than 35 feet, 0 otherwise) [Full Model]	0.281	-	0	1
Number of Horizontal Curves per segment (1 if 5 or more horizontal curves, 0 Otherwise) [Full Model]	0.736	-	0	1
Number of Horizontal Curves per segment (1 if 5 or more horizontal curves, 0 Otherwise) [USA Model]	0.622	-	0	1
Percentage of trucks (1 if greater than 21%, 0 otherwise) [Full Model]	0.626	-	0	1
Truck Percentage (1 if greater than 0.21, 0 otherwise) [USA Model]	0.239	-	0	1
Type of Junction Indicator (1 if no junction, 0 otherwise) [Full Model]	0.153	-	0	1
Asset Types				
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management or general repair/maintenance/rehabilitation/treatment or pavement repair/ maintenance/ treatment or vegetation/ tree control/ maintenance and removal, 0 otherwise) [A+B]	0.484	-	0	1
Asset type indicator (1 if culvert/ ditches/ gutters/drainage repair/ maintenance/replacement or general maintenance/repair/ rehabilitation/treatment, 0 otherwise) [PBC]	0.165	-	0	1
Asset type indicator (1 if Culvert/Ditches/Cutters/ Drainage Repair/Maintenance/Replacement, 0 otherwise) [Full Model]	0.148	-	0	1
Asset type indicator (1 if Electrical/Cable system Repair/Maintenance, 0 otherwise) [Full Model]	0.175	-	0	1
Asset type indicator (1 if Electrical/Cable system Repair/Maintenance, 0 otherwise) [USA Model]	0.205	-	0	1
Asset type indicator (1 if General Maintenance/Repair/ Rehabilitation/Treatment, 0 otherwise) [Full Model]	0.33	-	0	1
Asset type indicator (1 if Guardrail Maintenance/Repair, 0 otherwise) [Traditional]	0.126	-	0	1
Asset type indicator (1 if Guardrail Repair/Maintenance, 0 otherwise) [Full Model]	0.128	-	0	1
Asset type indicator (1 if Guardrail Repair/Maintenance, 0 otherwise) [USA Model]	0.161	-	0	1
Asset type indicator (1 if illumination Maintenance/Repair or litter removal or vegetation/ tree control/ maintenance/ removal,0 otherwise) [Warranty]	0.093	-	0	1
Asset type indicator (1 if management or guardrail repair/maintenance or illumination repair/ maintenance or landscape repair/ maintenance, 0 otherwise) [I/D]	0.27	-	0	1
Asset type indicator (1 if other asset type, 0 otherwise) [Warranty]	0.206	-	0	1
Asset type indicator (1 if other assets, 0 otherwise) [DBOM]	0.124	-	0	1

Table 6.55 Descriptive Statistics of Change Orders Likelihood Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Asset type indicator (1 if other types of assets, 0 otherwise) [Full Model]	0.164	-	0	1
Asset type indicator (1 if Rest Area, 0 otherwise) [Lane Rental]	0.235	-	0	1
Asset type indicator (1 if traffic Signals and signs, 0 otherwise) [Traditional]	0.202	-	0	1
Asset type indicator (1 if Traffic signs and signals, 0 otherwise) [Full Model]	0.133	-	0	1
Asset type indicator (1 if Traffic signs and signals, 0 otherwise) [USA Model]	0.147	-	0	1

Table 6.56 Change orders likelihood (logit) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Region Indicator (1 if North America, 0 otherwise)	-1.967	-4.250	0.000
Contract Type			
Contract Indicator (1 if Performance-Based Contract, 0 otherwise)	-4.906	-7.200	0.000
Contract Indicator (1 if A+B or ID, 0 otherwise)	-4.740	-8.250	0.000
Standard deviation of parameter density function	2.018	6.170	0.000
Contract Information			
Number of Bids (1 if 2 or 3, 0 otherwise)	1.048	3.630	0.000
Size of the contract (Lane-Miles)	0.019	4.790	0.000
Duration of the contract (years)	0.862	7.070	0.000
Standard deviation of parameter density function	0.239	5.900	0.000
Number of Assets (1 if greater than 3, 0 otherwise)	-2.829	-3.580	0.000
Standard deviation of parameter density function	1.832	5.770	0.000
Extension of the Contract (years)	0.632	5.350	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Median width (1 if greater than 35 feet, 0 otherwise)	0.996	2.780	0.005
Number of Horizontal Curves per segment (1 if 5 or more horizontal curves, 0 Otherwise)	-1.314	-2.820	0.005
Type of Junction Indicator (1 if no junction, 0 otherwise)	1.757	3.700	0.000
Average Annual Daily Traffic (1 if less than 13000, 0 otherwise)			
Percentage of trucks (1 if greater than 21%, 0 otherwise)	1.761	3.990	0.000
Asset Types			
Asset Type Indicator (1 if Culvert/Ditches/Cutters/Drainage Repair/Maintenance/Replacement, 0 otherwise)	2.397	4.550	0.000
Asset Type Indicator (1 if General Maintenance/Repair/ Rehabilitation/Treatment, 0 otherwise)	1.843	3.250	0.001
Asset Type Indicator (1 if Guardrail Repair/Maintenance, 0 otherwise)	-2.213	-5.180	0.000
Asset Type Indicator (1 if Electrical/Cable system Repair/ Maintenance, 0 otherwise)	-2.149	-3.870	0.000
Asset Type Indicator (1 if Traffic signs and signals, 0 otherwise)	-2.310	-5.290	0.000
Asset Type indicator (1 if other types of assets, 0 otherwise)	2.074	3.260	0.001
Model Summary			
Number of Observations	1074		
Log likelihood at Convergence	-136.926		
Restricted Log likelihood	-337.121		

Table 6.57 Change orders likelihood (logit) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Type			
Contract Indicator (1 if Performance-Based Contract, 0 otherwise)	-3.814	-6.290	0.000
Contract Indicator (1 if A+B or ID, 0 otherwise)	-4.349	-7.250	0.000
Standard deviation of parameter density function	1.537	4.530	0.000
Contract Information			
Inverse of the Cost of the Contract Award (in $1M)	-0.087	-2.700	0.007
Number of Bids (1 if 2 or 3, 0 otherwise)	0.816	2.600	0.009
Size of the contract (Lane-Miles)	0.010	2.920	0.004
Duration of the contract (years)	0.318	3.710	0.000
Standard deviation of parameter density function	0.195	5.350	0.000
Extension of the Contract (years)	0.534	4.330	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Horizontal Curves per segment (1 if 5 or more horizontal curves, 0 Otherwise)	-1.776	-4.310	0.000
Drainage system Indicator (1 if well drained or moderately well drained,0 otherwise)	2.442	3.820	0.000
Average Annual Daily Traffic (1 if less than 13000, 0 otherwise)	1.280	3.440	0.001
Truck Percentage (1 if greater than 0.21, 0 otherwise)	1.047	3.160	0.002
Asset Types			
Asset Type Indicator (1 if Guardrail Repair/Maintenance, 0 otherwise)	-2.213	-5.180	0.000
Asset Type Indicator (1 if Electrical/Cable system Repair/ Maintenance, 0 otherwise)	-2.149	-3.870	0.000
Asset Type Indicator (1 if Traffic signs and signals, 0 otherwise)	-2.310	-5.290	0.000
Model Summary			
Number of Observations	645		
Log likelihood at Convergence	-97.377		
Restricted Log likelihood	-229.806		

Table 6.58 Change orders likelihood (logit) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Size of the contract (in lane-miles)	-0.175	-2.480	0.013
Cost of the Contract (1 if greater than $ 12M, 0 otherwise)	2.934	1.920	0.054
Assets Type			
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management or general repair/ maintenance/ rehabilitation/ treatment or pavement repair/ maintenance/ treatment or vegetation/ tree control/ maintenance and removal, 0 otherwise)	1.670	2.400	0.017
Model Summary			
Number of Observations	31		
Log likelihood at Convergence	-6.180		
Restricted Log likelihood	-17.702		

Table 6.59 Change orders likelihood (Logit) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Duration of the contract (in years)	3.059	2.570	0.010
Cost of the Contract (1 if less than $25M, 0 otherwise)	-5.773	-1.750	0.080
Size of contract (in lane-miles)	-0.055	-2.090	0.037
Assets Type			
Asset type indicator (1 if other assets, 0 otherwise)	-6.354	-2.040	0.041
Model Summary			
Number of Observations	169		
Log likelihood at Convergence	-6.371		
Restricted Log likelihood	-22.528		

Table 6.60 Change orders likelihood (logit) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Duration of the contract (1 if greater than 3.8 years, 0 otherwise)	-2.787	-1.840	0.065
Size of the contract (in lane-miles)	0.052	2.400	0.016
Number of assets (1 if equal to two, 0 otherwise)	4.295	2.450	0.014
Asset Types			
Asset Type Indicator (1 if management or guardrail repair/ maintenance or illumination repair/ maintenance or landscape repair/ maintenance, 0 otherwise)	-5.536	-3.850	0.004
Model Summary			
Number of Observations	37		
Log likelihood at Convergence	-11.563		
Restricted Log likelihood	-22.517		

Table 6.61 Change orders likelihood (Logit) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Duration of contract (in years)	0.639	1.750	0.080
Cost of the Contract (in $100M)	18.396	1.790	0.074
Asset Types			
Asset Type Indicator (1 if Rest Area, 0 otherwise)	-3.229	-2.430	0.015
Model Summary			
Number of Observations	34		
Log likelihood at Convergence	-4.448		
Restricted Log likelihood	-12.315		

Table 6.62 Change orders likelihood (Logit) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Duration of the contract (1 if less than 4 years, 0 otherwise)	-2.348	-2.370	0.018
Size of the contract (1 if greater than 120 lane-miles, 0 otherwise)	1.781	2.200	0.028
Cost of the Contract (in $100M)	8.856	3.090	0.002
Assets Type			
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement or general maintenance/ repair/ rehabilitation/ treatment, 0 otherwise)	7.368	1.870	0.062
Model Summary			
Number of Observations	79		
Log likelihood at Convergence	-18.965		
Restricted Log likelihood	-38.397		

Table 6.63 Change orders likelihood (Logit) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	11.545	4.380	0.000
Contract Information			
Number of Assets (1 if greater than 2, 0 otherwise)	-7.162	-3.320	0.001
Inverse of the Cost of the Contract (in $100k)	-2.398	-2.910	0.004
Asset Types			
Asset Type Indicator (1 if Guardrail Maintenance/Repair, 0 otherwise)	-6.876	-3.160	0.002
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise)	-4.472	-3.150	0.002
Model Summary			
Number of Observations	198		
Log likelihood at Convergence	-10.836		
Restricted Log likelihood	-39.599		

Table 6.64 Change orders likelihood (Logit) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Information			
Duration of the contract (1 if greater than 3.5 years, 0 otherwise)	1.295	2.370	0.018
Size of the contract (1 if less than 30 lane-miles, 0 otherwise)	1.002	2.240	0.025
Asset Types			
Asset Type Indicator (1 if illumination Maintenance/Repair or litter removal or vegetation/ tree control/ maintenance/ removal, 0 otherwise)	-1.002	-1.730	0.083
Asset Type Indicator (1 if other asset type, 0 otherwise)	0.906	1.680	0.094
Model Summary			
Number of Observations	97		
Log likelihood at Convergence	-14.858		
Restricted Log likelihood	-22.508		

Table 6.65 Summary of Change Orders Likelihood Results

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Region Indicator (1 if North America, 0 otherwise) [Full Model]	↓								
Contract Type									
Contract Indicator (1 if A+B or ID, 0 otherwise) [Full Model]	(↓)								
Contract Indicator (1 if A+B or ID, 0 otherwise) [USA Model]		(↓)							
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [Full Model]	↓								
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [USA Model]		↓							
Contract Information									
Cost of the contract (1 if greater than $ 12M, 0 otherwise) [A+B]			↑						
Cost of the contract (1 if less than $ 25M, 0 otherwise) [DBOM]				↓					
Cost of the contract (in $100M) [Lane Rental]						↑			
Cost of the contract (in $100M) [PBC]							↑		
Duration of the contract (1 if greater than 3.5 years, 0 otherwise) [Warranty]									↑
Duration of the contract (1 if greater than 3.8 years, 0 otherwise) [I/D]					↓				
Duration of the contract (1 if less than 4 years, 0 otherwise) [PBC]							↓		
Duration of the contract (in years) [Lane Rental]						↑			
Duration of the contract (years) [DBOM]				↑					
Duration of the contract (years) [Full Model]	(↑)								
Duration of the contract (years) [USA Model]		(↑)							
Extension of the Contract (years) [Full Model]	↑								
Extension of the Contract (years) [USA Model]		↑							
Inverse of the Cost of the contract (in $100k) [Traditional]								↓	
Inverse of the Cost of the contract Award (in $1M) [USA Model]		↓							
Size of the contract (1 if greater than 120 lane-miles, 0 otherwise) [PBC]							↑		
Size of the contract (1 if less than 30 lane-miles, 0 otherwise) [Warranty]									↑
Size of the contract (in lane-miles) [A+B]			↓						
Size of the contract (in lane-miles) [DBOM]				↓					
Size of the contract (in lane-miles) [I/D]					↑				
Size of the contract (Lane-Miles) [Full Model]	↑								

Table 6.65 Summary of Change Orders Likelihood Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Size of the contract (Lane-Miles) [USA Model]		↑							
Number of assets (1 if equal to two, 0 otherwise) [I/D]					↑				
Number of assets (1 if greater than 2, 0 otherwise) [Traditional]								↓	
Number of assets (1 if greater than 3, 0 otherwise) [Full Model]	(↓)								
Number of bids (1 if 2 or 3, 0 otherwise) [Full Model]	↑								
Number of bids (1 if 2 or 3, 0 otherwise) [USA Model]		↑							
Road Geometry and Pavement Condition and Traffic Characteristics									
Average Annual Daily Traffic (1 if less than 13000, 0 otherwise) [USA Model]		↑							
Drainage system Indicator (1 if well drained or moderately well drained,0 otherwise) [USA Model]		↑							
Median width (1 if greater than 35 feet, 0 otherwise) [Full Model]	↑								
Number of Horizontal Curves per segment (1 if 5 or more horizontal curves, 0 Otherwise) [Full Model]	↓								
Number of Horizontal Curves per segment (1 if 5 or more horizontal curves, 0 Otherwise) [USA Model]		↓							
Percentage of trucks (1 if greater than 21%, 0 otherwise) [Full Model]	↑								
Truck Percentage (1 if greater than 0.21, 0 otherwise) [USA Model]		↑							
Type of Junction Indicator (1 if no junction, 0 otherwise) [Full Model]	↑								
Asset Types									
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management or general repair/maintenance/rehabilitation/treatment or pavement repair/ maintenance/ treatment or vegetation/ tree control/ maintenance and removal, 0 otherwise) [A+B]			↑						
Asset type indicator (1 if culvert/ ditches/ gutters/drainage repair/ maintenance/replacement or general maintenance/repair/ rehabilitation/treatment, 0 otherwise) [PBC]							↑		
Asset type indicator (1 if Culvert/Ditches/Cutters/ Drainage Repair/Maintenance/Replacement, 0 otherwise) [Full Model]	↑								
Asset type indicator (1 if Electrical/Cable system Repair/Maintenance, 0 otherwise) [Full Model]	↓								

Table 6.65 Summary of Change Orders Likelihood Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Asset type indicator (1 if Electrical/Cable system Repair/Maintenance, 0 otherwise) [USA Model]		↓							
Asset type indicator (1 if General Maintenance/Repair/ Rehabilitation/Treatment, 0 otherwise) [Full Model]	↑								
Asset type indicator (1 if Guardrail Maintenance/Repair, 0 otherwise) [Traditional]								↓	
Asset type indicator (1 if Guardrail Repair/Maintenance, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if Guardrail Repair/Maintenance, 0 otherwise) [USA Model]		↓							
Asset type indicator (1 if illumination Maintenance/Repair or litter removal or vegetation/ tree control/ maintenance/ removal,0 otherwise) [Warranty]									↓
Asset type indicator (1 if management or guardrail repair/maintenance or illumination repair/ maintenance or landscape repair/ maintenance, 0 otherwise) [I/D]					↓				
Asset type indicator (1 if other asset type, 0 otherwise) [Warranty]									↑
Asset type indicator (1 if other assets, 0 otherwise) [DBOM]				↓					
Asset type indicator (1 if other types of assets, 0 otherwise) [Full Model]	↑								
Asset type indicator (1 if Rest Area, 0 otherwise) [Lane Rental]						↓			
Asset type indicator (1 if traffic Signals and signs, 0 otherwise) [Traditional]								↓	
Asset type indicator (1 if Traffic signs and signals, 0 otherwise) [Full Model]	↓								
Asset type indicator (1 if Traffic signs and signals, 0 otherwise) [USA Model]		↓							

6.4 Time Delay Model Estimation Results

Time delay can cause reductions in cost savings and increase cost overruns. Under lane rental projects, time delay increases the user cost as well, which is utterly undesirable. In the planning stage, Agencies try to find the influential parameters that reduce time delay (Irfan et al. 2011).

Although, least square regression models can also be useful for estimation of duration, the hazard-based duration models provide additional insight into the underlying duration problems. In this section, hazard-based duration models are estimated to examine which contract characteristics and asset types affect the time delay of the project. Log-logistics, Weibull and Weibull with gamma heterogeneity models are developed, and the best specified model among these three is presented for each PPP contract type.

6.4.1 Hazard-Based Duration Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.66 to 6.75. The results can be summarized as follows:

- Project size (measured in lane-miles) is found to have various effects on the duration of the time delays. For warranties, PBC and design build contracts, an increase in the size of the project increases time delay; however, under some PPP types such as cost-plus-time, incentives/disincentives, and Traditional contracts, larger sized contracts reduce time delay.
- Time delay is intuitively affected by the contract duration (in years). A contract duration increase, increases time delay. This may be capturing the effect of larger projects, which can frequently be more comprehensive, and for which a minor change in the project's original scope is likely to result in time delay.
- Contracts with higher final costs are intuitively found to have greater time delay.
- With the exception of warranties, having more than two activity types will increase the duration of time delay for all other PPP contract types.
- The activity type is also crucial, and affects the duration of time delay. Activities such as bridge-tunnel, culvert, ditches, gutters and drainage system repair, maintenance, decrease the duration of time delay. This is in line with part research (Anastasopoulos et al., 2010a).

- The factors, the effect of which varies across the observations, are also presented in Tables 6.66 to 6.75, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.66 Descriptive Statistics of Time Delays Duration Models

Variables	Mean	Std. Dev	Min.	Max.
State Indicator (1 if Minnesota, 0 otherwise) [DBOM]	0.046	-	0	1
State Indicator (1 if Texas, 0 otherwise) [Full Model]	0.097	-	0	1
State Indicator (1 if Texas, 0 otherwise) [USA Model]	0.161	-	0	1
Contract Type				
Contract Indicator (1 if A+B or ID, 0 otherwise) [Full Model]	0.14	-	0	1
Contract Indicator (1 if A+B or ID, 0 otherwise) [USA Model]	0.105	-	0	1
Contract Indicator (1 if Design-Build Contract, 0 otherwise) [Full Model]	0.204	-	0	1
Contract Indicator (1 if Design-Build Contract, 0 otherwise) [USA Model]	0.262	-	0	1
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [Full Model]	0.134	-	0	1
Contract Characteristics				
Cost of the contract (1 if greater than $28M, 0 otherwise) [A+B & I/D]	0.191	-	0	1
Cost of the Contract (in $100M) [Full Model]	0.37	0.598	.500D-04	9.199
Cost of the Contract (in $100M) [Lane Rental]	0.113	0.092	0.002	0.355
Cost of the Contract (in $100M) [USA Model]	0.219	0.366	.500D-04	2.38
Cost of the Contract (in $100M, 0 otherwise) [DBOM]	0.277	0.289	0.006	2.38
Cost of the Contract (in $100M, 0 otherwise) [Warranty]	0.194	0.379	0.001	2.36
Duration of the contract (1 if greater than 2 years, 0 otherwise) [Lane Rental]	0.853	-	0	1
Duration of the contract (1 if greater than 4 years, 0 otherwise) [Traditional]	0.495	-	0	1
Duration of the contract (1 if greater than 5 years, 0 otherwise) [Warranty]	0.68	-	0	1
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [DBOM]	0.621	-	0	1
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [Full Model]	0	-	0	1
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [USA Model]	0.491	-	0	1
Size of the Contract (1 if greater than 180 lane-miles, 0 otherwise) [Traditional]	0.157	-	0	1
Size of the contract (1 if greater than 45 lane-miles, 0 otherwise) [A+B & I/D]	0.368	-	0	1
Size of the Contract (1 if less than 10 Lane-Miles, 0 otherwise) [USA Model]	0.38	-	0	1
Size of the contract (1 if less than 12 lane-miles, 0 otherwise) [DBOM]	0.355	-	0	1
Size of the contract (1 if less than 30 Lane-Miles, 0 otherwise) [Warranty]	0.907	-	0	1

Table 6.66 Descriptive Statistics of Time Delays Duration Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Natural logarithm of size of the contract (in lane-miles) [PBC]	4.483	2.162	-2.526	6.829
Number of assets (1 if greater than 1, 0 otherwise) [A+B & I/D]	0.603	-	0	1
Number of assets (1 if less than 2, 0 otherwise) [Traditional]	0.662	-	0	1
Number of Assets (1 if less than 3, 0 otherwise) [USA Model]	0.764	-	0	1
Number of Assets (1 if less than 3, 0 otherwise) [Warranty]	0.691	-	0	1
Number of Assets indicator (1 if less than 3, 0 otherwise) [Full Model]	0.75	-	0	1
Number of Bids indicator (1 if less than 5, 0 otherwise) [Full Model]	0.896	-	0	1
Number of Bids indicator (1 if less than 5, 0 otherwise) [USA Model]	0.887	-	0	1
Road Geometry and Pavement Condition and Traffic Characteristics				
Average Annual Daily Traffic (1 if less than 9000, 0 otherwise) [Full Model]	0.554	-	0	1
Number of Lanes (1 if 2 or 3 lanes, 0 otherwise) [Full Model]	0.919	-	0	1
Asset Types				
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management, 0 otherwise) [Traditional]	0.222	-	0	1
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management or culvert/ ditches/ gutter/ drainage repair/maintenance/ replacement or landscape repair/ maintenance or pavement repair/ maintenance/ treatment, 0 otherwise) [PBC]	0.544	-	0	1
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management or traffic signs and signals, 0 otherwise) [DBOM]	0.213	-	0	1
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise) [Traditional]	0.146	-	0	1
Asset Type Indicator (1 if Electrical/Cable system Repair/Maintenance, 0 otherwise) [Warranty]	0.289	-	0	1
Asset Type Indicator (1 if General Maintenance/Repair/Rehabilitation/Treatment, 0 otherwise) [Full Model]	0.33	-	0	1
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise) [Full Model]	0.057	-	0	1
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise) [USA Model]	0.076	-	0	1
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise) [Warranty]	0.072	-	0	1
Asset Type Indicator (1 if Mowing, 0 otherwise) [Full Model]	0.056	-	0	1

Table 6.66 Descriptive Statistics of Time Delays Duration Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Asset Type Indicator (1 if Mowing, 0 otherwise) [USA Model]	0.04	-	0	1
Asset type indicator (1 if pavement maintenance/ repair/ treatment, 0 otherwise) [Traditional]	0.101	-	0	1
Asset Type Indicator (1 if Pavement Repair/ Maintenance/ Treatment, 0 otherwise) [Full Model]	0.223	-	0	1
Asset Type Indicator (1 if Rest Area, 0 otherwise) [Full Model]	0.056	-	0	1
Asset Type Indicator (1 if Rest Area, 0 otherwise) [USA Model]	0.13	-	0	1
Asset type indicator (1 if rest areas, 0 otherwise) [Traditional]	0.167	-	0	1
Asset Type indicator (1 if Shoulder Repair/Maintenance, 0 otherwise) [Full Model]	0.069	-	0	1
Asset Type indicator (1 if Shoulder Repair/Maintenance, 0 otherwise) [USA Model]	0.051	-	0	1
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise) [Full Model]	0.133	-	0	1
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise) [USA Model]	0.147	-	0	1
Weather Condition				
Weather indicator (1 if no snowy days, 0 otherwise) [USA Model]	0.202	-	0	1

Table 6.67 Time delay hazard-based (Weibull) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-0.505	-6.510	0.000
State Indicator (1 if Texas, 0 otherwise)	-0.350	-6.840	0.000
Standard deviation of parameter density function	0.576	11.510	0.000
Contract Type			
Contract Indicator (1 if Performance-Based Contract, 0 otherwise)	-0.583	-10.650	0.000
Contract Indicator (1 if Design-Build Contract, 0 otherwise)	0.102	2.790	0.005
Contract Indicator (1 if A+B or ID, 0 otherwise)	-1.247	-16.810	0.000
Standard deviation of parameter density function	0.217	3.030	0.002
Contract Characteristics			
Number of Bids indicator (1 if less than 5, 0 otherwise)	0.499	10.930	0.000
Duration of the contract (1 if greater than 5.5 years, 0 otherwise)	0.764	23.330	0.000
Number of Assets indicator (1 if less than 3, 0 otherwise)	0.262	6.340	0.000
Cost of the Contract (in $100M)	0.411	11.490	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Lanes (1 if 2 or 3 lanes, 0 otherwise)	0.253	5.100	0.000
Average Annual Daily Traffic (1 if less than 9000, 0 otherwise)	-0.073	-2.540	0.011
Asset Types			
Asset Type Indicator (1 if General Maintenance/Repair/ Rehabilitation/Treatment, 0 otherwise)	-0.236	-6.570	0.000
Standard deviation of parameter density function	0.303	10.790	0.000
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise)	0.421	6.680	0.000
Asset Type Indicator (1 if Mowing, 0 otherwise)	-0.644	-8.520	0.000
Asset Type Indicator (1 if Pavement Repair/ Maintenance/ Treatment, 0 otherwise)	-0.168	-4.760	0.000
Asset Type Indicator (1 if Rest Area, 0 otherwise)	-0.590	-10.940	0.000
Standard deviation of parameter density function	0.609	13.560	0.000
Asset Type indicator (1 if Shoulder Repair/Maintenance, 0 otherwise)	-0.381	-5.920	0.000
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise)	0.176	3.830	0.000
Model Summary			
Number of Observations	1074		
Log likelihood at Convergence	-677.500		
Restricted Log likelihood	-1123.411		

