A New Decision-Support Model for Innovative Contracting Strategies through a Quantitative Analysis on Aspects of Project Performance

by

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Abstract

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Incentive/disincentive (I/D) and cost-plus-time (A+B) are the most widely used alternative contracting strategies for responding to the dual challenge of repairing aging infrastructure systems while minimizing traffic inconvenience to the traveling public. However, little is known about their impact on project performance aspects such as project schedule and cost. The lack of both systematic studies on these strategies and the proper analytical tools to assess them now prevents state highway agencies from budgeting accurately and realistically when they are considered for implementation. This study attempts to address these shortcomings by determining the effectiveness of these strategies and by developing a new decision-support model to promote their effective application.

A quantitative analysis drawing on 1,372 infrastructure improvement projects completed in California from 2000 to 2008 was conducted. The results of one-way ANOVA analyses show that I/D projects held a decisive schedule-saving advantage over the A+B and conventional projects, but that I/D increased project costs significantly more than the others because of a higher frequency of contract change orders. The results also revealed an effectiveness problem with use of A+B. When compared with conventional projects, A+B not only included extreme schedule overruns, but it also increased project costs far above the levels seen in conventional projects; both of these resulted from inaccuracies created by allowing contractors to bid on contract time. According to the analysis, the additional cost of using I/D was recouped by reduced construction time, but this tradeoff was not seen in A+B projects.

The quantitative analysis provides the basis for a new decision-support model's conceptual and theoretical analysis framework to help decision-makers determine realistic incentive amounts between a contractor's additional cost growth (lower bound) and a portion of the decrease in total time savings (upper bound). To quantify the lower and upper bounds, the model employs an integrated schedule/total time savings/cost growth analysis for expediting construction and it produces two types of incentives along with the maximum incentive amount, such as closure I/Ds and daily I/Ds.

The content of this study can better inform decision-makers when they select among contracting strategies for a given project and help determine the most realistic incentive amounts.

Carl L. Monismith

Professor

Civil and Environmental Engineering

DEDICATION

To my truly precious, beloved daughter,

Celine L. Choi

who is my hero and a gift from heaven.

And also to

Eunjung Lee,

who made all of this possible

for her endless love, patience, and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 GROWING NEED FOR EARLY PROJECT COMPLETION

From 1999 to 2001, approximately 30 percent of the highway construction projects in the United States were undertaken in urban areas (WisDOT, 2004). The typical major traffic disruption resulting from these urban highway construction projects results in major inconvenience to the traveling public and commercial enterprises that rely on these roadways. In the U.S. alone in 1998, estimated annual costs to road users, businesses, and transportation agencies caused by highway construction traffic delays totaled $43 billion (Edwards, 1998). The California Trucking Association estimates that early opening of a freeway saves "their commercial operators more than $250 per truck trip or $500,000 per day" in trucking costs (Carr, 1994).

In responding to the budgetary need for more cost-effective construction and pressure to reduce the consequences of urban highway traffic disruptions due to construction, many state highway agencies (SHAs), including California's, have changed their focus from development and construction of new facilities to maintenance and renewal of existing facilities (Herbsman et al., 1995; MDOT, 1997). Research into public perception has shown that the traveling public and affected businesses show a willingness to pay higher construction costs when they anticipate that shortened construction times will mitigate their overall inconvenience (Lee and Choi, 2006a).

1.2 ALTERNATIVE CONTRACTING METHODS

Transportation infrastructure improvement projects in heavily-trafficked urban areas inconvenience the traveling public. Among the undesirable impacts for both SHAs and the traveling public created by lane closures during construction are severe congestion, safety problems, and limited property access (Lee and Choi, 2006b). In particular, traffic disruptions at construction work zones (CWZs) on urban highway networks frequently create conflicts between SHAs and the nearby communities. To mitigate these problems, the Federal Highway Administration (FHWA) and the Transportation Research Board (TRB) have recommended experimenting with innovative approaches that have the potential to reduce construction time and diminish traffic disruption during construction (Herbsman and Glagola, 1998).

