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Improving Transportation Construction Project Performance: Development of a Model to Support the Decision-Making Process for Incentive/Disincentive Construction Projects, MTI Report 09-07

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MTI Report 09-07

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IMPROVING TRANSPORTATION CONSTRUCTION PROJECT PERFORMANCE: DEVELOPMENT OF A MODEL TO SUPPORT THE DECISION-MAKING PROCESS FOR INCENTIVE/DISINCENTIVE CONSTRUCTION PROJECTS

March 2010

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16. Abstract

This research presents a project time and cost performance simulation model to assist project planners and managers by providing a complete picture during the Incentive/Disincentive (I/D) contracting decision-making process of possible performance outcomes with probabilities based on historical data. This study was performed by collecting transportation construction project data. The collected project data from the Florida Department of Transportation were evaluated using time and cost performance indices and then statistical data analysis was performed to identify important factors that influence construction project time performance. Using Monte Carlo simulation procedures, this study demonstrated a methodology for developing an I/D project time and cost performance prediction model. User-friendly visual interfaces were developed to perform the simulation and report results using Visual Basic Application programming. The developed model was validated using additional cases of transportation construction projects.

Based on statistical analysis, this research found that several project factors influence I/D contracting performance. The important factors that had significant impacts on project performance were the effects of contract type, project type, district, project size, project length, maximum incentive amount, and daily I/D amount. In conclusion, the developed model applied to I/D contracting projects will be a useful tool to assist the project planners and managers during the decision-making process and will promote the efficient use of I/D contracting, which will benefit the traveling public by saving their travel time from construction delays. With additional project data, the developed model can be updated easily and the more data used for the model, the better the accuracy of prediction that can be expected.

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EXECUTIVE SUMMARY

BACKGROUND AND OBJECTIVE

Incentive/Disincentive (I/D) contracting, a well-known transportation construction contracting method, is designed to minimize the disruption of traffic flow in highway construction projects. Construction project planners and managers have used I/D contracting as one of their management tools to achieve their projects' objectives. As a result, I/D contracting has played an important role in improving project time performance. More than 35 state transportation agencies (STAs) have implemented I/D contracting to improve contractors' project time performance in transportation construction. Incentives have been used specifically to encourage the early completion of highway construction projects.

I/D contracting experiences in many states have been evaluated in terms of time and cost performance. It has been found that there were substantial project time savings from many project cases. However, it has also been reported that there have been many inefficient cases using I/D contracting for various transportation construction projects. These inefficiencies can often be attributed to a poor understanding of the factors that affect the suitability of using I/D contracts. Therefore, a better understanding of the relationships among such factors as contract types, project types, project sizes, project locations, incentive amounts, and other similar factors is key to providing clear guidance for the better use of I/D contracting.

The purpose of this research project is to develop a model to enhance the decision-making process for the selection of I/D projects. The proposed decision-making model would be a useful tool to efficiently assist transportation construction project planners and managers to become more knowledgeable and effective in their I/D contracting decision-making process. Eventually, the efficient use of I/D contracting will benefit the traveling public by saving their travel time and money from construction delays.

OVERVIEW OF METHODOLOGY

This research was performed by collecting transportation construction project data. The collected project data from the Florida Department of Transportation (FDOT) were evaluated using time and cost performance indices and then statistical data analysis was performed to identify important factors that influence construction project time performance. Using beta distributions of the input variables for the key factors, a decision support model was developed for prediction of I/D project time and cost performance. Finally, a new set of I/D contracting project cases was used to validate the developed decision support model.

RESEARCH OUTCOMES

This research investigated I/D contracting projects in transportation construction and developed a project performance decision support model to assist project planners and managers during the decision-making process by providing a complete picture of possible performance outcomes with probability based on historical data. Although 100% accurate prediction cannot be guaranteed, the outcome of this research will at least provide the decision makers with better understanding of project factors that influence I/D contracting project time and cost performance as well as systematic tools that allow them to learn lessons from their previous I/D contracting experience.

Outcomes of individual projects are affected by various factors. Based on statistical analysis, this research has found several project factors influencing I/D contracting project performance as follows:

- The important factors that had significant impacts on project time performance are contract type, project type, district, project size, and daily I/D amount.
- The important factors that had significant impacts on project cost performance include contract type, district, project size, project length, maximum incentive amount, and daily I/D amount.

This study demonstrated a methodology for developing an I/D project time and cost performance prediction model using Monte Carlo simulation. User-friendly visual interfaces were developed to perform the simulation and report results using VBA programming. The developed model was validated using 30 additional project cases of transportation construction. In summary, more than 93% of cases were fallen within the predicted performance range. In comparison to the broad range of the historical performance index data set, the performance prediction range of simulation results showed much narrower range (i.e. 15 to 49% of the historical data range) in order to predict the actual value for each case.

In conclusion, the developed model applied to I/D contracting projects will become a useful tool to assist the project planners during the decision-making process and will promote the efficient use of I/D contracting, which will benefit the public by saving their travel time from construction delays. With additional project data, the developed model can be updated easily and the more data used for the model, the better the accuracy of prediction that can be expected.

INTRODUCTION

RESEARCH BACKGROUND

Transportation construction activities frequently require a reduction in road capacity, so motorists as well as adjacent businesses must endure the delays, costs, and inconveniences associated with transportation construction. Road congestion caused by construction increases travel time, vehicle operating costs, road accidents and air pollution. Recognizing the problems that construction can produce, the Federal Highway Administration (FHWA) has continuously sought ways to minimize the negative impacts from construction operations. One key aspect has been to seek improvements in construction project performance and, more specifically, to accelerate project completion whenever possible.

Incentive/Disincentive (I/D) contracting, a well-known transportation construction contracting method, is designed to minimize the disruption of traffic flow in highway construction projects. Construction project planners and managers have used I/D contracting as one of their management tools to achieve their projects' objectives. As a result, I/D contracting has played an important role in improving project time performance. More than 35 State Transportation Agencies (STAs) have implemented I/D contracting to improve contractors' project time performances in transportation construction. Incentives have been used specifically to encourage the early completion of highway construction projects.

I/D contracting experiences in many states have been evaluated in terms of time and cost performance (Herbsman 1995, PinnacleOne 2004, MnDOT 2005, Ellis and Pyeon 2005, AASHTO 2006, Ellis et. al. 2007). It has been found that there were substantial project time savings from many project cases. However, it has also been reported that there have been many inefficient cases using I/D contracting for various transportation construction projects. For instance, many contractors were able to achieve maximum incentives without reducing the original contract time since the incentives were generally paid based on the extended contract duration, which included time extensions, supplemental agreement days, and weather days. These inefficiencies can often be attributed to a poor understanding of the factors that affect the suitability of using I/D contracts. Therefore, a better understanding of the relationships among such factors as contract types, project types, project sizes, project locations, incentive amounts, and other similar factors is key to providing clear guidance for the better use of incentive contracting (Pyeon 2005).

I/D for Early Completion

Until the mid-1980s, the FHWA had a firm policy based on the belief that "the FHWA should not have to pay 'extra' just to have a project completed early" (FHWA 1989). However, the new policy which allows participation in "bonus payments for early completion" was established in the late-1980s. This policy was partially based on the evaluation outcome of National Experimental and Evaluation Program Project #24 showing that I/D provisions are an important cost-effective management tool for a construction project. The FHWA published a technical advisory report titled *Incentive/Disincentive for Early Completion* in 1989 for providing "guidance for the development and administration of I/D provisions for early completion on highway construction projects or designated phase(s)."

The FHWA advisory defined the I/D provision as "a contract provision which compensates the contractor a certain amount of money for each day identified critical work is completed ahead of schedule and assesses a deduction for each day the contractor overruns the I/D time." It was also recommended that the use of I/D provisions be limited to "those critical projects where traffic inconvenience and delays are to be held to a minimum." With regard to the I/D dollar amounts, it was recommended that the amounts be based upon cost estimates of the following factors: traffic safety, traffic maintenance, and road user delay costs.

A clear distinction between I/D provisions and liquidated damages was mentioned in the FHWA's Contract Administration Core Curriculum Participant's Manual and Reference Guide (FHWA 2008). The functioning mechanisms of I/D provisions and liquidated damages are similar in that a penalty is charged when the contractor fails to complete the project on time. However, the purpose of each is different in that liquidated damages are designed to recover the STA's construction oversight costs but I/D provisions are designed to recover damage costs to the road users for delayed completion. In addition, I/D provisions are intended to motivate the contractor to complete the work on time, or earlier, by proposing incentives.

RESEARCH OBJECTIVE AND SCOPE

The purpose of this research project is to develop a model to enhance the decision-making process for the selection of I/D projects. The proposed decision-making model would be a useful tool to effectively and efficiently assist state and federal construction project planners and managers to become more knowledgeable and effective in their decision-making. Eventually, the efficient use of I/D contracting will benefit the traveling public by saving their travel time and money from construction delays.

In order to achieve the objectives of this research, this study aims to accomplish the following tasks:

1. To collect I/D transportation construction project data;
2. To evaluate project performance for each collected project;
3. To perform data analysis to identify important factors that influence I/D project performance;
4. To develop a model to support decision-making process for the selection of I/D projects;
5. To validate that model.

RESEARCH METHODOLOGY

In this section, a methodology is described for developing a decision support model for selection of I/D contracting to assist project planners and managers. First, research was performed by collecting transportation construction project data. Second, collected project data were evaluated using time and cost performance indices and then statistical data analysis was performed to identify important factors that influence construction project time performance. Third, using beta distributions of the input variables for the key factors, a decision support model was developed for prediction of I/D project time and cost performance. Finally, additional 30 I/D contracting project cases were studied using the developed decision support model and the results of the case studies were compared with actual performance results to validate the model. The cross-functional flowchart below (Figure 1) briefly illustrates the model development process.

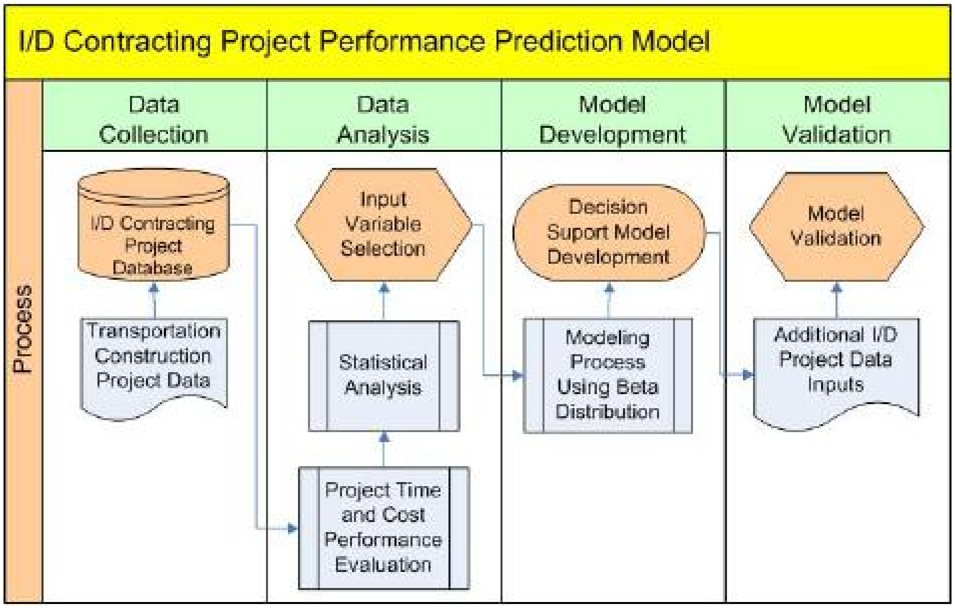


Figure 1 Model Development Process Flowchart

LITERATURE REVIEW

There have been various incentive plans used for transportation construction projects. They can be categorized into three groups: time-based incentives, cost-based incentives, and performance-based incentives. Christiansen (1987) recommended that financial incentive plans are more effective than non-financial incentive plans. Abu-Hijileh and Ibbs (1989) informed that the use of bonus-only incentives was more effective than the use of penalty-only. The design and implementation of the time-based incentive plans are relatively simple and economical. (Abu-Hijileh and Ibbs 1989) Therefore, the time-based incentive contracting for early completion of work has been most frequently used in highway construction. In this research, only I/D contracting for early completion was studied.

In this chapter, issues regarding guidance for I/D project selection and evaluation for I/D project performance have been reviewed and summarized. The literature review was performed by searching published papers, manuals, and reports on I/D contracting processes and evaluations. State-of-the-art information on I/D contracting from several STAs was obtained and then useful information for selection and evaluation of I/D contracting was summarized by states.

I/D PROJECT SELECTION

The FHWA encouraged STAs to develop their own I/D project selection criteria for the effective implementation of I/D provisions. Many STAs developed general guidelines for their states based on the FHWA's I/D project selection guidelines. The selection criteria for I/D contracting obtained from major STAs which frequently used I/D contracting has been summarized in this section.

According to the FHWA technical advisory, it was recommended that the use of I/D provisions should not be used routinely and should be limited to "the projects that severely disrupt highway traffic or highway services, significantly increase road user costs, have a significant impact on adjacent neighborhoods or businesses, or close a gap, thereby providing a major improvement in the highway system." During early project development, it is important to select I/D projects as early as possible. In order to guide STAs in identifying I/D projects early, the characteristics related to projects appropriate for the use of I/D provisions were suggested in the FHWA advisory report as follows (FHWA 1989):

- High traffic volume projects, generally in urban areas;
- Projects that will complete a gap in the highway system;
- Major reconstruction or rehabilitation on an existing facility that will severely disrupt traffic;
- Major bridges out of service; or
- Projects with lengthy detours.

The most recent research regarding selection of alternative contracting methods (ACM) including I/D was performed by Anderson and Damnjanovic (2008). They summarized the up-to-date practice of selecting I/D contracting in the NCHRP synthesis 379 report entitled *Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion*. The authors performed an online survey to the members of the AASHTO Subcommittee on Construction and reported that thirty agencies responding to the survey had used I/D contracting. According to the survey results, I/D contracting played a positive role to improve project time performance. However, the results indicated that project costs might be increased by using incentives. The authors explained that the project cost increase might be tolerable "if accompanied by a reduction in road user cost (RUC) as a result of early project completion" (Anderson and Damnjanovic 2008).

With regard to the perceptions about I/D contracting among the respondents, they summarized the survey responses based on the respondents' own opinions and the STAs' experiences. The most important advantage of I/D contracting was early or on-time project completion. However, many respondents cited several major disadvantages (Anderson and Damnjanovic 2008): 1) construction cost increase when incentives were used, 2) the potential for reduced quality by accelerating construction process, 3) problems regarding utility conflicts, and 4) potential increase in contractor disputes for change orders.

In addition, Anderson and Damnjanovic (2008) used surveys to investigate influencing factors for selection of ACM including I/D contracting. Initially, they summarized the four most commonly named influencing factors then asked each respondent to choose and/or add one or more of governing factors for selection of each ACM. Influencing factors named most frequently for selection of ACMs including I/D contracting methods were listed with descriptions in Table 1.

Table 1 Most Frequently Cited Influencing Parameters for Selection of ACMs

(Source: Anderson and Damjanovic 2008)

Influencing Factors	Descriptions
Project Size	Typically assessed in terms of the estimated cost of a project in dollars
Project Type	Typically assessed in terms of preservation (seal coats, thin overlays), rehabilitation (thick overlays), reconstruction projects (full replacement), and new construction
Project Complexity	Typically assessed in terms of project location, such as urban or suburban, in combination with a number of different components that defines project complexity, such as a combination of pavement and structures construction, utility conflicts, railroad crossings, significant traffic control requirements, and so forth
Critical Completion Date	Typically assessed in terms of requirements to complete a project faster as influenced by issues such as level of traffic disruption or meeting a target date (e.g., completion before a holiday or within one construction season)

The authors reported the survey results based on "the percentage of respondents citing the factor" in Figure 2. As shown in Figure 2, approximately 90% of respondents answered critical completion date as the most dominant factor in selecting I/D contracting. Approximately 52% identified project complexity as the driving factor for selection of I/D contracting. Project type (app. 38%) was ranked third followed by project size (app. 27%) and other factors (app. 13%).

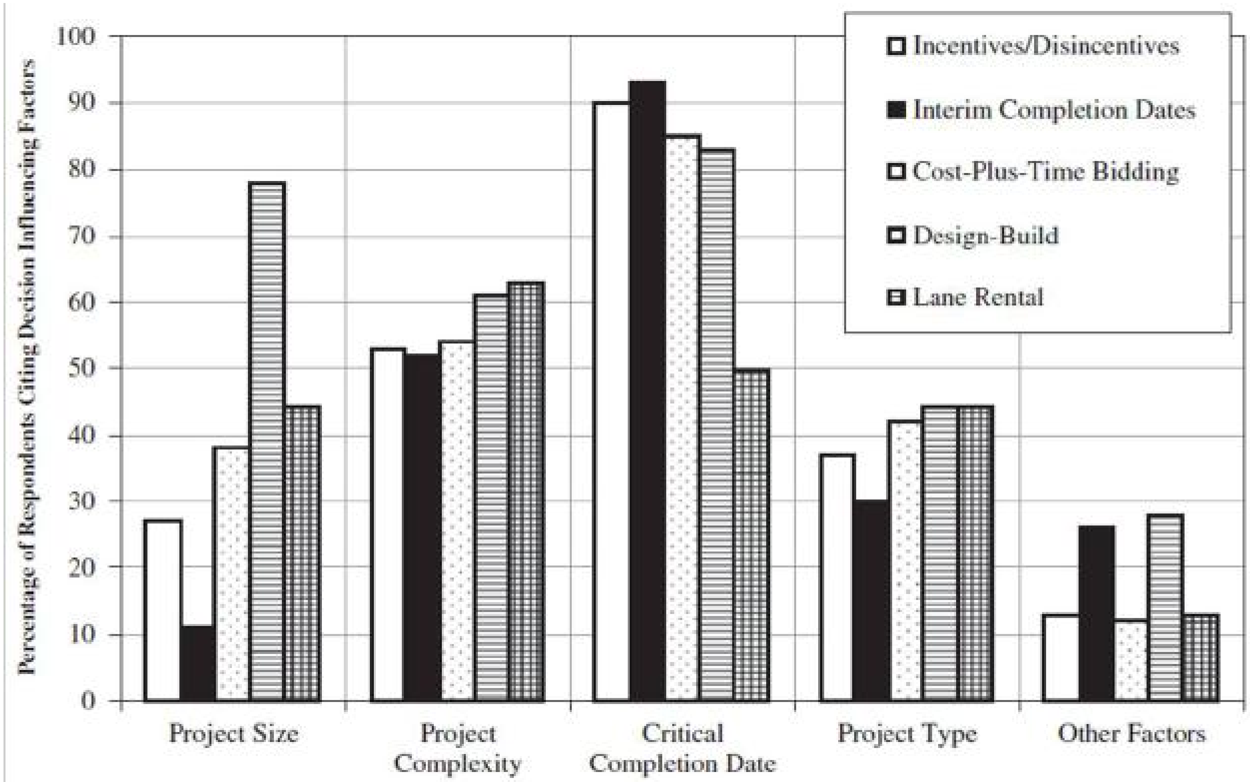


Figure 2 Selection Factors of Five Most Frequently Used ACMs
(Source: Anderson and Damnjanovic 2008)

Another comprehensive research for I/D contracting experience among various STAs was performed by Sillars and Leray (2007) and a summary process for executing I/D contracting in construction was proposed. They explained that the proposed model was similar in format to a model developed by Anderson and Russell (2001) as guidelines for warranty, multi-parameter, and best value contracting in the NCHRP Report 451. The proposed model included the different phases of the project life cycle and showed the stepwise procedures of I/D contracting implementation for STAs. The model for I/D contracting implementation is illustrated in Figure 3.

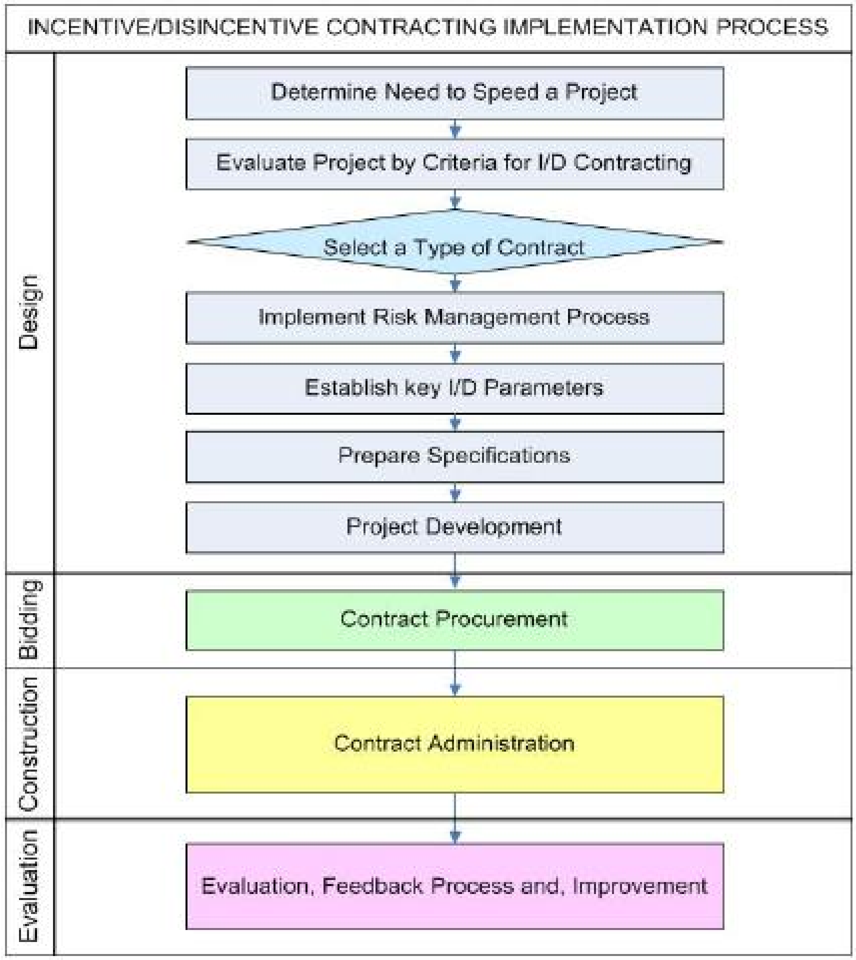


Figure 3 I/D Implementation Flowchart
(Source: Sillars and Leray 2007)

Since the FHWA provided the general I/D guidance for STAs in 1989, many agencies have developed their own guidelines for selection of I/D projects. Some of them have made up their own selection criteria and contracting manuals. Others developed their I/D contracting guiding principles by expanding the original FHWA guidance. In the following section, useful information for selection of I/D contracting was summarized by states.

California

California's Department of Transportation, Caltrans, recommended that I/D provisions be applied only for projects with a larger RUC than $5,000 per day in a manual entitled *Project Delivery Acceleration Tool Box: Improvements to the Project Delivery Process* (Caltrans 2006). In terms of the minimum RUC recommendation for selection of I/D projects, it was found that several states required a minimum RUC (Caputo and Scott 1996): $1,500 for South Dakota, $2,000 for North Carolina, and $3,000 for New York.