Table 6.68 Time delay hazard-based (Weibull) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-0.466	-5.980	0.000
State Indicator (1 if Texas, 0 otherwise)	-0.262	-3.970	0.000
Contract Type			
Contract Indicator (1 if Design-Build Contract, 0 otherwise)	0.303	5.200	0.000
Contract Indicator (1 if A+B or ID, 0 otherwise)	-0.775	-6.740	0.000
Standard deviation of parameter density function	0.121	3.780	0.000
Contract Characteristics			
Number of Bids indicator (1 if less than 5, 0 otherwise)	0.392	6.290	0.000
Duration of the contract (1 if greater than 5.5 years, 0 otherwise)	0.736	13.510	0.000
Size of the Contract (1 if less than 10 Lane-Miles, 0 otherwise)	-0.152	-2.950	0.003
Number of Assets (1 if less than 3, 0 otherwise)	0.464	7.950	0.000
Cost of the Contract (in $100M)	0.472	6.630	0.000
Asset Types			
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise)	0.420	4.700	0.000
Asset Type Indicator (1 if Mowing, 0 otherwise)	-0.341	-3.150	0.002
Asset Type Indicator (1 if Rest Area, 0 otherwise)	-0.417	-5.980	0.000
Standard deviation of parameter density function	0.818	11.470	0.000
Asset Type indicator (1 if Shoulder Repair/Maintenance, 0 otherwise)	-0.278	-3.050	0.002
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise)	0.196	3.000	0.003
Weather Condition			
Weather indicator (1 if no snowy days, 0 otherwise)	-0.174	-3.030	0.003
Model Summary			
Number of Observations	645		
Log likelihood at Convergence	-460.088		
Restricted Log likelihood	-701.947		

Table 6.69 Time delay hazard-based (Weibull) model (USA contracts): A+B and I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Size of the contract (1 if greater than 45 lane-miles, 0 otherwise)	-2.076	-3.260	0.001
Cost of the contract (1 if greater than $28M, 0 otherwise)	1.072	1.780	0.075
Number of assets (1 if greater than 1, 0 otherwise)	0.308	1.890	0.059
Model Summary			
Number of Observations	18		
Log likelihood at Convergence	-17.405		
Restricted Log likelihood	-23.815		

Table 6.70 Time delay hazard-based (Weibull) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	0.926	55.600	0.000
State Indicator (1 if Minnesota, 0 otherwise)	-0.539	-10.790	0.000
Standard deviation of parameter density function	0.107	2.750	0.006
Contract Characteristics			
Cost of the Contract (in $100M)	0.107	2.920	0.004
Duration of the contract (1 if greater than 5.5 years, 0 otherwise)	0.260	16.990	0.000
Standard deviation of parameter density function	0.079	9.660	0.000
Size of the contract (1 if less than 12 lane-miles, 0 otherwise)	-0.039	-2.250	0.025
Assets Types			
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management or traffic signs and signals, 0 otherwise)	-0.076	-3.550	0.000
Model Summary			
Number of Observations	169		
Log likelihood at Convergence	-15.875		
Restricted Log likelihood	-118.568		

Table 6.71 Time delay hazard-based (Weibull) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-1.230	-8.410	0.000
Contract Characteristics			
Cost of the Contract (in $100M)	1.543	2.910	0.004
Duration of the contract (1 if greater than 2 years, 0 otherwise)	0.833	5.410	0.000
Standard deviation of parameter density function	0.212	5.340	0.000
Model Summary			
Number of Observations	34		
Log likelihood at Convergence	-14.959		
Restricted Log likelihood	-25.885		

Table 6.72 Time delay hazard-based (Weibull) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Natural logarithm of size of the contract (in lane-miles)	0.102	5.970	0.000
Assets Type			
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management or culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement or landscape repair/ maintenance or pavement repair/ maintenance/ treatment, 0 otherwise)	-0.760	-6.530	0.000
Standard deviation of parameter density function	0.837	6.57	0.000
Model Summary			
Number of Observations	21		
Log likelihood at Convergence	-21.199		
Restricted Log likelihood	-25.885		

Table 6.73 Time delay hazard-based (Weibull) model (USA contracts): Traditional

Variables	Coefficient	*t*-stat	*P*-value
Contract Characteristics			
Size of the Contract (1 if greater than 180 lane-miles, 0 otherwise)	-0.178	-2.390	0.017
Duration of the contract (1 if greater than 4 years, 0 otherwise)	1.234	18.670	0.000
Number of assets (1 if less than 2, 0 otherwise)	-0.110	-2.190	0.029
Asset Types			
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management, 0 otherwise)	-0.878	-11.920	0.000
Standard deviation of parameter density function	1.321	17.300	0.000
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise)	-1.246	-16.180	0.000
Standard deviation of parameter density function	0.739	9.340	0.000
Asset type indicator (1 if pavement maintenance/ repair/ treatment, 0 otherwise)	-0.306	-2.980	0.003
Asset type indicator (1 if rest areas, 0 otherwise)	-0.120	-1.820	0.069
Model Summary			
Number of Observations	180		
Log likelihood at Convergence	-151.763		
Restricted Log likelihood	-294.220		

Table 6.74 Time delay hazard-based (Weibull) model (USA contracts): Warranties

Variables	Coefficient	*t*-stat	*P*-value
Contract Characteristics			
Cost of the Contract (in $100M)	0.461	9.500	0.000
Number of Assets (1 if less than 3, 0 otherwise)	0.371	4.200	0.000
Size of the contract (1 if less than 30 Lane-Miles, 0 otherwise)	-0.977	-17.300	0.000
Standard deviation of parameter density function	0.186	7.430	0.000
Duration of the contract (1 if greater than 5 years, 0 otherwise)	1.744	17.610	0.000
Asset Types			
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise)	0.458	4.750	0.000
Asset Type Indicator (1 if Electrical/Cable system Repair/ Maintenance, 0 otherwise)	-0.444	-7.910	0.000
Standard deviation of parameter density function	0.638	10.520	0.000
Model Summary			
Number of Observations	95		
Log likelihood at Convergence	-49.343		
Restricted Log likelihood	-133.368		

Table 6.75 Summary of Time Delays Duration Results

Variables	**Full Model**	**USA Model**	**A+B & I/D [USA]**	**DBOM [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
State Indicator (1 if Minnesota, 0 otherwise) [DBOM]				(↓)				
State Indicator (1 if Texas, 0 otherwise) [Full Model]	(↓)							
State Indicator (1 if Texas, 0 otherwise) [USA Model]		↓						
Contract Type								
Contract Indicator (1 if A+B or ID, 0 otherwise) [Full Model]	(↓)							
Contract Indicator (1 if A+B or ID, 0 otherwise) [USA Model]		(↓)						
Contract Indicator (1 if Design-Build Contract, 0 otherwise) [Full Model]	↑							
Contract Indicator (1 if Design-Build Contract, 0 otherwise) [USA Model]		↑						
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [Full Model]	↓							
Contract Characteristics								
Cost of the contract (1 if greater than $28M, 0 otherwise) [A+B & I/D]			↑					
Cost of the Contract (in $100M) [Full Model]	↑							
Cost of the Contract (in $100M) [Lane Rental]					↑			
Cost of the Contract (in $100M) [USA Model]		↑						
Cost of the Contract (in $100M, 0 otherwise) [DBOM]				↑				
Cost of the Contract (in $100M, 0 otherwise) [Warranty]								↑
Duration of the contract (1 if greater than 2 years, 0 otherwise) [Lane Rental]					(↑)			
Duration of the contract (1 if greater than 4 years, 0 otherwise) [Traditional]							↑	
Duration of the contract (1 if greater than 5 years, 0 otherwise) [Warranty]								↑
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [DBOM]				(↑)				
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [Full Model]	↑							
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [USA Model]		↑						
Size of the Contract (1 if greater than 180 lane-miles, 0 otherwise) [Traditional]							↓	
Size of the contract (1 if greater than 45 lane-miles, 0 otherwise) [A+B & I/D]			↓					
Size of the Contract (1 if less than 10 Lane-Miles, 0 otherwise) [USA Model]		↓						

Table 6.75 Summary of Time Delays Duration Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B & I/D [USA]**	**DBOM [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Size of the contract (1 if less than 12 lane-miles, 0 otherwise) [DBOM]				↓				
Size of the contract (1 if less than 30 Lane-Miles, 0 otherwise) [Warranty]								(↓)
Natural logarithm of size of the contract (in lane-miles) [PBC]						↑		
Number of assets (1 if greater than 1, 0 otherwise) [A+B & I/D]			↑					
Number of assets (1 if less than 2, 0 otherwise) [Traditional]							↓	
Number of Assets (1 if less than 3, 0 otherwise) [USA Model]		↑						
Number of Assets (1 if less than 3, 0 otherwise) [Warranty]								↑
Number of Assets indicator (1 if less than 3, 0 otherwise) [Full Model]	↑							
Number of Bids indicator (1 if less than 5, 0 otherwise) [Full Model]	↑							
Number of Bids indicator (1 if less than 5, 0 otherwise) [USA Model]		↑						
Road Geometry and Pavement Condition and Traffic Characteristics								
Average Annual Daily Traffic (1 if less than 9000, 0 otherwise) [Full Model]	↓							
Number of Lanes (1 if 2 or 3 lanes, 0 otherwise) [Full Model]	↑							
Asset Types								
Asset type indicator (1 if bridge-tunnel repair/ maintenance/ management, 0 otherwise) [Traditional]							(↓)	
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management or culvert/ ditches/ gutter/ drainage repair/maintenance/ replacement or landscape repair/ maintenance or pavement repair/ maintenance/ treatment, 0 otherwise) [PBC]						(↓)		
Asset type indicator (1 if bridge-tunnel repair/ maintenance/management or traffic signs and signals, 0 otherwise) [DBOM]				↓				
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise) [Traditional]							(↓)	
Asset Type Indicator (1 if Electrical/Cable system Repair/Maintenance, 0 otherwise) [Warranty]								(↓)

Table 6.75 Summary of Time Delays Duration Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B & I/D [USA]**	**DBOM [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Asset Type Indicator (1 if General Maintenance/Repair/Rehabilitation/Treatment, 0 otherwise) [Full Model]	(↓)							
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise) [Full Model]	↑							
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise) [USA Model]		↑						
Asset Type Indicator (1 if Illumination Repair/Maintenance, 0 otherwise) [Warranty]								↑
Asset Type Indicator (1 if Mowing, 0 otherwise) [Full Model]	↓							
Asset Type Indicator (1 if Mowing, 0 otherwise) [USA Model]		↓						
Asset type indicator (1 if pavement maintenance/ repair/ treatment, 0 otherwise) [Traditional]							↓	
Asset Type Indicator (1 if Pavement Repair/ Maintenance/ Treatment, 0 otherwise) [Full Model]								
Asset Type Indicator (1 if Rest Area, 0 otherwise) [Full Model]	(↓)							
Asset Type Indicator (1 if Rest Area, 0 otherwise) [USA Model]		(↓)						
Asset type indicator (1 if rest areas, 0 otherwise) [Traditional]							↓	
Asset Type indicator (1 if Shoulder Repair/Maintenance, 0 otherwise) [Full Model]	↓							
Asset Type indicator (1 if Shoulder Repair/Maintenance, 0 otherwise) [USA Model]		↓						
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise) [Full Model]	↑							
Asset Type indicator (1 if traffic Signals and signs, 0 otherwise) [USA Model]		↑						
Weather Condition								
Weather indicator (1 if no snowy days, 0 otherwise) [USA Model]		↓						

6.4.2 Time Delay Likelihood Model Estimation Results

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.76 to 6.84. The results can be summarized as follows:

- Contracts with longer duration (in years), size (in lane-miles), and cost (in USA dollars) are more likely to have time delay for almost all of the contracting types. Usually, more complicated projects have higher final cost and duration (in years); the likelihood of time delay occurrence under contracts with these characteristics is higher than in contracts with lower cost and duration.
- All warranty, lane rental, and design build contracts had a higher likelihood of time delay occurrence.
- Contracts in Texas (for Traditional contracts) are less likely to have time delay. In contrast, contracts in Alaska (for PBC contracts) are more likely to have time delay. This may be capturing weather specific unobserved heterogeneity.
- For cost-plus-time contracts, inclusion of two or more asset types results in a significant likelihood increase of time delay occurrence. This parameter has the opposite effect for PBC contracts.
- Culvert, ditches, gutters and drainage repair, maintenance and replacement activities are found to increase the likelihood of time delay occurrence.
- The factors, the effect of which varies across the observations, are also presented in Tables 6.76 to 6.84, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.76 Descriptive Statistics of Time Delays Likelihood Models

• Variables	Mean	Std. Dev	Min.	Max.
Region Indicator (1 if Africa 0 otherwise) [Full Model]	0.055	-	0	1
Region Indicator (1 if Latin 0 otherwise) [Full Model]	0.077	-	0	1
State indicator (1 if Alaska, 0 otherwise) [PBC]	0.089	-	0	1
State indicator (1 if Texas, 0 otherwise) [Traditional]	0.197	-	0	1
Contract Type				
Contract Indicator (1 if A+B or ID or PBC, 0 otherwise) [Full Model]	0.274	-	0	1
Contract Indicator (1 if A+B or ID, 0 otherwise) [USA Model]	0.105	-	0	1
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [USA Model]	0.122	-	0	1
Contract Indicator (1 if Warranty, 0 otherwise) [Full Model]	0.156	-	0	1
Contract Characteristics				
Bid Range (1 if less than $ 5M, 0 otherwise) [Full Model]	0.721	-	0	1
Cost of the contract (1 if less than $70M, 0 otherwise) [Traditional]	0.985	-	0	1
Cost of the Contract (in $100M) [A+B]	0.096	0.097	0.003	0.352
Cost of the Contract (in $100M) [Full Model]	0.37	0.598	.500D-04	9.199
Duration of the contract (1 if greater than 4.5 years, 0 otherwise) [Full Model]	0.549	-	0	1
Duration of the contract (1 if greater than 4.5 years, 0 otherwise) [USA Model]	0.633	-	0	1
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [PBC]	0.57	-	0	1
Duration of the contract (1 if less than 2 years, 0 otherwise) [Traditional]	0.409	-	0	1
Duration of the contract (in years) [A+B]	4.151	1.531	2	7.76
Duration of the contract (in years) [I/D]	4.273	1.547	2	6.32
Inverse of the award cost (in $1M) [Full Model]	1.3	4.223	0.001	69.5
Inverse of the bid amount (in $100k) [USA Model]	0.135	0.44	.944D-04	6.778
Inverse of the Cost of the Contract Award (in $1M) [USA Model]	2.014	5.138	0.004	69.5
Size of the contract (1 if greater than 30 Lane-Miles, 0 otherwise) [PBC]	0.81	-	0	1
Size of the contract (1 if less than 210 Lane-Miles, 0 otherwise) [Full Model]	0.549	-	0	1
Size of the contract (Lane-Miles) [Traditional]	86.49	123.411	0.06	880.5
Number of assets (1 if less than 2, 0 otherwise) [PBC]	0.595	-	0	1
Number of assets (1if greater than 2, 0 otherwise) [A+B]	0.258	-	0	1
Number of Bids indicator (1 if less than 4, 0 otherwise) [Full Model]	0.767	-	0	1
Road Geometry and Pavement Condition and Traffic Characteristics				
Average Annual Daily Traffic (1 if less than 19000, 0 otherwise) [USA Model]	0.771	-	0	1

Table 6.76 Descriptive Statistics of Time Delays Likelihood Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Highway Indicator (1 if Highway, 0 otherwise) [USA Model]	0.829	-	0	1
Inside Shoulder Width (1 if less than 8 feet, 0 otherwise) [Full Model]	0.562	-	0	1
Inside Shoulder Width (1 if less than 8, 0 otherwise) [USA Model]	0.584	-	0	1
Number of Lanes (1 if 2 lanes, 0 otherwise) [Full Model]	0.745	-	0	1
Number of Lanes indicator (1 if 2 lanes, 0 otherwise) [USA Model]	0.719	-	0	1
Vertical Curve Indicator (1 if 5 or greater number of Vertical Curves per segment, 0 otherwise) [Full Model]	3.407	-	1	6
Asset Types				
Asset Type Indicator (1 if Crack/pothole Sealing/Repair, 0 otherwise) [Full Model]	0.076	-	0	1
Asset Type Indicator (1 if Crack/Pothole Sealing/Repair, 0 otherwise) [USA Model]	0.098	-	0	1
Asset type indicator (1 if culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement, 0 otherwise) [Traditional]	0.146	-	0	1
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise) [PBC]	0.073	-	0	1

Table 6.77 Time delay likelihood (Logit) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Region Indicator (1 if Latin 0 otherwise)	-0.350	-6.840	0.000
Region Indicator (1 if Africa 0 otherwise)	0.576	11.510	0.000
Contract Type			
Contract Indicator (1 if Warranty, 0 otherwise)	3.177	1.990	0.046
Standard deviation of parameter density function	2.230	2.520	0.012
Contract Indicator (1 if A+B or ID or PBC, 0 otherwise)	-4.953	-12.230	0.000
Standard deviation of parameter density function	1.426	7.840	0.000
Contract Characteristics			
Number of Bids indicator (1 if less than 4, 0 otherwise)	0.947	4.000	0.000
Duration of the contract (1 if greater than 4.5 years, 0 otherwise)	1.845	6.820	0.000
Standard deviation of parameter density function	0.748	4.920	0.000
Size of the contract (1 if less than 210 Lane-Miles, 0 otherwise)	-1.211	-4.800	0.000
Inverse of the award cost (in $1M)	-0.096	-4.650	0.000
Standard deviation of parameter density function	0.063	3.210	0.001
Cost of the Contract (in $100M)	-0.492	-2.600	0.009
Bid Range (1 if less than $ 5M, 0 otherwise)	1.342	5.560	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Lanes (1 if 2 lanes, 0 otherwise)	0.751	3.790	0.000
Inside Shoulder Width (1 if less than 8 feet, 0 otherwise)	-0.398	-2.130	0.033
Standard deviation of parameter density function	0.207	1.760	0.079
Vertical Curve Indicator (1 if 5 or greater number of Vertical Curves per segment, 0 otherwise)	0.403	6.250	0.000
Standard deviation of parameter density function	0.081	3.080	0.002
Asset Types			
Asset Type Indicator (1 if Crack/pothole Sealing/Repair, 0 otherwise)	0.962	3.150	0.002
Model Summary			
Number of Observations	1074		
Log likelihood at Convergence	-200.336		
Restricted Log likelihood	-580.364		

Table 6.78 Time delay likelihood (Logit) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Type			
Contract Indicator (1 if Performance-Based Contract, 0 otherwise)	-6.864	-7.930	0.000
Standard deviation of parameter density function	2.257	4.940	0.000
Contract Indicator (1 if A+B or ID, 0 otherwise)	-6.513	-7.880	0.000
Standard deviation of parameter density function	2.186	4.590	0.000
Contract Characteristics			
Duration of the contract (1 if greater than 4.5 years, 0 otherwise)	1.772	4.490	0.000
Inverse of the bid amount (in $100k)	1.373	2.530	0.011
Inverse of the Cost of the Contract Award (in $1M)	-0.197	-3.990	0.000
Standard deviation of parameter density function	0.102	3.730	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Lanes indicator (1 if 2 lanes, 0 otherwise)	0.906	2.910	0.004
Inside Shoulder Width (1 if less than 8, 0 otherwise)	-0.562	-1.930	0.054
Average Annual Daily Traffic (1 if less than 19000, 0 otherwise)	-1.386	-3.270	0.001
Highway Indicator (1 if Highway, 0 otherwise)	1.422	3.450	0.001
Standard deviation of parameter density function	0.517	2.910	0.004
Asset Types			
Asset Type Indicator (1 if Crack/Pothole Sealing/Repair, 0 otherwise)	1.716	3.190	0.001
Standard deviation of parameter density function	1.873	3.830	0.000
Weather Condition			
Weather indicator (1 if the proportion of rainy days to total days of contract is higher than 0.1, 0 otherwise)	2.840	5.040	0.000
Standard deviation of parameter density function	0.839	5.050	0.000
Model Summary			
Number of Observations	645		
Log likelihood at Convergence	-122.918		
Restricted Log likelihood	-321.368		

Table 6.79 Time delay likelihood (Logit) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-3.747	-2.840	0.005
Contract Characteristics			
Cost of the Contract (in $100M)	7.896	1.990	0.047
Duration of the contract (in years)	0.452	1.830	0.067
Number of assets (1if greater than 2, 0 otherwise)	1.229	1.730	0.083
Model Summary			
Number of Observations	31		
Log likelihood at Convergence	-10.868		
Restricted Log likelihood	-18.676		

Table 6.80 Time delay likelihood (Logit) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	-32.878	-1.850	0.065
Standard deviation of parameter density function	3.215	1.800	0.071
Contract Information			
Duration of the contract (in years)	5.805	1.850	0.065
Model Summary			
Number of Observations	37		
Log likelihood at Convergence	-9.952		
Restricted Log likelihood	-20.527		

Table 6.81 Time delay likelihood (Probit) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
State indicator (1 if Alaska, 0 otherwise)	4.242	2.820	0.005
Contract Information			
Duration of the contract (1 if greater than 5.5 years, 0 otherwise)	-3.989	-2.950	0.003
Number of assets (1 if less than 2, 0 otherwise)	3.530	2.710	0.007
Size of the contract (1 if greater than 30 Lane-Miles, 0 otherwise)	-3.753	-3.010	0.003
Standard deviation of parameter density function	3.961	3.110	0.002
Assets Type			
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise)	6.127	2.760	0.006
Model Summary			
Number of Observations	79		
Log likelihood at Convergence	-33.276		
Restricted Log likelihood	-45.746		

Table 6.82 Time delay likelihood (Probit) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
State indicator (1 if Texas, 0 otherwise)	-1.255	-2.330	0.020
Contract Characteristics			
Duration of the contract (1 if less than 2 years, 0 otherwise)	-1.383	-2.780	0.005
Standard deviation of parameter density function	0.987	3.560	0.000
Size of the contract (Lane-Miles)	0.010	2.830	0.005
Standard deviation of parameter density function	0.005	2.050	0.040
Cost of the contract (1 if less than $70M, 0 otherwise)	2.185	5.620	0.000
Assets Type			
Asset type indicator (1 if culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement, 0 otherwise)	17.405	1.800	0.073
Model Summary			
Number of Observations	198		
Log likelihood at Convergence	-40.521		
Restricted Log likelihood	-60.318		

Table 6.83 Summary of Time Delays Likelihood Results

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**I/D [USA]**	**PBC [USA]**	**Traditional [USA]**
Region Indicator (1 if Africa 0 otherwise) [Full Model]	↑					
Region Indicator (1 if Latin 0 otherwise) [Full Model]	↓					
State indicator (1 if Alaska, 0 otherwise**)** [PBC]					↑	
State indicator (1 if Texas, 0 otherwise) [Traditional]						↓
Contract Type						
Contract Indicator (1 if A+B or ID or PBC, 0 otherwise) [Full Model]	(↓)					
Contract Indicator (1 if A+B or ID, 0 otherwise) [USA Model]		(↓)				
Contract Indicator (1 if Performance-Based Contract, 0 otherwise) [USA Model]		(↓)				
Contract Indicator (1 if Warranty, 0 otherwise) [Full Model]	↑					
Contract Characteristics						
Bid Range (1 if less than $ 5M, 0 otherwise) [Full Model]	↑					
Cost of the contract (1 if less than $70M, 0 otherwise) [Traditional]						↑
Cost of the Contract (in $100M) [A+B]			↑			
Cost of the Contract (in $100M) [Full Model]	↓					
Duration of the contract (1 if greater than 4.5 years, 0 otherwise) [Full Model]	(↑)					
Duration of the contract (1 if greater than 4.5 years, 0 otherwise) [USA Model]		↑				
Duration of the contract (1 if greater than 5.5 years, 0 otherwise) [PBC]					↓	
Duration of the contract (1 if less than 2 years, 0 otherwise) [Traditional]						(↓)
Duration of the contract (in years) [A+B]			↑			
Duration of the contract (in years) [I/D]				↑		
Inverse of the award cost (in $1M) [Full Model]	(↓)					
Inverse of the bid amount (in $100k) [USA Model]		↑				
Inverse of the Cost of the Contract Award (in $1M) [USA Model]		(↓)				
Size of the contract (1 if greater than 30 Lane-Miles, 0 otherwise) [PBC]					(↓)	
Size of the contract (1 if less than 210 Lane-Miles, 0 otherwise) [Full Model]	↓					
Size of the contract (Lane-Miles) [Traditional]						↑
Number of assets (1 if less than 2, 0 otherwise) [PBC]					↑	
Number of assets (1if greater than 2, 0 otherwise) [A+B]			↑			

Table 6.84 Summary of Time Delays Likelihood Results

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**I/D [USA]**	**PBC [USA]**	**Traditional [USA]**
Number of Bids indicator (1 if less than 4, 0 otherwise) [Full Model]	↑					
Road Geometry and Pavement Condition and Traffic Characteristics						
Average Annual Daily Traffic (1 if less than 19000, 0 otherwise) [USA Model]		↓				
Highway Indicator (1 if Highway, 0 otherwise) [USA Model]		(↑)				
Inside Shoulder Width (1 if less than 8 feet, 0 otherwise) [Full Model]	(↓)					
Inside Shoulder Width (1 if less than 8, 0 otherwise) [USA Model]		↓				
Number of Lanes (1 if 2 lanes, 0 otherwise) [Full Model]	↑					
Number of Lanes indicator (1 if 2 lanes, 0 otherwise) [USA Model]		↑				
Vertical Curve Indicator (1 if 5 or greater number of Vertical Curves per segment, 0 otherwise) [Full Model]	(↑)					
Asset Types						
Asset Type Indicator (1 if Crack/pothole Sealing/Repair, 0 otherwise) [Full Model]	↑					
Asset Type Indicator (1 if Crack/Pothole Sealing/Repair, 0 otherwise) [USA Model]		(↑)				
Asset type indicator (1 if culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement, 0 otherwise) [Traditional]						↑
Asset type indicator (1 if culvert/ ditches/ gutters/ drainage repair/ maintenance/ replacement, 0 otherwise) [PBC]					↑	

6.5 Accident Frequency Model Estimation Results

In recent years, many studies have been conducted to determine the influential parameters on accident frequency. Based on the literature, the most effective parameters on accident frequency are road geometry, pavement condition, and traffic characteristics. However, no studies, to the authors' knowledge, have been conducted to investigate the effect of various contracting approaches on accident frequency.