To satisfactorily deliver these costly, badly-needed infrastructure improvements, SHAs must close portions of highways while minimizing the impact of traffic changes during closures on the traveling public and area businesses. These apparently conflicting requirements demonstrate the challenge that SHAs face; they raise the need for alternative contracting strategies that can both reduce construction duration and lessen unfavorable traffic impact.

One groundbreaking way to reduce the duration of project is to offer contractors an early completion incentive bonus that is greater than the cost of utilizing extra resources to meet an accelerated schedule (Christiansen, 1987; Jaraiedi et al., 1993). Incentive/disincentive (I/D) contracting has become one of agencies' favored alternative strategies for motivating contractors to fulfill the public's expectation that projects will be completed early. Time-based I/D provisions are now the most widely used strategy for reducing construction time and they are preferred by SHAs and contractors alike because they can establish win-win situations for both parties (Ibarra et al., 2002). For example, use of these provisions can help agencies save on road-user delay costs by cutting construction time, while contractors can increase their profits by receiving an incentive bonus (Plummer et al., 1992).

Recently, cost-plus-time bidding, also known as A+B, has also become a widely used alternative contracting strategy for shortening construction time. Cost-plus-time bidding can take advantage of contractors' experience and innovations by utilizing their realistic estimates of construction schedule and cost. It is also known that this bidding process on cost and time can eliminate unqualified contractors (Herbsman et al., 1995).

2 PROBLEMS AND RESEARCH SETTING

2.1 PROBLEM STATEMENT

Since much of the transportation infrastructure in the U.S. has substantially deteriorated and is in emergent need of large-scale renewal, many SHAs now face the dual challenge of repairing aging infrastructure systems while trying to minimize traffic inconvenience to the traveling public. To complete projects sooner, SHAs have increasingly adopted alternative contracting strategies, including I/D and A+B. Although these two contracting strategies are the most widely used alternatives, little is known about their impact on aspects of project performance such as project schedule and cost. The lack of both systematic studies on these strategies and the proper analytical tools to assess them now prevents SHAs from budgeting accurately and realistically when they are considered for implementation.

2.1.1 Problem I: Disagreement about Effectiveness

Incentive/disincentive (I/D) implementation experiences to date indicate that the effectiveness of allowing contractors to receive monetary incentives in exchange for reduced construction times is debatable, largely because of the inaccuracy of agency engineers' estimates of contract times (Herbsman et al., 1995; Shen et al., 1999; Shr and Chen, 2004). Determination of contract times has relied to a great extent on the experience and judgment of the contracting agency engineers tasked with estimating the duration of project and realistic I/D rates (NYSDOT, 1999). Therefore, the accuracy of schedule estimates varies depending on a number of factors. Overestimation of contract times can result in contractors receiving incentive fees with little effort, which, according to some studies, has happened in 99 percent of the highway construction projects using contracts with I/D provisions (Herbsman and Ellis, 1995). Competitive contractors can also easily earn an incentive bonus without extra commitments for fast-track construction (Rister and Wang, 2004).

The problems described above are exemplified in the MacArthur Maze project, the reconstruction of two short spans of Interstate-580 (I-580) that collapsed in Oakland, California. The route is a major commuter route in the San Francisco Bay Area, so plans for its rapid repair were closely scrutinized by the public and the media. The contracting agency established a contract completion time of 50 days and included a $200,000 daily incentive/disincentive arrangement, with a cap of $5 million. The winning bid was for $876,075, about one-third of the total project cost. The contractor that submitted the bid appeared to be confident he could complete the project much sooner than was scheduled, and therefore he expected to recoup any shortfall amount by receiving an even larger incentive amount. In the end, the contractor completed the project in 25 days, and thus received the entire $5-million dollar maximum incentive. Later, however, when the original bids submitted by contractors for this project were analyzed using an established CPM schedule procedure, it was found that a more realistic project duration and total cost would have been 25 days (rather than 50) and $1.75 million dollars, prompting one researcher to point out that "there is no justification for this project to cost more than $1.8 million dollars, but the Department spent $5.88 million dollars, three times higher than the realistic cost of the project" (Astaneh-Asl, 2007).