According to Caltrans' *Innovative Procurement Practices* prepared by Trauner Consulting Services, project characteristics suitable for I/D contracting were described as follows (Trauner 2007):

- Projects requiring traffic restrictions, lane closures, or detours that would otherwise result in high user impacts (e.g., construction on major roadways, bridges, or interchanges having a high ADT; projects involving temporary lane, ramp, or bridge closures; emergency repair work).
- The project is relatively free of third party coordination concerns (e.g., utility, railroad, environmental issues, public opposition) that could affect the bid letting date or the project schedule.
- The I/D amount results in a favorable cost/benefit ratio to the traveling public (i.e., the benefit to the highway user exceeds the I/D amount, and this amount is high enough to motivate a contractor to accelerate).
- The agency has the ability to estimate the I/D time based on expedited production rates for similar work, historical records, or CPM scheduling.
- Emergency contracts.

In addition to the above guidelines, Trauner identified a qualitative evaluation of advantages and disadvantages for I/D contracting as shown in Table 2.

Table 2 Advantages and Disadvantages for I/D Contracting
(Source: Trauner 2007)

Advantages	Disadvantages
1. Significantly reduces project time 2. Encourages contractors to use time-saving means and methods to accelerate construction 3. Minimizes cost and time impacts to the traveling public for projects having high ADT 4. Shifts more risk to the contractor for providing the optimum combination of time, cost, and efficient planning and management of the work	1. Higher bid costs and project costs 2. Acceleration may over-extend agency and contractor personnel (however, the associated costs may be offset by the overall shorter construction duration). 3. Acceleration could compromise project quality. However, I/D projects may also motivate contractors to perform work correctly the first time to avoid time-consuming rework efforts. 4. The agency bears the risk of accurately estimating the critical I/D time and not delaying the I/D date. Agencies have reported that contractors may complete the I/D work and earn an incentive without expending extra effort and that contractors have earned incentives even when the project has been delayed. 5. Agencies have reported that disincentive payments are difficult to recover.

Florida

Florida Department of Transportation outlined the I/D contract selection in the document entitled *Alternative Contracting User's Guide*. In Florida, I/D contracting may be a stand-alone method, or may be applied to other alternative contracting techniques such as A+B, No Excuse Bonuses, Liquidated Savings, Lane Rental, Design-Build or any combination (FDOT 1997). For selection of I/D projects, urban reconstruction and bridge type projects were recommended as good candidates. However, it was not limited to the application of only those projects, but recommended to be applied for any projects that need to meet a specific completion date (FDOT 2000).

Minnesota

Minnesota Department of Transportation (MnDOT) developed innovative contracting guidelines in selecting I/D contracting projects. The selection criteria for I/D contracting were detailed by recommending good candidates and poor candidates to be considered early in the I/D selection process. The categorized candidates with project descriptions were listed in Table 3.

Table 3 Categorized Project Candidates Used for I/D Project Selection in Minnesota

(Source: MnDOT 2005)

Category	Project Descriptions
Good Candidates	• Projects with high road-user or business impacts • Bridge replacement projects • Detour projects • Unban pavement rehabilitation projects • Interstate (high volume) projects with major traffic impacts • A+B projects • Bridge rehabilitation projects • Projects with commitments to open a roadway as quickly as possible
Poor Candidates	• New construction projects with minimal impacts to road users • Projects where right-of way or utilities are not clearly identified • Traffic Management System • Steel fabrication • Landscaping

Ohio

The Ohio DOT's Innovative Contracting Manual published in 2006 provides general guidelines for selection of I/D projects. It recommends that the major consideration for selecting I/D contracting be based on the project, or a portion of the project, causing a significant delay or impact to the road users (Ohio DOT 2006). Ohio DOT not only took project types into consideration but also project size as important factors for selecting I/D projects. All time-sensitive projects and interstate lane closure projects are typical I/D projects at all project sizes.

Ohio DOT further provided various project types in detail for the purpose of I/D project selection requiring the district to execute some vital studies to verify "if a potential innovative contracting method is truly appropriate for the specific project" (Ohio DOT 2006). Table 4 shows project sizes and types recommended by Ohio DOT. The following criteria are used for I/D selection guidance in Ohio (Ohio DOT 2006):

- The project or a portion of the project results in a significant delay or impact to the road

users.
- The Department must have a good understanding of the construction time needed to complete the Incentive/Disincentive portion of the project.

Table 4 Project Sizes and Types Recommended by Ohio DOT

Project Size	Recommended Project Type
Small Projects	Bridge projects or bituminous resurfacing
Mid-Level Projects	Interstate resurfacing, or minor rehabilitation
Mega Projects	Corridor reconstruction or interstate rehabilitation
All Project Sizes	Time-sensitive projects: • New Construction – Relocation • Major Reconstruction • Major Widening • Minor Widening • New Bridge/Bridge Replacement • Four-Lane Resurfacing & Overlays • Bridge Rehabilitation, Repair & Widening • Bridge Painting • Culvert Construction, Reconstruction or Repair • New Interchange • Intersection Upgrade

South Dakota

In order to identify a candidate project for early completion during or immediately after the preliminary design, Caputo and Scott (1996) recommended the following project selection criteria for implementing time-based innovative contracting methods such as I/D, Cost plus Time (A+B) , A+B with I/D, and Lane Rental in South Dakota:

- High traffic volumes, with traffic restrictions, or lane closures resulting in road user cost estimates in excess of the liquidated damages for the project;
- Long detours causing delay in excess of 10 minutes;
- High accident rates or safety concerns during construction;
- Potentially significant impacts to the local community or economy; or
- Projects coordinated with special events.

After identifying candidate projects and estimating road user costs, the recommended procedures for selecting innovative contracting were to identify potential impacts, re-evaluate project by finalizing RUC, estimate time, choose a contract method, and develop special provisions. In case of no severe impact on the bidding date or the critical schedule, they recommended an innovative contracting method for more detailed project situations shown in Table 5.

Table 5 I/D Contracting Methods with Recommended Project Situation in South Dakota

(Source: Caputo and Scott 1996)

Contracting Methods	Recommended Conditions
I/D	RUC is high, and the monetary benefit equals or exceeds the incentives paid to the contractor to finish early; It is in the public interest to complete the project as soon as possible, or by a specific completion date; and The Department can estimate contract time based on similar projects or CPM scheduling.
A+B with I/D	RUC is high, and the monetary benefit equals or exceeds the incentives paid to the contractor to finish early; It is in the public interest to complete the project as soon as possible; and The Department seeks contractor expertise to estimate contract time.
A+B	The project does not require to be completed by a specific completion date; RUC is relatively low but other factors warrant expediting the project; and The Department seeks contractor expertise to estimate contract time.

I/D CONTRACTING EVALUATION

With the help of FHWA, Herbsman (1995) collected highway construction project data using A+B and A+B with I/D contracting from 15 states. Of a total of 101 project data collected, 41 completed projects used I/D provisions. He also conducted interviews with practitioners, contractors, and others involved in the innovative contracting process. During quantitative data analysis, he measured project time and cost performance for each project and analyzed the project performance by states and project types. Average time savings/overruns of the top five states that completed 10 projects or more per state were summarized in Table 6.

Table 6 Average Time Savings/Overruns by States: A+B and A+B with I/D

(Source: Herbsman 1995)

States	Number of Projects Completed	Percent Average Time Savings (+) / Overruns (-)
Maryland	28	13.37
North Carolina	13	27.73
Missouri	13	-4.54
New York	12	18.89
California	10	14.43

Average time savings from four states showed 18.6% and an average time overrun from one state for 13 projects was 4.54%. These results indicated that there could be some project factors that affect project performance. Herbsman (1995) further investigated a few case studies and concluded that “motivated contractors can reduce construction time with more accurate scheduling, more efficient managing of the project, and better use of their own resources." In the following section, useful information for evaluation of I/D contracting was summarized by states.

California

In California, project time and cost performance comparisons between 28 A+B projects (with or without I/D provisions) and 28 non-A+B projects were performed. In a report entitled *Summary Level Study of A+B Bidding*, it was found that A+B contracting showed positive impacts on time savings at the beginning of the projects and no significant time or cost overruns were found after construction began. (PinnacleOne 2004) Average time savings of 27% was reported as shown in Figure 4. Average cost growth amount on A+B projects ($4.6M) was greater than non-A+B projects ($3.8M). In addition, it was reported that the average claim amounts of the A+B projects ($0.85M) were approximately half that of the representative non-A+B ($1.72M).

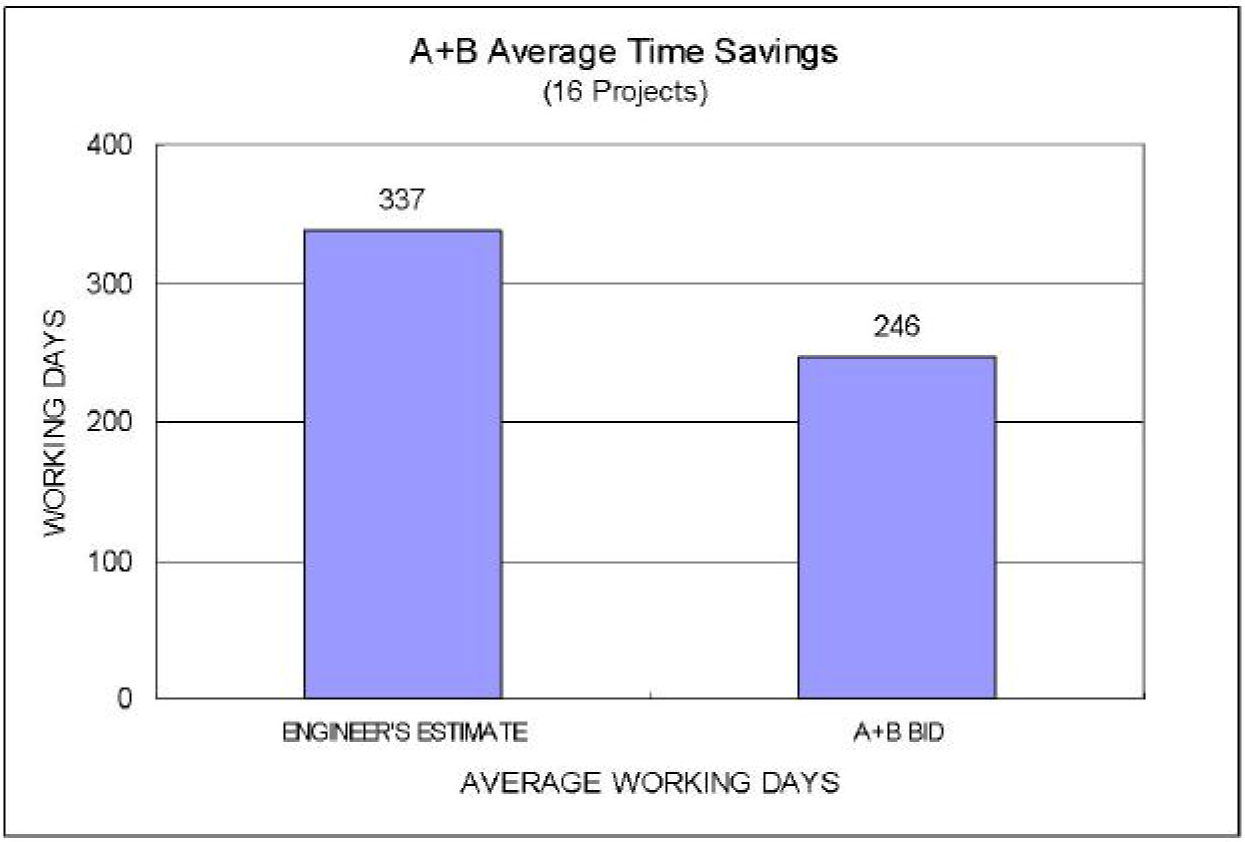


Figure 4 A + B Average Time Savings
(Source: PinnacleOne 2004)

Florida

With regard to evaluation of FDOT alternative contracting techniques including I/D contracting, Ellis et al. (2007) performed a comprehensive quantitative evaluation on FDOT construction projects as well as interviews with FDOT district engineers. The quantitative project cost and time evaluation results showed that total cost growth and time growth of the alternative contracting projects, including I/D, were lower than the traditional design-bid-build projects during construction. They concluded that the choice of contracting method did not seem to have an effect on project quality by investigating contractor past performance rating scores. Regarding FDOT I/D contracting practice, 144 projects were evaluated. Comparing to traditional design-bid-build contracting practice during the same research period, I/D projects showed average time savings of 16.5% but average cost overruns of 3.3%. These results indicated that there was a trade-off effect between project cost and time. It was also reported that “contractors achieved full or partial incentives approximately 51% of the time for I/D contracting projects” (Ellis et al. 2007).

Ellis et al. (2007) also performed interviews with FDOT district engineers regarding project selection of I/D contracting and reported the following findings:

- Project type, project cost, project duration, project location, and time of year were important factors when considering the use of I/D contract.
- Projects over $10 million, projects of longer duration and interstate projects were recommenced by applying I/D provision.
- Rural projects were only recommended, if having a high traffic volume.
- Using I/D contracts near hurricane season, caution was recommended.
- I/D contracting seems to work best when applied on large, interstate, or high-volume rural projects.

With regard to I/D contracting time performance evaluation, Pyeon (2005) further investigated incentive contracting techniques in Florida by analyzing various project factors. He found many significant factors that affect construction time performance using statistical analyses and developed a simulation model to predict project time performance as a framework. In this model, many processes, including categorization of variables, were functioned manually. More importantly, project cost performance was not considered in this model.

Michigan

The Michigan DOT evaluated 26 I/D projects let and completed in 1998 and 1999. Michigan DOT’s project time and cost evaluation results were briefly summarized in a report of the Contract Administration Section of the AASHTO Subcommittee on Construction. According to the report entitled *Primer on Contracting for the Twenty-first Century*, project time and cost performance were found as follows (AASHTO 2006):

- 65% of I/D projects were completed early.
- 12% were completed on time.
- 23% were completed late.
- Average I/D rate for all projects was $18,500.
- Average project user delay savings were $610,500.
- The use of I/D provisions indicated an average increase of 1.5% of the contract amount.

Oregon

Oregon DOT has used I/D provisions in two different forms: I/D only and A+B with I/D. Sillars (2007) pointed out that Oregon DOT like many other DOTs had limited experience and only a few people with I/D experience made decisions for the development of I/D contracting on an ad-hoc basis. On the other hand, he emphasized that developing standardized methods for the use of I/D contracting would benefit Oregon DOT by encouraging more frequent and effective use of I/D contracts, as well as many others by providing useful lessons learned from Oregon.

Sillars (2007) evaluated Oregon DOT's I/D contracting experience for 18 I/D contracting projects started between 1996 and 2005. Project values were varied ranging from $300,000 up to $65,200,000. From a frequency analysis of I/D projects, it was found that a maximum number of four I/D projects per year were released and reported that I/D contracting remained a somewhat uncommon practice in Oregon. However, as more I/D projects were practiced, he addressed "the need of better documentation and more consistent techniques" (Sillars 2007). An approximate value of each I/D project was categorized by year and illustrated in Figure 5.

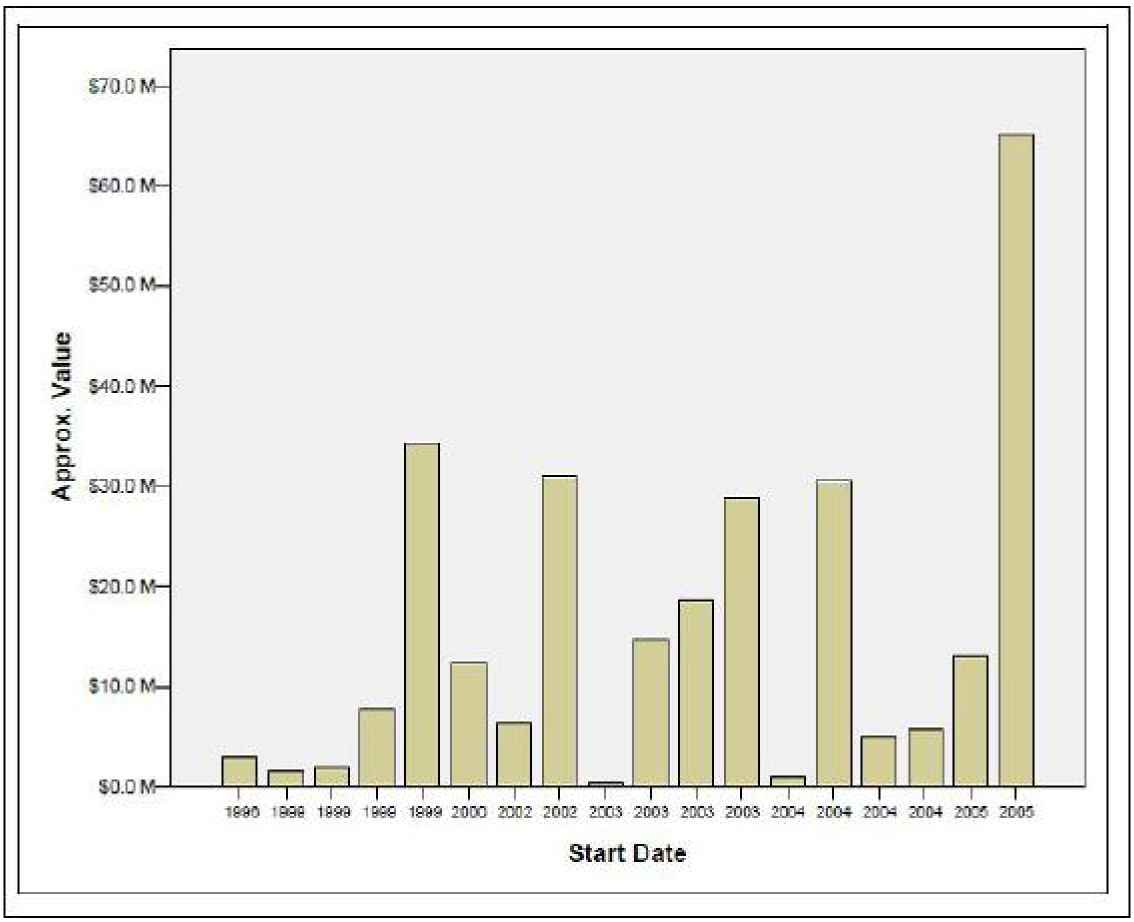


Figure 5 Oregon DOT I/D Project Size by Date
(Source: Sillars 2007)

SUMMARY OF LITERATURE REVIEW

Selection of I/D contracting guidelines by agencies are summarized in Table 7. The selection criteria for each STA listed in Table 7 were found in the following literature: FHWA 1989, Plummer 1992, Caputo and Scott 1996, FDOT 1997, MnDOT 2005, and Ohio DOT 2006. Many STAs developed their own selection criteria based on FHWA's guidelines. Although there were many similarities on the I/D selection criteria among STAs, it was also found there were many differences regarding the use of I/D contracting. It indicated that there were different levels of I/D contracting experience and preference based on their previous experience.

Through the literature review, it was found that there were many general guidelines developed by STAs, with many similarities and differences among their I/D contracting selection criteria. Some STAs performed qualitative evaluation of their I/D contracting practices and identified advantages and disadvantages for I/D contracting methods. In addition, several STAs performed quantitative evaluations of I/D contracting and reported project time and/or cost performances comparing with other contracting methods. However, no STAs have implemented a certain type of decision support system for selection of I/D contracting based on quantitative data analysis of the previous I/D contracting practices. It is important for STAs to learn from their previous I/D contracting experiences in order to improve I/D project performance and refine I/D usage. Therefore, it is recommended that more research efforts should be made to identify I/D contracting project factors influencing project performance and develop a decision support system using the influencing factors to assist project planners and managers for selection of I/D contracting.

Table 7 Summary of I/D Project Selection Criteria for Good Candidates

Agencies (Year)	Traffic and Business Impacts	Bridge	Roadway	Others
FHWA (1989)	High volume; High road-user cost or business impacts	Major bridge out of service	Major projects which severely disrupt traffic	Lengthy detour
Illinois DOT (1992)	Project type consideration (even with low volume): Road, River Structure	River structures involving economic impacts or next to central business district	Roadway projects involving economic impacts	Night time construction on urban freeway
Maryland DOT (1992)	High volume	N/A	N/A	Impairment of emergency service; Elimination of hazardous condition; Safety of traveler & contractor employee
SD DOT (1996)	Interstate lane closure and restriction; High road-user cost or business impacts; Long off-site detour (>10 min. delay)	Bridge closure with long off-site detour (>10 min. delay)	Signalized intersection reconstruction	Two-way traffic disruption for long period Project's impacts on public, pedestrian or work
FDOT (1997)	High road-user cost or business impacts	Yes	Reconstruction in urban area	
MnDOT (2005)	High road-user cost or business impacts; Interstate projects with major traffic impacts	Bridge rehab. & replacement involving high road-user or business impacts	Pavement rehabilitation in urban area with high road-user or business impacts	Commitment to open a roadway as soon as possible
Ohio DOT (2006)	All time-sensitive project; Interstate Lane Closure	Small project	Small bituminous project; Mid-Level projects (interstate resurfacing and minor rehabilitation); Mega projects (corridor reconstruction and Interstate rehabilitation)	N/A
Caltrans (2007)	Required traffic restriction (lane closure or detour on major roadway)	Bridge or interchange with a high ADT (temporary lane, ramp, bridge closures; emergency repair)	Temporary Lane on major roadway (High ADT)	Emergency contracts; I/D time; I/D amount (Favorable cost/benefit ratio and high enough); Relatively free of third party coordination concerns

In summary, there are many unanswered questions regarding I/D contracting project selection and evaluation. In order to enhance the decision-making process for the selection of I/D projects, the following questions should be addressed:

1. How effective were I/D contacting for given project situations in improving project time and cost performance?
2. Which variables are the important factors that affect project time and cost performance for an I/D project?
3. What levels of project time and cost performance can the project planner expect for an I/D project?

Better understanding of the answers to these questions will make state and federal transportation project planners and managers more knowledgeable and effective in their decision-making so that I/D contacting techniques may be applied in a more efficient way for transportation construction projects.

DATA COLLECTION

From previous research experience, the research team found that most DOTs did not have construction project information in a database or easily accessible elsewhere. (Pyeon 2005) When representatives of the DOTs were asked to provide construction project data, they responded that providing the project information would require considerable time and effort, and some project information was generally not tracked. For these reasons, project data collection is one of the most challenging tasks of this kind of research.

FDOT is the most active STA that has implemented I/D contracting in their transportation construction projects. The required project information for this study is located in several different systems within FDOT. From previous research experience, the research team has already obtained part of the required project data by contacting the FDOT construction database engineer. However, the project data does not include the most recent practices, which need to be updated in a construction project database.

In this study, the research team collected recent I/D contracting project information from FDOT. Due to time and resource limitations, I/D project data from other states were not collected. In the following sections, the project data collection process and I/D contracting project database construction procedures are described.

I/D PROJECT DATA

Transportation construction project data were obtained from the FDOT main office and district offices. Relevant project data, such as contract type, project type, duration, cost, location, length, maximum I/D dollar amount, daily I/D dollar amount, etc., were collected. FDOT I/D contracting project data in transportation construction were obtained from several sources, such as Construction Time and Cost Quarterly Reports, Time and Cost Analysis of Passed Alternative Contracts Reports, and FDOT WebFocus database. A total of 295 I/D contracting projects from the fiscal years 1998 through 2008 were utilized. Four different I/D contracting types were identified: 1) I/D only, 2) A+B with I/D, and 3) A+B Bonus with I/D. An example of I/D project sample data obtained from FDOT is shown in Table 8.