In this section, we investigate the effect of contract characteristics, such as duration, size and cost, etc., as well as traditional valid parameters on accident frequency. To that end, count data models are estimated, and the methodology used for change orders frequency is adopted.

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in Tables 6.85 to 6.95. The results can be summarized as follows:

- Contracts that were shorter in terms of size and duration have fewer accidents. Lower congestion around the project area for shorter duration can significantly decrease the number of accidents. This effect was captured for most of the PPP approaches.
- Higher contract cost is found to increase the number of accidents for design build contracts; while contracts with greater than $23M final cost are found to decrease accident frequency for lane rental contracts.

- Cost-plus-time and Traditional contracts on roadways with higher percentages of combination trucks have greater accident frequencies. Blind spots of the trucks could be the main reason for this increase in accident frequency.
- For PBC and design build contracts, large combination truck traffic (greater than 8 percent of the total AADT) reduces the accident frequency. This may be capturing driver-specific behavioral heterogeneity.
- Cost-plus-time contracts on segments with moderate traffic (3,900 to 52,800 vehicles/day), decrease accident frequency, as opposed to low and high traffic segments. On one hand, low traffic conditions may give drivers a safety feeling, which in turn can boost them to drive faster, making them more accident prone. On the other hand, high AADT may inevitably result in driving conflicts on consequently increase accident frequency.
- Higher standard deviation of IRI, PCR, and Rutting Depth indicates good pavement conditions before and after construction or maintenance work, which is in line with Sarwar and Anastasopoulos (2016). Therefore, an increase in the standard deviation of these pavement condition indices (reflecting big changes during the stud period), intuitively results in an accident frequency increase.
- Inadequate drainage is intuitively found to increase accident frequency for all PPP contract types..
- For incentives/disincentives contracts, large inside shoulders between 7.5 and 11 feet in width, are found decrease accident frequency. Also for PBC contracts, narrow inside shoulders (with less than 3.7 feet width) are found to increase accident frequency.

- Activities such as guardrail and illumination repair and maintenance improve the safety of the roadways and decrease accident frequencies in most of the contract types. However, these parameters are found to increase accident frequencies in traditional contracts. On the contrary, in 73 percent of Traditional contracts (random parameters with Normal distribution) that include crack, pothole sealing, repair, or pavement repair, maintenance and treatment, the accident frequency decreases. Improvement in the overall pavement condition is one of the major reasons that plays in the accident frequency reduction.
- Activities such as electrical, cable system repair and maintenance or installing traffic signals and signs, are also found to decrease accident frequencies. Having appropriate traffic signs, signals and road illumination, are naturally anticipated to provide better driving conditions, and hence improve the overall roadway safety.
- The factors, the effect of which varies across the observations, are also presented in Tables 6.85 to 6.95, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.84 Descriptive Statistics of Accident Frequency Analysis Models

Variables	Mean	Std. Dev	Min.	Max.
State Indicator (1 if Minnesota, 0 otherwise) [USA Model]	0.07	-	0	1
Contract Characteristics				
Cost of the contract (1 if greater than $ 23M, 0 otherwise) [Lane Rental]	0.176	-	0	1
Cost of the Project (1 if greater than $ 69M, 0 otherwise) [USA Model]	0.071	-	0	1
Duration of a contracts (1 if greater than 6 years, 0 otherwise) [PBC]	0.215	-	0	1
Duration of the contract (1 if between 3.5 and 6 years, 0 otherwise) [I/D]	0.405	-	0	1
Inverse of the Duration of a contracts [Traditional]	0.861	1.015	0.126	6.25
Inverse of the Duration of a contracts [Warranty]	0.462	0.63	0.05	3.704
Inverse of the Duration of Contract (years) [USA Model]	0.456	0.678	0.05	6.25
Inverse of the Duration of Contract [Full Model]	0.503	1.92	0.04	50
Inverse of the Size of the Contract (years) [USA Model]	0.902	3.144	0.001	50
Inverse of the Size of the Contract [Full Model]	0.563	2.475	0.001	50
Inverse of the Size of the Contract [A+B]	0.139	0.222	0.007	0.862
Inverse of the size of the contract [DBOM]	0.213	0.546	0.004	4.348
Inverse of the of the Size of the Contract [PBC]	0.311	1.465	0.001	12.5
Inverse of the of the Size of the Contract [Traditional]	1.343	3.201	0.001	16.667
Inverse of the of the Size of the Contract [Warranty]	1.511	3.223	0.002	25
Inverse of the Square Root of the Size of the Contract [I/D]	0.779	1.435	0.077	7.071
Inverse of the Square Root of the Size of the Contract [Lane Rental]	0.329	0.359	0.094	1.581
Log of the cost of the contract [DBOM]	16.8	0.904	13.229	19.288
Number of Assets indicator (1 if greater than 2, 0 otherwise) [PBC]	0.177	-	0	1
Number of Assets indicator (1 if greater than 2, 0 otherwise) [USA Model]	0.236	-	0	1
Number of Assets indicator (1 if less than 6 and greater than 1, 0 otherwise) [Lane Rental]	0.198	-	0	1
Square Root of the Cost of the Project [Full Model]	4817.275	3710.464	70.711	30329.4
Road Geometry and Pavement Condition and Traffic Characteristics				
10000th of square of Standard deviation of IRI (inches per mile) [A+B]	0.117	0.169	0.003	0.736
10000th of Squared of the Standard Deviation of IRI [DBOM]	0.204	1.436	0.001	18.629
Average AADT (1 if between 3900 and 52800, 0 otherwise) [DBOM]	0.645	-	0	1
Average AADT Indicator (1 if between 3,800 and 52,800 , 0 otherwise) [Traditional]	0.52	-	0	1
Average Annual Daily Traffic (1 if between 3900 and 52800 vehicle per day) [A+B]	0.516	-	0	1
Average IRI (1 if greater than 100 inches per mile, 0 otherwise) [PBC]	0.532	-	0	1

Table 6.84 Descriptive Statistics of Accident Frequency Analysis Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min.**	**Max.**
Average IRI (1 if between 100 and 170 inches per mile, 0 otherwise) [DBOM]	0.444	-	0	1
Average IRI (1 if between 100 and 170 inches per mile, 0 otherwise) [Traditional]	0.419	-	0	1
Average IRI (1 if between 64 and 100 inches per mile, 0 otherwise) [Warranty]	0.402	-	0	1
Average IRI (1 if greater than 170 inches per mile, 0 otherwise) [USA Model]	0.073	-	0	1
Average IRI (1 if greater than 64 inches per mile, 0 otherwise) [Full Model]	0.94	-	0	1
Average PCR (1 if between 80 and 90, 0 otherwise) [Traditional]	0.576	-	0	1
Average PCR (1 if between 85 and 92, 0 otherwise) [PBC]	0.278	-	0	1
Average PCR (1 if between 85 and 92, 0 otherwise) [Warranty]	0.361	-	0	1
Average PCR (1 if greater than 80, 0 otherwise) [Full Model]	0.96	-	0	1
Average Rutting Depth (1 if between 0.12 and 0.25 inches, 0 otherwise) [USA Model]	0.574	-	0	1
Average Rutting Depth (1 if greater than 0.25, 0 otherwise) [Warranty]	0.196	-	0	1
Average rutting depth (1 if greater than 0.3 inches, 0 otherwise) [Full Model]	0.039	-	0	1
Combination Trucks Indicator (1 if between 8% and 32%, 0 otherwise) [Traditional]	0.455	-	0	1
Combination Trucks Indicator (1 if greater than 8%, 0 otherwise) [PBC]	0.633	-	0	1
Drainage Indicator (1 if Moderately well drained or better, 0 otherwise) [Lane Rental]	0.618	-	0	1
Drainage Indicator (1 if Moderately well drained, 0 otherwise) [PBC]	0.228	-	0	1
Drainage Indicator (1 if poorly drained, 0 otherwise) [DBOM]	0.178	-	0	1
Drainage Indicator (1 if poorly or very poorly drained, 0 otherwise) [USA Model]	0.197	-	0	1
Inside Shoulder Indicator (1 if between 7.5 and 11 feet, 0 otherwise) [I/D]	0.244	0.086	0.137	0.59
Inside Shoulder Width Indicator (1 if greater than 11 feet, 0 otherwise) [Full Model]	0.219	-	0	1
Inside Shoulder width Indicator (1 if less than 3.7 feet, 0 otherwise) [PBC]	0.101	-	0	1
Intersection Indicator (1 if intersection exists, 0 otherwise) [Traditional]	0.571	-	0	1
Inverse of the Average AADT [Full Model]	0	0.001	.664D-05	0.008
Inverse of the Square Root of the Standard Deviation of IRI [I/D]	0.243	-	0	1
Log of the Average PCR [USA Model]	0.578	-	0	1
Median Barrier (1 if median barrier exists, 0 otherwise) [USA Model]	0.29	-	0	1

Table 6.84 Descriptive Statistics of Accident Frequency Analysis Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Median Barrier Indicator (1 if median barrier exists, 0 otherwise) [Full Model]	0.325	-	0	1
Median Barrier Indicator (1 if median barrier exists, 0 otherwise) [PBC]	0.354	-	0	1
Number of Lanes (1 if 3 lanes, 0 otherwise) [Full Model]	0.174	-	0	1
Outside Shoulder Indicator (1 if greater than 8.5 feet, 0 otherwise) [Traditional]	0.616	-	0	1
Percent of Combination Trucks [Full Model]	0.161	0.117	0	0.65
Square of combination trucks indicator (in percentage) [A+B]	0.038	0.056	0	0.185
Squared of Combination trucks indicator (percentage) [DBOM]	0.034	0.051	0	0.339
Standard Deviation of IRI (1 if between 11 and 30 inches per mile, 0 otherwise) [USA Model]	0.574	-	0	1
Standard Deviation of IRI [Traditional]	24.379	16.238	0.577	96.672
Standard Deviation of PCR (1 if between 5 and 8, 0 otherwise) [USA Model]	0.363	-	0	1
Standard Deviation of PCR (1 if between 8.5 and 12.5, 0 otherwise) [Lane Rental]	0.324	-	0	1
Standard Deviation of PCR (1 if greater than 12.5, 0 otherwise) [DBOM]	0.071	-	0	1
Standard Deviation of Rutting Depth (1 if between 0.05 and 0.12 inches, 0 otherwise) [Warranty]	0.361	-	0	1
Standard Deviation of Rutting Depth (1 if greater than 0.12 inches, 0 otherwise) [Traditional]	0.061	-	0	1
Standard Deviation of Rutting Depth [USA Model]	0.056	0.046	0	0.58
Asset Type				
Asset Type Indicator (1 if Bridge-Tunnel Repair /Maintenance/Management, 0 otherwise) [USA Model]	0.175	-	0	1
Asset Type Indicator (1 if Crack/Pothole Sealing/Repair or Pavement Repair/Maintenance/Treatment, 0 otherwise) [Traditional]	0.178	-	0	1
Asset Type Indicator (1 if Electrical/Cable system Repair/Maintenance or Traffic Signs and Signals, 0 otherwise) [PBC]	0.139	-	0	1
Asset Type Indicator (1 if guardrail repair/ maintenance or illumination repair/ maintenance, 0 otherwise) [DBOM]	0.284	-	0	1
Asset Type Indicator (1 if Guardrail Repair/Maintenance or Illumination Repair/Maintenance, 0 otherwise) [Traditional]	0.223	-	0	1
Asset Type Indicator (1 if Management or Litter Removal, 0 otherwise) [USA Model]	0.101	-	0	1
Weather Condition				
Weather indicator (1 if the proportion of snowy days to total days of contract is between 0.04 and 0.15, 0 otherwise) [Full Model]	0.161	-	0	1
Weather indicator (1 if the proportion of snowy days to total days of contract is between 0.04 and 0.15, 0 otherwise) [USA Model]	0.433	-	0	1

Table 6.85 Accident frequency (Negative Binomial) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.242	5.230	0.000
Contract Characteristics			
Inverse of the Duration of Contract	-0.730	-7.510	0.000
Inverse of the Size of the Contract	-7.285	-11.420	0.000
Square Root of the Cost of the Project	-29.839	-2.860	0.004
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Lanes (1 if 3 lanes, 0 otherwise)	0.390	4.010	0.000
Inside Shoulder Width Indicator (1 if between 11 and 20 feet, 0 otherwise)	0.221	2.500	0.012
Average IRI (1 if greater than 64 inches per mile, 0 otherwise)	1.393	2.730	0.006
Standard Deviation of IRI (1 if between 11 and 30 inches per mile, 0 otherwise)	-0.181	-2.430	0.015
Average PCR (1 if greater than 80, 0 otherwise)	-1.258	-3.840	0.000
Standard deviation of parameter density function	0.284	11.650	0.000
Inverse of the Average AADT	219.930	1.940	0.052
Percent of Combination Trucks	-0.853	-2.520	0.012
Weather Condition			
Weather indicator (1 if the proportion of snowy days to total days of contract is between 0.04 and 0.15, 0 otherwise)	-0.316	-3.920	0.000
Standard deviation of parameter density function	0.579	8.280	0.000
Model Summary			
Dispersion Parameter (α)	0.996	15.56	0.000
Number of Observations	1074		
Log likelihood at Zero	-13326.667		
Log likelihood at Convergence	-3464.346		

Table 6.86 Accident frequency (Negative Binomial) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	2.115	10.170	0.000
State Indicator (1 if Minnesota, 0 otherwise)	-0.459	-2.090	0.037
Contract Characteristics			
Cost of the Project (1 if greater than $ 69M, 0 otherwise)	-0.993	-5.620	0.000
Inverse of the Duration of Contract (years)	-0.504	-4.260	0.000
Inverse of the Size of the Contract (years)	-7.888	-12.320	0.000
Number of Assets indicator (1 if greater than 2, 0 otherwise)	-0.345	-2.810	0.005
Asset Type			
Asset Type Indicator (1 if Management or Litter Removal, 0 otherwise)	-0.271	-2.060	0.040
Asset Type Indicator (1 if Bridge-Tunnel Repair/Maintenance /Management, 0 otherwise)	0.458	2.800	0.005
Standard deviation of parameter density function	0.616	5.330	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Drainage Indicator (1 if moderate or better drainage system, 0 otherwise)	-0.079	-0.720	0.472
Average IRI (1 if greater than 170 inches per mile, 0 otherwise)	2.847	13.030	0.000
Standard Deviation of IRI (1 if between 11 and 30 inches per mile, 0 otherwise)	-0.275	-3.070	0.002
Log of the Average PCR	0.571	4.860	0.000
Standard deviation of parameter density function	0.944	12.240	0.000
Standard Deviation of PCR (1 if between 5 and 8, 0 otherwise)	-0.239	-2.500	0.012
Average Rutting Depth (1 if between 0.12 and 0.25 inches, 0 otherwise)	1.117	7.340	0.000
Standard Deviation of Rutting Depth	2.591	2.950	0.003
Weather Condition			
Weather indicator (1 if the proportion of snowy days to total days of contract is between 0.04 and 0.15, 0 otherwise)	-0.247	-2.590	0.010
Model Summary			
Dispersion Parameter (α)	1.214	11.980	0.000
Number of Observations	645		
Log likelihood at Zero	-8048.196		
Log likelihood at Convergence	-1851.734		

Table 6.87 Accident frequency (Poisson) model (USA contracts): A+B

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	1.577	22.110	0.000
Contract Characteristics			
Inverse of the Size of the Contract	5.359	6.610	0.000
Pavement Condition and Traffic Characteristics			
Square of combination trucks indicator (in percentage)	29.776	22.220	0.000
Average Annual Daily Traffic (1 if between 3900 and 52800 vehicle per day)	-3.077	-14.620	0.000
Standard deviation of parameter density function	4.794	21.800	0.000
10000^{th} of square of Standard deviation of IRI (inches per mile)	-1.724	-6.940	0.000
Model Summary			
Number of Observations	31		
Log likelihood at Zero	-344.913		
Log likelihood at Convergence	-141.464		

Table 6.88 Accident frequency (Poisson) model (USA contracts): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-value**
Contract Characteristics			
Inverse of the size of the contract	-4.158	-12.300	0.000
Log of the cost of the contract	0.114	24.150	0.000
Standard deviation of parameter density function	0.080	35.920	0.000
Asset Type			
Asset Type Indicator (1 if guardrail repair/ maintenance or illumination repair/ maintenance, 0 otherwise)	-0.320	-5.640	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Drainage Indicator (1 if poorly drained, 0 otherwise)	0.687	9.850	0.000
Standard deviation of parameter density function	0.378	7.070	0.000
Squared of Combination trucks indicator (percentage)	-4.431	-5.880	0.000
Average AADT (1 if between 3900 and 52800, 0 otherwise)	-0.413	-6.430	0.000
Average IRI (1 if between 100 and 170 inches per mile, 0 otherwise)	1.365	22.450	0.000
10000^{th} of Squared of the Standard Deviation of IRI	0.137	16.220	0.000
Standard Deviation of PCR (1 if greater than 12.5, 0 otherwise)	-0.773	-6.530	0.000
Model Summary			
Number of Observations	169		
Log likelihood at Zero	-2034.250		
Log likelihood at Convergence	-551.782		

Table 6.89 Accident frequency (Poisson) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.135	12.520	0.000
Contract Characteristics			
Duration of the contract (1 if between 3.5 and 6 years, 0 otherwise)	1.048	7.960	0.000
Inverse of the Square Root of the Size of the Contract	-9.597	-11.050	0.000
Standard deviation of parameter density function	8.229	13.130	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Inside Shoulder Indicator (1 if between 7.5 and 11 feet, 0 otherwise)	-1.611	-6.350	0.000
Inverse of the Square Root of the Standard Deviation of IRI	-2.120	-2.050	0.040
Model Summary			
Number of Observations	37		
Log likelihood at Zero	-381.643		
Log likelihood at Convergence	-91.381		

Table 6.90 Accident frequency (Poisson) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.862	4.990	0.000
Contract Characteristics			
Cost of the contract (1 if greater than $ 23M, 0 otherwise)	-1.060	-1.870	0.062
Number of Assets indicator (1 if less than 6 and greater than 1, 0 otherwise)	-1.904	-3.120	0.002
Inverse of the Square Root of the Size of the Contract	-8.111	-2.780	0.005
Road Geometry and Pavement Condition and Traffic Characteristics			
Drainage Indicator (1 if Moderately well drained or better, 0 otherwise)	0.758	1.750	0.080
Standard Deviation of PCR (1 if between 8.5 and 12.5, 0 otherwise)	-1.241	-2.900	0.004
Model Summary			
Number of Observations	34		
Log likelihood at Zero	-317.121		
Log likelihood at Convergence	-84.765		

Table 6.91 Accident frequency (Negative Binomial) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	2.789	6.03	0.000
Contract Characteristics			
Duration of a contracts (1 if greater than 6 years, 0 otherwise)	-0.952	-3.76	0.000
Number of Assets indicator (1 if greater than 2, 0 otherwise)	-1.047	-3.01	0.003
Inverse of the of the Size of the Contract	-4.705	-2.78	0.005
Asset Type			
Asset Type Indicator (1 if Electrical/Cable system Repair/Maintenance or Traffic Signs and Signals, 0 otherwise)	-0.744	-1.93	0.054
Road Geometry and Pavement Condition and Traffic Characteristics			
Drainage Indicator (1 if Moderately well drained, 0 otherwise)	-0.632	-2.29	0.022
Median Barrier Indicator (1 if median barrier exists, 0 otherwise)	0.622	2.63	0.008
Inside Shoulder width Indicator (1 if less than 3.7 feet, 0 otherwise)	0.7	1.88	0.600
Average IRI (1 if greater than 100 inches per mile, 0 otherwise)	1.389	5.36	0.000
Average PCR (1 if between 85 and 92, 0 otherwise)	-0.703	-2.07	0.039
Combination Trucks Indicator (1 if greater than 8%, 0 otherwise)	-0.587	-2.8	0.005
Model Summary			
Dispersion Parameter (α)	0.462	3.66	0.000
Number of Observations	79		
Log likelihood at Zero	-1016.35		
Log likelihood at Convergence	-231.271		

Table 6.92 Accident frequency (Negative Binomial) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	2.417	5.91	0.000
Contract Characteristics			
Inverse of the Duration of a contracts	-0.358	-2.47	0.014
Standard deviation of parameter density function	0.562	5.71	0.000
Inverse of the of the Size of the Contract	-10.935	-7.4	0.000
Asset Type			
Asset Type Indicator (1 if Guardrail Repair/Maintenance or Illumination Repair/Maintenance, 0 otherwise)	0.449	2.28	0.023
Asset Type Indicator (1 if Crack/Pothole Sealing/Repair or Pavement Repair/Maintenance/Treatment, 0 otherwise)	-0.347	-1.65	0.099
Standard deviation of parameter density function	0.554	3.43	0.001
Road Geometry and Pavement Condition and Traffic Characteristics			
Intersection Indicator (1 if intersection exists, 0 otherwise)	-0.329	-1.75	0.08
Outside Shoulder Indicator (1 if greater than 8.5 feet, 0 otherwise)	-0.37	-2.12	0.034
Average IRI (1 if between 100 and 170 inches per mile, 0 otherwise)	1.158	5.46	0.000
Standard Deviation of IRI	0.012	2.5	0.012
Average PCR (1 if between 80 and 90, 0 otherwise)	0.417	1.68	0.092
Standard Deviation of Rutting Depth (1 if greater than 0.12 inches, 0 otherwise)	0.571	2.03	0.042
Combination Trucks Indicator (1 if between 8% and 32%, 0 otherwise)	0.373	2.28	0.023
Average AADT Indicator (1 if between 3,800 and 52,800 , 0 otherwise)	-0.563	-2.44	0.015
Model Summary			
Dispersion Parameter (α)	1.608	6.72	0.000
Number of Observations	198		
Log likelihood at Zero	-2623.43		
Log likelihood at Convergence	-543.071		

Table 6.93 Accident frequency (Poisson) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.414	19.550	0.000
Contract Characteristics			
Inverse of the Duration of a contracts	-1.023	-8.800	0.000
Standard deviation of parameter density function	0.961	8.430	0.000
Inverse of the of the Size of the Contract	-5.779	-9.410	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Average IRI (1 if between 64 and 100 inches per mile, 0 otherwise)	-1.421	-6.200	0.000
Average Rutting Depth (1 if greater than 0.25, 0 otherwise)	1.603	13.990	0.000
Standard Deviation of Rutting Depth (1 if between 0.05 and 0.12 inches, 0 otherwise)	-0.362	-4.910	0.000
Average PCR (1 if between 85 and 92, 0 otherwise)	-0.691	-3.950	0.000
Standard deviation of parameter density function	0.494	4.330	0.000
Model Summary			
Number of Observations	97		
Log likelihood at Zero	-1183.754		
Log likelihood at Convergence	-159.345		