Experience has also raised questions about the effectiveness of bidding on cost and time (A+B). For instance, Christiansen reported that A+B bidding was ineffective largely because of the inherent inaccuracy of allowing contractors to specify contract time in the bidding (Christiansen, 1987). On the other hand, according to Herbsman et al., A+B is more effective and less expensive than the I/D strategy because: (1) schedule compression can be achieved prior to construction through competition rather than incentive payments; and (2) bidding on cost and time enables the contractor to devise better schedules and plans (Herbsman et al., 1995).

2.1.2 Problem II: Lack of Systematic Studies

Although many studies have examined the likely impact of I/D projects on schedule compression, no systematic studies have been undertaken to examine either the overall impact of I/D projects on changes to both project schedules and costs or to investigate where and why such changes occurred. Consequently, the effectiveness of using I/D provisions remains obscure. In effect, the absence of comprehensive data and of systematic studies hinders agencies' ability to determine whether to use an I/D and/or an A+B contracting strategy as compared to the conventional contracting method.

2.1.3 Problem III: Lack of Standardized Methods and Analytical Tools

A contracting agency that wants to use the I/D contracting method must first determine the monetary value of the time saved by earlier project delivery. However, determining realistic incentive dollar amounts based on the value of time saved is a challenge because of the lack of standardized methods and computerized analytical tools. Many researchers and practitioners agree that currently available tools cannot produce reliable, realistic estimates of monetary time value (Gillespie, 1998) and that neither standard computer tools nor a calculation procedure for determining I/D dollar amounts exist (FDOT, 2000).

2.2 RESEARCH STRUCTURE AND DELIVERABLES

This research is focused on:

- Quantitative analysis of the measurements and interpretations of data arising from an agency's selection of an innovative contracting strategy;
- Quantitative analysis of the observed impacts of the contracting strategy choice on project performance components such as schedule and cost, and;
- Development of a systematic decision-support computer model framework to aid selection of a solution that (1) helps agencies make better-informed decisions about whether or not to use an I/D provision and (2) determines the most reliable, realistic I/D amounts.

Incentive/disincentive (I/D) contracting, which is the major focus of the research presented in this study, is a means to ensure faster, less traffic-disruptive construction by motivating contractors to complete projects ahead of schedule. Because I/D projects are relatively large-scale and financed with public funds, the misapplication of I/D provisions results in a loss of public resources. Therefore, it is especially important that candidate projects be carefully selected and effectively implemented.

Proceeding from this understanding, a quantitative analysis was performed to determine effectiveness of the use of alternative contracting strategies. The deliverables for this stage of this study include:

(1) A literature review that establishes the current state of industry;

(2) Comprehensive summary of project data classified by contracting method, project type, and project scope; and,

(3) A summary evaluation of the effects of alternative contracting projects on schedule compression and cost increase compared to conventional projects.

The deliverables and findings from the quantitative analysis provided information needed for the next level of research to proceed. Based on the analysis results, a systematic analysis framework for a new decision-support computer model was developed to determine the most realistic I/D amount. Future research includes the development of a model prototype, followed by implementation studies on highway improvement projects to ensure that the model is robust and practical.

2.3 RESEARCH OBJECTIVES

To respond to both the public's desire for faster project delivery and SHA's corresponding need to complete projects early, this research has the following major goals:

- Determine the effectiveness of alternative contracting projects; and
- Devise a systematic analysis framework for a new decision-support computer model to promote ways to apply I/D more effectively.