I/D CONTRACTING DATABASE CONSTRUCTION FOR ANALYSIS

Although the FDOT construction time and cost quarterly reports were obtained electronically, they needed to be joined to create a single database. An Excel spreadsheet of Time and Cost Analysis of Passed Alternative Contracts Reports collected from a district office was then merged into the time and cost report database. Finally, Excel spreadsheets of roadway contract data and historical contract data obtained from FDOT WebFocus database were joined with the time and cost report database. A total of 295 I/D contracting project data were listed in the database. Relevant project data like contract type, project type, duration, cost, location, length, maximum I/D dollar amount, and daily I/D dollar amount were included in the I/D project database for analysis. The project data collected for analysis and included in model development is summarized in Tables 9 and 10.

Table 8 FDOT I/D Contracting Project Data Sample

Column Name	Data	Column Name	Data
Project ID	410678	Contract type	I/D
District	06	Roadway ID	87060000
County	Miami-Dade	Transportation system	Non-intrastate
Work mix	Bridge -painting	Location	SR A1A /Mcarthur CSWY
Let date	5/22/02	Project manager	Luis Amigo
Award date	6/19/02	Contractor	Mayo Contracting
Execution date	7/03/02	Project length	0.399 miles
Notice to proceed	8/2/02	Number of lanes	0
Work begin date	2/16/03	Number of lanes added	0
Final acceptance date	9/26/03	DOT original estimate	$1,501,000
DOT time estimate	240	Original contract amount	$1,976,732
Incentive days	239	Present contract amount	$2,083,065
Original contract days	240	Total amount paid	$1,979,886
Present contract days	267	Actual expenditure	$1,945,886
Days used	222	Actual Incentive paid	$34,000
Days suspended	0	Daily incentive amount	$2,000
Weather days	27	Max. incentive proposed	$105,000
Total work order TE	0	Total SA amount	$106,333
Total SA days	0	Production rate	$8,100
Number of SAs	2	Incentive production rate	$10,400
Incentive time maximum	188	Historical production rate	$7,700

Table 9 Summary of Construction Projects by Contract Types

District	Contract Type	Number of Projects	Total Contract Amount
1	A+B with I/D	11	$101,234,088
	I/D	22	$203,299,659
District 1 Total		**33**	**$304,533,747**
2	A+B with I/D	23	$134,369,850
	I/D	2	$3,853,518
District 2 Total		**25**	**$138,223,368**
3	A+B with I/D	19	$243,325,709
	I/D	8	$45,733,389
District 3 Total		**27**	**$289,059,098**
4	A+B with I/D	9	$116,752,055
	A+B Bonus with I/D	4	$199,693,064
	I/D	31	$226,169,502
District 4 Total		**44**	**$542,614,621**
5	A+B with I/D	15	$237,207,911
	I/D	13	$102,124,145
District 5 Total		**28**	**$339,332,056**
6	A+B with I/D	8	$35,029,381
	A+B Bonus with I/D	26	$345,650,232
	I/D	62	$83,698,282
District 6 Total		**96**	**$464,377,895**
7	A+B with I/D	9	$113,845,418
	A+B I/D Bonus	1	$7,861,142
	I/D	14	$92,001,259
District 7 Total		**24**	**$213,707,819**
8	A+B with I/D	6	$119,281,020
	A+B Bonus with I/D	1	$3,721,761
	I/D	11	$169,181,846
District 8 Total		**18**	**$292,184,627**
Grand Total		**295**	**$2,584,033,231**

Table 10 Summary of Construction Projects by Project Types

Project Work Type	Number of Projects	Total Construction Duration (Days)	Total Contract Amount
Access improvement	2	375	$4,750,119
Add lanes & reconstruction	66	38,610	$957,745,630
Add lanes & rehabilitate pavement	16	8,957	$252,154,000
Add right turn lane(s)	2	210	$436,396
Add thru lane(s)	1	130	$1,330,442
Add turn lane(s)	7	830	$4,234,520
Bridge—painting	2	440	$3,138,951
Bridge/culvert replacement	2	500	$4,741,346
Bridge-rehab and add lanes	1	925	$32,859,777
Bridge-repair/rehabilitation	14	2,612	$31,805,272
Construct bridge—low level	4	1,525	$17,509,373
Construct bridge—movable span	1	576	$23,445,002
Construct bridge—high level	1	500	$18,486,091
Construct/reconstruct median	1	120	$593,653
Federal aid resurface/repave	1	120	$2,944,870
Fender work	1	390	$2,284,662
Fixed guideway improvements	1	500	$3,494,000
Flexible pavement reconstruction	5	1,510	$24,633,355
Guardrail	5	1,156	$44,472,567
Highway-enhancement	1	152	$3,607,477
Interchange (major)	6	4,885	$233,479,355
Intersection (major)	2	1,345	$36,624,974
Intersection (minor)	7	640	$3,017,766
Landscaping	1	150	$2,212,452
Mill and resurface	1	150	$4,229,690
Miscellaneous construction	4	1,039	$10,730,812
Miscellaneous structure	1	525	$37,935,485
New road construction	6	3,185	$132,177,053
Replace low level bridge	19	6,194	$103,284,848
Replace medium level bridge	6	3,876	$74,358,292
Replace movable span bridge	4	3,485	$171,273,445
Resurfacing	79	18,034	$253,119,539
Rigid pavement reconstruction	2	1,082	$32,286,750
Rigid pavement rehabilitation	1	280	$6,630,067
Safety project	7	1,163	$9,759,660
Sidewalk	1	100	$420,608
Traffic signals	6	670	$1,978,393
Widen bridge	3	1,260	$18,062,628
Widen/resurface exist lanes	5	806	$17,783,911
Grand total	**295**	**109,007**	**$2,584,033,231**

DATA ANALYSIS

The purpose of the data analysis in this study was to identify important factors that influence construction project time and cost performance. The obtained I/D project data were evaluated using time and cost performance indices. Four performance indices were developed and used for analysis: (1) Time performance index based on original contract duration (OTPI); (2) Time performance index based on present contract duration (PTPI); (3) Cost performance index based on original contract cost (OCPI); and (4) Cost performance index based on present contract cost (PCPI). Next, statistical analyses were performed to identify any differences on project performance among project variables. Finally, significant factors that influence project performance were identified and summarized.

STATISTICAL ANALYSIS PROCESS

The construction project data used for this study consist of quantitative variables such as project length, cost, duration, and maximum or daily I/D dollar amounts, and qualitative variables such as project type, contract type, and project location. For the quantitative variables, correlation analysis was performed to identify potential key factors that might influence project performance. In the next step, factors selected for further analysis were classified using an appropriate categorization process. Finally, statistical analyses were performed to identify any differences among project variables.

Numerous statistical analyses were performed to investigate the possible differences on project performance among project factors. The following statistical analysis tests were used in this study: (1) the two-sample t-test was used to determine whether there was a significant difference between the means of the two groups, (2) the analysis of variance (ANOVA) test was performed to test the null hypothesis that all population means are equal, and (3) the multiple comparison test was performed to determine which means are different from which others whenever the ANOVA test is significant. Since each project was completed at a different location and in a different time, each project was assumed to be independent. In probability theory, a sufficiently large sample of independent random variables is approximately normally distributed. Since the central limit theorem justifies the approximation of large-sample statistics to the normal distribution, it is practical to assume that variables in this study with a large sample size are normally distributed. Therefore, it is reasonable to perform the hypothesis tests to identify factors that influence project performance among project variables.

For qualitative variables already categorized in several groups, an ANOVA test was performed to test the null hypothesis that all population means for the groups are equal. Sometimes, it was necessary that an appropriate grouping process be performed prior to the ANOVA test for qualitative variables with many different categories. For instance, each project has a major work type description (i.e., FDOT Work Mix), which briefly describes project characteristics. According to the major work type, projects were put into similar groups such as bridge rehabilitation/reconstruction, roadway rehabilitation/reconstruction, roadway resurfacing/paving, and others. Then, an ANOVA test was performed to test the null hypothesis that all population means for the major work type categories are equal. A multiple comparison procedure was performed whenever the F-test for the effect was significant in the ANOVA table to determine which means were different from which others.

EVALUATION OF PROJECT PERFORMANCE

Project performance was measured using two key parameters: time and cost. Using the time parameter, a project time performance index (TPI) for each project was determined based on the following formula:

$$TPI = \frac{Final\ Duration - Contract\ Duration}{Contract\ Duration}, \quad (1)$$

where a negative value of TPI means time savings and a positive value of TPI means time overruns. For example, a value of TPI = -0.05 indicates a 5% project time savings, while a value of TPI = +0.05 means a 5% time overrun.

The TPI was refined using details such as a time performance index based on original contract duration (OTPI) and a time performance index based on present contract duration (PTPI), which included time extensions and supplemental agreement days. However, the total number of days granted as weather days in accordance with specifications was not included when calculating both indices. Thus, OTPI and PTPI indices were calculated as:

$$OTPI = \frac{Final\ Duration - Original\ Contract\ Duration}{Original\ Contract\ Duration}, \quad (2)$$

$$PTPI = \frac{Final\ Duration - Present\ Contract\ Duration}{Present\ Contract\ Duration}, \quad (3)$$

Using the cost parameter, a project cost performance index (CPI) for each project was determined as follows:

$$CPI = \frac{Final\ Cost - Contract\ Cost}{Contract\ Cost}, \quad (4)$$

where a negative value of CPI means cost savings and a positive value of CPI means cost overruns. For example, a value of CPI = -0.05 means project cost savings of 5%, while a value of CPI = +0.05 means a 5% cost overrun.

The CPI was also refined using details such as a cost performance index based on original contract cost (OCPI) and a cost performance index based on present contract cost (PCPI), which included total work order amount, supplemental agreement amount, incentives paid, and other contract adjustments. These indices were calculated as:

$$OCPI = \frac{\text{Final Cost} - \text{Original Contract Cost}}{\text{Original Contract Cost}}, \tag{5}$$

$$PCPI = \frac{\text{Financial Cost} - \text{Present Contract Cost}}{\text{Present Contract Cost}}, \tag{6}$$

FACTORS INFLUENCING PROJECT PERFORMANCE

In order to identify important factors that influence construction project time and cost performance based on original contract and present contract, many project factors were studied. Although not presented in detail here, many variables were tested to identify key factors. The tested variables are listed below:

1. Contract type
2. Project location: district and county
3. Project type: work mix
4. Project length: number of lanes
5. DOT time estimate
6. Original contract duration
7. Days suspended
8. Weather days
9. (Weather days)/(Original contract duration)
10. (Days between let date and work begin date)/(Original contract duration)
11. (Total work order time extension)/(Original contract duration)
12. (Supplemental agreement days)/(Original contract duration)
13. DOT original cost estimate
14. Original contract cost
15. Daily incentive amount
16. Maximum incentive proposed
17. (Original contract cost)/(Original contract duration)
18. (Total supplemental agreement amount)/(Original contract cost)
19. (Total supplemental agreement amount)/(DOT's actual expenditure)
20. (Innovative contract adjustments amount)/(Original contract cost)
21. (Innovative contract adjustments amount)/(DOT's actual expenditure)

This section only describes statistically significant factors among all tested variables. Through statistical analysis, the significant factors were determined to be project size, contract type, project type, project length, maximum incentive proposed, daily incentive amount and district.

Factor 1: Contract Type

The I/D contracting technique has been used as a stand-alone method or with a combination of other contracting methods such as A+B and/or Bonus. Construction project data collected were categorized by three I/D contracting types: (1) I/D, (2) A+B with I/D, and (3)

A+B with I/D and Bonus. The contract type variables as qualitative variables were already categorized by three I/D contracting types. With 295 observations (I/D: 163, A+B I/D: 100, and A+B I/D Bonus:32), the boxplots, used for descriptive statistics, graphically depict the five-number summary of a data set consisting of the minimum, the lower quartile (the lowest 25% of the data), the median, the upper quartile (the highest 25% of the data), and the maximum. Results of box-and-whiskers plot comparison of time and cost performance of each contract type variable are illustrated in Figure 6.

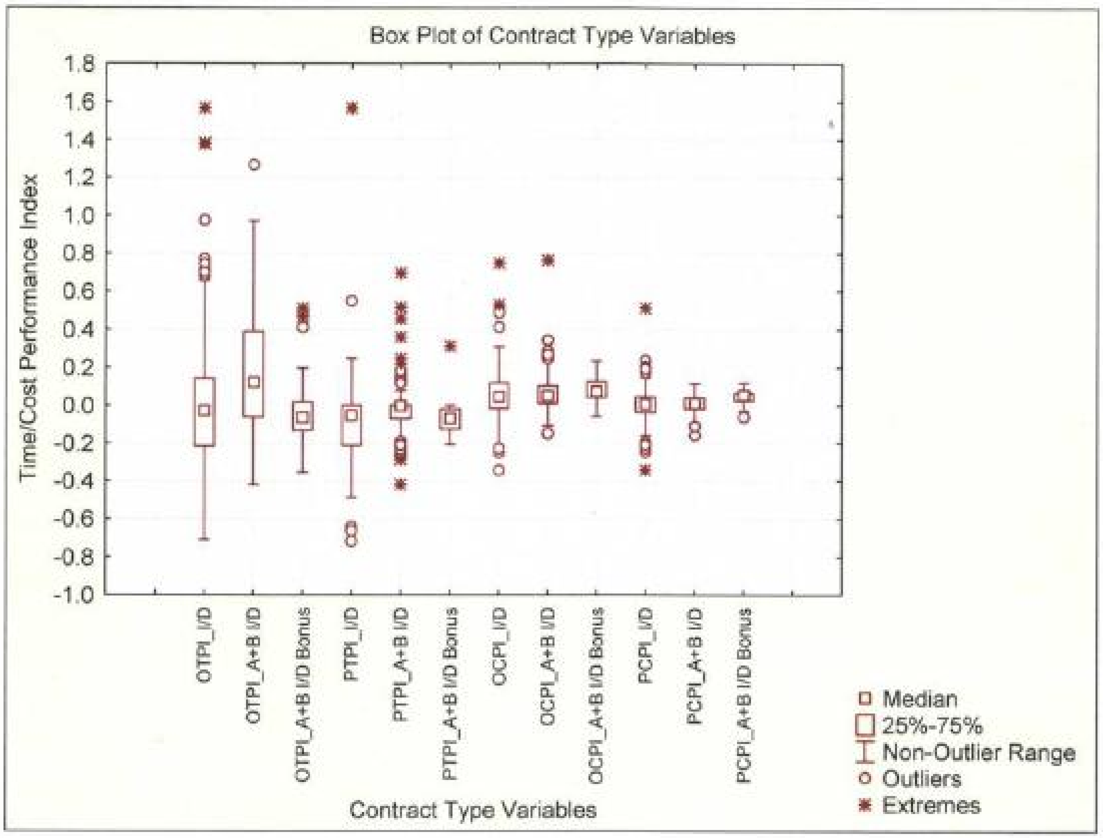


Figure 6 Box Plot of Contract Type Variables

For contract type variables of each project performance index, an ANOVA test was performed to test the null hypothesis that all three population means for the groups are equal. The F-test results are shown in Table 11. The statistical significance of the variables is given by the probability value (p-value) defined in this study to be significant when it is smaller than 0.05. Since the p-value is smaller than 0.05, it was concluded from this test that the effect of contract type is significant.

Further analysis was therefore needed to test which means are different from which others. The Tukey test was performed for multiple comparisons. The Tukey test results are shown in Table 11. Three possible cases investigated were: (1) I/D vs. A+B I/D, (2) I/D vs. A+B I/D Bonus, and (3) A+B I/D vs. A+B I/D Bonus. Although it was not found that there is any difference among contract type variables in the case of OCPI, the test results showed that the differences among contract type variables are significant in the case of OTPI, PTPI, and PCPI. It indicates that contract type variables have an influence on project performance.

Table 11 ANOVA and Tukey Test Results of Contract Type Variables

Contract Type Variables	F-value	p-value	Significant Tukey Tests (0.05 Level)
OTPI	9.623	< 0.001	A+B I/D – A+B I/D Bonus I/D – A+B I/D
PTPI	5.644	0.0039	I/D – A+B I/D
OCPI	0.445	0.6412	N/A
PCPI	4.586	0.0109	A+B I/D – A+B I/D Bonus I/D – A+B I/D Bonus

Factor 2: Project Type

Considering the variety of project situations, there are numerous work types in highway construction. Typically, each project consists of one major work type, which briefly describes project characteristics, and several other minor work types. Projects were grouped according to major work description for a further analysis to test the effect of project type. Major work types used in this study are listed in Appendix A. The project type variable classifications are also shown in the table in Appendix A. Four levels of project type variables used in this study were: (1) Bridge Rehabilitation/Reconstruction (BRR), (2) Roadway Rehabilitation/ Reconstruction (RRR), (3) Roadway Resurfacing/Paving (RRP), and (4) Others. The box-and-whiskers plot of time performance of each project type variable is shown in Figure 7.

After categorizing project work types, an ANOVA test was performed to test the null hypothesis that all four population means for the groups are equal. The F-test results are shown in Table 12. Since the p-value is smaller than 0.05, it was concluded from this test that the effect of project type is significant. Thus, further analysis was needed to test which means are different from which others. The Tukey test was performed for multiple comparisons to test six possible cases: (1) BRR vs. RRR, (2) BRR vs. RRP, (3) BRR vs. Others, (4) RRR vs. RRP, (5) RRR vs. Others, and (6) RRP vs. Others. All cases were tested and only conclusive cases are summarized in Table 12. Although it was not found that there is any difference among contract type variables in the case of OCPI and PCPI, the test results showed that the differences among contract type variables are significant in the case of OTPI and PTPI. This indicates that contract type variables have an influence on project time performance.

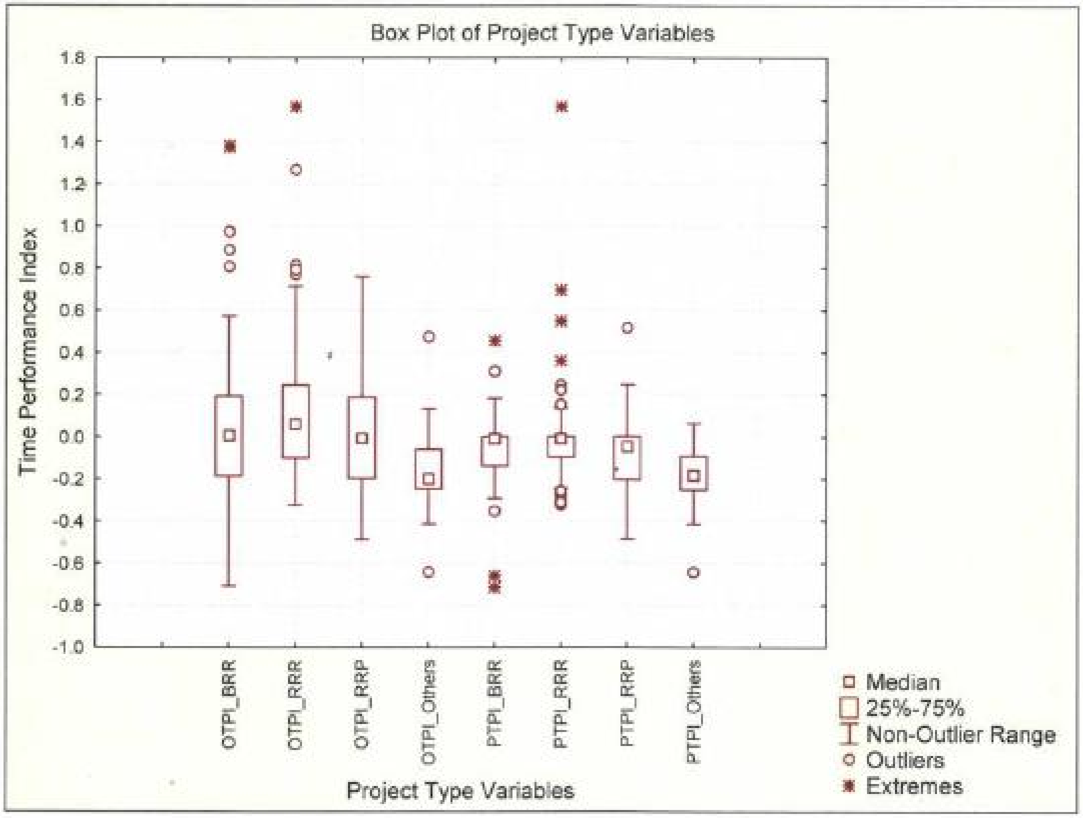


Figure 7 Box Plot of Project Type Variables

Table 12 ANOVA and Tukey Test Results of Project Type Variables

Project Type Variables	F-value	p-value	Significant Tukey Tests (0.05 Level)
OTPI	6.545	0.0003	BRR – Others RRR – Others RRP – Others
PTPI	6.212	0.0004	BRR – Others RRR – Others
OCPI	1.582	0.1938	N/A
PCPI	0.634	0.5936	N/A

Factor 3: District

There are eight transportation districts in Florida, including the turnpike district. Although each district generally has similar major divisions, the FDOT allows districts flexibility to manage their businesses using systems with which they feel most comfortable. Consequently, the organizational structure of each district varies. Since different district management systems may influence project performance before or during construction, the district variable was investigated. The levels of the district variable studied were as follows: (1) District 1, (2) District 2, (3) District 3, (4) District 4, (5) District 5, (6) District 6, (7) District 7, and (8) District 8. As a descriptive statistical summary, the box-and-whiskers plots of time performance of each district are illustrated in Figure 8.

Next, an ANOVA test was performed to test the null hypothesis that all eight population means for the groups are equal. The F-test results are shown in Table 13. Since the p-value is smaller than 0.05, it was concluded from this test that the effect of district is significant. As a result, further analysis was needed to test which means are different from which others. The Tukey test was performed for multiple comparisons to test all possible cases. In summary, only conclusive cases are included in Table 13. The test results showed that the differences among district variables are significant in all cases, OTPI, PTPI, OCPI and PCPI. This indicates that district variables have an influence on project time performance.