Table 6.94 Summary of Accident Frequency Analysis Results

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
State Indicator (1 if Minnesota, 0 otherwise) [USA Model]		↓							
Contract Characteristics									
Cost of the contract (1 if greater than $ 23M, 0 otherwise) [Lane Rental]						↓			
Cost of the Project (1 if greater than $ 69M, 0 otherwise) [USA Model]		↓							
Duration of a contracts (1 if greater than 6 years, 0 otherwise) [PBC]							↓		
Duration of the contract (1 if between 3.5 and 6 years, 0 otherwise) [I/D]					↑				
Inverse of the Duration of a contracts [Traditional]								(↓)	
Inverse of the Duration of a contracts [Warranty]									(↓)
Inverse of the Duration of Contract (years) [USA Model]		↓							
Inverse of the Duration of Contract [Full Model]	↓								
Inverse of the Size of the Contract (years) [USA Model]		↓							
Inverse of the Size of the Contract [Full Model]	↓								
Inverse of the Size of the Contract [A+B]			↑						
Inverse of the size of the contract [DBOM]				↓					
Inverse of the of the Size of the Contract [PBC]							↓		
Inverse of the of the Size of the Contract [Traditional]								↓	
Inverse of the of the Size of the Contract [Warranty]									↓
Inverse of the Square Root of the Size of the Contract [I/D]					(↓)				
Inverse of the Square Root of the Size of the Contract [Lane Rental]						↓			
Log of the cost of the contract [DBOM]				(↑)					
Number of Assets indicator (1 if greater than 2, 0 otherwise) [PBC]							↓		
Number of Assets indicator (1 if greater than 2, 0 otherwise) [USA Model]		↓							
Number of Assets indicator (1 if less than 6 and greater than 1, 0 otherwise) [Lane Rental]						↓			
Square Root of the Cost of the Project [Full Model]	↓								
Road Geometry and Pavement Condition and Traffic Characteristics									
10000th of square of Standard deviation of IRI (inches per mile) [A+B]			↓						
10000th of Squared of the Standard Deviation of IRI [DBOM]				↑					
Average AADT (1 if between 3900 and 52800, 0 otherwise) [DBOM]				↓					
Average AADT Indicator (1 if between 3,800 and 52,800 , 0 otherwise) [Traditional]								↓	
Average Annual Daily Traffic (1 if between 3900 and 52800 vehicle per day) [A+B]			(↓)						

Table 6.94 Summary of Accident Frequency Analysis Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Average IRI (1 if greater than 100 inches per mile, 0 otherwise) [PBC]							↑		
Average IRI (1 if between 100 and 170 inches per mile, 0 otherwise) [DBOM]				↑					
Average IRI (1 if between 100 and 170 inches per mile, 0 otherwise) [Traditional]								↑	
Average IRI (1 if between 64 and 100 inches per mile, 0 otherwise) [Warranty]									↓
Average IRI (1 if greater than 170 inches per mile, 0 otherwise) [USA Model]		↑							
Average IRI (1 if greater than 64 inches per mile, 0 otherwise) [Full Model]	↑								
Average PCR (1 if between 80 and 90, 0 otherwise) [Traditional]								↑	
Average PCR (1 if between 85 and 92, 0 otherwise) [PBC]							↓		
Average PCR (1 if between 85 and 92, 0 otherwise) [Warranty]									(↓)
Average PCR (1 if greater than 80, 0 otherwise) [Full Model]	(↓)								
Average Rutting Depth (1 if between 0.12 and 0.25 inches, 0 otherwise) [USA Model]		↑							
Average Rutting Depth (1 if greater than 0.25, 0 otherwise) [Warranty]									↑
Average rutting depth (1 if greater than 0.3 inches, 0 otherwise) [Full Model]									
Combination Trucks Indicator (1 if between 8% and 32%, 0 otherwise) [Traditional]								↑	
Combination Trucks Indicator (1 if greater than 8%, 0 otherwise) [PBC]							↓		
Drainage Indicator (1 if Moderately well drained or better, 0 otherwise) [Lane Rental]						↑			
Drainage Indicator (1 if Moderately well drained, 0 otherwise) [PBC]							↓		
Drainage Indicator (1 if poorly drained, 0 otherwise) [DBOM]				(↑)					
Drainage Indicator (1 if poorly or very poorly drained, 0 otherwise) [USA Model]		↓							
Inside Shoulder Indicator (1 if between 7.5 and 11 feet, 0 otherwise) [I/D]					↓				
Inside Shoulder Width Indicator (1 if greater than 11 feet, 0 otherwise) [Full Model]	↑								

Table 6.94 Summary of Accident Frequency Analysis Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Inside Shoulder width Indicator (1 if less than 3.7 feet, 0 otherwise) [PBC]							↑		
Intersection Indicator (1 if intersection exists, 0 otherwise) [Traditional]								↓	
Inverse of the Average AADT [Full Model]	↑								
Inverse of the Square Root of the Standard Deviation of IRI [I/D]					↓				
Log of the Average PCR [USA Model]		↑							
Median Barrier (1 if median barrier exists, 0 otherwise) [USA Model]									
Median Barrier Indicator (1 if median barrier exists, 0 otherwise) [Full Model]									
Median Barrier Indicator (1 if median barrier exists, 0 otherwise) [PBC]							↑		
Number of Lanes (1 if 3 lanes, 0 otherwise) [Full Model]	↑								
Outside Shoulder Indicator (1 if greater than 8.5 feet, 0 otherwise) [Traditional]								↓	
Percent of Combination Trucks [Full Model]	↓								
Square of combination trucks indicator (in percentage) [A+B]			↑						
Squared of Combination trucks indicator (percentage) [DBOM]				↓					
Standard Deviation of IRI (1 if between 11 and 30 inches per mile, 0 otherwise) [Full Model]	↓								
Standard Deviation of IRI [Traditional]								↑	
Standard Deviation of PCR (1 if between 5 and 8, 0 otherwise) [USA Model]		↓							
Standard Deviation of PCR (1 if between 8.5 and 12.5, 0 otherwise) [Lane Rental]						↓			
Standard Deviation of PCR (1 if greater than 12.5, 0 otherwise) [DBOM]				↓					
Standard Deviation of Rutting Depth (1 if between 0.05 and 0.12 inches, 0 otherwise) [Warranty]									↓
Standard Deviation of Rutting Depth (1 if greater than 0.12 inches, 0 otherwise) [Traditional]								↑	
Standard Deviation of Rutting Depth [USA Model]		↑							
Asset Type									
Asset Type Indicator (1 if Bridge-Tunnel Repair /Maintenance/Management, 0 otherwise) [USA Model]		(↑)							

Table 6.94 Summary of Accident Frequency Analysis Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Asset Type Indicator (1 if Crack/Pothole Sealing/Repair or Pavement Repair/Maintenance/Treatment, 0 otherwise) [Traditional]								(↓)	
Asset Type Indicator (1 if Electrical/Cable system Repair/Maintenance or Traffic Signs and Signals, 0 otherwise) [PBC]							↓		
Asset Type Indicator (1 if guardrail repair/ maintenance or illumination repair/ maintenance, 0 otherwise) [DBOM]				↓					
Asset Type Indicator (1 if Guardrail Repair/Maintenance or Illumination Repair/Maintenance, 0 otherwise) [Traditional]								↑	
Asset Type Indicator (1 if Management or Litter Removal, 0 otherwise) [USA Model]		↓							
Weather Condition									
Weather indicator (1 if the proportion of snowy days to total days of contract is between 0.04 and 0.15, 0 otherwise) [Full Model]	↓								
Weather indicator (1 if the proportion of snowy days to total days of contract is between 0.04 and 0.15, 0 otherwise) [USA Model]		↓							

6.6 Level of Service (Operation) Model Estimation Results

The level of service (LOS) is a qualitative measure of traffic quality, taking values from A (ideal conditions) to F (fully congested conditions). This measure is used for analyzing roads by classifying traffic flow and traffic quality level based on performance measures like speed, density, etc. (Anwaar et al., 2011). In this section, ordered probit models were developed to investigate how the various contract types can play a role in the LOS of roadways.

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in tables 6.95 to 6.105. The results can be summarized as follows:

- Larger sized contracts (in lane-miles) are more likely to have worse LOS, due to the anticipated congestion on and around the long work-zone.
- In all PPP contract types, it is intuitively found that the probability of having LOS A decreases, when the truck traffic increases.
- Low traffic (less than 4,000 vehicles/day) increases the probability of having better LOS.
- In most of the PPP contract types, good road geometry and pavement condition improves the LOS. These parameters allow drivers to drive safely on the roads. Median presence, appropriate inside and outside shoulder width, number of lanes, standard deviation and average of IRI, PCR and rutting depth, are all found to significantly increase the probability of having a better LOS.

- Presence of rest areas increases the probability of having a worse overall LOS for design-build contracts. A possible explanation could be that during the construction or maintenance of the rest areas, traffic congestion may occur. For traditional and warranty contracts, the probability of having a better LOS increases when rest areas is one of the included activities.
- Shoulder repair and maintenance activities increase the probability of a worse overall LOS; this may be capturing congestion effects due to possible lane closures and congestion during the project on or around the project area.
- The factors the effect of which varies across the observations, are also presented in Tables 6.95 to 6.105, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.95 Descriptive Statistics of Operation (LOS) Models

Variables	Mean	Std. Dev	Min	Max.
State Indicator (1 if Alaska, 0 otherwise) [Traditional]	0.101	-	0	1
State Indicator (1 if Minnesota, 0 otherwise) [USA Model]	0.07	-	0	1
Contract Characteristics				
10000 Times the Inverse of the Cost Award of the Project [Full Model]	0.013	0.042	0.835D-05	0.695
Contract Duration (in years) [PBC]	5.532	1.573	2	12
Contract Extension Indicator (1 if between 0 and 2.9 years, 0 otherwise) [Full Model]	0.217	-	0	1
Contract Extension Indicator (1 if between 0 and 2.9 years, 0 otherwise) [USA Model]	0.27	-	0	1
Inverse of the Square Root of the Duration of the Contract [USA Model]	0.585	0.337	0.224	2.5
Inverse of the Square Root of the Size of the Contract [USA Model]	0.523	0.794	0.033	7.071
Size of the Contract (in lane-miles) [DBOM]	30.05	31.679	0.23	249.79
Size of the Contract Indicator (1 if greater than 150 lane-miles, 0 otherwise) [Traditional]	0.253	-	0	1
Size of the Contract Indicator (1 if less than 150 lane-miles, 0 otherwise) [Warranty]	0.959	-	0	1
Size of the Contract Indicator (1 if less than 150 or more than 250 lane-miles, 0 otherwise) [PBC]	0.785	0.414	0	1
Log of contract duration [Full Model]	1.279	0.806	-3.912	3.219
Number of Asset Indicator (1 if between 3 and 6, 0 otherwise) [Warranty]	0.732	-	0	1
Number of Assets Indicator (1 if between 3 and 6, 0 otherwise) [Full Model]	0.081	-	0	1
Number of Assets indicator (1 if between 3 and 6, 0 otherwise) [USA Model]	0.087	-	0	1
Square Root of the Size of the Contract [A+B]	4.977	3.08	1.077	12.087
Asset Type				
Asset Type Indicator (1 if Bridge-Tunnel Repair/ Maintenance/ Management, 0 otherwise) [USA Model]	0.175	0.38	0	1
Asset Type Indicator (1 if Bridge-Tunnel Repair/ Maintenance/Management) [Full Model]	0.18	-	0	1
Asset Type Indicator (1 if Bridge-Tunnel Repair/Maintenance/ Management, 0 otherwise) [Warranty]	0.278	-	0	1
Asset type indicator (1 if culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement, 0 otherwise) [I/D]	0.162	-	0	1
Asset Type Indicator (1 if Culvert/Ditches/Gutters/Drainage Repair/Maintenance/Replacement or Electrical/Cable system Repair/Maintenance, 0 otherwise) [Full Model]	0.282	-	0	1
Asset Type Indicator (1 if Rest Areas, 0 otherwise) [DBOM]	0.095	-	0	1
Asset Type Indicator (1 if Rest Areas, 0 otherwise) [Traditional]	0.167	-	0	1

Table 6.95 Descriptive Statistics of Operation (LOS) Models (Continued)

Variables	**Mean**	**Std. Dev**	**Min**	**Max.**
Asset Type (1 if Rest Areas, 0 otherwise) [Warranty]	0.186	-	0	1
Asset type indicator (1 if shoulder repair/ maintenance, 0 otherwise) [I/D]	0.054	-	0	1
Road Geometry and Pavement Condition and Traffic Characteristics				
10000^{th} of Average AADT of Combination Trucks [I/D]	0.412	0.617	0	2.35
10000^{th} of Average AADT of Combination Trucks [Lane Rental]	0.123	0.171	0.004	0.954
Average AADT (1 if between 15200 and 52800, 0 otherwise) [PBC]	0.354	0.481	0	1
Average AADT (1 if less than 4000, 0 otherwise) [I/D]	0.351	-	0	1
Average AADT (1 if less than 4000, 0 otherwise) [Warranty]	0.412	-	0	1
Average AADT Indicator (1 if between 4000 and 52000, 0 otherwise) [USA Model]	0.247	0.437	0	2.35
Average AADT Indicator (1 if less than 4000, 0 otherwise) [A+B]	0.484	-	0	1
Average AADT Indicator (1 if less than 4000, 0 otherwise) [DBOM]	0.343	-	0	1
Average AADT Indicator (1 if less than 4000, 0 otherwise) [Full Model]	0.363	-	0	1
Average AADT Indicator (1 if less than 4000, 0 otherwise) [Lane Rental]	0.382	-	0	1
Average AADT Indicator (1 if less than 4000, 0 otherwise) [Traditional]	0.48	-	0	1
Average AADT of Combination Trucks (in 10K) [DBOM]	0.239	0.412	0	1.806
Average AADT of Combination Trucks [Traditional]	0.226	0.351	0	1.831
Average IRI Indicator (1 if between 100 and 137 inches per mile, 0 otherwise) [Warranty]	0.196	-	0	1
Average IRI Indicator (1 if between 64 and 137 inches per mile,0 otherwise) [Traditional]	0.747	-	0	1
Average IRI Indicator (1 if less than 64 or greater than 137 inches per mile, 0 otherwise) [USA Model]	0.722	-	0	1
Average PCR [DBOM]	87.65	4.27	72.917	99.5
Average PCR Indicator (1 if greater than 92, 0 otherwise) [USA Model]	0.186	-	0	1
Combination Trucks (1 if between 16% and 40%, 0 otherwise) [PBC]	0.316	0.468	0	1
Combination Trucks Indicator (1 if between 8% and 32%, 0 otherwise) [A+B]	0.677	-	0	1
Crash category Indicator (1 if a Property Damage Only, 0 otherwise) [USA Model]	0.597	-	0	1
Crash category Indicator (1 if a Property Damage Only, 0 otherwise) [Full Model]	0.657	-	0	1
Drainage Indicator (1 if well drained, 0 otherwise) [DBOM]	0.237	-	0	1

Table 6.95 Descriptive Statistics of Operation (LOS) Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Drainage Indicator (1 if well drained, 0 otherwise) [USA Model]	0.264	-	0	1
Highway Indicator (1 if highway, 0 otherwise) [Full Model]	0.845	-	0	1
Inside Shoulder Width Indicator (1 if between 3.7 and 7.5 feet, 0 otherwise) [USA Model]	0.237	-	0	1
Inside Shoulder Width Indicator (1 if between 3.7 and 7.5 feet, 0 otherwise) [Full Model]	0.227	-	0	1
Log of the Standard Deviation of Rutting Depth [Traditional]	-3.08	0.683	-4.717	-0.545
Median Barrier Indicator (1 if median barrier exists, 0 otherwise) [Full Model]	0.325	-	0	1
Median Indicator (1 if there is no median, 0 otherwise) [DBOM]	0.544	-	0	1
Number of Lanes Indicator (1 if greater than 1, 0 otherwise) [DBOM]	0.959	-	0	1
One 10000th of the Average AADT of Combination Trucks [Full Model]	0.32	0.518	0	4.321
One 10000th of the Average AADT of Combination Trucks [USA Model]	0.533	-	0	1
Percentage of Combination Trucks Indicator (1 if greater than 16%, 0 otherwise) [Warranty]	0.392	-	0	1
Squared of Standard Deviation of Rutting Depth (inches) [Full Model]	0.005	0.014	0	0.336
Standard Deviation of IRI (1 if greater than 30 inches per mile, 0 otherwise) [PBC]	0.278	0.451	0	1
Standard Deviation of IRI Indicator (1 if greater than 30 inches per mile, 0 otherwise) [Full Model]	0.297	-	0	1
Standard Deviation of IRI Indicator (1 if greater than 30 inches per mile, 0 otherwise) [USA Model]	0.274	-	0	1
Standard Deviation of PCR (1 if greater than 8.5, 0 otherwise) [PBC]	0.443	0.5	0	1
Standard Deviation of PCR Indicator (1 if greater than 12.5, 0 otherwise) [A+B]	0.097	-	0	1
Standard Deviation of Rutting Depth (inches) [USA Model]	0.056	0.046	0	0.58
Standard Deviation of Rutting Depth Indicator (1 if greater than 0.05, 0 otherwise) [Lane Rental]	0.559	-	0	1
Weather Condition				
Squared of the Proportion of Snow Days [Full Model]	0.004	0.008	0	0.076

Table 6.96 Level of service (Ordered Probit) model (All contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	4.031	19.000	0.000
Standard deviation of parameter density function	0.776	22.640	0.000
Contract Characteristics			
Log of Contract Duration	0.366	6.810	0.000
Contract Extension Indicator (1 if between 0 and 2.9 years, 0 otherwise)	0.456	5.040	0.000
10000 Times the Inverse of the Cost Award of the Project	6.006	7.070	0.000
Inverse of the Size of the Contract	-0.097	-4.730	0.000
Asset Type			
Asset Type Indicator (1 if Bridge-Tunnel Repair/Maintenance /Management)	0.389	3.770	0.000
Asset Type Indicator (1 if Culvert/Ditches/Gutters/Drainage Repair/Maintenance/Replacement or Electrical/Cable system Repair/Maintenance, 0 otherwise)	-0.272	-2.640	0.008
Road Geometry and Pavement Condition and Traffic Characteristics			
Highway Indicator (1 if highway, 0 otherwise)	-0.283	-2.470	0.013
Median Barrier Indicator (1 if median barrier exists, 0 otherwise)	-0.185	-2.290	0.022
Squared of Standard Deviation of Rutting Depth (inches)	-9.267	-4.000	0.000
Standard Deviation of IRI Indicator (1 if greater than 30 inches per mile, 0 otherwise)	-0.169	-2.060	0.039
Standard deviation of parameter density function	0.552	8.050	0.000
Average AADT Indicator (1 if less than 4000, 0 otherwise)	-2.683	-22.550	0.000
One 10000th of the Average AADT of Combination Trucks	2.229	16.770	0.000
Standard deviation of parameter density function	1.340	13.290	0.000
Weather Condition			
Squared of the Proportion of Snow Days	21.798	5.080	0.000
Model Summary			
μ_1	2.286	18.580	0.000
μ_2	4.112	26.920	0.000
μ_3	5.498	31.540	0.000
μ_4	7.968	30.510	0.000
Number of Observations	1074		
Log likelihood at Zero	-1815.269		
Log likelihood at Convergence	-1364.770		

Table 6.97 Level of service (Ordered Probit) model (USA contracts)

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	1.692	8.290	0.000
State Indicator (1 if Minnesota, 0 otherwise)	-0.476	-2.570	0.010
Standard deviation of parameter density function	0.814	4.910	0.000
Contract Characteristics			
Inverse of the Square Root of the Duration of the Contract	-0.940	-5.730	0.000
Contract Extension Indicator (1 if between 0 and 2.9 years, 0 otherwise)	0.367	3.570	0.000
Inverse of the Square Root of the Size of the Contract	-0.693	-5.880	0.000
10000 times the Inverse of Cost Award	3.295	2.660	0.008
Asset Type			
Asset Type Indicator (1 if Bridge-Tunnel Repair/ Maintenance/ Management, 0 otherwise)	0.265	2.280	0.023
Road Geometry and Pavement Condition and Traffic Characteristics			
Inside Shoulder Width Indicator (1 if between 3.7 and 7.5 feet, 0 otherwise)	0.194	1.940	0.052
Average IRI Indicator (1 if less than 64 or greater than 137 inches per mile, 0 otherwise)	0.451	4.120	0.000
Standard Deviation of IRI Indicator (1 if greater than 30 inches per mile, 0 otherwise)	-0.179	-1.800	0.072
Average PCR Indicator (1 if greater than 92, 0 otherwise)	0.955	4.640	0.000
Standard Deviation of Rutting Depth (inches)	-2.181	-1.920	0.055
One 10000th of the Average AADT of Combination Trucks	0.906	8.590	0.000
Average AADT Indicator (1 if between 4000 and 52000, 0 otherwise)	1.078	9.020	0.000
Model Summary			
μ_1	1.539	13.660	0.000
μ_2	2.652	19.920	0.000
μ_3	3.464	24.200	0.000
μ_4	4.510	26.670	0.000
Number of Observations	645		
Log likelihood at Zero	-1082.429		
Log likelihood at Convergence	-832.862		

Table 6.98 Level of service (Ordered Probit) model (USA contracts): A+B

Variables	Coefficient	*t*-stat	*P*-value
Contract Characteristics			
Square Root of the Size of the Contract	0.402	7.400	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of PCR Indicator (1 if greater than 12.5, 0 otherwise)	2.72	3.830	0.000
Combination Trucks Indicator (1 if between 8% and 32%, 0 otherwise)	1.421	3.400	0.001
Average AADT Indicator (1 if less than 4000, 0 otherwise)	-1.105	-2.520	0.012
Model Summary			
μ_1	1.255	3.790	0.000
μ_2	3.043	8.410	0.000
μ_3	5.119	10.70	0.000
μ_4	6.178	9.130	0.000
Number of Observations	31		
Log likelihood at Zero	-44.914		
Log likelihood at Convergence	-30.961		

Table 6.99 Level of service (Ordered Probit) model (USA contracts): DBOM

Variables	Coefficient	*t*-stat	*P*-value
Constant	-7.549	-2.750	0.006
Contract Characteristics			
Size of the Contract (in lane-miles)	0.022	4.780	0.000
Asset Type			
Asset Type Indicator (1 if Rest Areas, 0 otherwise)	0.789	2.260	0.024
Road Geometry and Pavement Condition and Traffic Characteristics			
Number of Lanes Indicator (1 if greater than 1, 0 otherwise)	-0.874	-2.140	0.032
Standard deviation of parameter density function	0.285	5.350	0.000
Drainage Indicator (1 if well drained, 0 otherwise)	0.517	2.490	0.013
Median Indicator (1 if there is no median, 0 otherwise)	0.636	3.390	0.001
Average PCR	0.118	3.940	0.000
Average AADT Indicator (1 if less than 4000, 0 otherwise)	-1.103	-3.910	0.000
Average AADT of Combination Trucks (in 10K)	0.864	2.530	0.012
Standard deviation of parameter density function	0.911	3.880	0.000
Model Summary			
μ_1	1.771	6.480	0.000
μ_2	3.529	10.310	0.000
μ_3	4.771	12.100	0.000
μ_4	6.904	9.480	0.000
Number of Observations	169		
Log likelihood at Zero	-270.428		
Log likelihood at Convergence	-192.713		

Table 6.100 Level of service (Ordered Probit) model (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.857	10.550	0.000
Assets Type			
Asset type indicator (1 if culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement, 0 otherwise)	-1.439	-2.590	0.010
Asset type indicator (1 if shoulder repair/ maintenance, 0 otherwise)	2.781	3.420	0.001
Traffic Characteristics			
Average AADT (1 if less than 4000, 0 otherwise)	-3.171	-6.530	0.000
10000^{th} of Average AADT of Combination Trucks	1.455	3.500	0.001
Model Summary			
μ_1	1.828	3.950	0.000
μ_2	3.927	12.890	0.000
μ_3	4.829	16.780	0.000
μ_4	6.250	12.420	0.000
Number of Observations	37		
Log likelihood at Zero	-64.124		
Log likelihood at Convergence	-37.850		

Table 6.101 Level of service (Ordered Probit) model (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-value**
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of Rutting Depth Indicator (1 if greater than 0.05, 0 otherwise)	0.874	2.510	0.012
Average AADT Indicator (1 if less than 4000, 0 otherwise)	-1.109	-2.570	0.010
10000^{th} of Average AADT of Combination Trucks	2.461	2.680	0.007
Model Summary			
μ_1	0.738	4.080	0.000
μ_2	1.510	6.140	0.000
Number of Observations	34		
Log likelihood at Zero	-46.838		
Log likelihood at Convergence	-37.539		

Table 6.102 Level of service (Ordered Probit) model (USA contracts): PBC

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	4.636	5.460	0.000
Contract Characteristics			
Contract Duration (in years)	-0.174	-1.790	0.073
Size of the Contract Indicator (1 if less than 150 or more than 250 lane-miles, 0 otherwise)	-1.247	-3.260	0.001
Road Geometry and Pavement Condition and Traffic Characteristics			
Standard Deviation of PCR (1 if greater than 8.5, 0 otherwise)	-0.590	-2.120	0.034
Standard Deviation of IRI (1 if greater than 30 inches per mile, 0 otherwise)	-0.631	-2.200	0.028
Standard deviation of parameter density function	1.087	3.940	0.000
Combination Trucks (1 if between 16% and 40%, 0 otherwise)	0.736	2.210	0.027
Average AADT (1 if between 15200 and 52800, 0 otherwise)	0.931	2.660	0.008
Model Summary			
μ_1	1.920	4.940	0.000
μ_2	2.678	6.170	0.000
μ_3	3.367	7.370	0.000
μ_4	4.719	8.770	0.000
Number of Observations	79		
Log likelihood at Zero	-131.852		
Log likelihood at Convergence	-105.272		