Tasks to achieve these objectives include:

1. Investigate whether use of incentive/disincentive (I/D) provisions affects construction duration;
2. Determine whether use of alternative contracting methods on infrastructure improvement projects significantly shortens their duration compared to conventional projects;
3. Examine whether I/D projects increase project costs above the levels seen in A+B and conventional projects; and
4. Devise a systematic analysis framework for a new, computerized decision-support model.

Results of this research provide a conceptual and theoretical framework for a new computer model to aid decision-makers in determining more realistic I/D amounts. This model has the potential to assist SHAs to: (1) make better informed decisions when choosing an I/D contracting strategy; and (2) allocate more accurate, realistic budgets for I/D projects.

2.4 RESEARCH METHODOLOGIES AND HYPOTHESES

As a basis for developing methodologies to meet the aforementioned research objectives, this research compared I/D projects with projects that were contracted solely with A+B methods and with projects contracted with a conventional contract. A one-way ANOVA analysis was used as a methodology. As part of the analysis, appropriate planned comparison and Post-hoc tests were conducted to test the validity of the following research hypotheses:

- I/D contracting projects shorten project duration significantly more than other contracting methods.
- Cost increase for I/D is significantly greater than cost increase for other contracting methods.

2.5 RESEARCH ASSUMPTIONS

- All projects were independently implemented and completed. Each analysis on project schedule and cost was also independently performed. All project data to be examined are therefore assumed to be statistically independent.
- Some projects were constructed at night and some during the day. Contractors' labor productivity during daytime and nighttime were assumed to be equivalent.
- Contractors' individual production performance and work experiences were assumed to be identical.
- It is assumed that agency engineers were not biased in setting the original contract duration.
- It is assumed that the contracting agency's choice of A+B and I/D projects was unbiased.

2.6 LIMITATIONS

There are three basic types of incentives: cost-based incentives, quality-based incentives, and time-based incentives. This research is limited to the time-based incentives applied to infrastructure improvement projects in California over the eight years from 2000 to 2008.

Time-based incentives can be divided into two categories: linear incentives and escalating incentives. Shr and Chen defined these concepts as follows: "for the linear I/D, contractors receive or are charged the same daily amount regardless of the number of days completed early or late. For the escalating I/D, the earlier or later a job is completed, the greater the daily amount paid to or assessed against the contractor" (Shr and Chen, 2004). This research will only take linear I/D into account.

2.7 CONTRIBUTIONS OF THE RESEARCH

The research results and decision-support model will help Caltrans make a better-informed decision when choosing an appropriate contracting strategy and allocate more accurate, realistic budgets for alternative contracting projects. Benefits to the agency include less time spent developing engineering project plans (e.g., calculating I/D dollar amounts). Solutions to problems and contributions of this research are defined in Table 2.1.

Table 2.1 Problems, Solutions, and Contributions

Problems	Solutions and Contributions
Problem I: Disagreement about alternative projects' effectiveness	▪ Evaluate the effectiveness on schedule performance, cost growth, and contract changes by comparing alternative contracting projects with conventionally contracted projects. ▪ Contribution - Promote the effective application of these alternative strategies by knowing the percentages and overall performance.
Problem II: Lack of data and systematic studies	▪ Conduct a methodical quantitative analysis. ▪ Contributions: - Provide comprehensive evaluation data. - Provide a synthesized analysis approach and make recommendations for taking the next step to effectively use alternative contracting strategies.
Problem III: Lack of standardized methods and analytical tools	▪ Develop a standardized analysis procedure of the new decision-support model. ▪ Contributions: - Help select an appropriate contracting strategy that varies depending on a number of factors. - Allocate more accurate, realistic budgets. - Lessen the agency effort required for project development. - Facilitate decision-making processes.

3 LITERATURE REVIEW

A review of pertinent literature on the subject of I/D contracting strategy was conducted to gain insight into the various criteria to consider in selecting an I/D contracting method and to identify problems in current practice for determining contract completion time and cost (e.g., I/D dollar amounts). This literature review provides a summary and a comprehensive overview of crucial elements in the implementation of I/D provisions. The following seven sections summarize the key elements to be addressed when applying I/D provisions; the current state of industry practice in determining the value of time and contract completion time; and the impacts on contractors and agencies, costs and schedules, and administration and project operations.