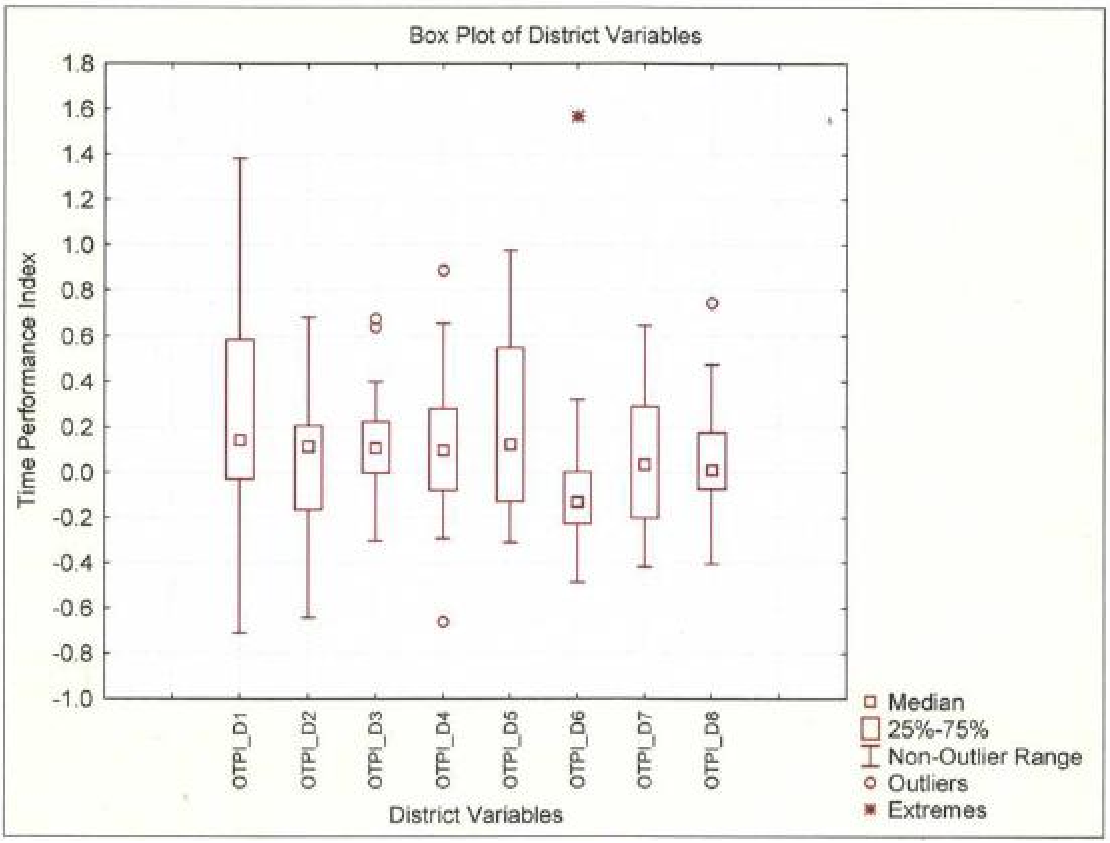


Figure 8 Box Plot of District Variables

Table 13 ANOVA and Tukey Test Results of District Variables

District Variables	F-value	p-value	Significant Tukey Tests (0.05 Level)
OTPI	7.579	<0.0001	District 1 – District 6 District 3 – District 6 District 4 – District 6 District 5 – District 6
PTPI	2.487	0.0171	District 1 – District 6
OCPI	6.735	<0.0001	District 4 – District 6 District 6 – District 8
PCPI	4.460	<0.0001	District 1 – District 8 District 2 – District 8 District 3 – District 8 District 4 – District 8 District 5 – District 8 District 6 – District 8 District 7 – District 8

Factor 4: Project Size

The original contract cost for each project is a quantitative variable. The contract amounts of the projects studied ranged from $114,185 to $99,537,000. The project size variable used in this study is the daily project cost, which can be calculated using the following formula:

$$\text{Daily Project Cost} = \frac{\text{Original Contract Cost}}{\text{Original Contract Duration}}, \qquad (7)$$

Daily project cost, also a quantitative variable, ranged from $1,014 to $96,638. Correlation analysis between daily project cost and performance indices was performed and the result showed a positive relationship with each index. Next, the categorization process, using quartiles of a distribution box-and-whiskers plot analysis, was performed. The distribution of data was divided using the inter-quartile range (IQR), which is the distance between the lower quartile (Q_1) and the upper quartile (Q_3). Daily project costs of Q_1 and Q_3 were $9,152 and $24,450, respectively, with IQR = $15,298. The groups of daily project cost variables were: (1) project size small (PSS; <$9,152), (2) project size medium (PSM; $9,152-$24,450), and (3) project size large (PSL; >$24,450). Results of the box-and-whiskers plot comparison of time and cost performance of each project size variable are illustrated in Figure 9.

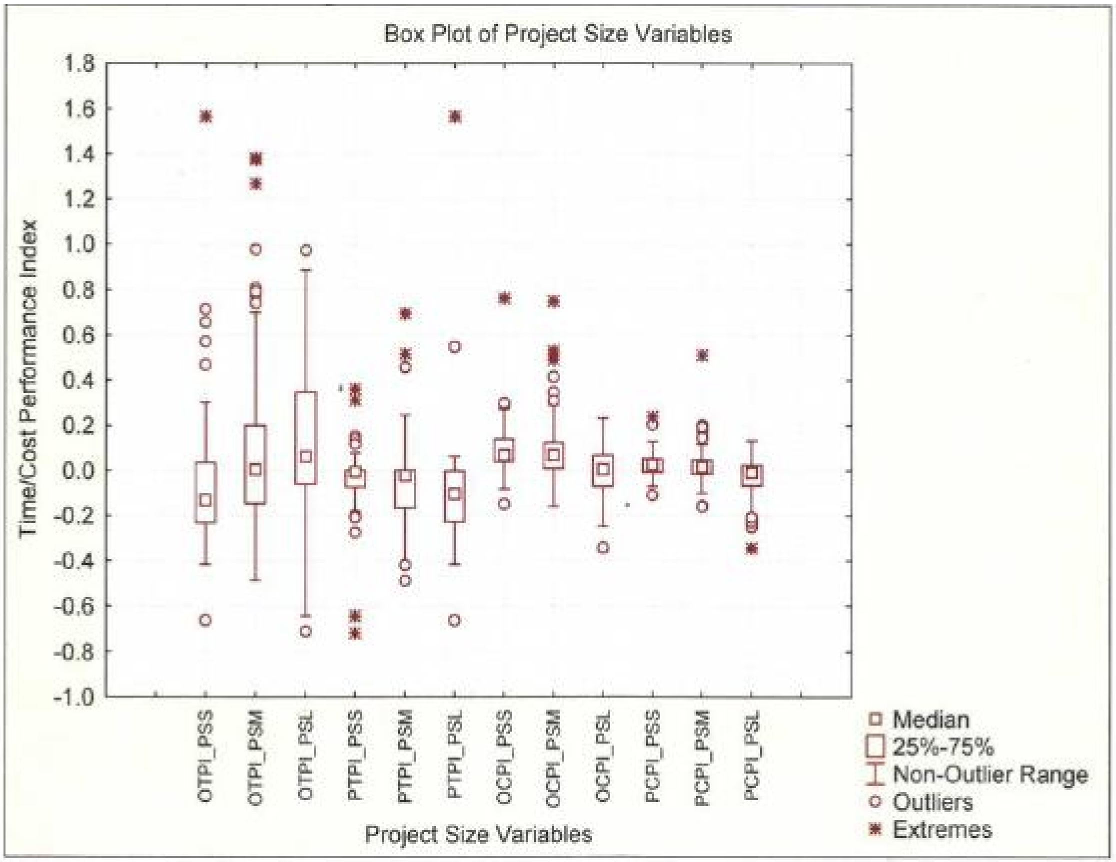


Figure 9 Box Plot of Project Size Variables

Next, an ANOVA test was performed to test the null hypothesis that all three population means for the groups are equal. The F-test results are shown in Table 14. Since the p-value is smaller than 0.05, it was concluded from this test that the effect of project size is significant. Thus, further analysis was needed to test which means are different from which others. Tukey tests were performed for multiple comparisons. The Tukey test results are shown in Table 14. Two out of three possible cases were significant. They were: (1) PSS vs. PSM and (2) PSS vs. PSL. Although it was not found that there is any difference among project size variables in the case of PTPI, the test results showed that the differences among project size variables are significant in the case of OTPI, OCPI, and PCPI. It indicates that project size variables have an influence on project performance.

Table 14 ANOVA and Tukey Test Results of Project Size Variables

Project Size Variables	F-value	p-value	Significant Tukey Tests (0.05 Level)
OTPI	7.186	0.0009	PSS – PSM PSS – PSL
PTPI	1.945	0.1448	N/A
OCPI	16.788	< 0.001	PSS – PSM PSS – PSL
PCPI	15.877	< 0.001	PSS – PSM PSS – PSL

Factor 5: Project Length

Project length data collected from 136 projects were used for analysis. Project lengths, a quantitative variable, ranged from 0.001 to 23.5 miles. Typically, project lengths of roadway resurfacing/paving type projects were longer than any project types with an average of 4.23 miles. On the other hand, projects types like low level bridge construction, movable span bridge replacement, safety, traffic signals, minor intersection, and add turn lane(s) had relatively short project length than other projects.

Initially, correlation analyses between the project length and performance indices were performed. Test results showed a small positive relationship with OCPI and PCPI and a small negative relationship with OTPI and PTPI between two variables. For further analysis, a categorization process was followed. Considering the distribution of the dataset, project length data was divided by the mean value of total project length (2.8 miles). The two groups of project length variables were: (1) project length below average (PLBA; <2.8 miles) and (2) project length above average (PLAA; >2.8 miles). As a descriptive statistical summary, box-and-whiskers plots of time and cost performance of each project length variable are illustrated in Figure 10.

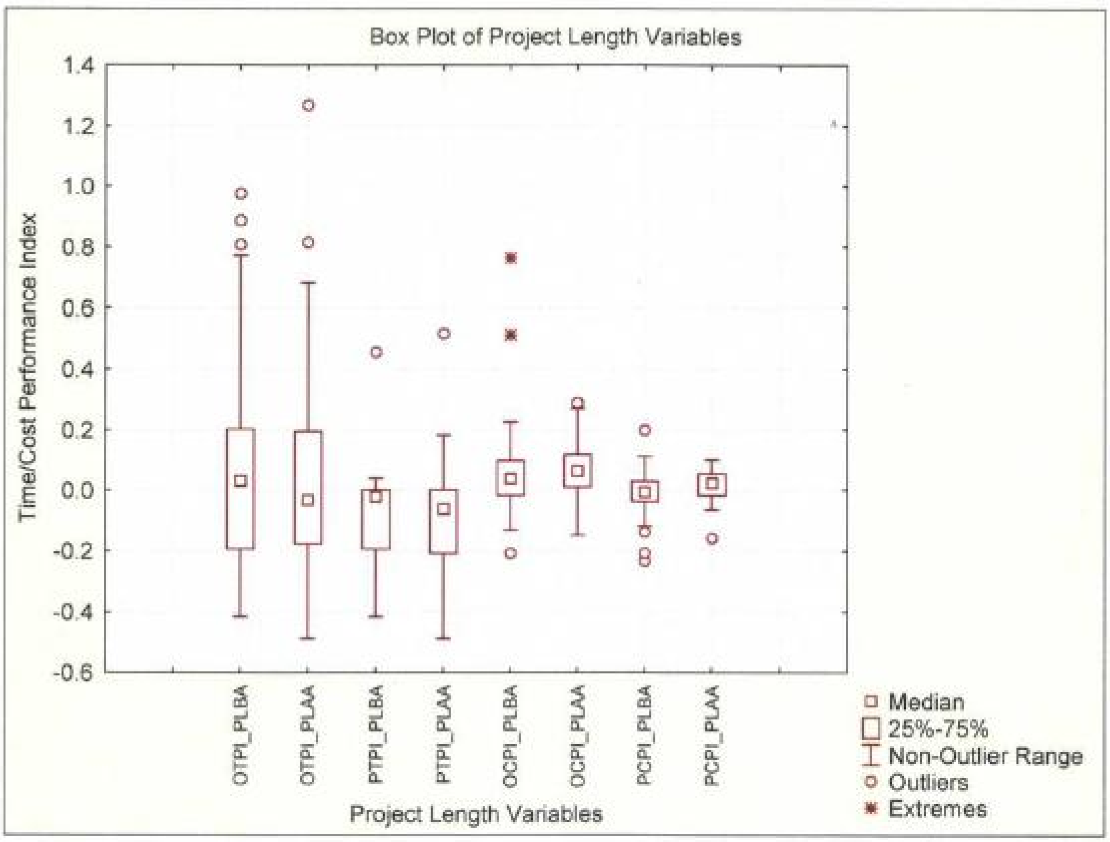


Figure 10 Box Plot of Project Length Variables

After categorizing project length variables, statistical significance tests were performed to determine the possible differences in project performance between project length variables. The two-sample t-test was used to determine whether there is a significant difference between the means of the two groups, PLBA and PLAA. In this statistical analysis, 68 observations from each variable were compared. Summary statistics of project length variables and the t-test results with p-value and significance are shown in Table 15. Although the t-test for project time performance was not significant, the t-test for project cost performance in the case of PCPI was significant at the 0.05 confidence level. The t-test result showed sufficient evidence that the average project cost performance from the two groups, PLBA and PLAA, are not the same. It indicates that project length variables have an influence on project cost performance.

Table 15 Two Sample t-Test Results of Project Length Variables

Project Length Variables	t-Test Statistics	p-value	Significant Tests (0.05 Level)
OTPI	0.358	0.7213	N/A
PTPI	0.516	0.6064	N/A
OCPI	-0.695	0.4888	N/A
PCPI	-2.743	0.0070	PLBA – PLAA

Factor 6: Maximum Incentive Amount

The maximum incentive amount proposed for each project is a quantitative variable. The various amounts ranged from $3,000 to $2,643,559 and the average incentive proposed amount was $370,548 per project. Initially, correlation analysis between maximum incentive amounts and performance indices was performed and the result showed a positive relationship with each index. Next, the categorization process, using quartiles of a distribution a box-and-whiskers plot analysis, was performed. The distribution of data was divided using the IQR. The maximum incentives of Q1 and Q3 were $45,000 and $450,000, respectively, with IQR = $405,000. The groups of maximum incentive amount variables were: (1) maximum incentive proposed small (MIS; <$45,000), (2) maximum incentive proposed medium (MIM; $45,000-$450,000), and (3) maximum incentive proposed large (MIL; >$450,000). As a descriptive statistical summary, box-and-whiskers plots on time and cost performance of maximum incentive variables are illustrated in Figure 11.

After categorizing maximum incentive amount variables, an ANOVA test was performed to test the null hypothesis that all three population means for the groups are equal. The F-test results are shown in Table 16. Since the p-value is smaller than 0.05, it was concluded from this test that the effect of maximum incentive amount is significant. Thus, further analysis was needed to test which means are different from which others. Tukey tests were performed for multiple comparisons. The Tukey test results are shown in Table 16. Three possible cases were tested: (1) MIS vs. MIM, (2) MIS vs. MIL, and (3) MIM vs. MIL.

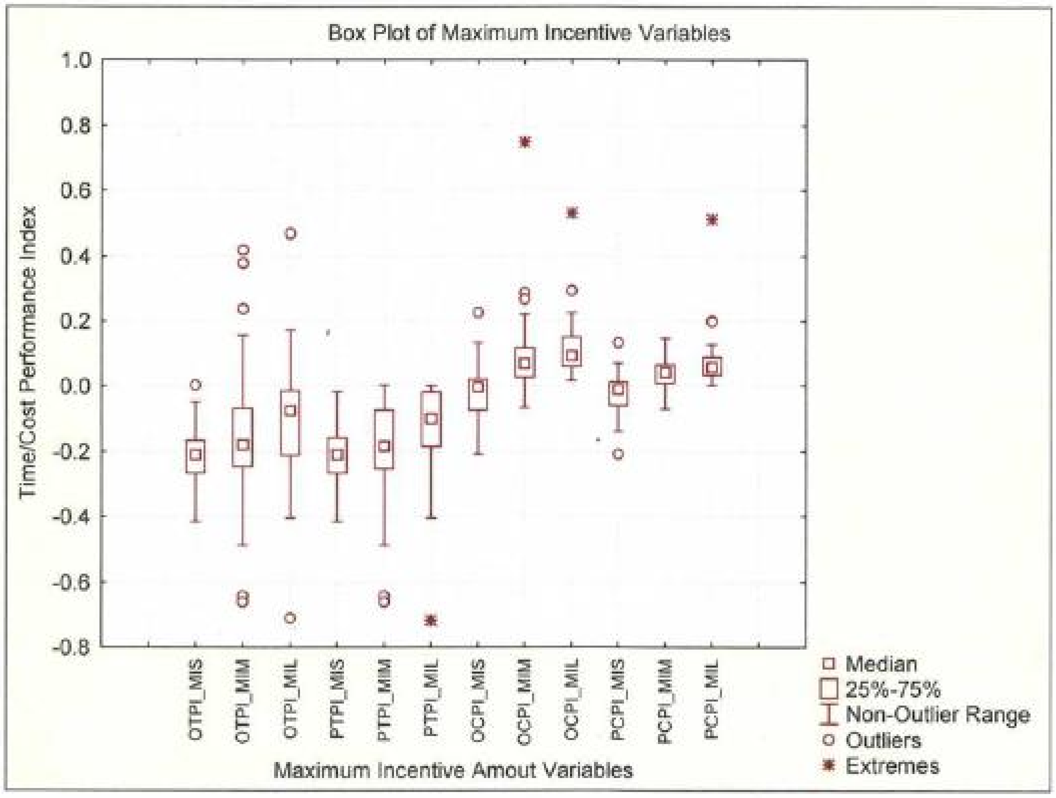


Figure 11 Box Plot of Maximum Incentive Amount Variables

With regard to project time performance, no test was significant to conclude that there is any difference among maximum incentive amount variables. However, the tests were significant in both cases of OCPI and PCPI regarding project cost performance. The test results showed that there are significant differences among maximum incentive amount variables. This indicates that maximum incentive amount variables have an influence on project cost performance.

Table 16 ANOVA and Tukey Test Results of Maximum I/D Amount Variables

Maximum I/D Amount Variables	F-value	p-value	Significant Tukey Tests (0.05 Level)
OTPI	2.335	0.1016	N/A
PTPI	1.849	0.1622	N/A
OCPI	11.611	< 0.001	MIS – MIM MIS – MIL
PCPI	18.065	< 0.001	MIS – MIM MIS – MIL MIM – MIL

Factor 7: Daily I/D Amount

The daily I/D amount for each project is a quantitative variable. The various I/D amounts ranged from $600 to $10,000 and the average daily I/D amount was $3,390 per project. Initially, correlation analysis between daily I/D amounts and performance indices was performed and the result showed a positive relationship with each index. Next, the categorization process, using quartiles of a distribution a box-and-whiskers plot analysis, was performed. The distribution of data was divided using the IQR. Daily I/D amounts of Q_1 and Q_3 were \$2,000 and \$4,000, respectively, with IQR = \$2,000. The groups of daily I/D amount variables were: (1) daily I/D amount small (DIS; <\$2,000), (2) daily I/D amount medium (DIM; \$2,000-\$4,000), and (3) daily I/D amount large (DIL; >\$4,000). As a descriptive statistical summary, box-and-whiskers plots of time and cost performance of daily I/D amount variables are illustrated in Figure 12.

After categorizing daily I/D amount variables, an ANOVA test was performed to test the null hypothesis that all three population means for the groups are equal. The F-test results are shown in Table 17. Since the p-value is smaller than 0.05, it was concluded from this test that the effect of daily I/D amount is significant. Thus, further analysis was needed to test which means are different from which others. Tukey tests were performed for multiple comparisons. The Tukey test results are shown in Table 17. Three possible cases tested were as follows: (1) DIS vs. DIM, (2) DIS vs. DIL, and (3) DIM vs. DIL.

With regard to project time performance, the tests were not significant to conclude that there is any difference among daily I/D amount variables in the case of PTPI. However, a comparison between DIS and DIL was significant in the case of OTPI. The result showed that there is a significant difference between daily I/D amount variables. This indicates that daily I/D amount variables have an influence on project time performance. With regard to project cost performance, the tests were significant in both cases of OCPI and PCPI. The test results showed that there are significant differences among daily I/D amount variables. This indicates that daily I/D amount variables have an influence on project cost performance.

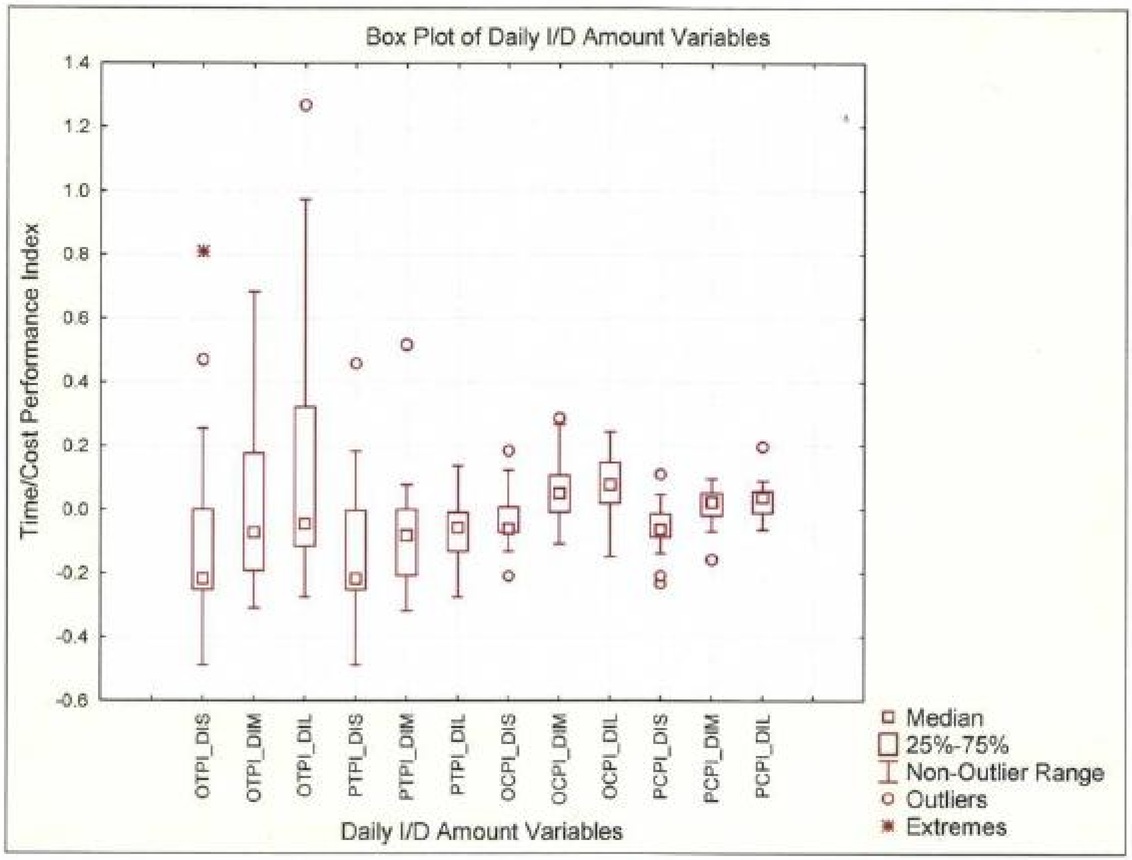


Figure 12 Box Plot of Daily I/D Amount Variables

Table 17 ANOVA and Tukey Test Results of Daily I/D Amount Variables

Daily I/D Amount Variables	F-value	p-value	Significant Tukey Tests (0.05 Level)
OTPI	4.699	0.0112	DIS – DIL
PTPI	2.989	0.0549	N/A
OCPI	13.298	< 0.001	DIS – DIM DIS – DIL
PCPI	17.247	< 0.001	DIS – DIM DIS – DIL

SUMMARY OF DATA ANALYSIS

Outcomes of individual projects are affected by various factors. This research has found several project factors influencing I/D contracting performance based on statistical analysis as follows:

- The important factors that had significant impacts on project time performance were the effects of contract type, project type, district, project size, and daily I/D amount.
- The important factors that had significant impacts on project cost performance were the effects of contract type, district, project size, project length, maximum incentive amount, and daily I/D amount.

The results of project data analysis will help decision makers understand project key factors that affect project time and cost performance. The important findings from data analysis are summarized as follows:

- A+B Bonus with I/D contracting was most effective to improve original project time performance.
- Project type "Others" showed better project time performance compared to roadway or bridge project types. It is important for decision makers to understand that higher traffic impact is generally expected for any construction projects of roadway or bridge types during construction.
- Project time performance of I/D contracting projects completed in District 6 were significantly better than any other districts.
- Project contract amount was not an important factor that influences project performance. However, daily project cost (also know as project size) had an influence on project performance. For instance, the smaller projects in terms of daily cost tended to be more efficient to improve original project time and cost performance.