Table 6.103 Level of service (Ordered Probit) model (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	3.225	4.690	0.000
State Indicator (1 if Alaska, 0 otherwise)	0.659	1.980	0.047
Contract Characteristics			
Size of the Contract Indicator (1 if greater than 150 lane-miles, 0 otherwise)	0.931	3.720	0.000
Standard deviation of parameter density function	2.915	5.820	0.000
Asset Type			
Asset Type Indicator (1 if Rest Areas, 0 otherwise)	-3.565	-6.320	0.000
Standard deviation of parameter density function	2.859	5.960	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Average IRI Indicator (1 if between 64 and 137 inches per mile,0 otherwise)	1.264	4.690	0.000
Log of the Standard Deviation of Rutting Depth	-0.580	-3.560	0.000
Average AADT Indicator (1 if less than 4000, 0 otherwise)	-2.644	-8.460	0.000
Standard deviation of parameter density function	1.857	7.500	0.000
Average AADT of Combination Trucks	0.950	4.330	0.000
Model Summary			
μ_1	4.374	7.340	0.000
μ_2	6.145	9.080	0.000
μ_3	7.373	10.390	0.000
μ_4	8.860	11.440	0.000
Number of Observations	198		
Log likelihood at Zero	-337.428		
Log likelihood at Convergence	-226.515		

Table 6.104 Level of service (Ordered Probit) model (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-value**
Constant	2.362	1.920	0.055
Contract Characteristics			
Size of the Contract Indicator (1 if less than 150 lane-miles, 0 otherwise)	-2.211	-1.880	0.060
Number of Asset Indicator (1 if between 3 and 6, 0 otherwise)	1.847	3.520	0.000
Standard deviation of parameter density function	2.807	6.080	0.000
Asset Type			
Asset Type Indicator (1 if Bridge-Tunnel Repair/Maintenance /Management, 0 otherwise)	2.410	4.810	0.000
Asset Type (1 if Rest Areas, 0 otherwise)	-2.492	-3.940	0.000
Road Geometry and Pavement Condition and Traffic Characteristics			
Average IRI Indicator (1 if between 100 and 137 inches per mile, 0 otherwise)	-0.931	-2.040	0.041
Average AADT (1 if less than 4000, 0 otherwise)	-6.322	6.1	0.000
Percentage of Combination Trucks Indicator (1 if greater than 16%, 0 otherwise)	1.106	2.960	0.003
Model Summary			
μ_1	4.535	5.2	0.000
μ_2	8.314	5.96	0.000
μ_3	10.212	6.44	0.000
Number of Observations	97		
Log likelihood at Zero	-150.465		
Log likelihood at Convergence	-98.059		

Table 6.105 Summary of Operation (LOS) Analysis Results

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
State Indicator (1 if Alaska, 0 otherwise) [Traditional]								↑	
State Indicator (1 if Minnesota, 0 otherwise) [USA Model]		(↓)							
Contract Characteristics									
10000 Times the Inverse of the Cost Award of the Project [Full Model]	↑								
10000 Times the Inverse of the Cost Award of the Project [USA Model]		↑							
Contract Duration (in years) [PBC]							↓		
Contract Extension Indicator (1 if between 0 and 2.9 years, 0 otherwise) [Full Model]	↑								
Contract Extension Indicator (1 if between 0 and 2.9 years, 0 otherwise) [USA Model]		↑							
Inverse of the Square Root of the Duration of the Contract [USA Model]		↓							
Inverse of the Square Root of the Size of the Contract [USA Model]		↓							
Size of the Contract (in lane-miles) [DBOM]				↑					
Size of the Contract Indicator (1 if greater than 150 lane-miles, 0 otherwise) [Traditional]								(↑)	
Size of the Contract Indicator (1 if less than 150 lane-miles, 0 otherwise) [Warranty]									↓
Size of the Contract Indicator (1 if less than 150 or more than 250 lane-miles, 0 otherwise) [PBC]							↓		
Log of contract duration [Full Model]	↑								
Number of Asset Indicator (1 if between 3 and 6, 0 otherwise) [Warranty]									(↑)
Number of Assets Indicator (1 if between 3 and 6, 0 otherwise) [Full Model]									
Number of Assets indicator (1 if between 3 and 6, 0 otherwise) [USA Model]									
Square Root of the Size of the Contract [A+B]			↑						
Asset Type									
Asset Type Indicator (1 if Bridge-Tunnel Repair/ Maintenance/ Management, 0 otherwise) [USA Model]		↑							
Asset Type Indicator (1 if Bridge-Tunnel Repair/ Maintenance/Management) [Full Model]	↑								
Asset Type Indicator (1 if Bridge-Tunnel Repair/Maintenance/ Management, 0 otherwise) [Warranty]									↑

Table 6.105 Summary of Operation (LOS) Analysis Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Asset type indicator (1 if culvert/ ditches/ gutter/ drainage repair/ maintenance/ replacement, 0 otherwise) [I/D]					↓				
Asset Type Indicator (1 if Culvert/Ditches/ Gutters/ Drainage Repair /Maintenance/Replacement or Electrical/Cable system Repair/Maintenance, 0 otherwise) [Full Model]	↓								
Asset Type Indicator (1 if Rest Areas, 0 otherwise) [DBOM]				↑					
Asset Type Indicator (1 if Rest Areas, 0 otherwise) [Traditional]								(↓)	
Asset Type indicator(1 if Rest Areas, 0 otherwise) [Warranty]									↓
Asset type indicator (1 if shoulder repair/ maintenance, 0 otherwise) [I/D]					↑				
Road Geometry and Pavement Condition and Traffic Characteristics									
10000^{th} of Average AADT of Combination Trucks [I/D]					↑				
10000^{th} of Average AADT of Combination Trucks [Lane Rental]						↑			
Average AADT (1 if between 15200 and 52800, 0 otherwise) [PBC]							↑		
Average AADT (1 if less than 4000, 0 otherwise) [I/D]					↓				
Average AADT (1 if less than 4000, 0 otherwise) [Warranty]									↑
Average AADT Indicator (1 if between 4000 and 52000, 0 otherwise) [USA Model]									
Average AADT Indicator (1 if less than 4000, 0 otherwise) [A+B]			↓						
Average AADT Indicator (1 if less than 4000, 0 otherwise) [DBOM]				↓					
Average AADT Indicator (1 if less than 4000, 0 otherwise) [Full Model]	↓								
Average AADT Indicator (1 if less than 4000, 0 otherwise) [Lane Rental]						↓			
Average AADT Indicator (1 if less than 4000, 0 otherwise) [Traditional]								(↓)	
Average AADT of Combination Trucks (in 10K) [DBOM]				(↑)					
Average AADT of Combination Trucks [Traditional]								↑	
Average IRI Indicator (1 if between 100 and 137 inches per mile, 0 otherwise) [Warranty]									↑

Table 6.105 Summary of Operation (LOS) Analysis Results (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Average IRI Indicator (1 if between 64 and 137 inches per mile,0 otherwise) [Traditional]								↑	
Average IRI Indicator (1 if less than 64 or greater than 137 inches per mile, 0 otherwise) [USA Model]		↑							
Average PCR [DBOM]				↑					
Average PCR Indicator (1 if greater than 92, 0 otherwise) [USA Model]		↑							
Combination Trucks (1 if between 16% and 40%, 0 otherwise) [PBC]							↑		
Combination Trucks Indicator (1 if between 8% and 32%, 0 otherwise) [A+B]			↑						
Drainage Indicator (1 if well drained, 0 otherwise) [DBOM]				↑					
Drainage Indicator (1 if well drained, 0 otherwise) [USA Model]									
Highway Indicator (1 if highway, 0 otherwise) [Full Model]	↓								
Inside Shoulder Width Indicator (1 if between 3.7 and 7.5 feet, 0 otherwise) [USA Model]		↑							
Log of the Standard Deviation of Rutting Depth [Traditional]								↓	
Median Barrier Indicator (1 if median barrier exists, 0 otherwise) [Full Model]	↓								
Median Indicator (1 if there is no median, 0 otherwise) [DBOM]				↑					
Number of Lanes Indicator (1 if greater than 1, 0 otherwise) [DBOM]				(↓)					
One 10000th of the Average AADT of Combination Trucks [Full Model]	(↑)								
One 10000th of the Average AADT of Combination Trucks [USA Model]		↑							
Percentage of Combination Trucks Indicator (1 if greater than 16%, 0 otherwise) [Warranty]									↑
Squared of Standard Deviation of Rutting Depth (inches) [Full Model]	↓								
Standard Deviation of IRI (1 if greater than 30 inches per mile, 0 otherwise) [PBC]							(↓)		
Standard Deviation of IRI Indicator (1 if greater than 30 inches per mile, 0 otherwise) [Full Model]	(↓)								
Standard Deviation of IRI Indicator (1 if greater than 30 inches per mile, 0 otherwise) [USA Model]		↓							

Table 6.105 Summary of Operation (LOS) Analysis Results (Continued)

Variables	**Full Model**	**USA Model**	**A+B [USA]**	**DBOM [USA]**	**I/D [USA]**	**Lane Rental [USA]**	**PBC [USA]**	**Traditional [USA]**	**Warranty [USA]**
Standard Deviation of PCR (1 if greater than 8.5, 0 otherwise) [PBC]							↓		
Standard Deviation of PCR Indicator (1 if greater than 12.5, 0 otherwise) [A+B]			↑						
Standard Deviation of Rutting Depth (inches) [USA Model]		↓							
Standard Deviation of Rutting Depth Indicator (1 if greater than 0.05, 0 otherwise) [Lane Rental]						↑			
Weather Condition									
Squared of the Proportion of Snow Days [Full Model]	↑								

6.7 Pavement (Asset) Condition Model Estimation Results

The improvement of the overall pavement condition of roadways is one common activity that PPP contracts include. This improvement can be captured by pavement condition indicators, such as the International Roughness Index (IRI), the Pavement Condition Rating (PCR), and the Rutting Depth (Anastasopoulos et al., 2013).

The theory behind the development of the IRI was to capture the reaction of a single tire on a vehicle suspension to roughness in the pavement surface while the speed is 50 mph. Higher values for IRI (in inches per mile) show a reduction in the quality of the pavement condition (Anastasopoulos et al., 2011b). PCR is typically used to indicate the overall pavement condition. This pavement condition indicator is measured on a scale from 0 to 100, with higher values indicating better pavement condition. Rutting depth is another pavement condition indicator used in this study. This indicator presents the depth of potholes and cracks along the segment; therefore, lower values are more desirable. The three pavement performance indicators are model jointly, in a system of seemingly unrelated regression equations (SURE).

Descriptive statistics and model estimation results (including goodness-of-fit measures) based on the USA PPP contract types are presented in tables 6.106 to 6.116. The results can be summarized as follows:

- For cost-plus-time contracts, higher truck traffic is found to worsen the pavement performance. This finding is in line with Mannering et al. (2009).

- The overall pavement condition is found to improve for PPP contract types that have better drainage systems. This finding is in line with Anastasopoulos (2009), and is valid for most PPP contract types.
- The duration of the contract affects significantly two types of contracts: design-build, and incentives/disincentives contracts. An increase in the duration of the project is found to reduce the pavement condition.
- Low AADT for incentives/disincentives contracts increases the PCR; however, in the other PPP approaches, it decreases PCR.
- Activities such as pavement repair, maintenance, and treatment improve the pavement condition for all PPP contract types.
- The factors, the effect of which varies across the observations, are also presented in Tables 6.106 to 6.116, and are observed when the standard deviation of the parameter density function of the parameter is statistically significant.

Table 6.106 Descriptive Statistics of Asset (Pavement) Condition Models

Variables	Mean	Std. Dev	Min.	Max.
Dependent variable: International Roughness Index (in./mi)				
State indicator (1 if Alaska, 0 otherwise) [DBOM]	0.071	-	0.000	1.000
Pavement Condition				
Drainage indicator variable (1 if well drained, 0 otherwise) [DBOM]	0.237	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Full Model]	0.278	0.448	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [PBC]	0.278	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [USA Model]	0.264	0.441	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Warranty]	0.320	-	0.000	1.000
Standard deviation of IRI (1 if less than 35 inches per mile, 0 otherwise) [Warranty]	0.763	-	0.000	1.000
Standard deviation of IRI [DBOM]	28.052	35.559	3.141	431.612
Standard deviation of IRI [Full Model]	26.288	21.599	0.577	431.612
Standard deviation of IRI [Traditional]	24.379	16.238	0.577	96.672
Standard deviation of IRI [USA Model]	25.716	23.331	0.577	431.612
Asset condition				
Asset type indicator (1 if pavement repair/ maintenance/rehabilitation/ treatment, 0 otherwise) [PBC]	0.139	-	0.000	1.000
Number of assets per lane mile [Lane Rental]	0.199	0.531	0.000	2.500
Number of assets per lane mile [PBC]	0.088	0.371	0.000	2.273
Number of assets per lane mile [Traditional]	0.628	2.449	0.000	16.667
Number of assets per lane mile [USA Model]	0.384	2.435	0.000	50.000
Number of assets per lane mile [Warranty]	0.412	0.928	0.000	4.762
Traffic Characteristics				
1000th of Average AADT of Combination Trucks [Lane Rental]	1.228	1.713	0.036	9.542
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [A+B]	0.194	-	0.000	1.000
Truck indicator variable (1 if percentage of truck is greater than 15 %, 0 otherwise) [A+B]	0.323	-	0.000	1.000

Table 6.106 Descriptive Statistics of Asset (Pavement) Condition Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Dependent variable: Pavement Condition Rating (0-100 scale)				
Contract Characteristics				
Duration of the contract(1 if greater than 5 years, 0 otherwise) [Traditional]	0.581	-	0.000	1.000
Traffic Characteristics				
1000th of Average AADT of Combination Trucks [I/D]	4.124	6.171	0.000	23.496
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [A+B]	0.194	-	0.000	1.000
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [DBOM]	0.266	-	0.000	1.000
Natural logarithm of Average annual daily truck traffic (in 1000)	-0.665	1.816	-5.286	2.908
Natural logarithm of Average annual daily truck traffic (in 1000) [Full Model]	-0.116	1.735	-5.286	3.766
Truck volume indicator variable (1 if truck volume is equal or greater than 500 and less than 1000, 0 otherwise) [Full Model]	0.168	0.374	0.000	1.000
Pavement Condition				
Drainage indicator variable (1 if well drained, 0 otherwise) [DBOM]	0.237	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Full Model]	0.278	0.448	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [PBC]	0.278	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [USA Model]	0.264	0.441	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Warranty]	0.320	-	0.000	1.000
Standard deviation of PCR [A+B]	9.111	3.053	3.753	16.634
Standard deviation of PCR [DBOM]	7.707	3.078	0.775	16.289
Standard deviation of PCR [Traditional]	7.528	3.017	1.443	15.187
Standard deviation of PCR [USA Model]	7.652	3.039	0.775	16.634
Standard deviation of PCR [Warranty]	7.110	2.947	1.549	15.317
Asset condition				
Asset type indicator (1 if pavement repair/ maintenance/ rehabilitation/ treatment, 0 otherwise) [Lane Rental]	0.088	-	0.000	1.000
Number of assets per lane mile [Full Model]	0.238	1.895	0.000	50.000
Number of assets per lane mile [Lane Rental]	0.199	0.531	0.000	2.500
Number of assets per lane mile [PBC]	0.088	0.371	0.000	2.273
Number of assets per lane mile [Traditional]	0.628	2.449	0.000	16.667
Number of assets per lane mile [USA Model]	0.384	2.435	0.000	50.000
Number of assets per lane mile [Warranty]	0.412	0.928	0.000	4.762
Weather Condition				
Summation of proportion of rainy and snowy days [Full Model]	0.970	0.530	0.000	2.000

Table 6.106 Descriptive Statistics of Asset (Pavement) Condition Models (Continued)

Variables	Mean	Std. Dev	Min.	Max.
Dependent variable: Rutting depth (inches)				
State indicator (1 if Minnesota, 0 otherwise) [DBOM]	0.036	-	0.000	1.000
Contract Characteristics				
Duration of the contract (1 if greater than 5 years, 0 otherwise) [DBOM]	0.805	-	0.000	1.000
Pavement Condition				
Drainage indicator variable (1 if somewhat poorly drained, 0 otherwise) [Traditional]	0.268	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [DBOM]	0.237	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Full Model]	0.278	0.448	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [I/D]	0.297	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Lane Rental]	0.353	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [PBC]	0.278	-	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [USA Model]	0.264	0.441	0.000	1.000
Drainage indicator variable (1 if well drained, 0 otherwise) [Warranty]	0.320	-	0.000	1.000
Standard deviation of rutting depth (1 if greater than 0.09 inches, 0 otherwise) [Warranty]	0.732	-	0.000	1.000
Standard deviation of Rutting depth (in inches) [PBC]	0.056	0.043	0.009	0.257
Standard deviation of Rutting depth [DBOM]	0.042	0.027	0.012	0.123
Standard deviation of Rutting depth [DBOM]	0.059	0.041	0.000	0.202
Standard deviation of Rutting depth [Full Model]	0.057	0.044	0.000	0.580
Standard deviation of Rutting depth [Lane Rental]	0.051	0.029	0.010	0.113
Standard deviation of Rutting depth [USA Model]	0.056	0.046	0.000	0.580
Asset condition				
Asset type indicator (1 if pavement repair/ maintenance/rehabilitation/ treatment, 0 otherwise) [PBC]	0.139	-	0.000	1.000
Number of assets per lane mile [Lane Rental]	0.199	0.531	0.000	2.500
Number of assets per lane mile [PBC]	0.088	0.371	0.000	2.273
Number of assets per lane mile [Traditional]	0.628	2.449	0.000	16.667
Number of assets per lane mile [USA Model]	0.384	2.435	0.000	50.000
Number of assets per lane mile [Warranty]	0.412	0.928	0.000	4.762
Traffic Characteristics				
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [A+B]	0.194	-	0	1

Table 6.107 Seemingly Unrelated Regression Equation Model (All Contracts)

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	104.175	77.880	0.0000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-8.605	-3.630	0.0003
Standard deviation of IRI	0.273	15.830	0.0000
Model Summary			
Number of Observations	1074		
R-Squared	0.139		
Adjusted R-Squared	0.138		
Dependent variable: Average PCR			
Constant	87.936	521.770	0.0000
Traffic Characteristics			
Natural logarithm of Average annual daily truck traffic (in 1000)	-0.043	-1.860	0.0636
Truck volume indicator variable (1 if truck volume is equal or greater than 500 and less than 1000, 0 otherwise)	-0.196	-1.840	0.0664
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	1.261	4.410	0.0000
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	0.053	2.480	0.0131
Weather Condition			
Summation of proportion of rainy and snowy days	-0.145	-1.920	0.0546
Model Summary			
Number of Observations	1074		
R-Squared	0.016		
Adjusted R-Squared	0.012		
Dependent variable: Average RUT			
Constant	0.164	65.710	0.0000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-0.018	-4.010	0.0001
Standard deviation of Rutting depth	0.029	2.030	0.0426
Model Summary			
Number of Observations	1074		
R-Squared	0.026		
Adjusted R-Squared	0.024		

Table 6.108 Seemingly Unrelated Regression Equation Model (U.S. Contracts)

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	103.135	57.130	0.0000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-11.633	-3.530	0.0004
Standard deviation of IRI	0.362	16.210	0.0000
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-1.918	-3.210	0.0013
Model Summary			
Number of Observations	645		
R-Squared	0.201		
Adjusted R-Squared	0.197		
Dependent variable: Average PCR			
Constant	88.720	359.200	0.0000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	1.600	4.060	0.0000
Standard deviation of PCR	-0.124	-6.960	0.0000
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	0.268	3.760	0.0000
Model Summary			
Number of Observations	645		
R-Squared	0.081		
Adjusted R-Squared	0.077		
Dependent variable: Average RUT			
Constant	0.166	47.840	0.0000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-0.026	-4.040	0.0001
Standard deviation of Rutting depth	0.034	1.730	0.0840
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-0.004	-3.330	0.0009
Model Summary			
Number of Observations	645		
R-Squared	0.054		
Adjusted R-Squared	0.049		

Table 6.109 Seemingly Unrelated Regression Equation (USA contracts): A+B

Variables	Coefficient	*t*-stat	*P*-Value
Dependent variable: Average IRI			
Constant	119.966	18.310	0.000
Traffic Characteristics			
Truck indicator variable (1 if percentage of truck is greater than 15 %, 0 otherwise)	6.593	3.929	0.093
Average Annual Daily Traffic (1 if greater than 16000, 0 otherwise)	-37.386	-2.490	0.013
Model Summary			
Number of Observations	31		
R-Squared	0.129		
Adjusted R-Squared	0.067		
Dependent variable: Average PCR			
Constant	87.451	98.690	0.0000
Pavement Condition			
Standard deviation of PCR	-0.110	-1.790	0.073
Traffic Characteristics			
Average Annual Daily Traffic (1 if greater than 16000, 0 otherwise)	4.456	2.880	0.004
Model Summary			
Number of Observations	31		
R-Squared	0.249		
Adjusted R-Squared	0.196		
Dependent variable: Average RUT			
Constant	0.171	15.220	0.000
Pavement Condition			
Standard deviation of Rutting depth	0.236	3.190	0.001
Traffic Characteristics			
Average Annual Daily Traffic (1 if greater than 16000, 0 otherwise)	-0.063	-2.550	0.011
Model Summary			
Number of Observations	31		
R-Squared	0.215		
Adjusted R-Squared	0.159		

Table 6.110 Seemingly Unrelated Regression Equation (USA contracts only): DBOM

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	102.888	31.620	0.000
State Indicator (1 if Alaska, 0 otherwise)	12.777	2.970	0.003
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-16.266	-2.560	0.011
Standard deviation of IRI	0.532	16.940	0.000
Model Summary			
Number of Observations	169		
R-Squared	0.408		
Adjusted R-Squared	0.397		
Dependent variable: Average PCR			
Constant	87.581	198.840	0.0000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	1.975	2.720	0.007
Standard deviation of PCR	-0.080	-2.380	0.018
Traffic Characteristics			
Average Annual Daily Traffic (1 if greater than 16000, 0 otherwise)	0.834	3.420	0.001
Model Summary			
Number of Observations	169		
R-Squared	0.072		
Adjusted R-Squared	0.055		
Dependent variable: Average RUT			
Constant	0.160	19.650	0.000
State Indicator (1 if Minnesota, 0 otherwise)	0.027	2.45	0.014
Contract Characteristics			
Duration of contract(1 if greater than 5, 0 otherwise)	0.011	2.100	0.036
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-0.037	-2.760	0.006
Standard deviation of Rutting depth	0.184	4.000	0.000
Model Summary			
Number of Observations	169		
R-Squared	0.086		
Adjusted R-Squared	0.075		

Table 6.111 Seemingly Unrelated Regression Equation (USA contracts): I/D

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	95.017	20.230	0.000
Model Summary			
Number of Observations	37		
R-Squared	0.000		
Adjusted R-Squared	0.000		
Dependent variable: Average PCR			
Constant	89.933	133.580	0.000
Traffic Characteristics			
Average annual daily truck traffic (in 1000)	-0.059	-2.170	0.030
Model Summary			
Number of Observations	37		
R-Squared	-0.007		
Adjusted R-Squared	-0.036		
Dependent variable: Average RUT			
Constant	0.135	13.960	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	0.013	2.730	0.006
Model Summary			
Number of Observations	37		
R-Squared	0.049		
Adjusted R-Squared	0.022		

Table 6.112 Seemingly Unrelated Regression Equation (USA contracts): Lane Rentals

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	104.602	15.880	0.000
Traffic characteristics			
Natural logarithm of truck percentage	-1.061	-2.040	0.041
Model Summary			
Number of Observations	37		
R-Squared	0.030		
Adjusted R-Squared	0.010		
Dependent variable: Average PCR			
Constant	89.756	136.790	0.0000
Contract Characteristics			
Duration of contract(1 if greater than 5, 0 otherwise)	-0.555	-1.710	0.086
Traffic Characteristics			
Average annual daily truck traffic (1 if between 500 and 1000, 0 otherwise)	1.184	2.380	0.027
Model Summary			
Number of Observations	37		
R-Squared	0.054		
Adjusted R-Squared	0.036		
Dependent variable: Average RUT			
Constant	0.135	13.960	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	0.012	2.590	0.001
Model Summary			
Number of Observations	37		
R-Squared	0.047		
Adjusted R-Squared	0.020		

Table 6.113 Seemingly Unrelated Regression Equation (USA contracts only): PBC

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	112.158	30.30	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-12.104	-1.710	0.088
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-27.110	-3.140	0.002
Model Summary			
Number of Observations	79		
R-Squared	0.162		
Adjusted R-Squared	0.140		
Dependent variable: Average PCR			
Constant	87.157	181.260	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	1.815	1.980	0.048
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	4.268	3.830	0.000
Asset type indicator (1 if Pavement repair, maintenance, and treatment, 0 otherwise)	0.812	2.53	0.012
Model Summary			
Number of Observations	79		
R-Squared	0.229		
Adjusted R-Squared	0.198		
Dependent variable: Average RUT			
Constant	0.161	21.340	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-0.024	-1.720	0.086
Standard deviation of Rutting depth (in inches)	0.089	2.190	0.029
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-0.046	-2.750	0.006
Model Summary			
Number of Observations	79		
R-Squared	0.169		
Adjusted R-Squared	0.136		