3.1 SELECTION CRITERIA

Several studies contain information on the selection criteria for determining whether or not to apply a time-based I/D provision (Christiansen, 1987; Plummer et al., 1992; Jaraiedi et al., 1995; NYSDOT, 1999; Living, 2002; Ibarra et al., 2002; Rister and Wang, 2004; Shr and Chen, 2004). In general, the use of time-based I/D contracting method is limited to heavily trafficked, fast-track projects where achieving the earliest possible project completion is needed to minimize inconvenience to the traveling public. Phase 1 will determine what types of projects are suited to fast-track construction using the selection criteria resulting from the literature review. These selection criteria for employing a time-based I/D provision are:

- Heavy traffic volumes and anticipated high road user cost (RUC) increases due to construction,

- Major rehabilitation of a system already in use that will severely disrupt the current flow of traffic,
- Work that will complete a gap in the highway system,
- Limited access to detour routes,
- Significant impact on public safety and abutting businesses, and
- Significant impact on emergency service.

Considering these criteria, time-based I/D provisions should be used carefully since they usually increase costs to the contracting agency and use public resources (Jaraiedi et al., 1995; Gillespie, 1998). How candidate projects are selected and which criteria are the most important ones in the selection process will be further examined and evaluated through a continuous review of pertinent literature.

3.2 DETERMINATION OF PROJECT COMPLETION TIME

In the implementation of time-based I/D projects, the determination of contract time may be the most important factor that directly influences effectiveness. The Federal Highway Administration (FHWA) defines contract time for time-based I/D projects as "the time (completion date in a calendar-day basis) established for the contractor to complete critical work ahead of schedule on identified projects. This time is effective immediately when traffic is impacted by the project and normally ends when unrestricted traffic is permitted on the identified projects" (FHWA, 1989).

In the time-based I/D contracting method, the contracting agency determines how long it will take to complete the project. Estimation of contract completion time by the agency is presented as part of the bid documents. In determining contract time, a critical path method (CPM) analysis or a manual calculation is typically used as the basis for the average production performance of the contractor (Christiansen, 1987; Ohio DOT, 1990; IDOT, 1990; Herbsman et al., 1995) and historical information (Plummer et al., 1992). Some researchers believe that an experienced competitive contractor can reduce construction time and receive an incentive bonus without an additional commitment of resources especially because of the previously noted tendency of agencies to overestimate contract time (Herbsman and Ellis, 1995). Moreover, the related literature points out that systematic approaches to determining contract completion times have rarely been found in current industry practice.

3.3 DETERMINATION OF ROAD USER COST

Although some innovative states have employed the concept of daily RUC in estimating the value of time, there has not been a formally established nationwide calculation procedure (Herbsman et al., 1995). In the A+B contracting method, the daily RUC serves to help the contractor determine the monetary value of time (B) when making a bid. In the I/D contracting method, daily RUC is used as the basis for determining an appropriate I/D amount.

Daily RUC is defined as "the estimated daily cost to the traveling public resulting from the construction work being performed" (Ibarra et al., 2002). The RUC is comprised of the following three elements: (1) the travel time change due to delays during construction, (2) the average number of passengers per vehicle, and (3) the hourly cost per passenger (Shr and Chen, 2003). Externalities such as air-quality cost and vehicle noise factors have rarely been reflected in the calculation of RUC (Gillespie, 1998). The bottom line for determining daily I/D rates is that the rates must reflect an overriding time-saving benefit for the traveling public (Herbsman et al., 1995; Plummer et al., 1992). In other words, to be effective, the I/D amount should be greater than the increases in the contractor's additional costs and smaller than total RUC (Rister and Wang, 2004). Even if there is a high RUC, most states have refused to use an amount equal to RUC as an incentive because of budget limitations. Therefore, how effectively the initial RUC can be discounted is important for the effective use of the time-based I/D contracting method.