In summary, significant/non-significant factors at the 0.05 level based on statistical analysis are shown in Table 18. Project time and cost performances grouped by contract types and categorized by project types are shown in Table 19.

Table 18 Summary of Significant (S) or Non-significant (NS) Factors by Indices

Variables	OTPI	PTPI	OCPI	PCPI
Contract Type	S	S	NS	S
Project Type	S	S	NS	NS
District	S	S	S	S
Project Size	S	NS	S	S
Project Length	NS	NS	NS	S
Max. Incentive Amount	NS	NS	S	S
Daily I/D Amount	S	NS	S	S

Table 19 Project Performance Summary by Contract Types and Project Types

Contract Type	Project Type Category	Number of Projects	Average			
			OTPI	PTPI	OCPI	PCPI
I/D	Bridge Rehabilitation/Reconstruction	29	0.022	-0.126	0.054	0.005
	Roadway Rehabilitation/Reconstruction	51	0.102	-0.038	0.086	-0.001
	Roadway Resurfacing/Paving	59	-0.005	-0.102	0.046	-0.005
	Others	24	-0.184	-0.188	0.037	0.015
I/D Total		163	0.007	-0.099	0.059	0.001
A+B I/D	Bridge Rehabilitation/Reconstruction	25	0.167	-0.006	0.060	-0.008
	Roadway Rehabilitation/Reconstruction	52	0.197	-0.007	0.075	0.014
	Roadway Resurfacing/Paving	20	0.160	-0.059	0.049	0.004
	Others	3	-0.020	-0.164	0.061	0.012
A+B I/D Total		100	0.176	-0.022	0.066	0.007
A+B I/D Bonus	Bridge Rehabilitation/Reconstruction	5	0.128	0.004	0.105	0.028
	Roadway Rehabilitation/Reconstruction	18	-0.025	-0.071	0.086	0.053
	Roadway Resurfacing/Paving	9	-0.085	-0.093	0.057	0.037
A+B I/D Bonus Total		32	-0.018	-0.065	0.081	0.045
Grand Total		295	0.061	-0.069	0.063	0.008

DECISION SUPPORT MODEL DEVELOPMENT

In this chapter, a model to support the decision-making process for I/D construction projects is presented. A project performance prediction model using Monte Carlo simulation was developed. The development process is described in detail. To predict project time and cost performance, Monte Carlo simulation procedures were adopted for the development of a spreadsheet-based decision support model. The factors that affect I/D project performance were employed as input variables. In the modeling process, beta distributions were selected as the theoretical distribution of the input variables used for the Monte Carlo simulation. For this study, the *@Risk* Version 5.5 add-in for *Microsoft Excel* was implemented to perform the Monte Carlo simulation procedures. Graphic User Interfaces were designed using *Visual Basic Application* programming. The entire development process of the decision support model is illustrated in Figure 13.

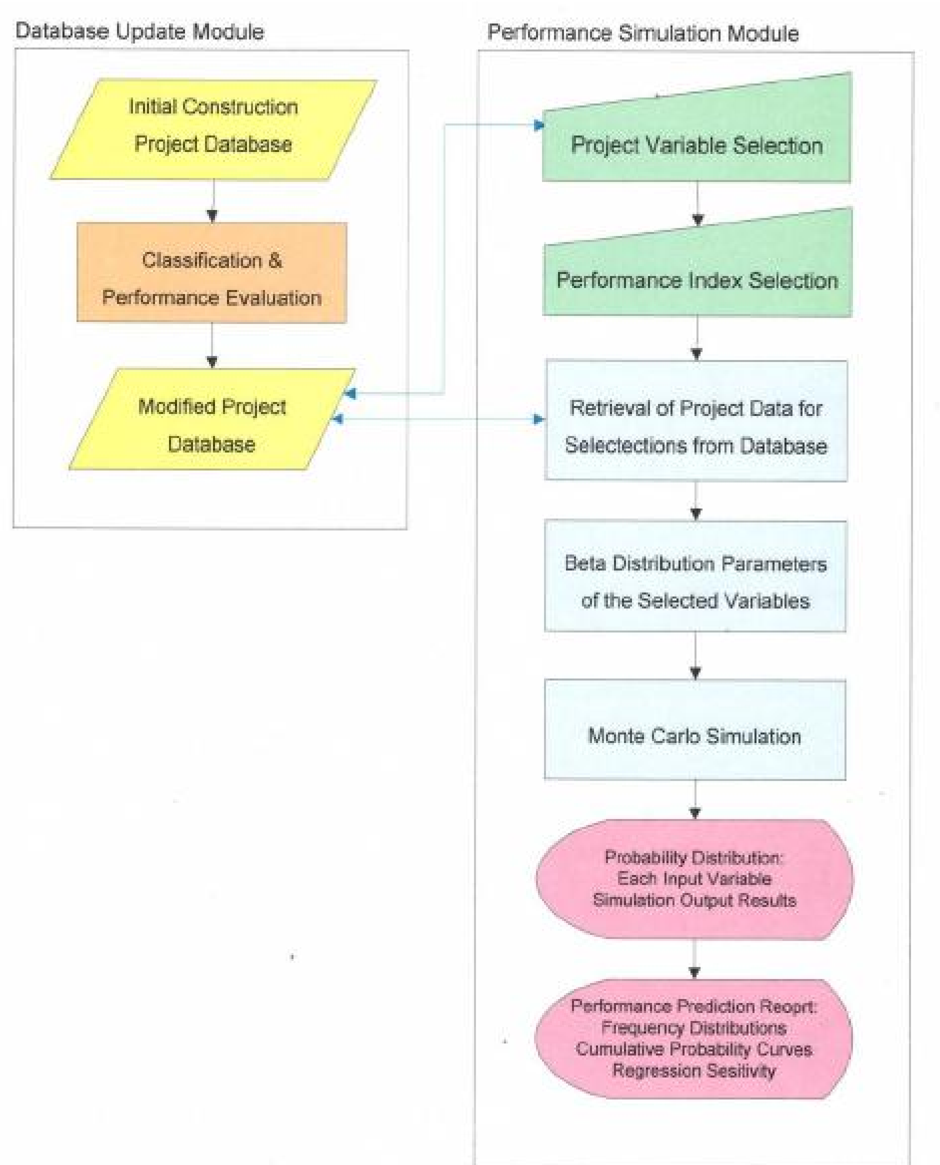


Figure 13 Flow Chart of I/D Performance Simulation Model Development Process

The decision support model consists of two modules: (1) a database update module, and (2) a performance simulation module. The database update module includes the "Classification and Performance Evaluation" process. During this process, each project in the initial construction project database was automatically classified and its time and cost performance was automatically evaluated as well. As an outcome of this process, a modified project database was generated to be used as inputs of the performance simulation module.

There are three parts in the performance simulation module: (1) Selection of project variables and performance index as simulation inputs, (2) Monte Carlo simulation procedures, and (3) Graphs and reports of simulation output results, including distributions of possible results, frequency distributions of possible output values, cumulative probability curves, and regression sensitivity analysis displayed as a bar chart.

DATABASE UPDATE MODULE

The database update module is designed to provide inputs for performance simulation as well as update the construction project database in the future. This module consists of three parts: (1) Initial construction project database, including all raw project data, (2) Classification and performance evaluation process categorizing project data into similar groups and evaluating each project with four performance indices, OTPI, PTPI, OCPI and PCPI, calculated using Eq. (1, 2, 3, and 4), respectively, and (3) Modified project database including input variables of the performance simulation module as an outcome of the classification and performance evaluation process. All variables and selection criteria used for performance simulation are listed as follows:

1. Contract type variables are categorized into three groups.
    1.1. A+B
    1.2. A+B Bonus
    1.3. I/D

2. Project work type variables are grouped into four categories using work-mix classification shown in Appendix A.
    2.1. Bridge Rehabilitation/Reconstruction
    2.2. Roadway Rehabilitation/Reconstruction
    2.3. Roadway Resurfacing/Paving
    2.4. Others

3. District variables include all eight districts.
    3.1. District 01
    3.2. District 02
    3.3. District 03
    3.4. District 04
    3.5. District 05
    3.6. District 06
    3.7. District 07
    3.8. District 08

4. Project size variables are grouped into three levels. In case project size data are not available, an “N/A” option is given to the user.
   4.1. Small: < $9,152 (25th Percentile)
   4.2. Medium: $9,152–$24,450
   4.3 Large: > $24,450 (75th Percentile)
   4.4. N/A

5. Project length variables are categorized into two groups. In case project length data are not available, an “N/A” option is given to the user.
   5.1. Below Average: < 2.8 Miles (Mean Value)
   5.2. Above Average: ≥ 2.8 Miles
   5.3. N/A

6. Maximum incentive proposed amount variables are grouped into three levels. In case maximum incentive amount data are not available, an “N/A” option is given to the user.
   6.1. Small: < $45,000 (25th Percentile)
   6.2. Medium: $45,000–$450,000
   6.3. Large: > $450,000 (75th Percentile)
   6.4. N/A

7. Daily I/D amount variables are grouped into three levels. In case daily I/D amount data are not available, an “N/A” option is given to the user.
   7.1. Small: < $2,000 (25th Percentile)
   7.2. Medium: $2,000–$4,000
   7.3. Large: > $4,000 (75th Percentile)
   N/A

The selection criteria of all variables are determined based on the existing project database. Once the initial project database is updated, then the selection criteria will be automatically recalculated and stored in the modified database. In addition, it will automatically update drop down boxes for selecting project inputs in the performance simulation module.

PERFORMANCE SIMULATION MODULE

The I/D project performance simulation module is designed to select project variables and performance index as simulation inputs, perform Monte Carlo simulation procedures, and generate user-friendly simulation results. During selection of input variables and performance index, the system retrieves the selected project performance indices which belong to the selected input variables from the modified database in the database update module.

In order to perform Monte Carlo simulation, the modeling procedure used herein is based on the flexibility of beta distributions that provides various shapes of probability distribution. A beta probability density function can be formulated using shape parameters and the lower boundary (a) and the upper boundary (b) of the distribution:

$$f(x) = \frac{(x-a)^{p-1}\,(b-x)^{q-1}}{B(p,q)(b-a)^{p+q-1}}, \tag{8}$$

where $a \le x \le b$, p and q represent shape parameters, and $B(p,q)$ represents a beta function. Beta functions used in Eq. (8) are defined as:

$$B(p,q) = \int_0^1 x^{p-1}(1-x)^{q-1}dx, \tag{9}$$

where

$$p = \{(\bar{x}-a)/(b-a)\}\left[\frac{\{(\bar{x}-a)/(b-a)\}\,\{1-(\bar{x}-a)/(b-a)\}}{S^2/(b-a)^2} - 1\right], \tag{10}$$

$$q = [1-\{(\bar{x}-a)/(b-a)\}]\left[\frac{\{(\bar{x}-a)/(b-a)\}\,\{1-(\bar{x}-a)/(b-a)\}}{S^2/(b-a)^2} - 1\right], \tag{11}$$

where $\bar{x}$ represents the sample mean and S^2 represents the sample variance.

The shape parameters and the lower and upper boundaries were determined from a dataset of each input variable. Using the beta distribution given in Eq. (8), such data of each variable were fitted into its own shape. An example of generating parameters of beta distribution is shown in Appendix B.

Monte Carlo Simulation Procedures

The Monte Carlo simulation method, a stochastic analysis, is a well known method for handling uncertainty and has been widely used as an aid in decision-making processes (Guyonnet et al. 1999 and Schuyler 2001). This approach was used to estimate potential project time and cost performance in this study. Figure 14 illustrates the Monte Carlo simulation procedures for an example of OTPI simulation.

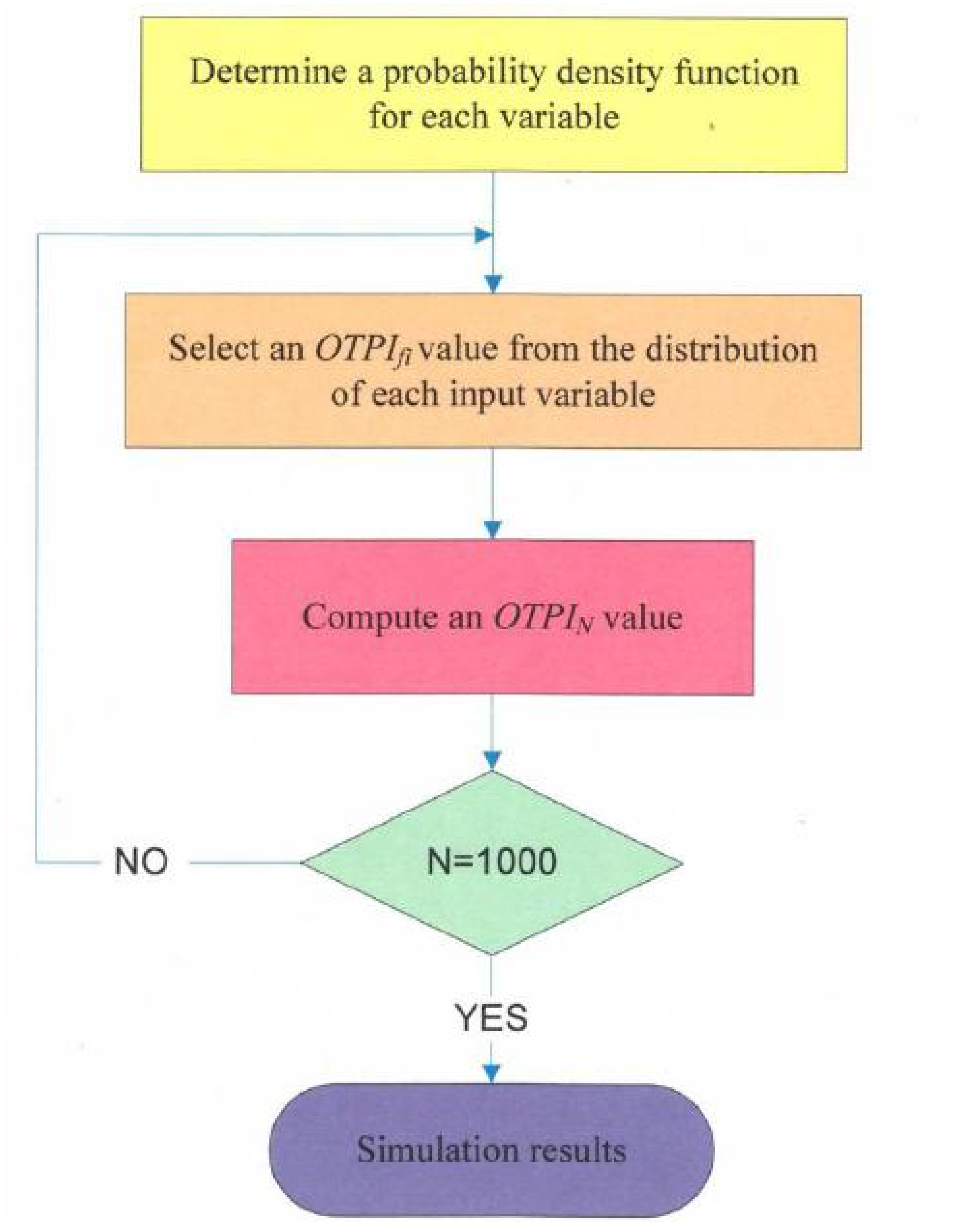


Figure 14 Flowchart of Monte Carlo Simulation Procedures

The following five steps describe the Monte Carlo simulation procedures for an example of OTPI simulation shown in Figure 14.

Step 1: A beta probability density function for each variable was determined computing the parameters, p, q, a, and b in Eq. (10) and (11).

Step 2: Considering the probability density of each input variable, an $OTPI$ value was randomly generated from the distribution of each input variable.

Step 3: An $OTPI_N$ value was computed using the following formula:

$$OTPI_N = \sum_{f=1}^{n} \text{OTPI}_{fi} \text{ X } W_i, \quad (12)$$

where the $OTPI_N$ represents an $OTPI$ value generated from each iteration process. The N represents the number of iterations, usually $N = 1000$. The $OTPI_{fi}$ represents an $OTPI$ value generated from the input variables. The subscript fi stands for the i^{th} factor selected in simulations. The n represents the number of input variables considered in this study, $n = 7$. The W_i represents the weight of each input variable.

The variance of each input variable was used to assign weights to input variables. The assigned weights were calculated using the following formula:

$$W_i = \left(\frac{w_i}{\sum_{i=1}^{n} w_i} \right), \quad (13)$$

where $w_i = \left(\frac{1}{S_i^2} \right)$ and $\sum_{i=1}^{n} w_i = 1$.

The weighting process considered the impact of input variables. Since smaller variance is more desirable for developing a prediction model, the process assigned more weight to the variables that have smaller variance. Thus, each simulation included not only the most dominant variable but also the least dominant variable among input variables.

Step 4: The iteration process was performed N times. A value of $OTPI_N$ was computed and stored iteration by iteration. The process stopped when the number of iterations reached the desired level.

Step 5: A cumulative frequency curve and a histogram of all $OTPI_N s$ were plotted and the summary statistics of simulation results were reported. A tornado graph was plotted to determine what factors had the most influence on the success of the project. Regression sensitivity for $OTPI$ was reported.

Tools and Programming for Simulation

In this study, the *@Risk* Version 5.5 add-in for *Microsoft Excel* was implemented to perform Monte Carlo simulation procedures. The *@Risk* functions and types are accessible to programmers of *Excel Visual Basic for Applications (VBA)* and allow them to automate the process of editing *@Risk* settings using code, as well as starting and controlling an *@Risk* simulation to obtain simulation results (*@Risk 2009* and Kimmel 2003). Graphic User Interfaces were developed using *VBA* programming. Input forms as data entry screens were created in the *Visual Basic Editor*.

Figure 15 shows a screen snapshot of the main page of I/D contracting decision support model. A dialog box of project variable selection for a roadway resurfacing project is shown in Figure 16. The input dialog box includes seven options of project variable selections. Each drop down box has two to eight levels of the variable with "N/A" as one of the options.

When the "NEXT" button is clicked in the project variable selection dialog box, the dialog box of project performance selection, shown in Figure 17, pops up. The user then selects one of the performance indices. When the "START" button is clicked in the form displayed in Figure 17, a report of simulation results is generated and displayed, as shown in Figure 18.