Table 6.114 Seemingly Unrelated Regression Equation (USA contracts): Traditional

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	105.902	35.100	0.000
Pavement Condition			
Standard deviation of IRI	0.124	2. 490	0.003
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-3.266	-2.990	0.003
Model Summary			
Number of Observations	198		
R-Squared	0.076		
Adjusted R-Squared	0.067		
Dependent variable: Average PCR			
Constant	88.359	220.490	0.000
Contract Characteristics			
Duration of contract (1 if less than 6 year, 0 otherwise)	0.507	2.800	0.005
Traffic Characteristics			
Natural logarithm of Average annual daily truck traffic (in 1000)	-0.113	-2.370	0.018
Pavement Condition			
Standard deviation of PCR	-0.056	-1.990	0.047
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	0.480	3. 870	0.000
Model Summary			
Number of Observations	198		
R-Squared	0.076		
Adjusted R-Squared	0.062		
Dependent variable: Average RUT			
Constant	0.157	31.780	0.000
Pavement Condition			
Drainage indicator variable (1 if somewhat poorly drained, 0 otherwise)	0.007	2.370	0.018
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-0.006	-3.260	0.001
Asset type indicator (1 if illumination repair, and maintenance or litter removal, or traffic signs and signals, 0 otherwise)	-0.011	-2.230	0.026
Model Summary			
Number of Observations	198		
R-Squared	0.047		
Adjusted R-Squared	0.032		

Table 6.115 Seemingly Unrelated Regression Equation (USA contracts): Warranties

Variables	**Coefficient**	***t*-stat**	***P*-Value**
Dependent variable: Average IRI			
Constant	127.615	20.180	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-25.645	-2.62	0.009
Standard deviation of IRI (1if less than 35, 0 otherwise)	-5.822	-1.810	0.070
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-16.290	-3.300	0.001
Model Summary			
Number of Observations	97		
R-Squared	0.196		
Adjusted R-Squared	0.170		
Dependent variable: Average PCR			
Constant	88.167	110.670	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	3.538	3.170	0.001
Standard deviation of PCR	-0.210	-3.800	0.000
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	1.975	3.510	0.000
Model Summary			
Number of Observations	97		
R-Squared	0.235		
Adjusted R-Squared	0.210		
Dependent variable: Average RUT			
Constant	0.182	14.860	0.000
Pavement Condition			
Drainage indicator variable (1 if well drained, 0 otherwise)	-0.054	-2.830	0.005
Standard deviation of rutting depth (1 if less than 0.07 inches, 0 otherwise)	0.012	1.910	0.056
Asset condition			
Number of assets indicator (1 if 1 per mile, 0 otherwise)	-0.029	-3.070	0.002
Model Summary			
Number of Observations	97		
R-Squared	0.122		
Adjusted R-Squared	0.093		

Table 6.116 Summary of Asset (Pavement) Condition Models

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Dependent variable: International Roughness Index (in./mi)									
State indicator (1 if Alaska, 0 otherwise) [DBOM]				↑					
Pavement Condition									
Drainage indicator variable (1 if well drained, 0 otherwise) [DBOM]				↑					
Drainage indicator variable (1 if well drained, 0 otherwise) [Full Model]	↓								
Drainage indicator variable (1 if well drained, 0 otherwise) [PBC]							↓		
Drainage indicator variable (1 if well drained, 0 otherwise) [USA Model]		↓							
Drainage indicator variable (1 if well drained, 0 otherwise) [Warranty]									↓
Standard deviation of IRI (1 if less than 35 inches per mile, 0 otherwise) [Warranty]									↓
Standard deviation of IRI [DBOM]									
Standard deviation of IRI [Full Model]	↑								
Standard deviation of IRI [Traditional]								↑	
Standard deviation of IRI [USA Model]		↑		↓					
Asset condition									
Asset type indicator (1 if pavement repair/ maintenance/rehabilitation/ treatment, 0 otherwise) [PBC]									
Number of assets per lane mile [Lane Rental]									
Number of assets per lane mile [PBC]							↓		
Number of assets per lane mile [Traditional]								↓	
Number of assets per lane mile [USA Model]		↓							
Number of assets per lane mile [Warranty]									↓
Traffic Characteristics									
1000th of Average AADT of Combination Trucks [Lane Rental]						↓			
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [A+B]			↓						
Truck indicator variable (1 if percentage of truck is greater than 15 %, 0 otherwise) [A+B]			↑						

Table 6.116 Summary of Asset (Pavement) Condition Models (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Dependent variable: Pavement Condition Rating (0-100 scale)									
Contract Characteristics									
Duration of the contract(1 if greater than 5 years, 0 otherwise) [Traditional]								↑	
Traffic Characteristics									
1000^{th} of Average AADT of Combination Trucks [I/D]					↓				
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [A+B]			↑						
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [DBOM]				↑					
Natural logarithm of Average annual daily truck traffic (in 1000) [Full Model]	↓								
Natural logarithm of Average annual daily truck traffic (in 1000) [Traditional]								↓	
Truck volume indicator variable (1 if truck volume is equal or greater than 500 and less than 1000, 0 otherwise) [Full Model]	↓								
Pavement Condition									
Drainage indicator variable (1 if well drained, 0 otherwise) [DBOM]				↑					
Drainage indicator variable (1 if well drained, 0 otherwise) [Full Model]	↑								
Drainage indicator variable (1 if well drained, 0 otherwise) [PBC]							↑		
Drainage indicator variable (1 if well drained, 0 otherwise) [USA Model]		↑							
Drainage indicator variable (1 if well drained, 0 otherwise) [Warranty]									↑
Standard deviation of PCR [A+B]			↓						
Standard deviation of PCR [DBOM]				↓					
Standard deviation of PCR [Traditional]								↓	
Standard deviation of PCR [USA Model]		↓							
Standard deviation of PCR [Warranty]									↓
Asset condition									
Asset type indicator (1 if pavement repair/ maintenance/ rehabilitation/ treatment, 0 otherwise) [PBC]							↑		
Number of assets per lane mile [Full Model]	↑								
Number of assets per lane mile [PBC]							↑		
Number of assets per lane mile [Traditional]								↑	
Number of assets per lane mile [USA Model]		↑							
Number of assets per lane mile [Warranty]									↑
Weather Condition									
Summation of proportion of rainy and snowy days [Full Model]	↓								

Table 6.116 Summary of Asset (Pavement) Condition Models (Continued)

Variables	Full Model	USA Model	A+B [USA]	DBOM [USA]	I/D [USA]	Lane Rental [USA]	PBC [USA]	Traditional [USA]	Warranty [USA]
Dependent variable: Rutting depth (inches)									
State indicator (1 if Minnesota, 0 otherwise) [DBOM]				↑					
Contract Characteristics									
Duration of the contract (1 if greater than 5 years, 0 otherwise) [DBOM]				↑					
Pavement Condition									
Drainage indicator variable (1 if somewhat poorly drained, 0 otherwise) [Traditional]								↑	
Drainage indicator variable (1 if well drained, 0 otherwise) [DBOM]				↓					
Drainage indicator variable (1 if well drained, 0 otherwise) [Full Model]	↓								
Drainage indicator variable (1 if well drained, 0 otherwise) [I/D]					↑				
Drainage indicator variable (1 if well drained, 0 otherwise) [Lane Rental]						↑			
Drainage indicator variable (1 if well drained, 0 otherwise) [PBC]							↓		
Drainage indicator variable (1 if well drained, 0 otherwise) [USA Model]		↓							
Drainage indicator variable (1 if well drained, 0 otherwise) [Warranty]									↓
Standard deviation of rutting depth (1 if greater than 0.09 inches, 0 otherwise) [Warranty]									↑
Standard deviation of Rutting depth (in inches) [PBC]							↑		
Standard deviation of Rutting depth [DBOM]									
Standard deviation of Rutting depth [DBOM]				↑					
Standard deviation of Rutting depth [Full Model]	↑								
Standard deviation of Rutting depth [USA Model]		↑							
Asset condition									
Asset type indicator (1 if pavement repair/ maintenance/rehabilitation/ treatment, 0 otherwise) [PBC]									
Number of assets per lane mile [Lane Rental]									
Number of assets per lane mile [PBC]							↓		
Number of assets per lane mile [Traditional]								↓	
Number of assets per lane mile [USA Model]		↓							
Number of assets per lane mile [Warranty]									↓
Traffic Characteristics									
Average Annual Daily Traffic (1 if greater than 16000 vehicle per day, 0 otherwise) [A+B]			↑						

6.8 Chapter Summary

This Chapter provided model estimation results. The next Chapter presents the PPP effectiveness evaluation procedure and the Excel-Based Expert system.

CHAPTER 7. PPP EFFECTIVENESS EVALUATION

7.1 Introduction

Following the identification of the factors affecting the MOEs (cost savings, cost overrun, time delay, change orders, accidents, operations, and asset condition) described above, the extent to which specific Agency goals are achieved for each PPP alternative is investigated. These goals include the identification of the PPP approach that generates the highest benefits for the Agency and the users. The most appropriate decision will be one that is associated with the highest possible level of effectiveness and the least possible cost to the Agency, user, or both. Application of the framework to specific commonly encountered scenarios yields a set of decision matrices from which a simple Excel-based electronic expert system is developed. The pairwise comparison method is used for generating this decision-making expert system.

7.2 Comparison Framework

Pairwise comparison, proposed by Marie Jean Antoine Nicolas de Caritat, is a method that considers head-to-head matches of all candidates to find the most successful one.

Analytical Hierarchy Process (AHP) is one of the popular ways for performing the pairwise comparison. Weights of the performance criteria are estimated by allowing decision makers to consider the objective and subjective factors in the evaluation of the relative importance of each criterion (Saaty, 1977). In this method, decision makers can input the weights based on their experience and knowledge. The following reciprocal matrix was used for pairwise comparisons between two performance measures:

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{1n} & \cdots & 1 \end{bmatrix} \quad (8.1)$$

where, each a_{ij} is the ratio of the weights of criteria i and j,

$$w_i/w_j = a_{ij} \qquad \text{for } i, j = 1,2,3, \ldots , n \quad (8.2)$$

where, n is the total number of performance criteria. And w_i , w_j are relative weights of the pair of performance criteria.

Next, the relative weights were calculated, using eigenvectors:

$$Aw = nw \quad (8.3)$$

where, w is the vector of weights known as eigenvector of matrix A. To avoid inconsistency, a triangular relationship was used:

$$a_{ij} = a_{ik} * a_{kj}, \text{for } i, j = 1,2, \ldots , n. \quad (8.4)$$

Therefore, equation 8.3 becomes:

$$Aw = \lambda w \quad (8.5)$$

where, λ is set of eigenvectors of matrix A. n can be calculated with estimated λs as follows:

$$\sum_{i=1}^{n} \lambda_i = n. \quad (8.6)$$

To find a unique set of weights, Equation 8.4 becomes:

$$Aw = \lambda_{Max} w \quad (8.7)$$

where, w is the eigenvector for corresponding λ_{Max}. To normalize the solution, w can be replaced with $\overline{w}$:

$$\overline{w} = \frac{1}{\alpha} w \qquad \text{where } a = \sum_{i=1}^{n} w_i. \quad (8.8)$$

To test the consistency of the results, the Consistency Index and Ratio were used. The Consistency index uses the deviation of λ_{Max} from n and is defined as:

$$CI = \frac{\lambda_{Max} - n}{n - 1} \quad (8.9)$$

The overall consistency of AHP was calculated with consistency ratio:

$$CR = \frac{CI}{RI} \quad (8.10)$$

where, RI is the random index derived from reciprocal matrices and its value can be derived from Table 8.1. To declare the winner alternative in the multi-criteria pairwise comparison, two sets of pairwise comparison should be conducted: (1) pairwise comparison among all criteria (MOEs); and (2) pairwise comparison among all alternative PPP contract types for each MOE. Note that this kind of comparison is feasible only when the number of alternatives is limited.

Table 7.1 Random Index Matrix

Order of Matrix (n)	Average Random Index
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

* Note that, for values larger than 10, the random index can be derived using extrapolation.

In order to establish relative weights for the set of the 13 MOEs (criteria) using AHP, the first step is to construct a comparison matrix, as shown in Table 8.2. The values for each pair of MOE give their relative importance.

Table 7.2 Random Index Matrix

	MOE_1	MOE_2	…	MOE_{13}
MOE_1	1	7	…	5
MOE_2	1/7	1	…	1/3
…	…	…	…	…
MOE_{13}	1/5	3	…	1

Next, the column entries corresponding to each MOE are summed and then each column entry is divided by the respective column sum, yielding the new matrix A_{norm} presented in Table 8.3.

Table 7.3 Reciprocal Matrix (Anorm)

	MOE_1	MOE_2	…	MOE_{13}
MOE_1	0.74	0.64	…	0.79
MOE_2	0.11	0.09	…	0.05
…	…	…	…	…
MOE_{13}	0.15	0.27	…	0.16

To obtain normalized relative weights corresponding to each MOE, the rows of A_{norm} are summed and averaged. Finally, the consistency ratio is determined as described previously.

The next step includes the determination of the pairwise comparison between each of the 7 PPP types with respect to each MOE. Table 8.4 presents a generalized example.

Table 7.4 Pairwise Comparison for the 7 PPP types with respect to each MOEi

MOE$_i$	PPP$_1$	PPP$_2$	…	PPP$_7$	Col. entries divided by corresponding col. sums				Row Sums	Normalized Weights
PPP$_1$	1	3	…	7	1/S$_1$	3/S$_2$	…	7/S$_3$	RS$_1$	NW$_1$
PPP$_2$	0.33	1	…	2	0.33/S$_1$	1/S$_2$	…	2/S$_3$	RS$_2$	NW$_2$
…	…	…	…	…	…	…	…	…	…	…
PPP$_7$	0.14	0.5	…	1	0.14/S$_1$	0.5/S$_2$	…	1/S$_3$	RS$_7$	NW$_7$
Col. Sum	S$_1$	S$_2$	…	S$_7$						

Multiplying the normalized weights for each PPP type and each MOE, a ranking of the PPP types gives the best PPP option (Table 8.5).

Table 7.5 Selection of the most effective PPP type

	Normalized Weights			
	MOE$_1$	MOE$_2$	…	MOE$_{13}$
PPP$_1$	NW$_{1-1}$	NW$_{2-1}$	…	NW$_{13-1}$
PPP$_2$	NW$_{1-2}$	NW$_{2-2}$	...	NW$_{13-2}$
…	…	…	…	…
PPP$_7$	NW$_{1-7}$	NW$_{2-7}$	…	NW$_{13-7}$

MOE	Weights
MOE$_1$	W$_{MOE1}$
MOE$_2$	W$_{MOE2}$
…	…
MOE$_{13}$	W$_{MOE13}$

PPP	Final Weight*
PPP$_1$	FW$_1$
PPP$_2$	FW$_2$
…	…
PPP$_7$	FW$_7$

* $FW_1 = (NW_{1-1} \times W_{MOE1}) + (NW_{2-1} \times W_{MOE2}) + \ldots + (NW_{13-1} \times W_{MOE13})$

The PPP type with the highest final weight is the most effective.

Based on the statistical modeling results presented in Chapter 7, and the pairwise comparison and AHP presented in the current Chapter, an Excel-based application is developed, consisting of the following elements:

(a) A set of input values (reflecting the effect of the statistically significant parameters in Tables 6.1 through 6.116 in Chapter 6) inserted by the user. Table 7.6 presents the Input field in the Excel-based application

(b) The statistical model estimation results presented in Tables 6.1 through 6.116 in Chapter 6.

(c) The pairwise comparison and analytical hierarchy process matrices. These matrices are running in the background and are invisible to the user, except the original reciprocal matrix (A), shown in Table 7.6.

(d) The resulting predicted values of the MOEs for each PPP type using the input values (a) and the statistical model estimation results (b). Table 7.8 presents the MOE results field in the Excel-based application.

(e) An output field is identifying which PPP type is the most effective, as a result of the pairwise comparison and analytical hierarchy process. Table 7.8 presents the Output field in the Excel-based application.

Table 7.6 Input Field in the Excel-based Application

Input Values of the Excel-Based Expert System		
	Insert Values Here	
Spatial Information		
State indicator (1 if Minnesota, 0 otherwise)	0	0 or 1
State indicator (1 if Virginia, 0 otherwise)	1	0 or 1
State indicator (1 if Indiana, 0 otherwise)	0	0 or 1
State indicator (1 if Texas, 0 otherwise)	0	0 or 1
State indicator (1 if Alaska, 0 otherwise)	0	0 or 1
Contract Characteristics		
Contract Duration	6	years
Size of contract	8.7	Lane-Miles
Number of Asset Types	2	No.
Cost of Contract	52,718,000.00	USD
Activities		
Bridge-Tunnel Repair/Maintenance/Management	1	0 or 1
Crack/Pothole Sealing/Repair	0	0 or 1
Culvert/Ditches/Gutters/Drainage Repair/Maintenance/Replacement	0	0 or 1
Emergency Facilities Maintenance/Response	0	0 or 1
Management	0	0 or 1
General Maintenance/Repair/Rehabilitation/Treatment	0	0 or 1
Guardrail Repair/Maintenance	0	0 or 1
Illumination Repair/Maintenance	0	0 or 1
Landscape Repair/Maintenance	0	0 or 1
Litter Removal	0	0 or 1
Electrical/Cable system Repair/Maintenance	0	0 or 1
Mowing	0	0 or 1
Pavement Repair/Maintenance/Treatment	1	0 or 1
Rest Areas	0	0 or 1
Shoulder Repair/Maintenance	0	0 or 1

Table 7.6 Sample input values of the Excel-based expert system (Continued)

Activities		
Traffic Signs and Signals	0	0 or 1
Vegetation/Tree Control/Maintenance/Removal	0	0 or 1
Other	0	0 or 1
All services	0	0 or 1
Accident/Operation Specific Information (before/during/after construction/ Preservation)		
Average Annual Daily Traffic, AADT	2570	vehicle/day
Truck Percentage	0.204	0.XX
Median Width	68	feet
Inside Shoulder Width	13.1	feet
Outside Shoulder Width	8.2	feet
Relation to Junction (0: No junction, 1: Intersection, 2: intersection (with interchange))	2	0,1, or 2
Traffic way Flow (0: No median, 1:Median (no barrier), 2: Median (barrier))	2	0,1, or 2
Drainage System	5	
Highway Indicator (1 if highway, 0 otherwise)	1	0 or 1
Number of Lanes	2	No.
Presence of Horizontal Curve (1 if exist, 0otherwise)	0	0 or 1
Number of Horizontal Curves per segment (1 if higher than 5, 0 otherwise)	0	0 or 1
Presence of Vertical Curve (1 if exist, 0 otherwise)	1	0 or 1
Number of Vertical Curves per segment (1 if higher than 5, 0 otherwise)	0	0 or 1
Functional Class of Road (0:Rural, 1:Urban)	1	0 or 1
Asset Condition Specific Information (before/during/after construction/ Preservation)		
Average of International Roughness Index	166	in/mi
Standard Deviation of International Roughness Index	12.442	in/mi
Average of Pavement Condition Rating (in scale 0-100)	79.77	
Standard Deviation of Pavement Condition Rating (in scale 0-100)	15.317	
Average of Rutting Depth	0.308	inches
Standard Deviation of Rutting Depth	0.049	inches

Table 7.7 Original Reciprocal Matrix A Field in the Excel-based Application

Input weights	Predicted Likelihood of Cost Saving
Predicted Likelihood of Cost Saving	1
Predicted percent of Cost Saving	0.5
Predicted Likelihood of Cost Overrun	2
Predicted percent of Cost Overrun	2
Predicted Likelihood of Time Delay	3
Predicted Time Delay	3
Predicted Likelihood of Change Orders	0.2
Predicted Number of Change Orders	0.4
Predicted Accident frequency	0.3
Predicted Operational Condition	4
Predicted Asset Condition (Ave. IRI)	0.5
Predicted Asset Condition (Ave. PCR)	0.5
Predicted Asset Condition (Ave. rutting Depth)	0.5

Table 7.8 MOE Results Field in the Excel-Based Application

Output Values of the Excel-Based expert system							
	A+B	DBOM	I/D	Lane Rentals	PBC	Traditional	War
Predicted Likelihood of Cost Saving	0.963	1.000	0.889	1.000	0.480	0.290	0.011
Predicted percent of Cost Saving	1.498	1.411	17.842	8.779	9.851	0.753	3.437
Predicted Likelihood of Cost Overrun	0.207	0.409	1.000	0.626	0.000	0.953	1.000
Predicted percent of Cost Overrun	-0.087	-2.663	-16.353	9.280	-5.418	25.620	28.412
Predicted Likelihood of Time Delay	0.286	1.000	0.876	1.000	0.632	0.899	1.000
Predicted Time Delay (years)	1.000	2.923	1.000	0.688	0.589	0.372	3.143
Predicted Likelihood of Change Orders	0.828	1.000	0.060	0.979	0.534	1.000	0.909
Predicted Number of Change Orders	0.907	2.121	1.452	5.018	2.275	6.373	7.106
Predicted Accident frequency	8.455	0.001	0.089	0.001	0.002	0.000	0.001
Predicted Operational Condition	3.000	4.000	4.000	3.000	4.000	1.000	2.000
Predicted Asset Condition (Average IRI)	126.559	93.341	101.708	54.832	66.373	101.530	60
Predicted Asset Condition (Average PCR)	87.281	89.432	89.756	96.403	94.956	88.847	96.732
Predicted Asset Condition (Average Rutting Depth)	0.174	0.137	0.147	0.063	0.075	0.146	0.055

Best Contract Type for the defined Project	PBC

Figure 7.1 presents a flowchart of the Excel-based application's structure. The application uses the information inserted by the user, including characteristics of the project, contract, roadway segment, etc. (see Table 7.6). The values are directly linked to the inherent statistical models (Tables 6.1 through 6.116 in Chapter 6), where the inserted values are multiplied by their corresponding coefficients. For each MOE, the functional forms presented in Chapter 5 are used to estimate the predicted MOE values. The predicted MOE values (Table 7.8) are used in conjunction with the weights (Table 7.7) and linked in the inherent pairwise comparison and AHP matrices (Equations 7.1 through 7.10, and Tables 7.1 through 7.8). The process yields the most efficient PPP type (Output; see Table 7.8) given the Input (Table 7.6) information provided by the user.

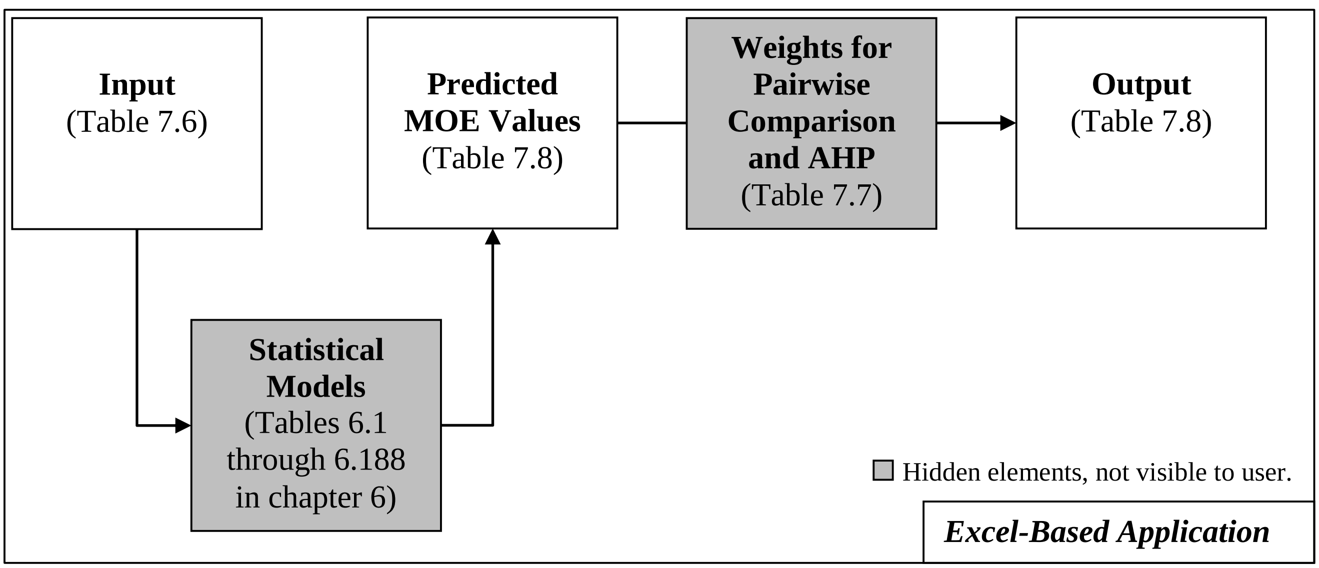

Figure 7.1 - Excel-Based Application Structure

7.3 Evaluation Results

To evaluate the Excel-based decision making system, several (three) random contracts from each PPP type were selected and used as input. The Excel-based application provided values for the measures of effectiveness by PPP contract type, which were then compared with the originally observed MOE values.

For example, the Excel-based application proposes the use of incentives/disincentives and Warranty for two of the contracts that were originally let by cost-plus-time contracting; the application also supports the use of cost-plus-time contracting for the third contract. By selecting the proposed contract types, the following benefits are anticipated: increase in cost savings by 8 percent; reduction in cost overrun by 2 percent; time delay reduction by 0.1 years; change orders reduction; overall pavement condition improvement (the average IRI, PCR, and rutting depth are improved by 36 in/mi, 3.5 percent, and 0.9 inches, respectively); LOS improvement (from D to A); and significant reduction in accident frequencies (from 61 accidents to 9).

The expert system proposes the use of cost-plus-time and incentives/disincentives when the random selected design-build project information is inserted. By selecting the proposed contract types, the following benefits are anticipated: 1.5 to 17 percent cost savings increase; 0.31 percent cost overrun reduction; LOS improvement (from D to B, and from E to D); 1.5 to 2 years of time delay reduction; and change orders reduction from 4 to 0.

For two of the incentives/disincentives contracts, the expert system supports the use of this contracting approach. For the third one, which involves pavement preservation activities, the system proposes the use of a warranty contract, and yields the following anticipated benefits: 1.15 percent cost savings increase; LOS improvement from D to B; and cost overrun reduction by 4 percent.