The most widely used state-of-practice software for calculating RUC is the *Highway Capacity Software* (*HCS*). This is based on the Highway Capacity Manual (HCM) and *MicroBENCOST* (Gillespie, 1998). *QUEWZ, QuickZone*, and *HCS* are being widely used for the calculation of queue length and work zone delays (Benekohal et al., 2003). *MicroBENCOST* emerged as an alternative to *QUEWZ*, which has been used since the early 1980s. *MicroBENCOST* was based on the 1985 HCM and the 1977 AASHTO "Red Book," with special emphasis on the calculation of vehicle operating cost (TTI, 1993). Developed in 1995, *HCS* is a computer version of the HCM for calculating RUC (University of Florida, 1995). The FHWA recently developed the Microsoft *Excel* spreadsheet-based *QuickZone* as an estimating tool for work zone delays (FHWA, 2005). *QuickZone* was developed to evaluate traveler delays due to construction. It provides a complete and realistic view of total construction costs based on the estimation and quantification of work-zone delays and the resulting user costs (FHWA, 2005).

3.4 DETERMINATION OF DAILY I/D AMOUNT

Methods for determining the daily I/D amounts have evolved over the years and they vary from one state highway agency (SHA) to another. Even though I/D amounts are determined by RUCs in some innovative states, the majority of SHAs still use a percentage of the total project cost to determine them (Benekohal et al., 2003). The same value is typically used for both the daily incentive and disincentive with some exceptions (Plummer et al., 1992; Jaraiedi et al., 1995; Benekohal et al., 2003).

The work of Plummer et al. shows a conventional way to manually determine the initial I/D amounts (Plummer et al., 1992). According to the study, 5% of total project cost is first determined to serve as the maximum incentive amount. [FHWA also recommends a cap of 5% of the total project cost be used as the maximum incentive (Ibarra et al., 2002).] To calculate the (maximum possible) daily I/D amount, the initial maximum incentive amount is divided by the number of days that are saved by utilizing the I/D fast-track schedule. After the determination of the daily I/D amount, the maximum number of days for the incentive payment should be determined by the difference in the number of days required to complete the project using an accelerated schedule versus an I/D schedule (Jaraiedi et al., 1995). The maximum number of days is limited to 30% of the engineer's time estimate for that phase (NYSDOT, 1999). The maximum incentive amount is then capped by multiplying the daily incentive dollar amount. In general, the maximum incentive amount is limited to 5% of the total construction cost (Herbsman et al., 1995; Arditi et al., 1997; Shr and Chen, 2003).

The critical problem in this conventional way of manually determining I/D amounts is that it does not reflect time savings to road users, an accurate construction schedule and production rate, and the specific needs for early completion due to the heavy traffic volumes through the CWZ.

The daily I/D amount has increased over time from a range of $1,000 to $5,000 (IDOT 1991) and $2,500 to $5,000 (Herbsman et al., 1995) to a range of $5,000 to $20,000 (Yakowenko, 2000). The daily I/D amount is usually higher in urban areas than in rural areas due to higher urban RUCs (Benekohal et al., 2003). In most states, where the time-based I/D provisions have been implemented, the initial daily I/D amount is adjusted downward to provide a favorable benefit-cost ratio for the contractors and the traveling public (Plummer et al., 1992; Herbsman et al., 1995).

3.5 PROS AND CONS

Generally, time-based I/D provisions increase costs for both agencies and contractors, but agencies benefit by the time saved by road users and the contractors benefit from incentive bonuses. The research experience of Herbsman and Ellis indicates that 99% of the contractors in thirty-five states who contracted with I/D provisions on highway infrastructure projects received an incentive bonus (Herbsman et al., 1995; Herbsman and

Ellis, 1995), which supports the assertion that overestimation of contract completion time is prevalent.