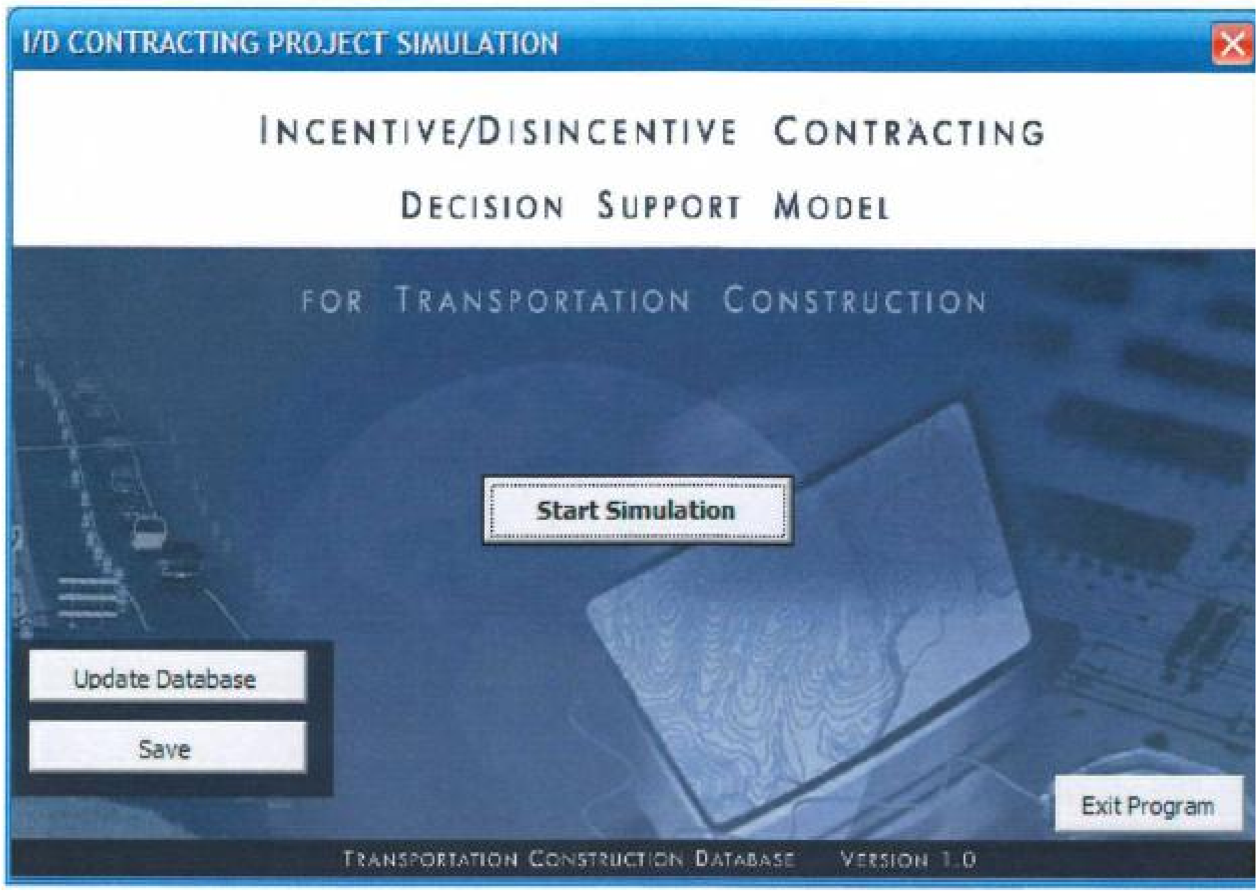


Figure 15 Main Page of I/D Contracting Decision Support Model

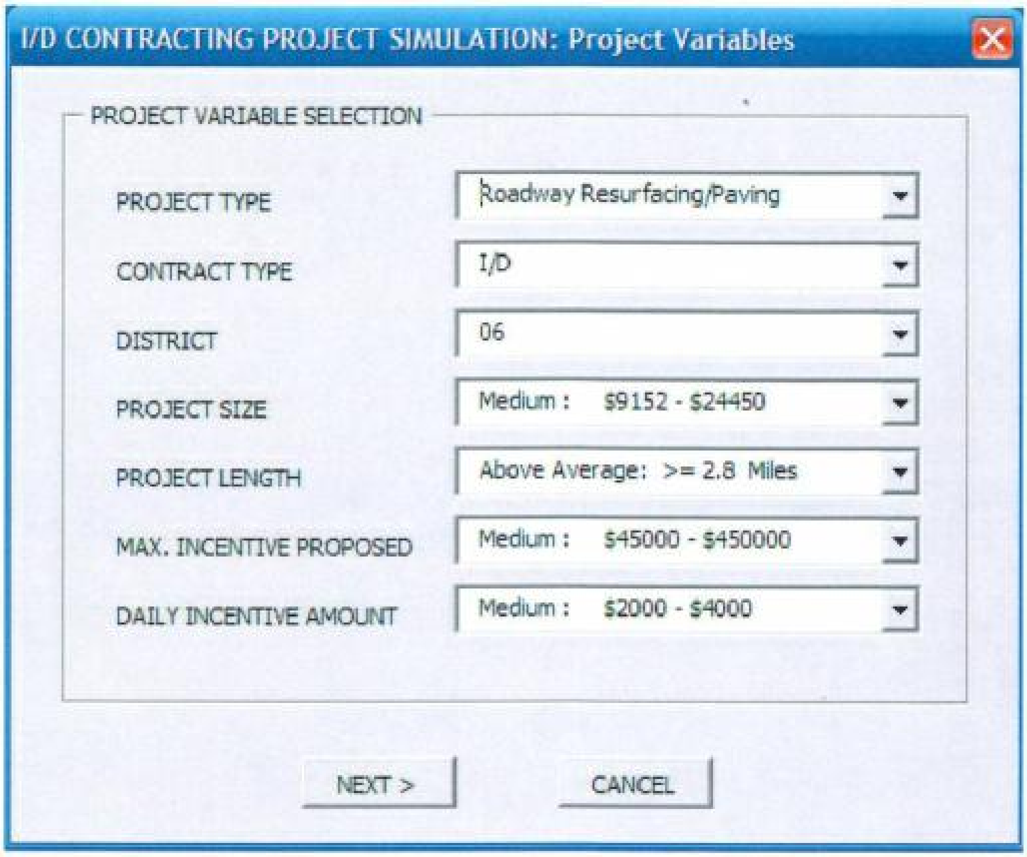


Figure 16 Project Variable Selection Dialog Box for Project FIN 412481

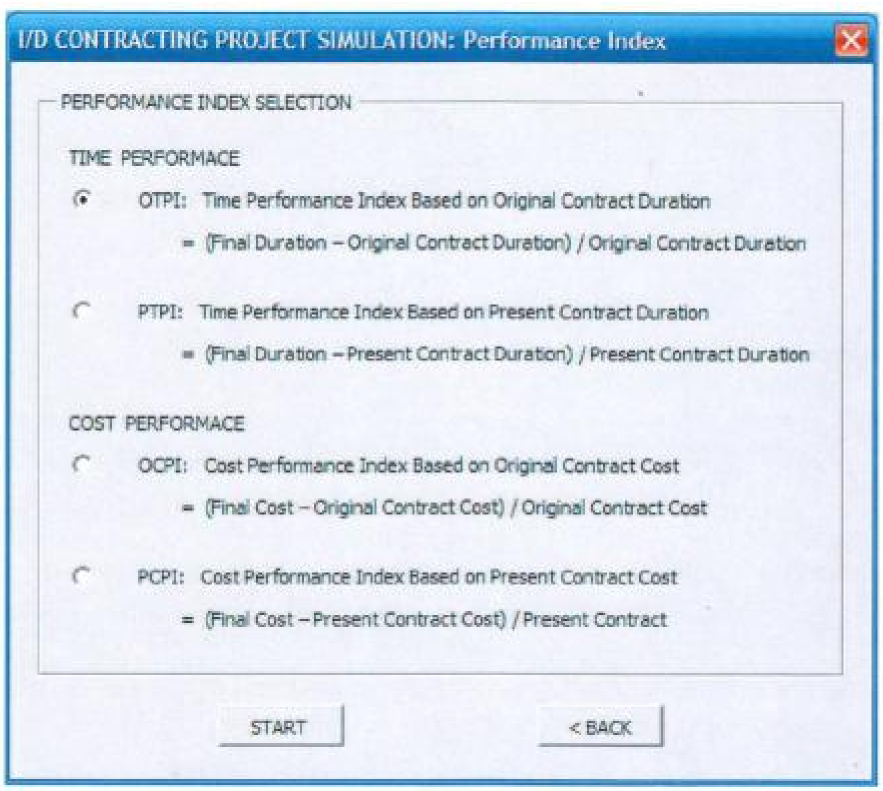
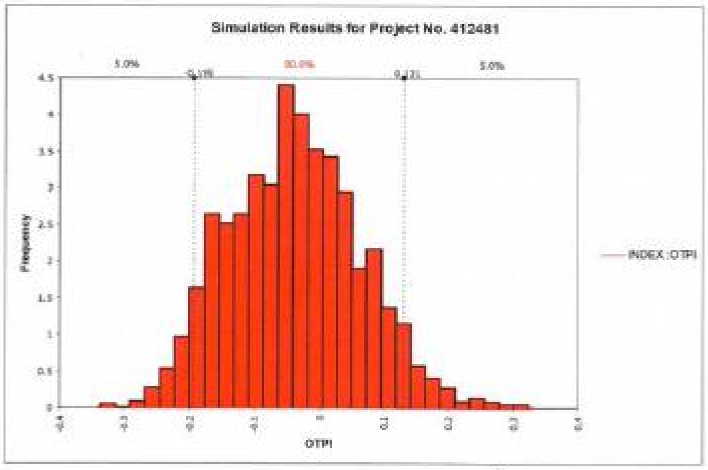
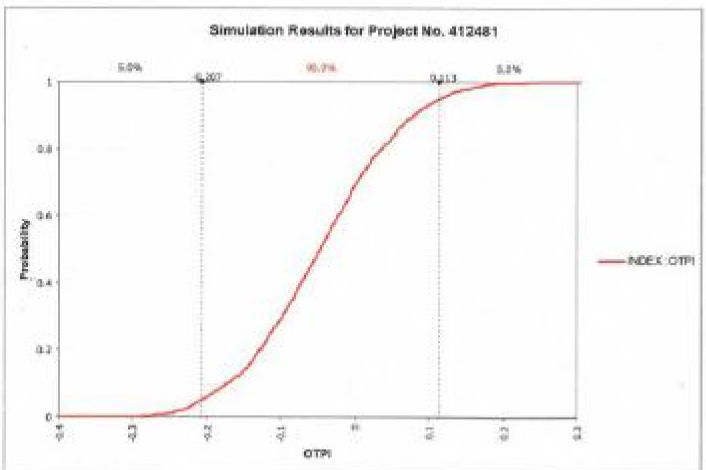


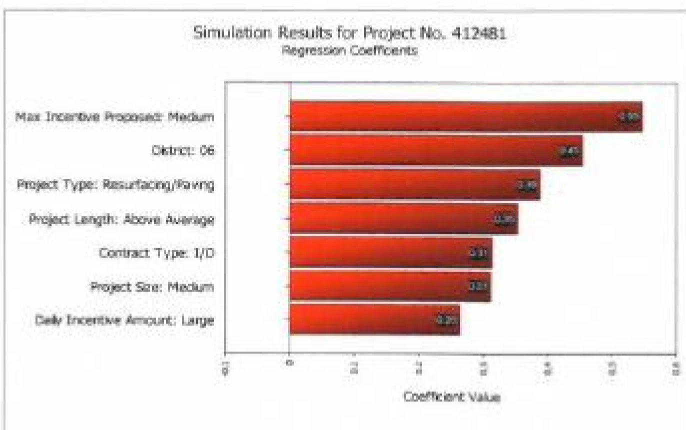
Figure 17 Performance Index Selection Dialog Box



Simulation Summary Information	
Workbook Name	I-D_SimulationModel_V1-2
Number of Simulations	1
Number of Iterations	1000
Number of Inputs	7
Number of Outputs	1
Sampling Type	Latin Hypercube
Simulation Start Time	10/29/09 23:11:43
Simulation Duration	00:00:01
Random # Generator	Mersenne Twister
Random Seed	96174649



Summary Statistics for INDEX :OTPI			
Statistics		Percentile	
Minimum	-0.3364	5%	-0.1947
Maximum	0.3228	10%	-0.1733
Mean	-0.0390	15%	-0.1519
Std Dev	0.1003	20%	-0.1291
Variance	0.010067796	25%	-0.1118
Skewness	0.205762125	30%	-0.0947
Kurtosis	2.881355153	35%	-0.0815
Median	-0.0406	40%	-0.0625
Mode	0.0052	45%	-0.0524
Left X	-0.1947	50%	-0.0406
Left P	5%	55%	-0.0292
Right X	0.1306	60%	-0.0162
Right P	95%	65%	-0.0012
Diff X	0.3253	70%	0.0101
Diff P	90%	75%	0.0277
#Errors	0	80%	0.0456
Filter Min	Off	85%	0.0665
Filter Max	Off	90%	0.0909
#Filtered	0	95%	0.1306



Regression and Rank Information for INDEX			
Rank	Name	Regr	Corr
1	Max Incentive Pr	0.547	0.531
2	District : 06 / Ris	0.454	0.398
3	Project Type : R	0.388	0.324
4	Project Length :	0.352	0.335
5	Contract Type :	0.312	0.275
6	Project Size : M	0.311	0.283
7	Daily Incentive Ar	0.263	0.278

Figure 18 Report of Project Performance Simulation Results for Project No. 412481

Interpretation of Simulation Results

A probability distribution is well known as a device for presenting the quantified risk for a variable. The simulation result is also easy to understand since the output probability distribution graphically displays the probabilities and users can get a feel for the risks involved. Since the output probability distribution describes a range of possible values and their likelihood of occurrence, the decision-maker can easily recognize that some outcomes are more likely to occur than others.

A histogram of all $OTPI_N s$ and a cumulative frequency curve of all $OTPI_N s$ are shown in Figure 19 and 20, respectively. The interpretation of the histogram and cumulative curve can answer the following questions from the project planners:

1. What is the most likely $OTPI$ value of the simulation result?
2. What is the probability that the actual project time performance will be ahead of schedule or on time?
3. What is the probability that the actual project cost will not exceed project contracting amount?
4. What is the project planner's certainty that the project performance index will be higher than a specific level?

A tornado graph that demonstrates what factors have the most influence on the success of the project is shown in Figure 21. In this example case, the most dominant factor was the maximum incentive amount while the least dominant factor was daily I/D amount. The probability that the actual project time performance will be ahead of schedule or on time is approximately 70%.

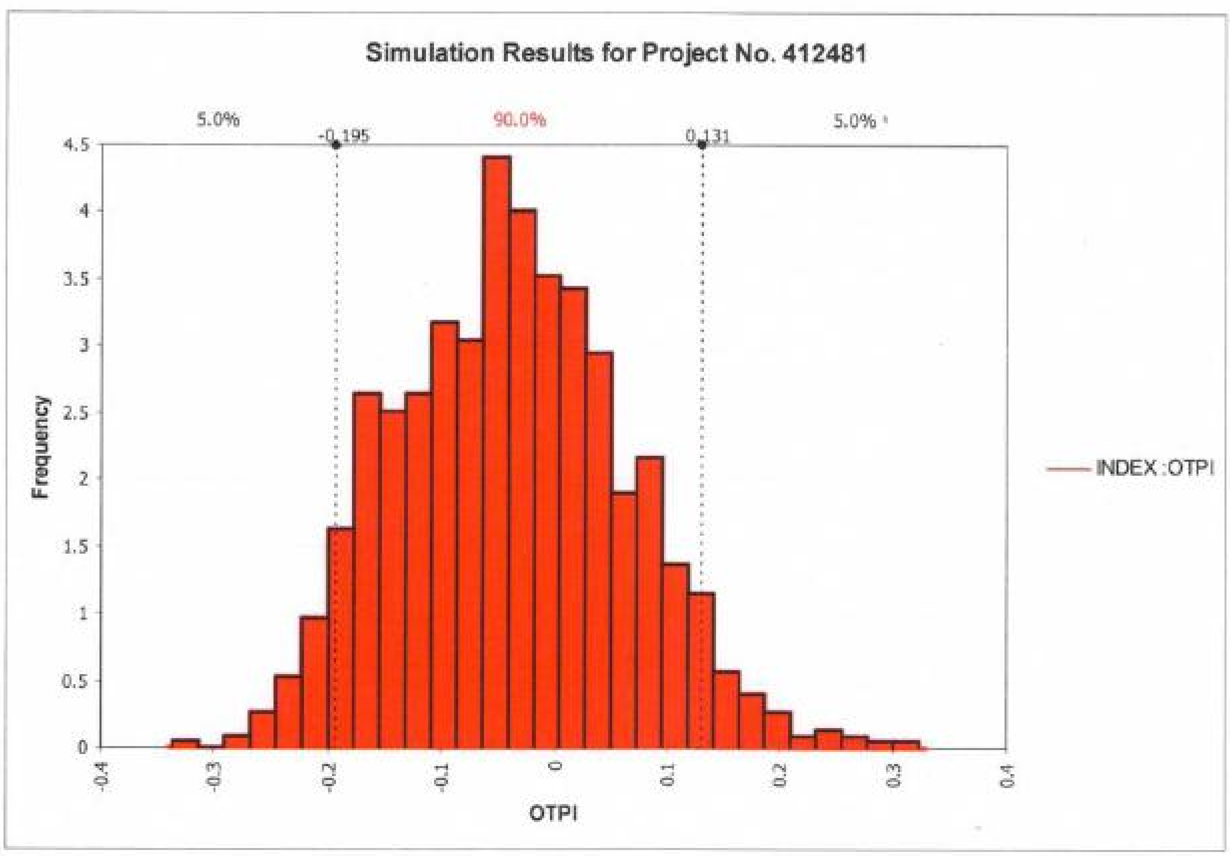


Figure 19 Histogram of OTPI Simulation Results for Project No. 412481

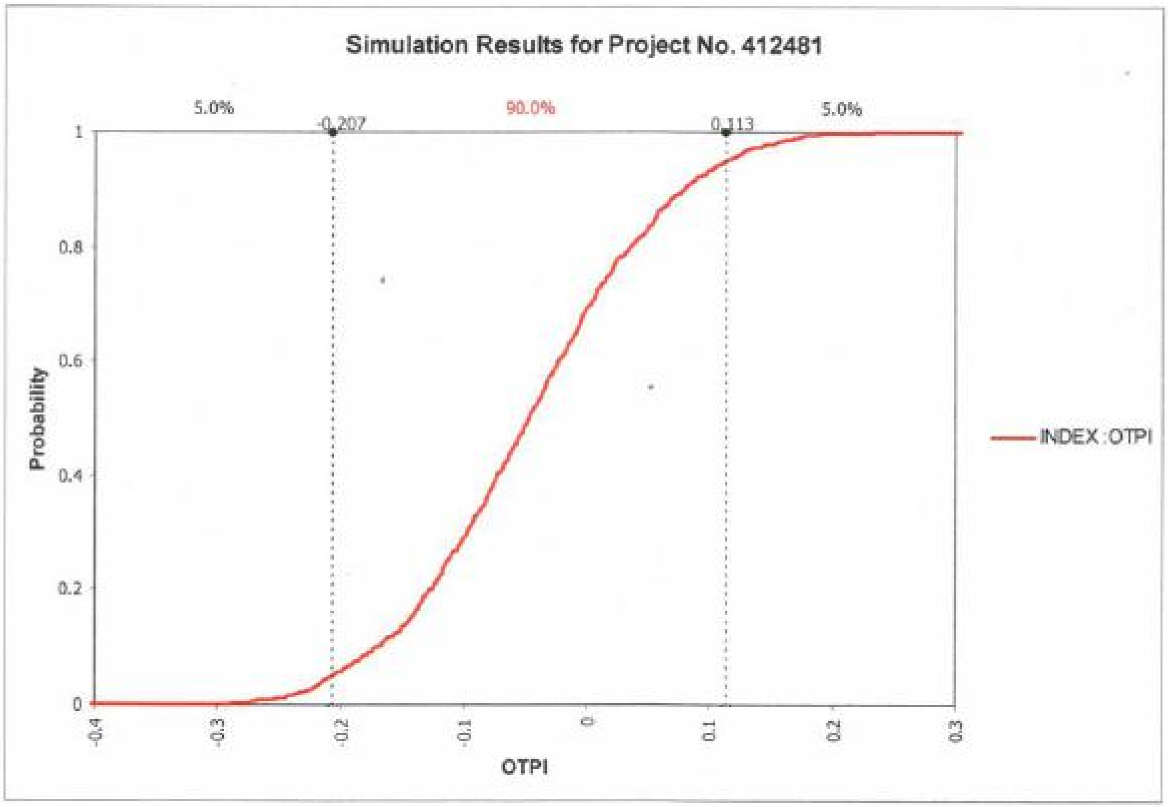


Figure 20 Cumulative Curve of OTPI Simulation Results for Project No. 412481

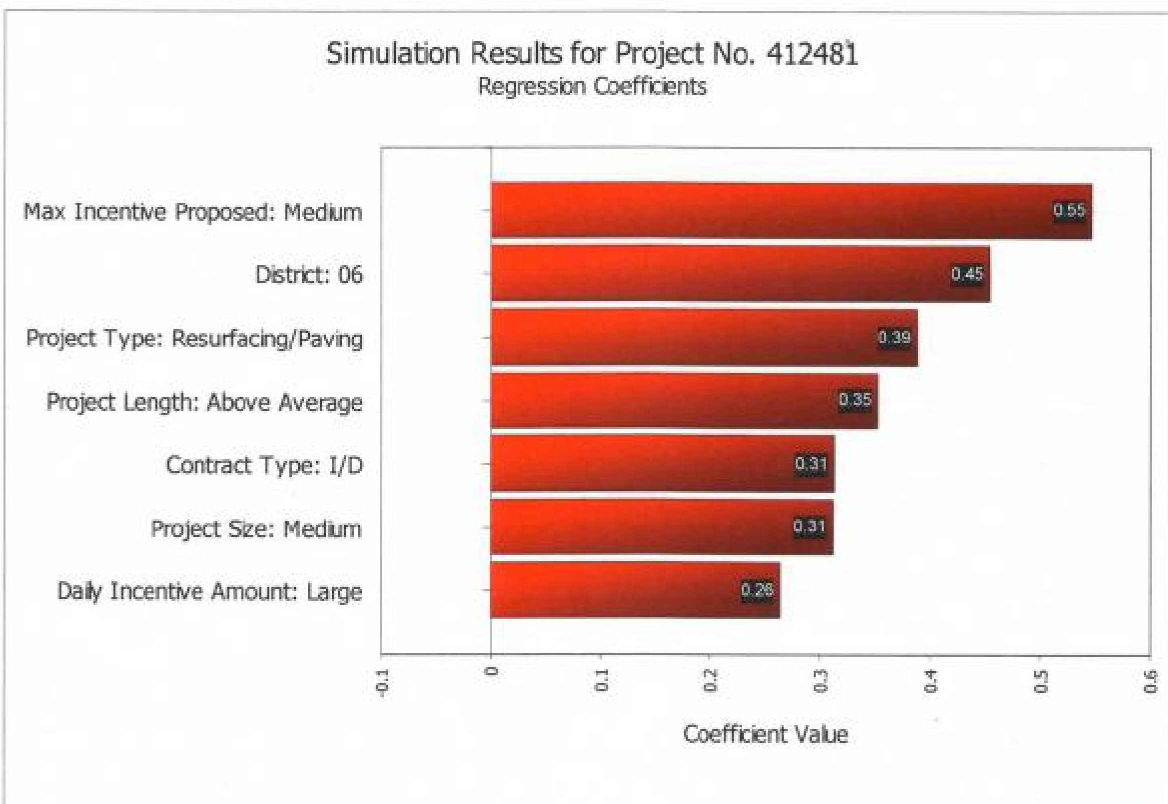


Figure 21 Tornado Graph of OTPI Simulation Results for Project No. 412481

MODEL VALIDATION

Unlike a regression prediction model, the developed simulation model is not designed to predict a specific value but instead is designed to predict a range of values with probability. It is also possible that an actual value falls out of a prediction range of the simulation model because the prediction results are based on the performance of historical projects. However, the accuracy of the performance prediction range is important to ensure the project planners can use the developed model with confidence. As a result, the developed simulation model needs to be validated through project case studies.

PROJECT DATA FOR VALIDATION

A total of 30 additional FDOT construction projects not included in developing the proposed model were used to investigate the prediction accuracy of the simulation model. All projects were completed in Florida and accepted in fiscal year 2007 to 2008. All three contract types were used for 16 different project work types. There were ten resurfacing projects completed and eight add lane or turn lane projects using I/D, A+B I/D, or A+B Bonus I/D.

Project duration varied from 50 to 1200 days and original contract amounts ranged from $513,256 to $80,159,992. The daily I/D amounts varied from $2,000 to $10,000 and the maximum incentive amount proposed ranged from $50,000 to $4,600,000. Twenty-one contractors completed 30 projects and each contractor finished up to three projects during the case study period. The input data of the 30 cases used in the simulation are shown in Table 20.

Of the 30 I/D projects, contractors were able to achieve incentives from 21 projects and the overall incentive achievement rate was approximately 70%. Total incentive amount paid was $9,993,235 and the incentive amounts achieved varied from $9,900 to $4,600,000 with an average of $326,708. During the case study period, one contractor was charged with a disincentive of $192,000 from a resurfacing project. Approximately 27% of the time, contractors were not able to achieve incentives or were not charged with any disincentives. Table 21 shows the number of projects and dollar amounts paid for incentives by contract types as well as by project types during the case study period.

VALIDATION METHOD AND RESULTS

For the model validation purpose, an analysis of project performance prediction range was used to test whether an actual performance value falls within the expected boundary of the minimum and the maximum of simulation values. Four simulations were run for each project case and a total of 120 simulations were performed in the cases of *OTPI, PTPI, OCPI*, and *PCPI*.

Table 20 Input Data Used in OPTI Simulation

Case	Contract Type	Project Type	District	Project Size	Project Length*	Max. Incentive*	Daily I/D Amount*
1	A+B I/D	RRR	03	PSL	N/A	N/A	N/A
2	A+B I/D	RRR	05	PSM	PLAA	N/A	N/A
3	A+B Bonus I/D	RRR	06	PSL	PLBA	MIL	N/A
4	A+B Bonus I/D	RRR	06	PSL	N/A	MIL	DIL
5	A+B I/D.............	RRR	05	PSL	PLAA	N/A	N/A
6	A+B I/D	RRR	05	PSL	PLAA	N/A	N/A
7	I/D	RRR	06	PSM	N/A	N/A	N/A
8	I/D	RRR	06	PSS	N/A	N/A	N/A
9	I/D	BRR	02	PSL	N/A	N/A	N/A
10	I/D	Others	04	PSM	N/A	N/A	N/A
11	I/D	RRP	06	PSM	N/A	N/A	N/A
12	A+B I/D	RRR	05	PSL	PLBA	N/A	N/A
13	I/D	RRR	08	PSM	N/A	N/A	N/A
14	A+B I/D	RRR	05	PSL	PLAA	N/A	N/A
15	I/D	RRR	06	PSS	N/A	N/A	N/A
16	A+B I/D	RRR	01	PSL	PLAA	N/A	N/A
17	I/D	Others	06	PSS	N/A	MIS	DIM
18	I/D	RRP	04	PSM	N/A	N/A	N/A
19	I/D	RRP	04	PSM	N/A	N/A	N/A
20	I/D	RRP	04	PSM	N/A	N/A	N/A
21	I/D	RRP	06	PSM	PLAA	MIM	DIL
22	I/D	RRP	04	PSM	N/A	N/A	N/A
23	I/D	RRP	06	PSS	N/A	MIS	DIS
24	I/D	RRP	06	PSM	PLAA	MIM	DIL
25	I/D	RRP	06	PSM	N/A	MIM	DIL
26	A+B I/D	RRP	05	PSL	PLBA	N/A	N/A
27	I/D	RRP	06	PSS	N/A	MIM	DIM
28	I/D	RRR	06	PSM	PLAA	N/A	N/A
29	I/D	Others	06	PSS	N/A	N/A	N/A
30	I/D	Others	06	PSS	N/A	N/A	N/A

* Note that not all project data were available.