For two of the lane rental contracts, the expert system supports the use of this contracting approach. For the third one, the system proposes the use of incentives/disincentives, and yields the following anticipated benefits: 9 percent cost savings increase; 31 percent cost overrun reduction; 1 year time delay reduction; significant improvement in the overall pavement condition; reduction in the number of change orders (by 4); and reduction in the number of accidents (by 4).

For two of the PBC contracts, the expert system supports the use of this contracting approach. For the third one, the system proposes the use of the design-build contract, and yields the following anticipated benefits: reduction in the number of change orders (from 11 to 3); reduction in the number of accidents (from 32 to 8); and significant improvement of the overall pavement condition.

For the traditional contracts, the expert system proposes the use of PBC and lane rentals. By selecting the proposed contract types, the following benefits are anticipated: 14 to 22 percent cost savings increase; 2 to 30 percent cost overrun reduction; 5 months to 2 years reduction in time delay; reduction in the number of change orders (by 4); reduction in the number of accidents (by 1, and from 43 to 1); and significant improvement of the overall pavement condition.

For the warranty contracts, the expert system proposes the use of PBC and lane rentals. By selecting the proposed contract types, the following benefits are anticipated: 4 to 40 percent cost savings increase; 5 to 35 percent cost overrun reduction; 2 years reduction in time delay; reduction in the number of change orders (from 5 to 4); reduction in the number of accidents (from 57 to 39); LOS improvement (from E to C).

Table 7.9 Summary of the Excel-Based Expert system results

Original Contracting Approach	Proposed Contracting Approach	Cost Savings Percentage	Cost Overrun Percentage	Time Delays duration	Change Orders Frequency	Accident Analysis	Operation Analysis	Asset (Pavement) Condition
A+B	I/D	↑	↑	↓	↑	↑	↓	↑
	Warranty	↓	↓	↑	↑	↓	↑	↑
	A+B	-	-	-	-	-	-	-
DBOM	A+B	↑	↓	↓	↓	↑	↑	↓
	I/D	↑	↓	↓	↓	↑	↑	↓
	I/D	↑	↑	↓	↓	↑	↑	↓
I/D	I/D	-	-	-	-	-	-	-
	I/D	-	-	-	-	-	-	-
	Warranty	↑	↓	↑	↑	-	↑	↑
Lane Rentals	Lane Rentals	-	-	-	-	-	-	-
	Lane Rentals	-	-	-	-	-	-	-
	I/D	↑	↓	↓	↓	↓	-	↑
PBC	PBC	-	-	-	-	-	-	-
	PBC	-	-	-	-	-	-	-
	DBOM	↓	↑	↑	↓	↓	↓	↑
Traditional	PBC	↑	↓	↓	↓	↓	↓	↑
	Lane Rentals	↑	↑	↓	-	↓	-	↑
	Lane Rentals	↑	↓	↓	↑	-	↓	↑
Warranty	Lane Rentals	↑	↓	↓	↑	-	↓	↓
	PBC	↑	↓	↓	↓	↓	↑	↓
	PBC	↑	↓	↑	↓	-	-	↓

7.4 Chapter Summary

This Chapter presented an evaluation of the effectiveness of the various PPP contracting types. Using the model estimation results of the statistical models presented in the Chapter 6, and pairwise comparison and analytical hierarchy process (presented in the current Chapter), an Excel-based application expert system was developed, and its applicability was demonstrated using several contracts from the existing database. The results reveal that significant improvements can be accomplished in terms of cost savings, cost overrun, time delay, change orders, operations, safety, and pavement condition, when an optimal PPP contracting approach is selected.

CHAPTER 8. CONCLUSION

8.1 Introduction

At the current time, most Agencies do not have a set of straightforward guidelines by which they can decide whether to adopt PPP for a given project, and if to adopt one, which type of PPP should be adopted. Before such a decision can be made in an informed manner, the Agency needs to develop and implement a PPP evaluation and decision-support framework that will incorporate the PPP costs and benefits for the different types of highway construction, preservation, or operation.

In this study, statistical models were developed for various measures of effectiveness (cost saving, cost overrun, time delays, change orders, asset management, safety, and operations) by PPP contract types. These models provided an appropriate context for developing an Excel-based expert system. This expert system can be useful for Agencies to select the most beneficial contracting approach for a certain transportation project.

8.2 Contributions

The primary objective of this study was to identify the best possible contract type and contractual conditions for transportation projects. The results support the initial hypothesis that, in cases of tight schedules and complicated designs, PPP contracting has advantages over traditional contracting approaches. The estimated statistical models investigated the relative costs and benefits of PPP and Non-PPP contracts, such as:

- Project cost savings, mitigation of cost overrun, time delay, and change orders;
- Improvements in asset condition, safety, and operations during and after construction and preservation; and
- Improved quality and system performance as a by-product of the adopted optimal PPP approach from the use of innovative materials and management techniques.

This study is of interest to public and private agencies who are concerned with allocating the most appropriate contract type to various transportation projects. The contribution of this study is summarized as follows:

- Providing a set of straightforward guidelines by which agencies can decide whether to adopt PPP for a given project, and if to adopt one, which type of PPP should be adopted.
- To the authors' knowledge, this is a first study that investigates the influence of contract characteristics on various measures of effectiveness by PPP contract type.
- This study also accounts for unobserved heterogeneity, by allowing the parameter effects to vary across the observations, using random parameters statistical modeling.

8.3 Discussion of Research Results and Lessons Learned

Statistical models were developed to investigate the effect of each measure of effectiveness on each PPP contracting approach. Using the model estimation results, the pairwise comparison and the analytical hierarchy process, the most appropriate PPP approach to the transportation project was identified. The most significant findings, which are derived from this study, can be summarized as follows:

- Duration (in years) is one of the contract characteristics that significantly influenced the expert system's outcome. Increasing the duration of the project can result in cost savings reduction (both amount and likelihood). The results also show that longer durations result in a cost overrun and time delay increase. Also, projects with many change orders have longer durations. Projects with shorter durations result in improved safety conditions (in terms of reduction in the number of accidents).
- The size of the project (in terms of lane-miles) is another contract characteristic that influences this study's measures of effectiveness. In most of the PPP contracting approaches (cost-plus-time, design-build and its derivatives, PBC, and incentives/disincentives), long contracts result in cost savings reduction, and cost overrun and time delay increase. On the contrary, contracts with smaller size experience safety improvements (in terms of reduction in the number of accidents).
- If more assets are included in a contract, a cost savings reduction is anticipated, and a subsequent cost overrun and time delay increase.

- The activity types included in the contract have various effects on the MOEs under different PPP types. For example, for activities such as guardrail, shoulder repair and maintenance, traffic signs and signals, electrical and cable repair and maintenance, lane rentals is the most appropriate contract type – in terms of improvements in most MOEs. For crack and pothole sealing, and pavement repair and maintenance, warranties is the most beneficial contract type – in terms of improvements in the cost related MOEs (primarily). For projects with many and variable activities such as management, or bridge repair and maintenance, performance-based contracting is the most appropriate contract type – in terms of improvements in most MOEs.
- Roadway safety (accident frequencies) is found to be affected by a number of factors by PPP type, such as roadway geometrics (shoulder width, median presence, number of horizontal and vertical curves), pavement condition (IRI, PCR and rutting depth), and traffic characteristics (AADT and truck percentage).
- The level of service is found to be affected by road geometrics, traffic characteristics, activity types, and some of the project characteristics, such as the duration and size of the project. The findings support the fact that good roadway geometry and pavement condition generally improve the level of service.
- Asset (pavement) condition is found to be affected by a number of factors, such as drainage system performance, AADT, pavement condition (IRI, PCR, and rutting depth), and activity types (mostly related to the pavement condition

improvement, such as crack and pothole sealing and repair or pavement repair, maintenance and treatment).

8.4 Limitations

The data used for this study contained various PPP approaches; however, some of them, such as cost-plus-time, incentives/disincentives and lane rentals, had fewer observations across the USA (about 40 contracts). This inevitably may influence the performance and results of the estimated models for these contract types.

An analysis was also conducted using very limited data from the State of New York. The data included pavement condition, traffic volumes, and cost information for several roadway segments in the state. The limited amount of information did not allow for a rigorous comparison of the NY data with the available data from other USA states. To that end, a series of t-tests were conducted, to investigate whether the data that were both available in the used database and the collected NY data had similarities, in terms of averages and standard deviations. The results were inconclusive, which warrants further investigation through the collection of similar parameters as identified and used in the presented study.

8.5 Directions for Future Research

Based on the findings of this study, a possible direction for future work is as follows:

- Cost and time/schedule discrepancies (e.g., cost overrun, time delay, etc.) in roadway construction, maintenance, rehabilitation and preservation, are typically caused by change orders. However, there are frequent cases where these discrepancies occur due to factors that fall outside what defines a change order, such as weather conditions, work site accidents, traffic disruptions, and so on. Such discrepancies are frequently found in the literature to be incorporated as part of a change order. To that end, it is assumed that the same factors that cause cost and time/schedule discrepancies due to change orders, coincide with the factors that cause cost and time/schedule discrepancies due to other causes (no-change-order related). The problem becomes more complex when the mechanisms of different PPP contracting approaches are considered. It is, therefore, of great value to investigate change-order and no-change order related cost and time/schedule discrepancies by PPP type, in order to complement the decision support framework of this study with decisions regarding the origin of the discrepancies. This is anticipated to enhance the developed PPP evaluation and decision support framework, in order for roadway agencies to use it and more accurately decide whether to adopt a PPP for a given project, and if affirmative, what type of PPP to adopt, such that there is maximum benefit to the agency.
- A second extension involves the investigation of the performance and effectiveness of PPP pavement rehabilitation treatments, in terms of extending the pavement life. This would involve the development of a decision making tool that could possibly save for the Agency millions of tax payers' money, by

offering a selection of PPP pavement rehabilitation treatment options that would last the longest given funding limitations.

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APPENDIX

Appendix A Expert System Comparison Results

Measures of effectiveness	A+B			
	Actual	Predicted	Actual	Predicted
% of Cost Saving	9%	17.86%	9%	2.30%
% of Cost Overrun	-13%	-0.72%	-42%	-44.18
Time Delay (years)	0.5	0.4	-0.62	0.64
Number of Change Orders	0	1.45	0	2.307
Accident frequency	1	3.82	61	8.624
Operational Condition	4	5	4	1
Asset Condition (Average IRI)	93	87.57	136.5	101.813
Asset Condition (Average PCR)	90	90.76	86.19	89.444
Asset Condition (Average Rutting Depth)	0.115	0.12	0.21	0.128
Proposed Contract Type	I/D		Warranties	

Measures of effectiveness	DBOM					
	Actual	Predicted	Actual	Predicted	Actual	Predicted
% of Cost Saving	0%	1.50%	0%	17.86%	2%	17.86%
% of Cost Overrun	10%	-0.31%	-11%	-2.09%	-2%	-16.23%
Time Delay (years)	2.2	1	2.5	1	3	1
Number of Change Orders	4	0.31	5	1.45	7	1.46
Accident frequency	0	4.33	0	0.28	0	0.03
Operational Condition	4	2	5	4	5	4
Asset Condition (Average IRI)	54.66	89.17	89.89	99.01	45.167	101.39
Asset Condition (Average PCR)	97.16	91.14	91.75	89.76	99.5	89.76
Asset Condition (Average Rutting Depth)	0.06	0.11	0.11	0.15	0.04	0.15
Proposed Contract Type	A+B		I/D		I/D	

Measures of effectiveness	I/D	
	Actual	Predicted
% of Cost Saving	12%	13.136
% of Cost Overrun	23%	18.067
Time Delay (years)	-0.7	0.249
Number of Change Orders	2	4.899
Accident frequency	0	0.391
Operational Condition	4	2
Asset Condition (Average IRI)	98.5	95.991
Asset Condition (Average PCR)	88.6	90.868
Asset Condition (Average Rutting Depth)	0.14	0.128
Proposed Contract Type	Warranties	

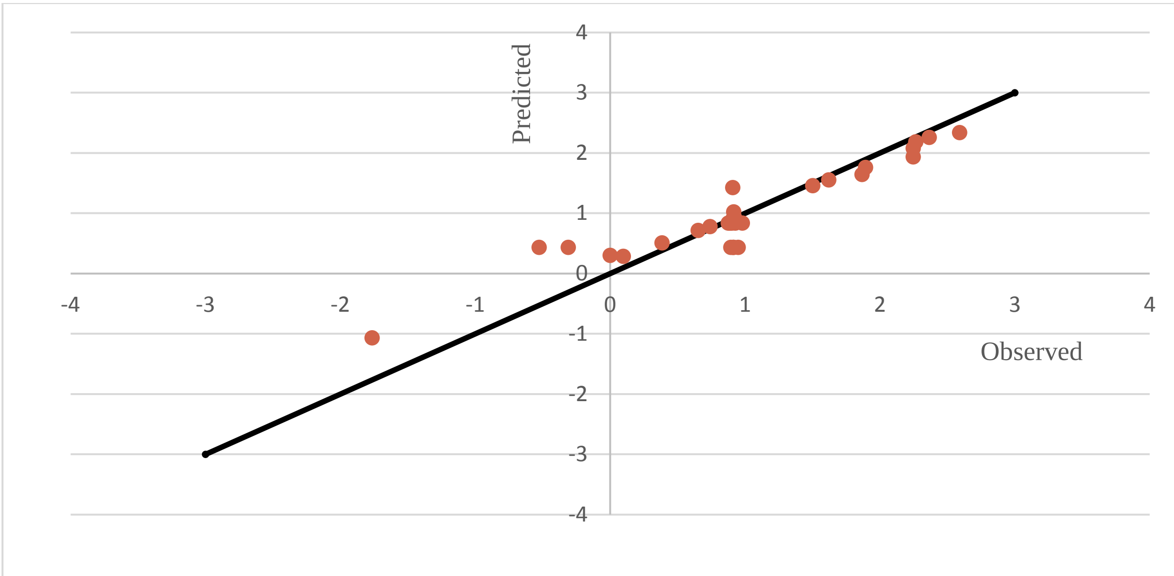
Measures of effectiveness	Lane Rentals	
	Actual	Predicted
% of Cost Saving	8%	17.865
% of Cost Overrun	40%	8.263
Time Delay (years)	1.2	0.125
Number of Change Orders	4	1.452
Accident frequency	6	0.491
Operational Condition	4	4
Asset Condition (Average IRI)	111.67	102.166
Asset Condition (Average PCR)	86.87	89.201
Asset Condition (Average Rutting Depth)	0.15	0.147
Proposed Contract Type	I/D	

Measures of effectiveness	PBC	
	Actual	Predicted
% of Cost Saving	4%	-24.21%
% of Cost Overrun	35%	41.75%
Time Delay (years)	2.4	4.18
Number of Change Orders	11	2.46
Accident frequency	32	8.47
Operational Condition	2	1
Asset Condition (Average IRI)	151.5	113.92
Asset Condition (Average PCR)	82.74	86.69
Asset Condition (Average Rutting Depth)	0.243	0.17
Proposed Contract Type	DBOM	

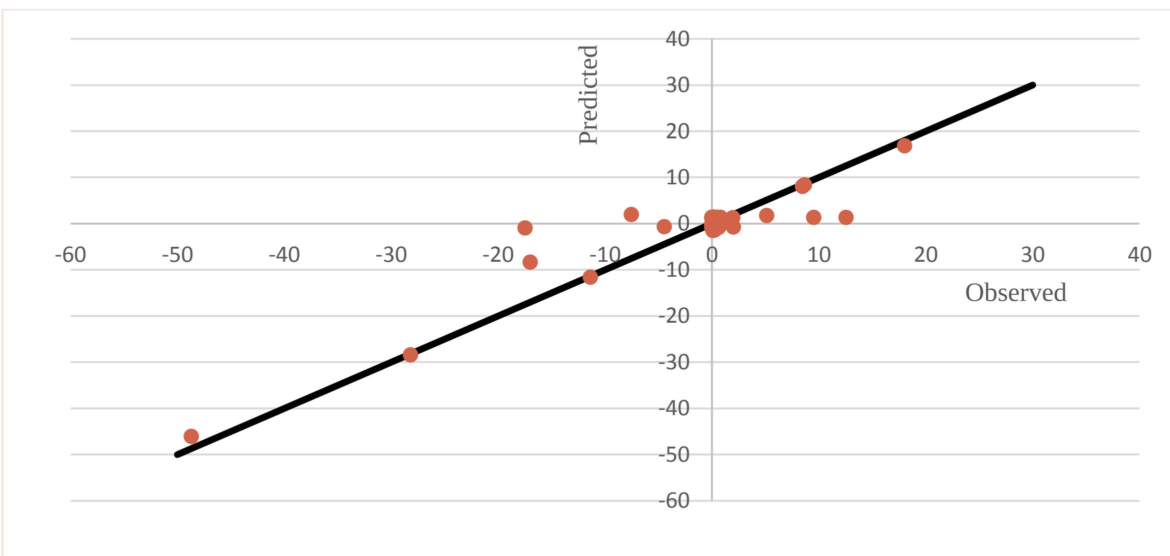
Measures of effectiveness	Traditional					
	Actual	Predicted	Actual	Predicted	Actual	Predicted
% of Cost Saving	0%	14.561	-1.54%	35.38%	0%	13.10%
% of Cost Overrun	-5%	-3.646	-4%	7.99%	40%	9.28
Time Delay (years)	2.435	0.632	3	0.68	1	0.674
Number of Change Orders	9	4.721	5	5.018	2	5.018
Accident frequency	7	6.35	43	0.965	0	0
Operational Condition	1	3	5	5	0	2
Asset Condition (Average IRI)	144.667	100.054	109.167	121.978	61.17	43.58
Asset Condition (Average PCR)	82	89.784	87	87.013	94.4	99.7
Asset Condition (Average Rutting Depth)	0.258	0.145	0.15	0.182	0.07	0.031
Proposed Contract Type	PBC		Lane Rentals		Lane Rentals	

Measures of effectiveness	Warranties					
	Actual	Predicted	Actual	Predicted	Actual	Predicted
% of Cost Saving	-4.2%	39.69%	0.00%	14.561	6%	9.851
% of Cost Overrun	46.7%	11.80%	19%	-4.036	0%	-5.418
Time Delay (years)	0.36	0.295	3	0.666	0.5	0.589
Number of Change Orders	0	1.318	10	4.721	6	2.275
Accident frequency	0	0	57	39.338	0	0.002
Operational Condition	1	2	5	3	4	4
Asset Condition (Average IRI)	59	108.172	166	112.158	47	60
Asset Condition (Average PCR)	96.94	88.114	79.77	87.969	99	96.732
Asset Condition (Average Rutting Depth)	0.07	0.148	0.308	0.165	0.05	0.055
Proposed Contract Type	Lane Rentals		PBC		PBC	

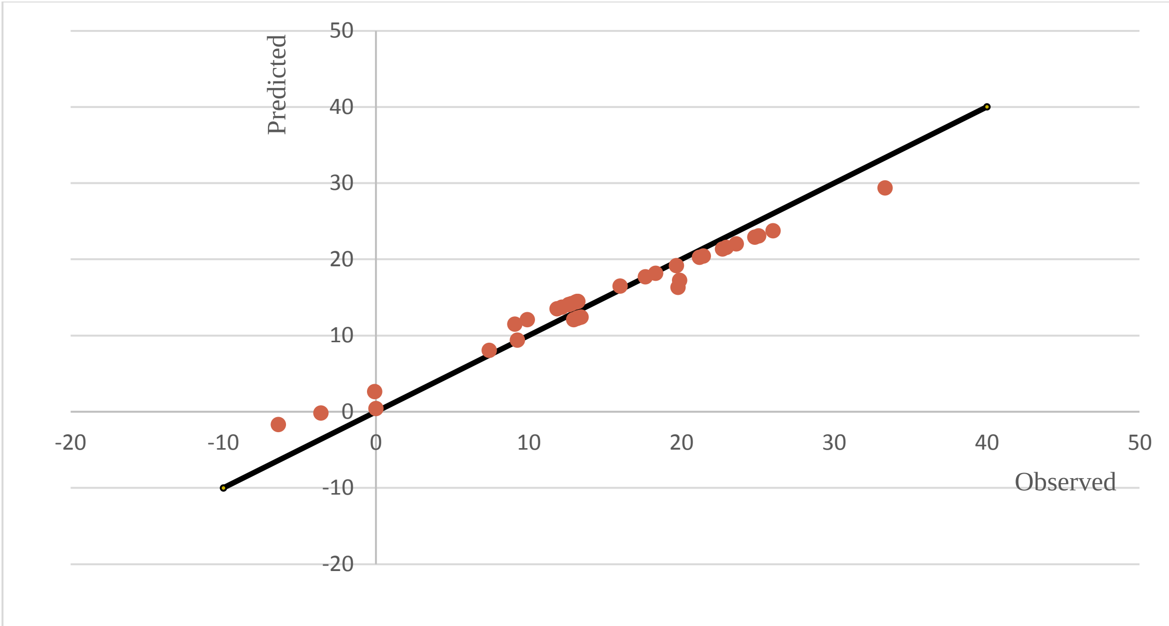
Appendix B Observed vs. Predicted Values



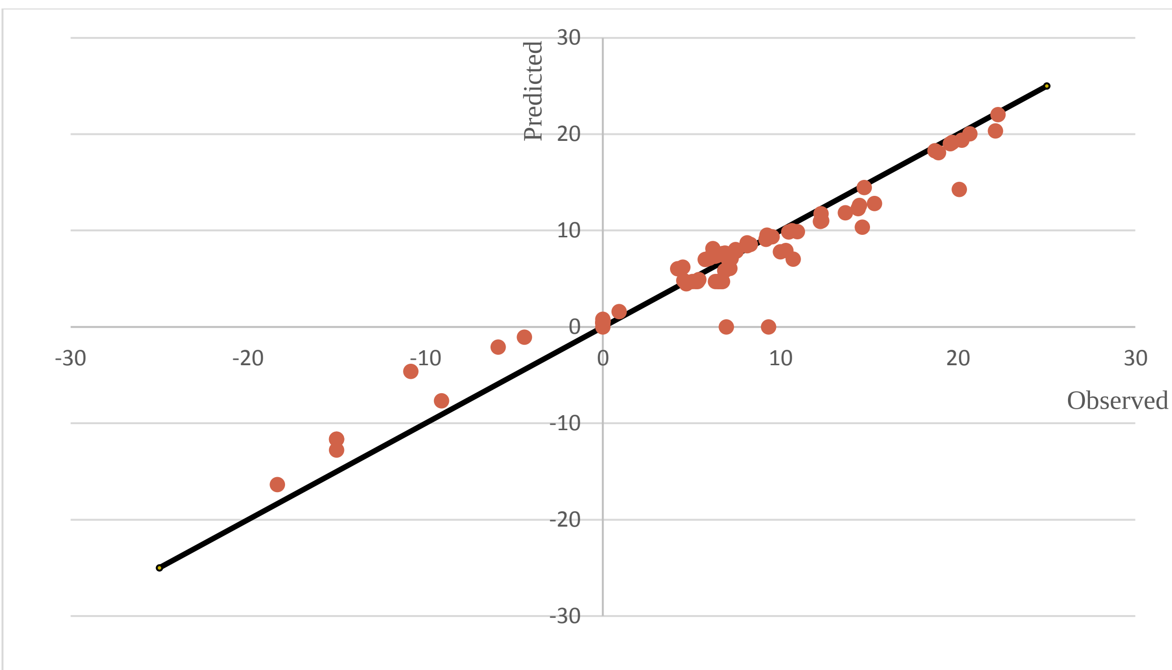
Cost savings models (Linear Regression) for USA contracts: A+B



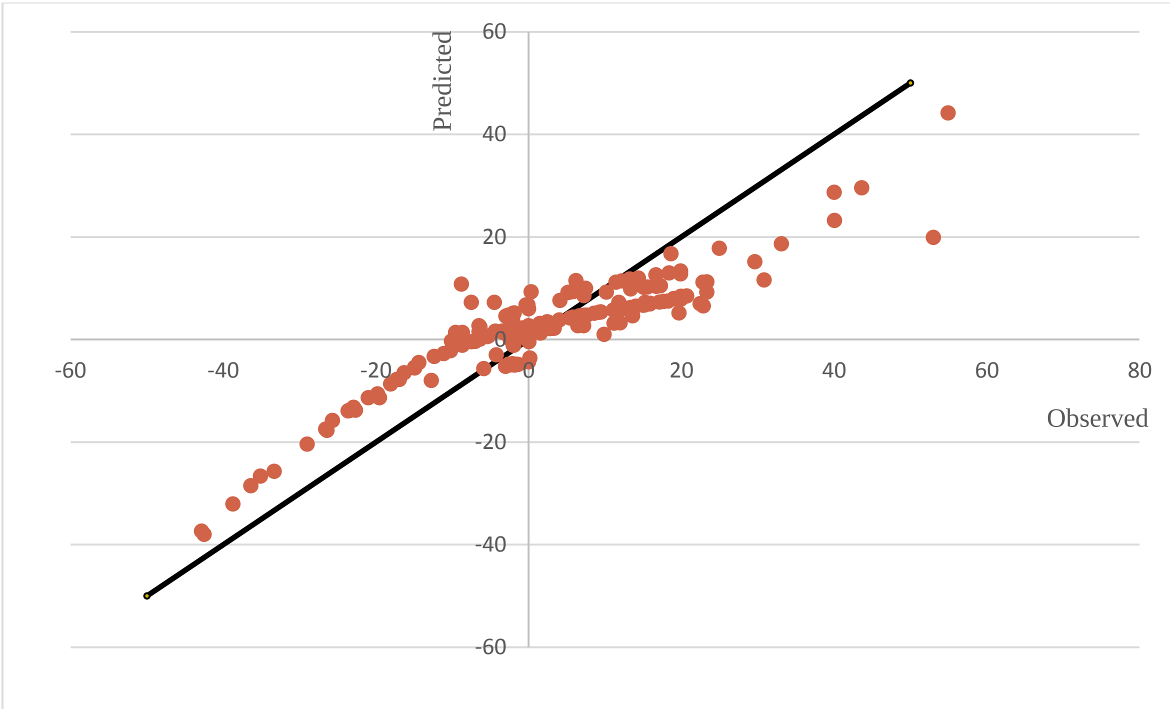
Cost savings models (Linear Regression) for USA contracts: DBOM