Following is a list of pros and cons of the I/D contracting method compared with the conventional contracting method:

1. Pros

- I/D contracting reduces construction time by 50% (Christiansen, 1987; Jaraiedi et al., 1995). For example, 93.3% of I/D projects were completed on time or sooner whereas 41.2% of non-I/D projects were completed on time or ahead of schedule (Arditi et al., 1997).
- I/D contracting minimizes inconvenience to the traveling public and affected enterprises (Lee and Choi, 2006a).
- I/D contracting improves construction labor productivity by 25 to 30% and shortens schedules by 15 to 25% (Abu-Hijleh and Ibbs, 1989).
- I/D contracting lowers agency risks by transferring them to the contractor (disincentive clause) (Ashley and Workman, 1985; Arditi and Yasamis, 1998).
- I/D contracting provides a better definition of project objectives and a better definition of project design (Ibbs and Abu-Hijleh, 1988).
- I/D contracting improves safety performance (Ashley and Workman, 1985).
- I/D contracting results in higher project bids because contractors expect to receive incentive bonuses (Arditi et al., 1997), an advantage for agencies trying to reduce costs to the public.

2. Cons

- Increased cost to the contracting agency, if not effectively implemented (Jaraiedi et al., 1995).
- Higher frequency and magnitude of change orders (Arditi et al., 1997).
- Higher probability of budget overflows (Arditi et al., 1997).
- More vulnerable to legal disputes between agency and contractor (Ashley and Workman, 1985; Arditi et al., 1997; Gillespie, 1998; Ibarra et al., 2002).
- Difficulty in administration (Ashley and Workman, 1985).
- Greater effort required in project coordination and administration (Christiansen, 1987).

3.6 CASE STUDIES

3.6.1 California

Caltrans is one of the leading SHAs when it comes to I/D provisions. Prior to 1994, Caltrans used the I/D provisions in the Ventura Improvement Project, where the goal was to reconstruct and rehabilitate three heavily trafficked portions of the existing freeway (US 101). The project also included three bridge reconstructions. The general contractor for each portion was eligible to receive an incentive bonus of $6,000 per day if the work was completed in 120 days or less, and was subject to a disincentive to pay the same amount if the work took longer than 120 days (Gillespie, 1998).

To expedite the rebuilding of the portions of the Los Angeles highway system damaged by the Northridge earthquake in 1994, Caltrans used record-breaking incentive payments for the earliest possible completion of construction. For example, in the rehabilitation of Interstate-10 in Los Angeles, the contractor completed the project 66 days ahead of schedule and received an incentive bonus of $200,000 per day (Gillespie, 1998).

In 1998, Caltrans, which oversees a 78,000 lane-km state highway system, began implementing its Long-life Pavement Rehabilitation Strategies (LLPRS) program to rebuild approximately 2,800 lane-km of deteriorated high-volume urban freeways with pavements designed to last more than thirty years with minimal maintenance (Caltrans, 1998). In general, the LLPRS projects are constructed as fast-track projects with the implementation of time-related I/D provisions in the belief that the extra expense of incentive fees will be paid off in the time savings of road users traveling through CWZs. The fast-track concepts of the time-based I/D provisions have been validated and successfully implemented in the following three experimental time-critical LLPRS projects.

I/D Pilot Project: I-10 Concrete Rehabilitation in Pomona

Various I/D provisions were used in the rehabilitation of Interstate-10 Pomona pilot-project, where 2.8 lane-km of deteriorated truck-lane was rebuilt during one 55-hour weekend closure with around-the-clock operations. In this project, an incentive payment was to be made to the contractor in the amount of $600 per lane-meter for each lane-meter replaced in excess of 2,000 lane-meters during the weekend closure. A disincentive would be assessed in the amount of $250 per lane-meter for each lane meter less than 2,000 lane-meters. The incentives were capped at $500,000. The contractor was awarded a $500,000 incentive payment for completing more than 2.0 lane-km of the contractual threshold (Lee et al., 2002).