Table 21 I/D Amount Achieved by Contract Types

Contract Type	Project Work Description	No. of Projects	Incentive Paid(+) / Disincentive Charged(-)
I/D	Add turn lane(s)	2	$280,000
	Bridge-repair/rehabilitation	1	$500,000
	Drainage improvements	1	$73,000
	Highway access improvement	1	$0
	Interchange (major)	1	$0
	Intersection (minor)	1	$28,000
	Pedestrian safety improvement	1	$34,000
	Resurfacing	9	$1,060,135 / -$192,000
	Rigid pavement reconstruction	1	$200,000
	Safety improvement	1	$40,000
	Sidewalk	1	$9,900
I/D Total		20	$2,033,035
A+B I/D	Add lanes & reconstruct	2	$406,000
	Add lanes & rehabilitate pavement	2	$392,200
	Interchange (major)	2	$798,000
	New road construction	1	$372,000
	Resurfacing	1	$0
A+B I/D Total		8	$1,968,200
A+B Bonus I/D	Add lanes & reconstruct	2	$5,800,000
A+B Bonus I/D Total		2	$5,800,000
Grand Total		**30**	**$9,801,235**

OTPI Simulation Case Study Results

An analysis of the prediction range of each simulation was performed in order to evaluate whether the actual *OTPI* value falls within the expected boundaries of the minimum and the maximum. Of the 30 project cases studied, the actual *OTPI* values of two projects fell outside this expected maximum boundary. Two projects exceeded the expected maximum by 0.222 and 0.258, respectively. They are an average of 31% greater than the expected range (35% of historical *OTPI dataset*). However, in most cases, the actual *OTPI* values fell within the limits, as shown in Figure 22.

The mean value of historical *OTPI* data used in this model was 0.062 and the minimum and maximum *OTPIs* were -0.710 (i.e. 71% time savings) and 1.567 (i.e. 156.7% time overruns). It was calculated that the range of the historical data set is 2.277 (i.e. 227.7%). In comparison to this broad range, the time performance prediction range of *OTPI* simulation results showed much narrower range (i.e. 18% to 49% of the historical data range) in order to predict the actual *OTPI* for each case. Considering these circumstances, the prediction range of actual *OTPI* was reasonably accurate in that approximately 93% of cases were within the predicted range. The simulation results for *OTPI* are shown in Table 22.

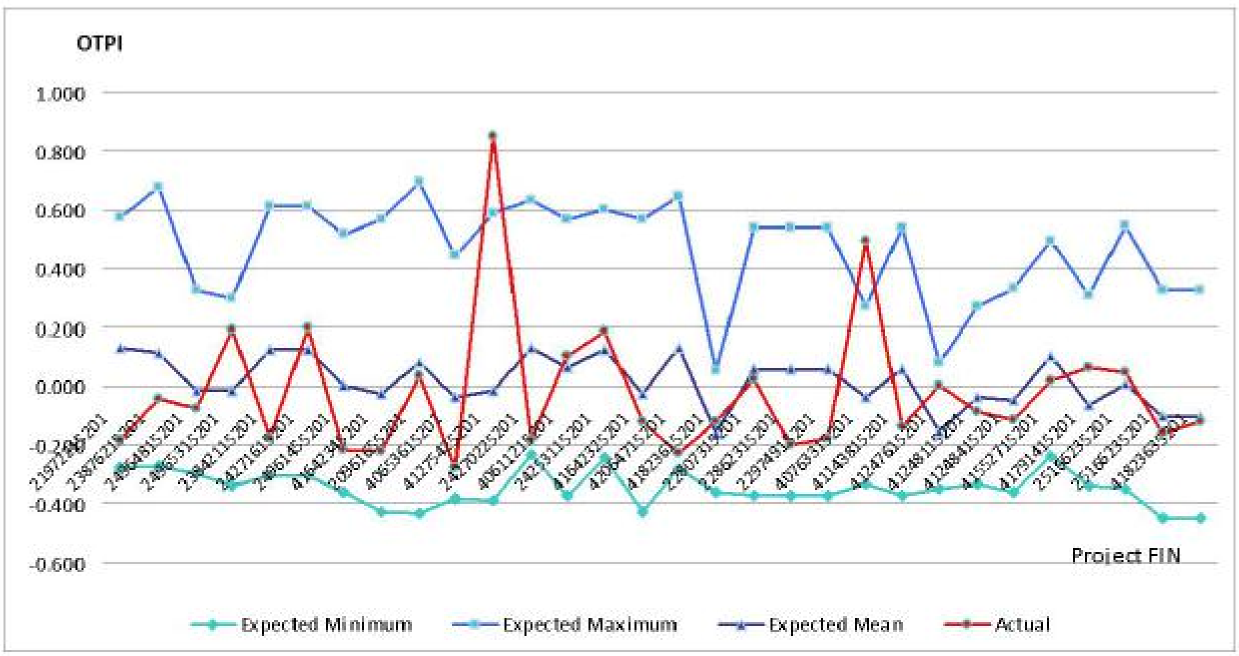


Figure 22 OTPI Simulation Case Study Results

Table 22 OTPI Simulation Results

Case	Project FIN	Expected minimum	Expected maximum	Expected mean	Actual OTPI	Most Dominant Factor	Correlation
1	21972215201	-0.279	0.569	0.129	-0.179	District	0.625
2	23876215201	-0.271	0.676	0.114	-0.043	Contract Type	0.472
3	24964815201	-0.300	0.324	-0.015	-0.078	Contract Type	0.526
4	24965315201	-0.336	0.298	-0.015	0.189	Contract Type	0.545
5	23842115201	-0.307	0.609	0.127	-0.177	Contract Type	0.459
6	24271615201	-0.307	0.609	0.127	0.197	Contract Type	0.459
7	24961455201	-0.363	0.516	0.000	-0.214	District	0.632
8	41642345201	-0.427	0.563	-0.027	-0.221	District	0.622
9	20961655201	-0.431	0.694	0.082	0.033	District	0.557
10	40653615201	-0.380	0.443	-0.034	-0.276	Project Type	0.635
11	41275425201	-0.390	0.590	-0.016	0.848	District	0.601
12	24270225201	-0.232	0.632	0.130	-0.183	Project Length	0.482
13	40611215201	-0.374	0.565	0.064	0.102	District	0.576
14	24253115201	-0.246	0.599	0.127	0.189	Contract Type	0.457
15	41642325201	-0.427	0.563	-0.027	-0.120	District	0.622
16	42064715201	-0.281	0.643	0.131	-0.229	Contract Type	0.468
17	41823615201	-0.363	0.054	-0.157	-0.120	Max Incentive	0.776
18	22807315201	-0.373	0.536	0.055	0.027	Project Type	0.566
19	22862315201	-0.373	0.536	0.055	-0.198	Project Type	0.566
20	22974915201	-0.373	0.536	0.055	-0.174	Project Type	0.566
21	40763315201	-0.334	0.272	-0.039	0.494	Max Incentive	0.549
22	41143815201	-0.373	0.536	0.055	-0.135	District	0.566
23	41247615201	-0.348	0.083	-0.153	0.000	Max Incentive	0.805
24	41248115201	-0.334	0.272	-0.039	-0.089	Max Incentive	0.549
25	41248415201	-0.362	0.332	-0.050	-0.115	Max Incentive	0.556
26	41552715201	-0.240	0.492	0.102	0.020	Project Type	0.533
27	41791415201	-0.341	0.310	-0.066	0.064	Max Incentive	0.545
28	25166235201	-0.350	0.540	0.010	0.048	District	0.587
29	25166235201	-0.450	0.327	-0.102	-0.161	Project Type	0.595
30	41823635201	-0.450	0.327	-0.102	-0.121	Project Type	0.595

PTPI Simulation Case Study Results

An analysis of prediction range was performed in order to evaluate whether the actual *PTPI* values fall within the expected boundaries of the minimum and the maximum. Of the 30 project cases, the actual *PTPI* values of only one project fell outside of the expected maximum boundary. It was close to the expected upper boundary but exceeded the expected maximum by 0.057, which is 17% greater than the expected range (15% of historical *PTPI* dataset). However, in all other cases, the actual *PTPI* values fell within the limits, as shown in Figure 23.

The mean value of historical *PTPI* data used in this model was -0.069 and the minimum and maximum *PTPIs* were -0.717 (i.e. 71.7% time savings) and 1.567 (i.e. 156.7% time overruns). Therefore, the range of the historical *PTPI* data set was 2.284 (i.e. 228.4%). In comparison to this broad range, the time performance prediction range of *PTPI* simulation results showed much narrower range (i.e. 15 to 30% of the historical data range) in order to predict the actual *PTPI* for each case. Considering these circumstances, the prediction range of actual *PTPI* was quite accurate in that approximately 97% of cases were within the predicted range. The simulation results for *PTPI* are shown in Table 23.

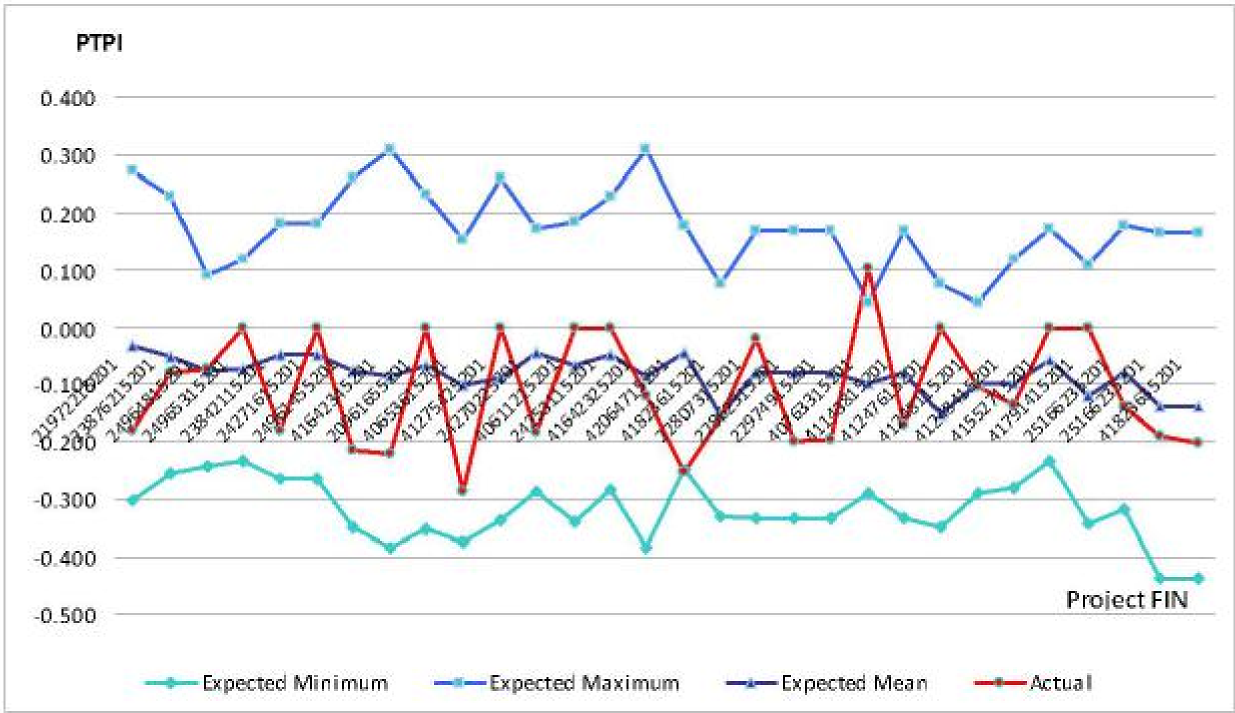


Figure 23 PTPI Simulation Case Study Results

Table 23 PTPI Simulation Results

Case	Project FIN	Expected Minimum	Expected Mean	Actual PTPI	Most Dominant Factor	Correlation
1	21972215201	-0.302	-0.031	-0.179	District	0.557
2	23876215201	-0.256	-0.052	-0.079	Contract Type	0.479
3	24964815201	-0.244	-0.075	-0.075	Contract Type	0.592
4	24965315201	-0.234	-0.073	0.000	Contract Type	0.521
5	23842115201	-0.264	-0.048	-0.179	Contract Type	0.486
6	24271615201	-0.264	-0.048	0.000	Contract Type	0.486
7	24961455201	-0.349	-0.075	-0.214	Project Size	0.616
8	41642345201	-0.383	-0.086	-0.221	Contract Type	0.523
9	20961655201	-0.352	-0.068	0.000	Project Size	0.522
10	40653615201	-0.375	-0.102	-0.287	District	0.575
11	41275425201	-0.338	-0.089	0.000	Project Type	0.581
12	24270225201	-0.286	-0.047	-0.183	Project Length	0.531
13	40611215201	-0.340	-0.067	-0.002	District	0.646
14	24253115201	-0.282	-0.048	0.000	Contract Type	0.523
15	41642325201	-0.383	-0.086	-0.120	Contract Type	0.523
16	42064715201	-0.250	-0.045	-0.253	Contract Type	0.493
17	41823615201	-0.332	-0.155	-0.158	Max Incentive	0.627
18	22807315201	-0.334	-0.078	-0.019	District	0.538
19	22862315201	-0.334	-0.078	-0.198	District	0.538
20	22974915201	-0.334	-0.078	-0.197	District	0.538
21	40763315201	-0.291	-0.099	0.101	Daily I/D Amount	0.499
22	41143815201	-0.334	-0.078	-0.172	District	0.538
23	41247615201	-0.349	-0.152	0.000	Max Incentive	0.664
24	41248115201	-0.291	-0.099	-0.104	Daily I/D Amount	0.499
25	41248415201	-0.282	-0.100	-0.137	Daily I/D Amount	0.571
26	41552715201	-0.232	-0.058	0.000	Project Length	0.490
27	41791415201	-0.343	-0.120	0.000	Daily I/D Amount	0.487
28	25166235201	-0.319	-0.080	-0.141	Project Length	0.514
29	25166235201	-0.437	-0.138	-0.188	Project Type	0.614
30	41823635201	-0.437	-0.138	-0.201	Project Type	0.614

OCPI Simulation Case Study Results

An analysis of prediction range was performed in order to evaluate whether the actual *OCPI* values fall within the expected boundaries of the minimum and the maximum. Of the 30 project cases, the actual *OCPI* values of two projects fell outside of the expected maximum or minimum boundaries. One was very close to the expected lower boundary, but exceeded the expected minimum by -0.011, which is 4% smaller than the expected range (25% of historical *OCPI* dataset). The other project case exceeded the expected maximum by 0.105, which is 35% greater than the expected range (26% of historical *OCPI* dataset). However, in all other cases, the actual *OCPI* values fell within the limits, as shown in Figure 24.

The mean value of historical *OCPI* data used in this model was 0.063 and the minimum and maximum *OCPIs* were -0.345 (i.e. 34.5% cost savings) and 0.763 (i.e. 76.3% cost overruns). It was calculated that the range of the historical *OCPI* data set is 1.107 (i.e. 110.7%). In comparison to this relatively broad range, the cost performance prediction range of *OCPI* simulation results showed much narrower range (i.e. 20 to 43% of the historical data range) in order to predict the actual *OCPI* for each case. Considering these circumstances, the prediction range of actual *OCPI* was reasonably accurate in that approximately 93% of cases were within the predicted range. The simulation results for *OCPI* are shown in Table 24.

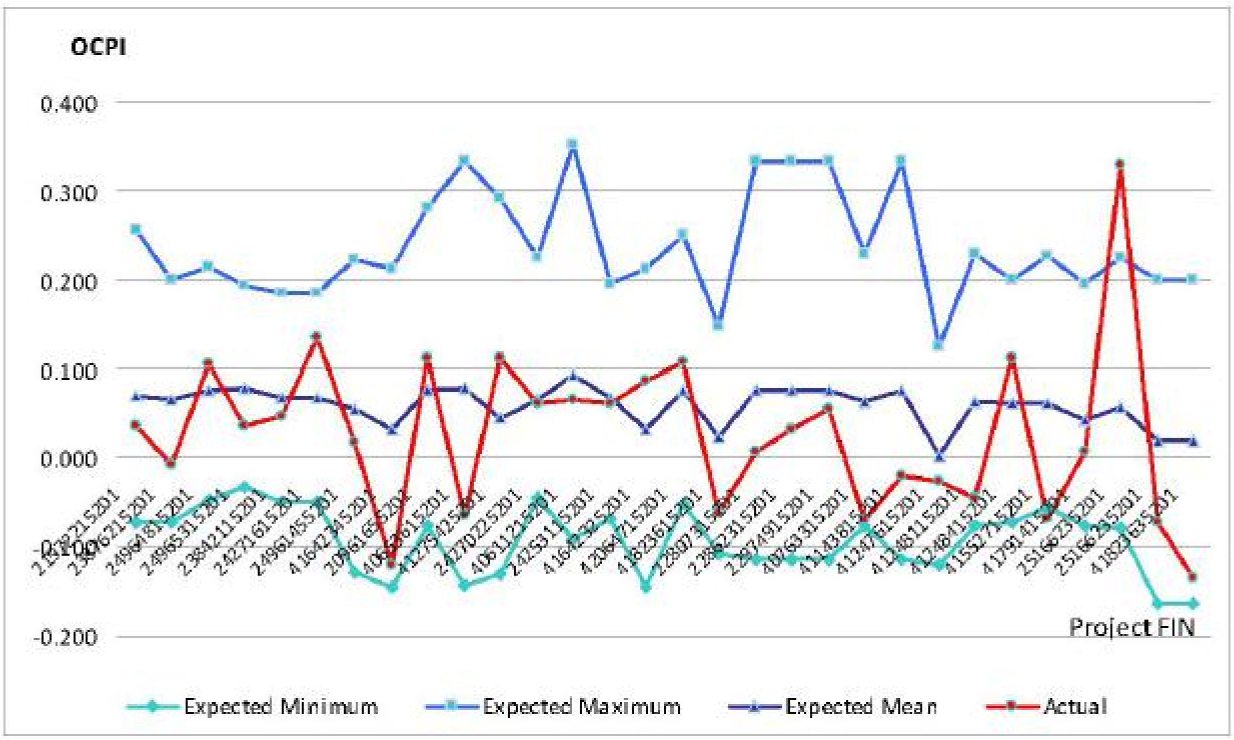


Figure 24 OCPI Simulation Case Study Results

Table 24 OCPI Simulation Results

Case	Project FIN	Expected Minimum	Expected Maximum	Expected Mean	Actual OCPI	Most Dominant Factor	Correlation
1	21972215201	-0.073	0.256	0.070	0.036	District	0.550
2	23876215201	-0.073	0.199	0.066	-0.007	District	0.553
3	24964815201	-0.047	0.214	0.076	0.106	Contract Type	0.636
4	24965315201	-0.033	0.194	0.079	0.036	Contract Type	0.567
5	23842115201	-0.049	0.184	0.068	0.047	District	0.614
6	24271615201	-0.049	0.184	0.068	0.134	District	0.614
7	24961455201	-0.129	0.222	0.054	0.017	District	0.575
8	41642345201	-0.146	0.212	0.032	-0.120	District	0.544
9	20961655201	-0.078	0.281	0.076	0.112	District	0.549
10	40653615201	-0.143	0.333	0.079	-0.063	Project Size	0.585
11	41275425201	-0.131	0.292	0.045	0.111	District	0.586
12	24270225201	-0.045	0.224	0.066	0.061	District	0.636
13	40611215201	-0.091	0.353	0.094	0.064	Project Type	0.531
14	24253115201	-0.069	0.195	0.068	0.061	District	0.613
15	41642325201	-0.146	0.212	0.032	0.087	District	0.544
16	42064715201	-0.051	0.249	0.076	0.108	Project Length	0.543
17	41823615201	-0.108	0.148	0.023	-0.063	Daily I/D Amount	0.543
18	22807315201	-0.115	0.333	0.075	0.007	Project Type	0.518
19	22862315201	-0.115	0.333	0.075	0.032	Project Type	0.518
20	22974915201	-0.115	0.333	0.075	0.054	Project Type	0.518
21	40763315201	-0.076	0.229	0.063	-0.071	Project Length	0.419
22	41143815201	-0.115	0.333	0.075	-0.019	Project Type	0.518
23	41247615201	-0.120	0.124	0.002	-0.027	Daily I/D Amount	0.493
24	41248115201	-0.076	0.229	0.063	-0.045	Project Length	0.419
25	41248415201	-0.073	0.199	0.061	0.112	Daily I/D Amount	0.464
26	41552715201	-0.057	0.227	0.062	-0.068	District	0.667
27	41791415201	-0.077	0.195	0.042	0.008	Daily I/D Amount	0.545
28	25166235201	-0.078	0.223	0.058	0.328	Project Length	0.560
29	25166235201	-0.165	0.199	0.019	-0.072	District	0.582
30	41823635201	-0.165	0.199	0.019	-0.134	District	0.582

PCPI Simulation Case Study Results

An analysis of prediction range was performed in order to evaluate whether the actual *PCPI* values fall within the expected boundaries of the minimum and the maximum. Of the 30 project cases, the actual *PCPI* values of only one project fell outside of the expected minimum boundary. It exceeded the expected minimum by -0.039, which is 26% greater than the expected range (18% of historical PCPI dataset). However, in all other cases, the actual PCPI values fell within the limits, as shown in Figure 25.

The mean value of historical *PCPI* data used in this model was 0.008 (i.e. 0.8% cost overruns) and the minimum and maximum *PCPIs* were -0.345 (i.e. 34.5% cost savings) and 0.511 (i.e. 51.1% cost overruns). The range of the historical *PCPI* data set was 0.855 (i.e. 85.5%). In comparison to this relatively broad range, the cost performance prediction range of *PCPI* simulation results showed much narrower range (i.e. 15 to 33% of the historical data range) in order to predict the actual *PCPI* for each case. Considering these circumstances, the prediction range of actual *PCPI* was quite accurate in that approximately 97% of cases were within the predicted range. The simulation results for *PCPI* are shown in Table 25.