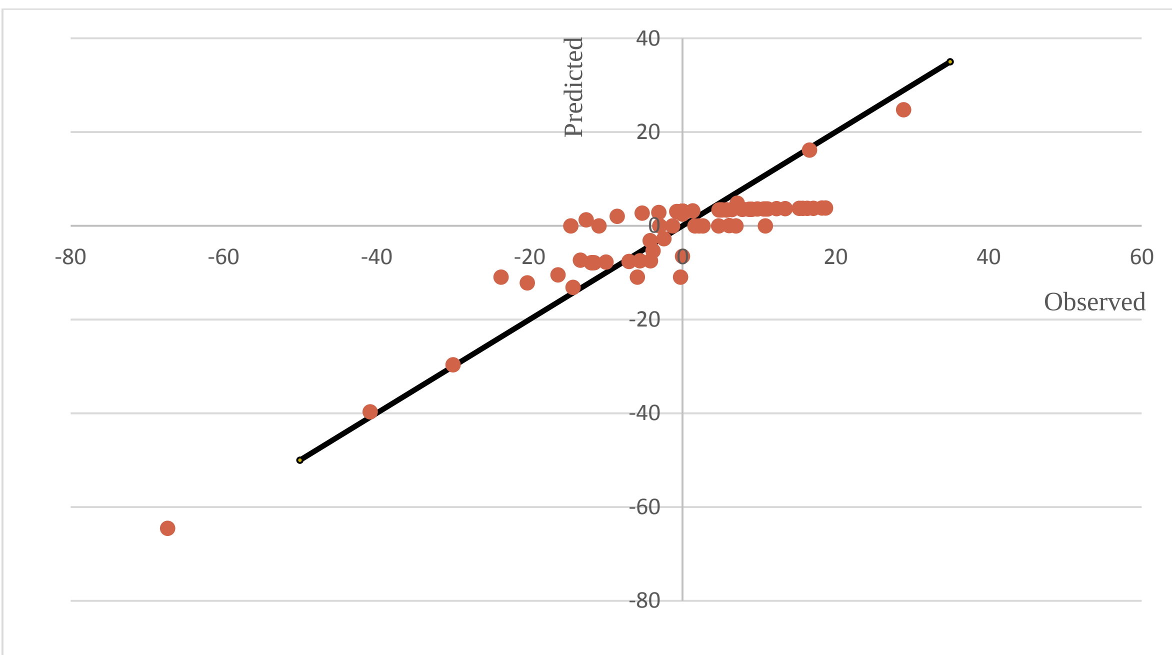
Cost savings models (Linear Regression) for USA contracts: I/D



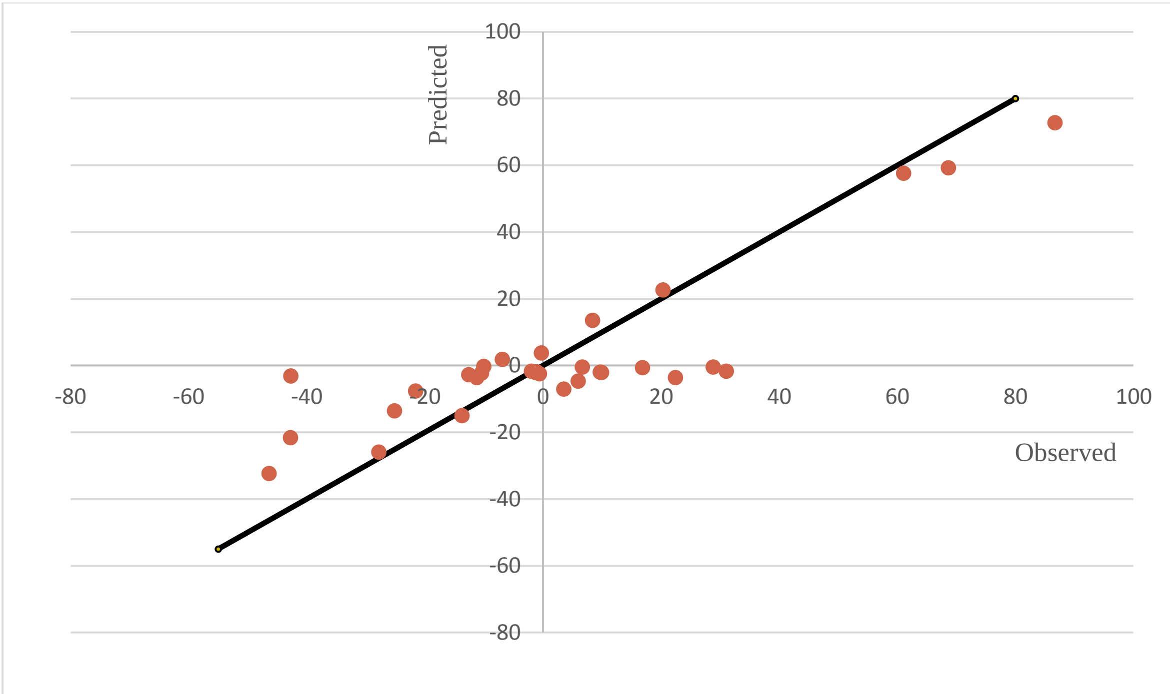
Cost savings models (Linear Regression) for USA contracts: PBC



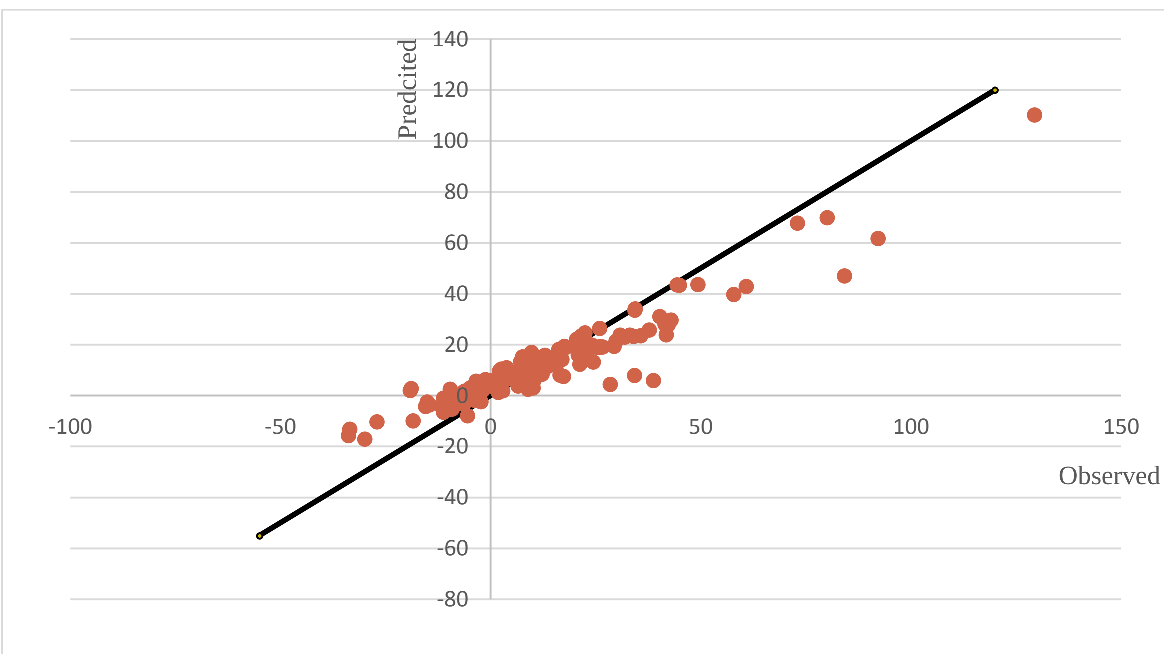
Cost savings models (Linear Regression) for USA contracts: Traditional



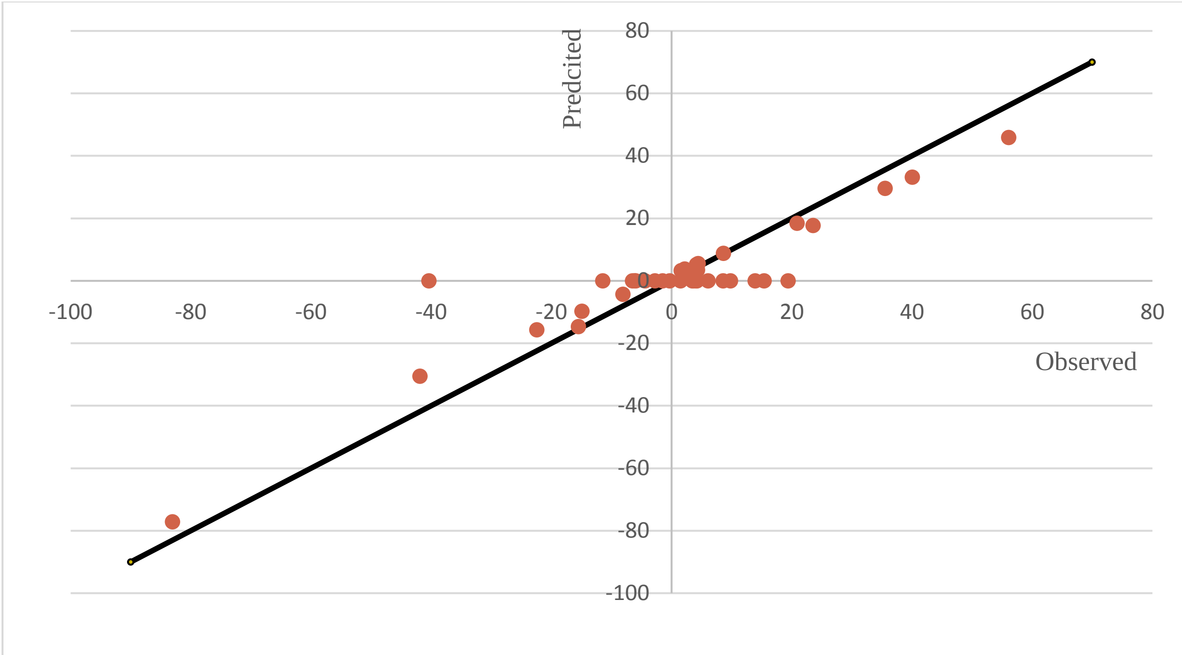
Cost savings models (Linear Regression) for USA contracts: Warranties



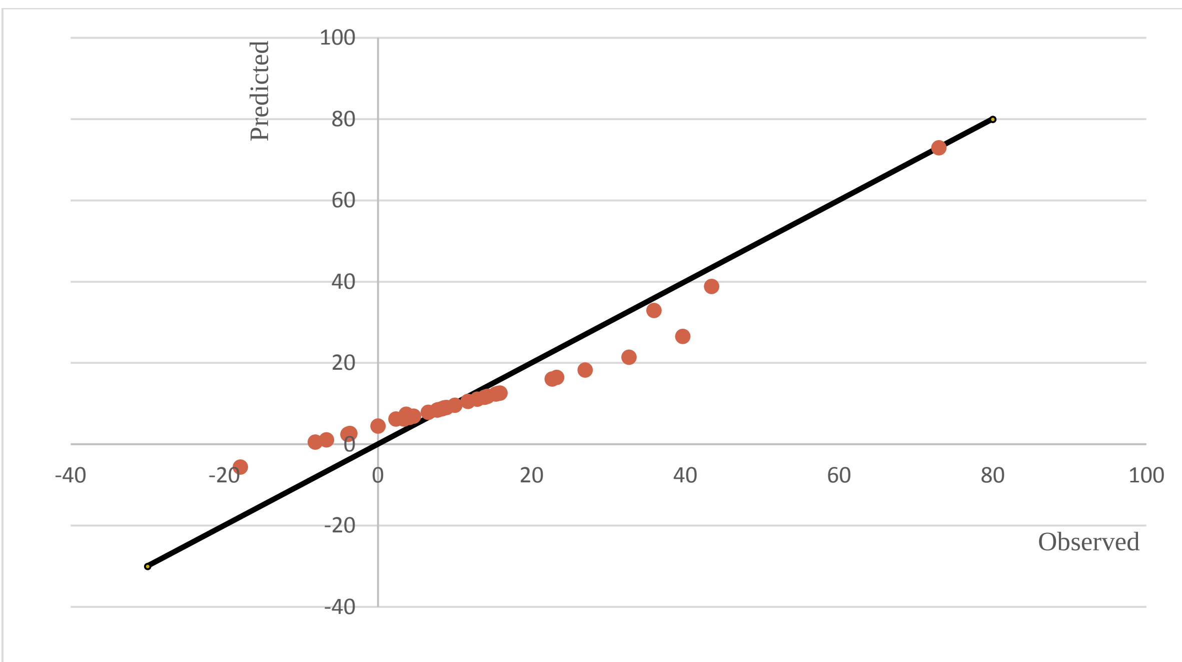
Cost overrun models (Linear Regression) for USA contracts: A+B



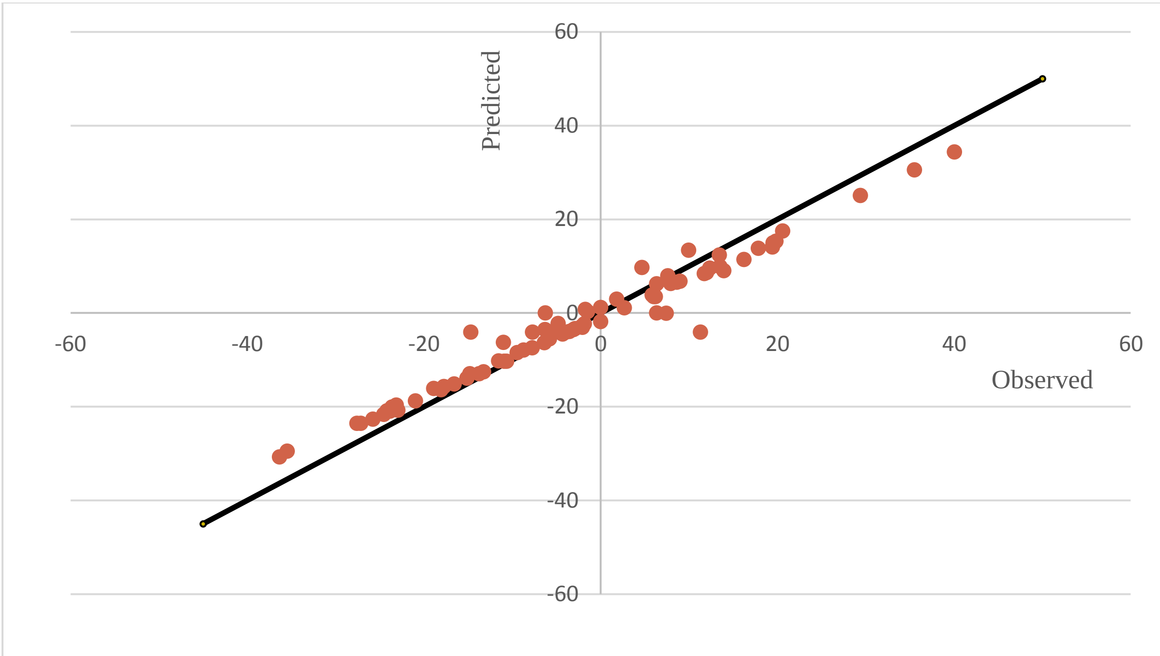
Cost overrun models (Linear Regression) for USA contracts: DBOM



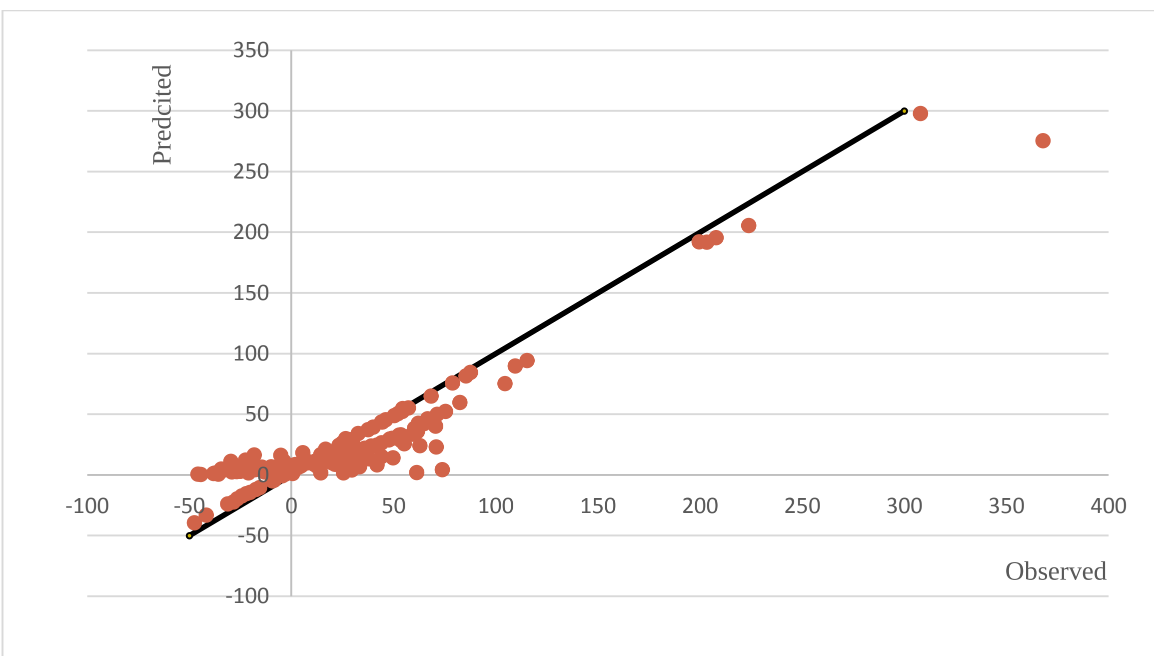
Cost overrun models (Linear Regression) for USA contracts: I/D



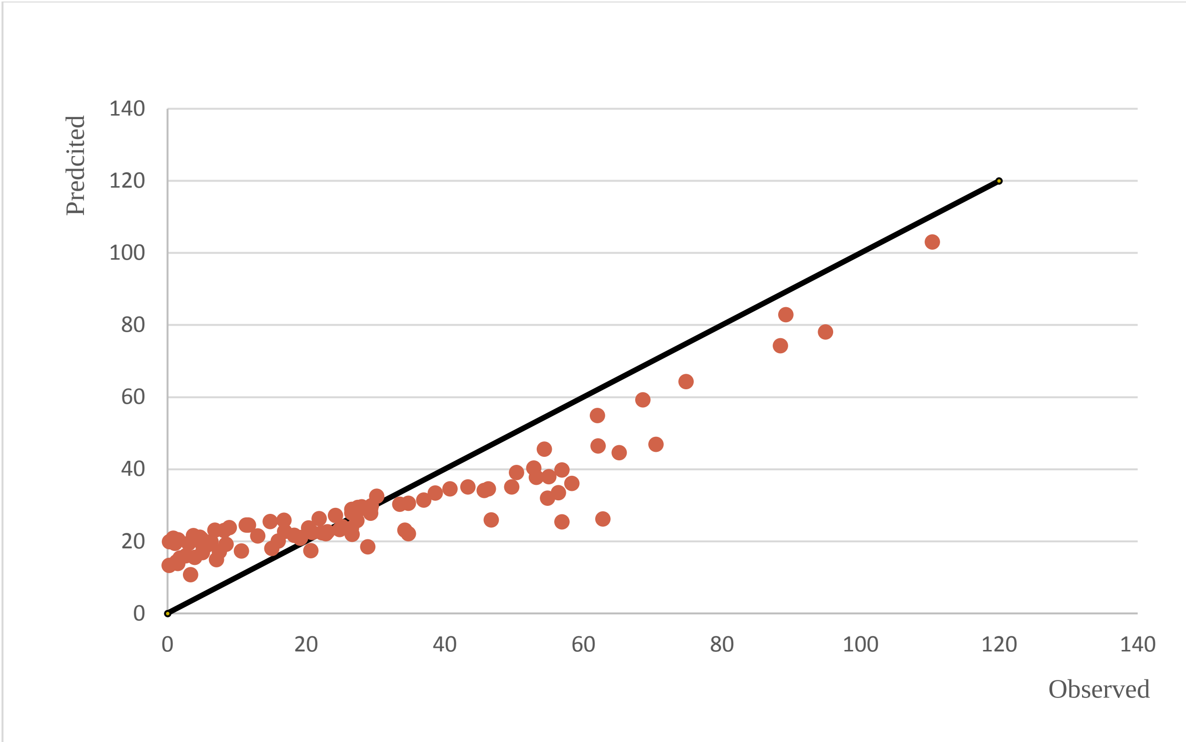
Cost overrun models (Linear Regression) for USA contracts: Lane Rentals



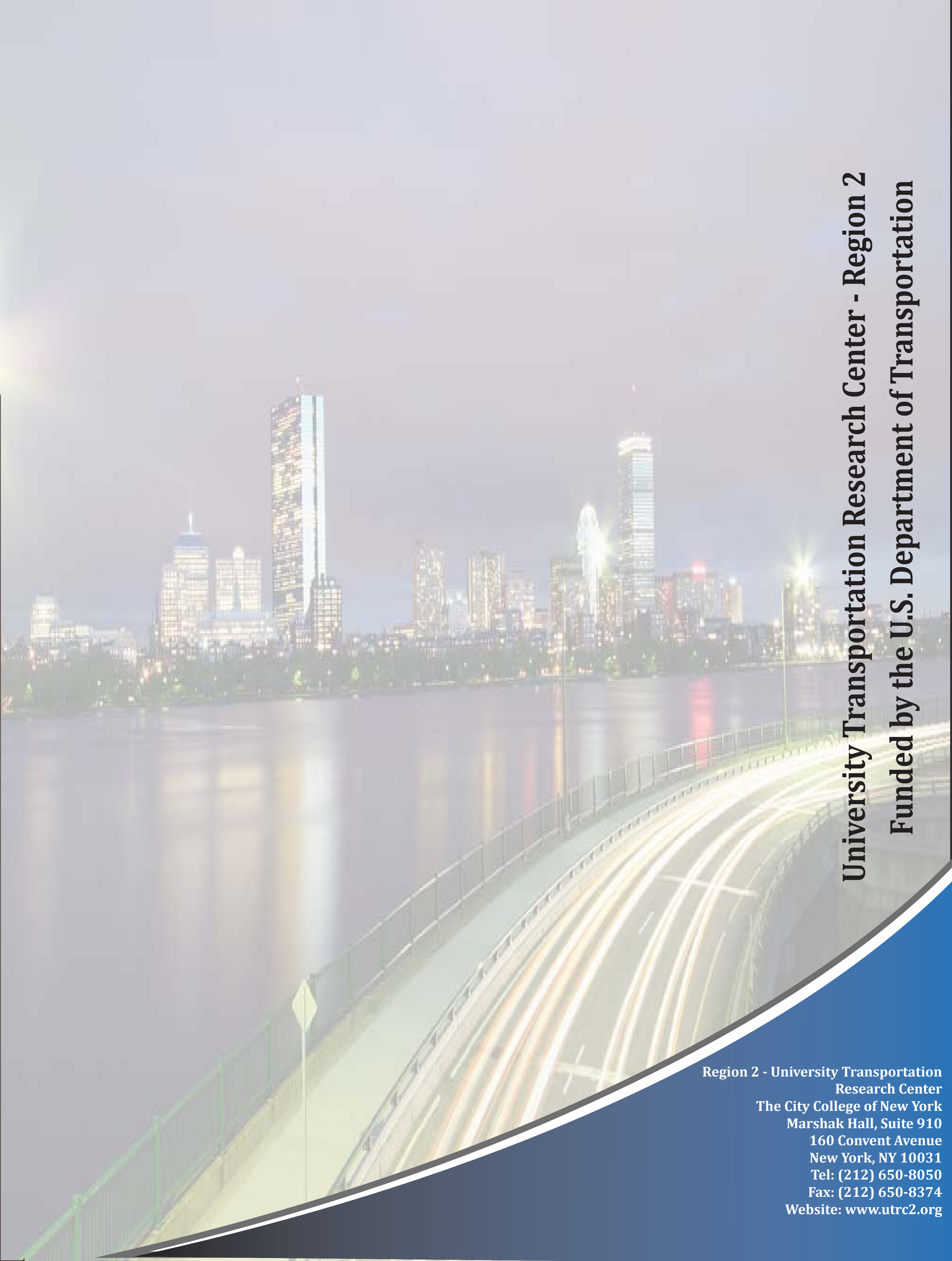
Cost overrun models (Linear Regression) for USA contracts: PBC



Cost overrun models (Linear Regression) for USA contracts: Traditional



Cost overrun models (Linear Regression) for USA contracts: Warranties



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