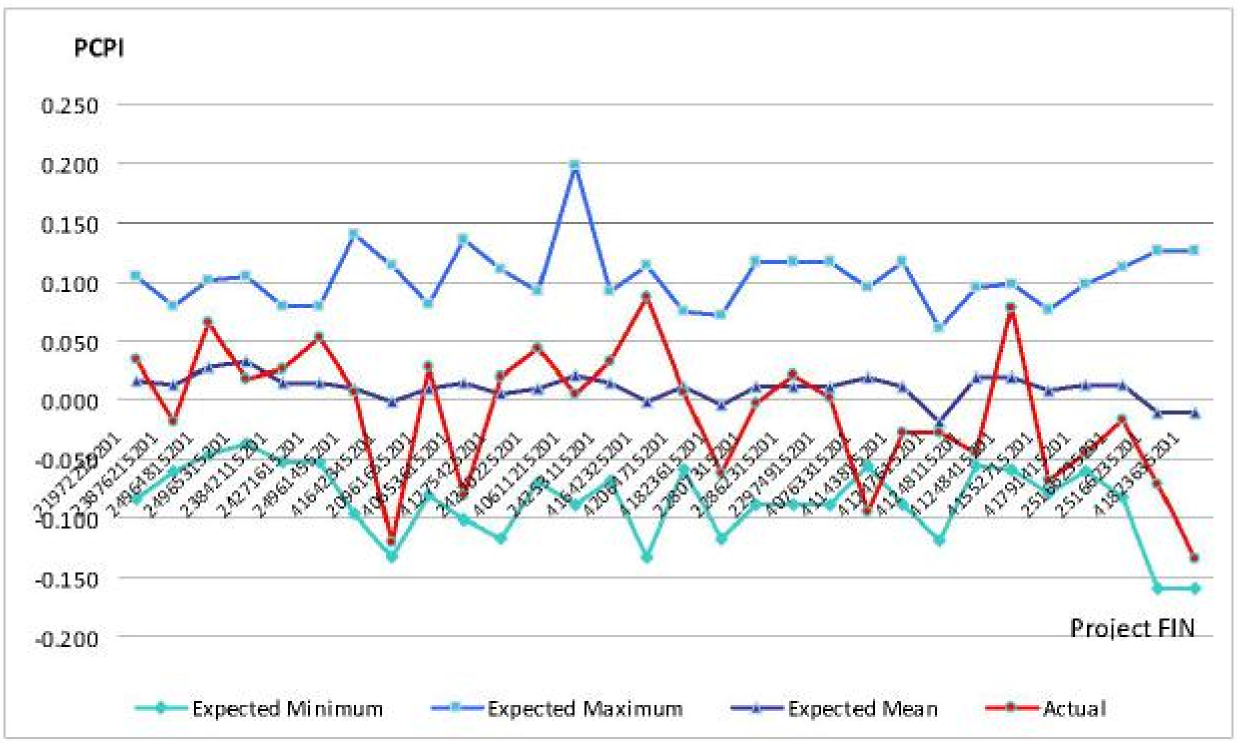


Figure 25 PCPI Simulation Case Study Results

Table 25 PCPI Simulation Results

Case	Project FIN	Expected Minimum	Expected Maximum	Expected Mean	Actual PCPI	Most Dominant Factor	Correlation
1	21972215201	-0.084	0.104	0.017	0.034	Contract Type	0.602
2	23876215201	-0.060	0.080	0.013	-0.018	Contract Type	0.472
3	24964815201	-0.046	0.102	0.028	0.065	Contract Type	0.616
4	24965315201	-0.037	0.105	0.033	0.019	Contract Type	0.553
5	23842115201	-0.052	0.080	0.014	0.026	Contract Type	0.490
6	24271615201	-0.052	0.080	0.014	0.052	Contract Type	0.490
7	24961455201	-0.096	0.140	0.010	0.008	Project Type	0.569
8	41642345201	-0.133	0.114	-0.001	-0.120	Project Type	0.593
9	20961655201	-0.081	0.080	0.010	0.027	District	0.638
10	40653615201	-0.101	0.136	0.015	-0.081	District	0.684
11	41275425201	-0.117	0.111	0.005	0.020	Project Type	0.562
12	24270225201	-0.070	0.092	0.010	0.043	Contract Type	0.514
13	40611215201	-0.088	0.198	0.021	0.006	Project Type	0.635
14	24253115201	-0.068	0.091	0.014	0.033	Contract Type	0.478
15	41642325201	-0.133	0.114	-0.001	0.087	Project Type	0.593
16	42064715201	-0.058	0.075	0.012	0.008	District	0.477
17	41823615201	-0.116	0.071	-0.003	-0.063	Daily I/D Amount	0.604
18	22807315201	-0.089	0.117	0.011	-0.003	Daily I/D Amount	0.604
19	22862315201	-0.089	0.117	0.011	0.021	Daily I/D Amount	0.604
20	22974915201	-0.089	0.117	0.011	0.002	Daily I/D Amount	0.604
21	40763315201	-0.055	0.095	0.020	-0.094	Max Incentive	0.509
22	41143815201	-0.089	0.117	0.011	-0.028	Daily I/D Amount	0.604
23	41247615201	-0.118	0.061	-0.019	-0.027	Project Type	0.509
24	41248115201	-0.055	0.095	0.020	-0.045	Max Incentive	0.509
25	41248415201	-0.058	0.098	0.020	0.077	Max Incentive	0.588
26	41552715201	-0.079	0.076	0.008	-0.068	Contract Type	0.513
27	41791415201	-0.061	0.098	0.013	-0.045	Max Incentive	0.554
28	25166235201	-0.082	0.112	0.013	-0.016	Project Length	0.580
29	25166235201	-0.159	0.127	-0.010	-0.072	District	0.536
30	41823635201	-0.159	0.127	-0.010	-0.134	District	0.536

CONCLUSIONS AND RECOMMENDATIONS

This research investigated I/D contracting projects in transportation construction and developed a project time and cost performance simulation model to assist project planners and managers during the decision-making process by providing a complete picture of possible performance outcomes with probability based on historical data. Although 100% accurate prediction cannot be guaranteed, the outcome of this research will at least provide the decision makers with better understanding of project factors that influence I/D contracting project time and cost performance as well as systematic tools that allow them to learn lessons from their previous I/D contracting experience.

CONCLUSIONS

Outcomes of individual projects are affected by various factors. Based on statistical analysis, this research has found several project factors influencing I/D contracting project performance as follows:

- The important factors that had significant impacts on project time performance are contract type, project type, district, project size, and daily I/D amount.
- The important factors that had significant impacts on project cost performance include contract type, district, project size, project length, maximum incentive amount, and daily I/D amount.

This study demonstrated a methodology for developing an I/D project time and cost performance prediction model using Monte Carlo simulation. User-friendly visual interfaces were developed using VBA programming to perform the simulation and report results. The developed model was validated using 30 additional project cases of transportation construction. Considering the following results, the performance prediction range of the developed model were fairly accurate:

- *OTPI* simulation results used only 18 to 49% of the historical *OTPI* data range in order to predict the actual *OTPI* value for each case and approximately 93% of cases were within the predicted range.
- *PTPI* simulation results used only 15 to 30% of the historical *PTPI* data range in order to predict the actual *PTPI* value for each case and approximately 97% of cases were within the predicted range.
- *OCPI* simulation results used only 20 to 43% of the historical *OCPI* data range in order to predict the actual *OCPI* value for each case and approximately 93% of cases were within the predicted range.
- *PCPI* simulation results used only 15 to 33% of the historical *PCPI* data range in order to predict the actual *PCPI* value for each case and approximately 97% of cases were within the predicted range.

The developed model presents simulation results of I/D contracting performance in the form of probability distributions with the expected value, the worst case, and the best case. The decision-maker needs to decide from the results if the expected and best-case values of I/D project performance are sufficient to outweigh the worst-case value. This detailed elaboration on the expected, the worst, and the best case approach will help project planners by providing possible project performance outcomes with probability from historical project data.

In conclusion, the developed model applied to I/D contracting projects will be a useful tool to assist the project planners during the decision-making process and will promote the efficient use of I/D contracting, which will ultimately benefit the traveling public by saving their travel time from construction delays. With additional project data, the developed model can be updated easily and the more data used for the model, the better the accuracy of prediction that can be expected.

RECOMMENDATIONS AND LIMITATIONS

Because this model was developed using only significant factors identified from FDOT I/D contracting project data, it cannot be universally used for all transportation agencies in the United States. It is possible that some factors such as project location, weather, and district management of other states can affect construction project performance differently from their impacts on construction performance in Florida. Consequently, the project data used in this model cannot represent all I/D contracting practices completed in other states. However, it should be noted that the usefulness of the model structure and development procedure is applicable to any state.

The factors and coefficients in the model may vary depending on specific data in each state. However, it will only require few adjustments such as data classification and coding systems since each STA has slightly different project work types and might have a different number of districts. With these modifications, the model can be used as a helpful tool to assist the I/D contracting decision-making process if similar data used in this study is available.

Quantitative input variables provide only two or three levels of categories and some qualitative input variables provide fewer levels than actually exist due to I/D project data limitations. Despite the fact that the model will not guarantee project time and cost performance, it could greatly improve the accuracy of prediction if further developed with more project data.

For the development of a more refined I/D contracting tool to assist decision-makers, it is necessary to invest more research efforts in the following areas:

- Collection of more transportation construction project data from more STAs;
- Examination of the impacts of more project factors, such as annual average daily traffic, speed limits, number of change orders, quality of contract documents, and similar attributes; and
- Investigation into more detailed categories in order to make simulation conditions more similar to actual conditions.

APPENDIX A: DATA CLASSIFICATION AND CODING TABLES

Table 26 Work Type Codes

Main Code	Work Type
100000	Bridge Rehabilitation/Reconstruction
200000	Roadway Rehabilitation/Reconstruction
300000	Roadway Resurfacing/Paving
400000	Others

Table 27 Work Mix Classification and Coding

1st Digit	2nd Digit	Code	Work Mix
3	01	301	ACCESS IMPROVEMENT
2	01	201	ADD LANES & RECONSTRUCT
2	02	202	ADD LANES & REHABILITATE PVMNT
2	03	203	ADD LEFT TURN LANE(S)
2	04	204	ADD RIGHT TURN LANE(S)
2	05	205	ADD THRU LANE(S)
2	06	206	ADD TURN LANE(S)
4	01	401	ADV TRAVELER INFORMATION SYSTM
4	02	402	BIKE PATH/TRAIL
1	01	101	BRIDGE—PAINTING
1	02	102	BRIDGE OPERATIONS
1	03	103	BRIDGE REHABILITATION
1	04	104	BRIDGE/CULVERT REPLACEMENT
1	05	105	BRIDGE—NEW STRUCTURE
1	06	106	BRIDGE—REHAB AND ADD LANES
1	07	107	BRIDGE—REPAIR/REHABILITATION
1	08	108	BRIDGE—REPLACE AND ADD LANES
4	03	403	BUILDING REPAIR/REHABILITATION
4	04	404	CLEAR ZONE CLEAR & GRUB
1	09	109	CONST. BRIDGE—LOW LEVEL
1	10	110	CONST. BRIDGE—MOVABLE SPAN
4	05	405	CONST/EXPAND ADMIN FACILITY
4	06	406	CONST/EXPAND TERMINAL FACILITY
4	07	407	CONST/RELOCATE SECURITY FENCE
1	11	111	CONSTRUCT BRIDGE—HIGH LEVEL
1	12	112	CONSTRUCT BRIDGE CULVERT
4	08	408	CONSTRUCT CULVERT
4	09	409	CONSTRUCT SPECIAL STRUCTURE
4	10	410	CONSTRUCT/RECONSTRUCT MEDIAN

4	11	411	CORRIDOR IMPROVEMENT
4	12	412	CRITICAL HABITATS
4	12	413	DRAINAGE IMPROVEMENTS
4	14	414	EMERGENCY OPERATIONS
4	15	415	ENVIRONMENTAL ACTION
3	02	302	FEDERAL AID RESURFACE/REPAVE
4	16	416	FENDER WORK
1	13	113	FIXED GUIDEWAY IMPROVEMENTS
2	07	207	FLEXIBLE PAVEMENT RECONSTRUCTIONS
4	17	417	FRONT AGE ROAD
4	18	418	FUNDING ACTION
4	19	419	GUARDRAIL
4	20	420	HWY-ENHANCEMENT
4	21	421	HWY-RECONSTRUCTION
2	08	208	INTERCHANGE (MAJOR)
2	09	209	INTERCHANGE (MINOR)
4	22	422	INTERCONNECTION
2	10	210	INTERSECTION (MAJOR)
2	11	211	INTERSECTION (MINOR)
4	23	243	ITS COMMUNICATION SYSTEM
4	24	424	ITS FREEWAY MANAGEMENT
4	25	425	ITS SURVEILLANCE SYSTEM
4	26	426	LANDSCAPING
4	27	427	LIGHTING
4	28	428	MCCO WEIGH STATION STATIC ONLY
4	29	429	MCCO WEIGH STATION STATIC/WIM
3	03	303	MILL AND RESURFACE
4	30	430	MISCELLANEOUS CONSTRUCTION
1	14	114	MISCELLANEOUS STRUCTURE
4	31	431	MULTI-LANE RECONSTRUCTION
4	32	432	N/A
2	12	212	NEW ROAD CONSTRUCTION
4	33	433	OVERHEAD SIGNING
3	04	304	PAVE SHOULDERS
1	15	115	PEDESTRIAN OVERPASS
4	34	434	PERIODIC MAINTENANCE
4	35	435	PRELIMINARY ENGINEERING
4	36	436	RAIL CROSSING IMPROVEMENTS
4	37	437	RAIL IMPROVEMENT
4	38	438	RAILROAD CROSSING
4	39	439	RAILROAD SIGNAL
1	16	116	REPLACE HIGH LEVEL BRIDGE
1	17	117	REPLACE LOW LEVEL BRIDGE
1	18	118	REPLACE MEDIUM LEVEL BRIDGE

1	19	119	REPLACE MOVABLE SPAN BRIDGE
1	20	120	REPLACE OR WIDEN BR CULVERT
4	40	440	REPLACE OR WIDEN CULVERT
4	41	441	REPLACE RAILROAD BRIDGE
4	42	442	REST AREA
4	43	443	REST AREA (DUAL)
3	05	305	RESURFACING
2	13	213	RIGID PAVEMENT RECONSTRUCTION
2	14	214	RIGID PAVEMENT REHABILITATION
2	15	215	ROAD RECONSTRUCTION - 2 LANE
4	44	444	ROUTINE MAINTENANCE CONTRACTS
4	45	445	SAFETY PROJECT
4	46	446	SIDEWALK
4	47	447	SIGNING/PAVEMENT MARKINGS
3	06	306	SKID HAZARD OVERLAY
4	48	448	SPECIAL SURVEYS
3	07	307	STATE PAVE SHOULDERS & RESURF.
3	08	308	STATE RESURFACE/REPAVE
4	49	449	TOLL PLAZA
4	50	450	TRAFFIC CONTROL DEVICES/SYSTEM
4	51	451	TRAFFIC OPS IMPROVEMENT
4	52	452	TRAFFIC SIGNAL UPDATE
4	53	453	TRAFFIC SIGNALS
3	09	309	URBAN CORRIDOR IMPROVEMENTS
4	54	454	WELCOME STATION
4	55	455	WETLANDS INVOLVEMENT
1	21	121	WIDEN BRIDGE
1	22	122	WIDEN BRIDGE AND ADD LANES
3	10	310	WIDEN/RESURFACE EXIST LANES

APPENDIX B: BETA DISTRIBUTION PARAMETERS

An Example of Project Performance Data and Beta Distributions

Table 28 Performance Index Sample Data

Project Type Category	Contract Type	District	Classified Project Size	Classified Project Length	Classified Max Incentive Proposed	Classified Daily Incentive Amount
OTPI	OTPI	OTPI	OTPI	OTPI	OTPI	OTPI
-0.028	0.026	1.567	0.131	0.131	-0.247	0.131
0.680	-0.028	-0.048	0.026	0.055	-0.103	-0.247
0.427	0.055	-0.125	-0.028	0.089	-0.044	0.113
0.126	0.772	-0.030	0.055	-0.247	0.419	0.171
-0.041	-0.225	-0.050	0.772	0.680	-0.168	0.419
0.760	0.089	-0.050	-0.225	-0.103	-0.192	0.205
-0.211	-0.247	-0.147	-0.247	0.072	-0.643	-0.168
0.052	0.680	-0.137	0.680	0.171	-0.218	0.040
0.475	0.072	-0.051	-0.103	-0.211	-0.303	-0.192
0.681	-0.175	-0.067	0.427	0.419	-0.246	0.681
-0.168	0.713	-0.264	0.072	-0.168	-0.152	0.176
0.192	0.126	0.320	-0.175	0.035	0.156	0.571
0.182	-0.041	0.172	0.126	0.475	-0.211	-0.168
-0.303	-0.710	-0.096	-0.041	-0.192	-0.115	0.441
0.676	-0.643	-0.208	0.139	0.681	0.237	0.197
0.087	0.192	-0.230	0.113	-0.117	-0.082	0.215
0.345	0.139	0.132	0.171	-0.168	0.024	-0.218
0.143	0.146	-0.139	-0.211	0.253	-0.017	-0.303
-0.211	0.106	0.022	-0.328	0.197	0.133	0.676
0.269	0.182	-0.286	0.205	0.192	-0.008	-0.004
0.242	-0.303	-0.143	0.052	0.139	-0.068	-0.246
-0.115	0.188	-0.125	-0.168	-0.218	-0.007	-0.211

Table 29 Parameters and Weightings of Selected Project Variables

Index	Factor	Mean (x)	Variance (s^2)	a	b	p	q	RiskBeta General	Weighting (w)
OTPI	Project Type : Roadway Resurfacing/Paving	0.036	0.073	-0.489	0.760	1.751	2.419	-0.047	13.608
OTPI	Contract Type : I/D	-0.008	0.104	-0.710	1.567	2.980	6.681	0.170	9.641
OTPI	District : 06	-0.098	0.057	-0.489	1.567	1.976	8.411	-0.486	17.496
OTPI	Project Size : Medium	0.046	0.088	-0.489	1.381	2.024	5.059	-0.146	11.324
OTPI	Project Length : Above Average	-0.001	0.067	-0.489	0.681	1.668	2.334	-0.293	15.024
OTPI	Max Incentive Proposed : Medium	-0.156	0.038	-0.661	0.419	3.079	3.514	-0.422	26.160
OTPI	Daily Incentive Amount : Medium	-0.007	0.066	-0.311	0.681	0.657	1.490	-0.261	15.055
								PERFORMANCE INDEX	**-0.2634**

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACM	Alternative Contracting Method
ADT	Average Daily Traffic
ANOVA	Analysis of Variance
A+B	Cost Plus Time Bidding
BRR	Bridge Rehabilitation/Reconstruction
Caltrans	California Department of Transportation
CCO	Contract Change Order
DIL	Daily Incentive/Disincentive Amount Large
DIM	Daily Incentive/Disincentive Amount Medium
DIS	Daily Incentive/Disincentive Amount Small
DOT	Department of Transportation
DSS	Decision Support System
EA	Six Alphanumeric Characters Assigned for a Project
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
I/D	Incentive or Disincentive
IQR	Inter-quartile Range
MIL	Maximum Incentive Proposed Large
MIM	Maximum Incentive Proposed Medium
MIS	Maximum Incentive Proposed Small
MnDOT	Minnesota Department of Transportation
NCHRP	National Cooperative Highway Research Program
OCPI	Cost Performance Index Based on Original Contract
OTPI	Time Performance Index Based on Present Contract
PCPI	Cost Performance Index Based on Original Contract
PLAA	Project Length Above Average
PLBA	Project Length Below Average
PSL	Project Size Large
PSM	Project Size Medium
PSS	Project Size Small
PTPI	Time Performance Index Based on Present Contract
RRP	Roadway Resurfacing/Paving
RRR	Roadway Rehabilitation/Reconstruction
RUC	Road User Cost
SA	Supplemental Agreement
STA	State Transportation Agency
STA	State Transportation Agency
TE	Time Extension
VBA	Visual Basic Application

BIBLIOGRAPHY

Abu-Hijileh, Samer F., and Ibbs, William. "Schedule-Based Construction Incentives." *Journal of Construction Engineering and Management*, 115(3) (1989): 430-443.

American Association of State Highway and Transportation Officials (AASHTO). "Primer on Contracting for the Twenty-first Century." Report, Contract Administration Section of the AASHTO Subcommittee on Construction, Fifth Edition. Washington DC, 2006.

Anderson, Stuart D. and Damnjanovic, Ivan D. "Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion." National Cooperative Highway Research Program (NCHRP). NCHRP synthesis 379, Transportation Research Board, National Research Council. Washington DC, 2008.

Anderson, Stuart D. and Russell, Jeffrey. "Guidelines for Warranty, Multi-parameter, and Best Value Contracting." NCHRP Report 451 (2001). Washington DC, 2007. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_451-a.pdf, accessed March 3, 2009.

California Department of Transportation (Caltrans). "Project Delivery Acceleration Tool Box" (2006). http://www2.dot.ca.gov/hq/oppd/projaccel/2008-Acceleration-Toolbox-Final.pdf, accessed July 14, 2009.

Caputo, F., and Scott, S. "Criteria and Guidelines for Innovative Contracting." Final Report SD95-07-F. South Dakota Department of Transportation. Pierre, South Dakota, 1996.

Christiansen, Dennis L. "An Analysis of the Use of Incentive/Disincentive Contracting Provisions for Early Project Completion." *Transportation Management for Major Highway Reconstruction, Special Report 212*. Washington DC: Transportation Research Board, 1987.

Ellis, Ralph and Pyeon, Jae-Ho. "A Study of Simulation-Based Contract Incentives and Disincentives Usage." Construction Research Congress: Broadening Perspectives. American Society of Civil Engineers, San Diego, CA, 2005.

Ellis, Ralph, Pyeon, Jae-Ho, Herbsman, Zohart J., Minchin, Edward, & Molenaar, Keith. "Evaluation of Alternative Contracting Techniques on FDOT Construction Projects." Final Report. Tallahassee, FL: Florida Department of Transportation, 2007.

Federal Highway Administration (FHWA). "Incentive/Disincentive for Early Contract Completion." FHWA Technical Advisory T5080.10, Washington DC, 1989. http://www.fhwa.dot.gov/legsregs/directives/techadvs/t508010.htm, accessed November 2, 2008.

————. “Contract Administration Core Curriculum Participant’s Manual and Reference Guide.” Office of Infrastructure and Office of Program Administration, Contract Administration Group, FHWA, Washington DC, 2008. http://www.fhwa.dot.gov/programadmin/contracts/index.htm, accessed June 20, 2009.

Florida Department of Transportation (FDOT). “Alternative Contracting User’s Guide.” Draft Report, Tallahassee, FL, 1997.

————. “Alternative Contracting Methods.” Office of Inspector General Audit Report 04B-0001, Tallahassee, FL, 2000.

“Guide to Using @Risk VBA Macro Language.” *Risk Analysis and Simulation Add-In for Microsoft Excel Version 5.5*. Newfield, NY: Palisade Corporation, 2009.

Herbsman, Zohar. “A+B Bidding Method—Hidden Success Story for Highway Construction.” *Journal of Construction Engineering and Management,* 121(4) (1995): 430–437.

Kimmel, Paul T., Green, John, Bullen, Stephen, Bovey, Rob, Rosenberg, Robert, and Patterson, Brian. *Excel 2003 VBA Programmer’s Reference.* Indianapolis, IN: Wiley Publication, Inc., 2004.

Minnesota Department of Transportation (MnDOT). “Innovative Contracting in Minnesota 2000 to 2005.” Office of Construction and Innovative Contracting. MnDOT, Minnesota, 2005.

Ohio Department of Transportation (ODOT). (2006). “Innovative Contracting Manual.” Division of Construction Management. http://www.dot.state.oh.us/Divisions/ConstructionMgt/Admin/Innovative Contracting/InnovativeContractingManual04102006.pdf, accessed July 14, 2009.

Plummer, Ralph, Jaraiedi, Majid and Aber, Mary S. “Development of Criteria for Incentives/Disincentives in Highway Construction Contracts.” Final Report, U.S. Department of Transportation, FHWA, and West Virginia Division of Highways, 1992.

Pyeon, Jae-Ho. “Development of a Simulation Model to Predict the Impact of Incentive Contracts on Transportation Construction Project Time Performance.” Ph.D. Dissertation, Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL, 2005.

Sillars, David. “Establishing Guidelines for Incentive/Disincentive Contracting at ODOT.” Final Report, FHWA-OR-RD-07-07, Oregon Department of Transportation. Salem, Oregon and Federal Highway Administration, Washington DC, 2007.

Sillars, David and Leray, Jean Pol Armijos. "Incentive/Disincentive Contracting Practices for Transportation Projects." *Alternative Project Delivery Procurement and Contracting Methods for Highways*. Construction Research Council, ISBN-13: 978-0-7844-0886-5. Reston, VA: The Construction Institute of ASCE, 2007: 129–152.

Trauner Consulting Services. "Innovative Procurement Practices." Alternative Procurement and Contracting Methods, Caltrans (2007). http://www.dot.ca.gov/hq/oppd/contracting/InnovativeProcurementPractices.pdf, accessed March 4, 2009.

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