I/D Demonstration Project: I-710 Asphalt Rehabilitation in Long Beach

Caltrans included time-based incentive/disincentive (I/D) provisions in the I-710 Project contract to achieve faster delivery of construction with less traffic disruption during lane closures. Deteriorating PCC pavement was replaced with a long-life asphalt concrete pavement in eight 55-hour weekend closures. The I/D provisions specified that the contractor was eligible to receive an incentive bonus of $100,000 per weekend closure if the project was completed earlier than Caltrans' initial plan of ten weekend closures. Conversely, the contractor was subject to a disincentive in the same amount. An incentive cap of $500,000 was the specified maximum incentive amount; there was no specified upper limit on the disincentive amount. Motivated by the I/D clauses, the contractor committed additional resources, completed the project two weekends early, and received a $200,000 incentive bonus (Lee et al., 2005a).

I/D Implementation Project: I-15 Fast-Track Concrete Rehabilitation in Devore

Detailed I/D provisions were applied on the Interstate-15 Devore urban highway reconstruction project in October 2004, as the first large-scale I/D implementation project. Motivated by the I/D provision, the contractor completed a 4.5-km stretch of badly damaged concrete truck lanes in only two 215-hour (about 9 days) one-roadbed continuous closures, with 24/7 construction operations (Lee and Choi, 2006b). Due to high traffic volume during closures and the public desire for early completion, three levels of time-based incentive provisions were specified in the contract to ensure the earliest possible completion of closures: (1) I/D clauses in a closure and daily basis, (2) late opening disincentives for the segment with the three-lane section, and (3) cost plus time (A+B) contracting for the entire project. Two types of I/D provisions were specified for the extended closures: primary incentives for the total number closures and secondary incentives for the total closure days (Lee et al., 2005b).

The contractor was eligible for a closure incentive bonus of $300,000 if a one-roadbed continuous closure was completed in a time period equal to or less than two units of a specified time segment (111 hours per unit), and was subject to a closure disincentive without a limit if the closure took longer than three units of this time segment (an extra time segment was given for flexibility). In addition to this closure incentive requirement, the contractor was eligible to receive a daily incentive (secondary) bonus of $75,000 if the reconstruction was completed in fewer than nineteen days (a total of 456 hours), and was subject to a daily disincentive penalty without a limit. A late lane-opening penalty of $5,900 per 15-minute period without limitation was to be charged if the closure was not completely opened to traffic by 5 A.M. Friday to accommodate the highest weekday commuter and weekend leisure traffic volumes headed to Las Vegas. The final incentive amount was adjusted downward because of state budget limitations, and $600,000 was used as the incentive cap (Lee and Choi, 2006b).

3.6.2 Florida

The Florida Department of Transportation (FDOT) realized that overestimation of contract completion times had prevailed in industry practice because engineers' experiences and average contractor performance rates had been widely used in determining the duration of projects. In response, FDOT reduced contract times by 20% without experiencing any major delays in project completion dates (Herbsman et al., 1995).

In 1996, the Florida Legislature authorized the Department to use alternative contracting techniques with the goals of controlling time and cost increases on construction projects. Accordingly, since 1996, the FDOT has maintained the Alternative and Innovative Contracting Program to promote the use of innovative contracting methods of highway construction in order to minimize the inconvenience to the traveling public, adjacent businesses, and communities (FDOT 2000). Based on a report issued by the Office of Inspector General in the FDOT, a total of sixty-one I/D contracting projects were completed from the years 1996 to 2000, and approximately $7.3 million were paid as incentive bonuses for early project completion (FDOT, 2000).

3.6.3 Michigan

The Michigan Department of Transportation (MDOT) often utilizes time-based I/D provisions in association with an A+B (cost-plus-time) bidding procedure (Gillespie, 1998) because the contract completion time estimated by the winning bidder would be more realistic than the contract time estimated by the contracting agency (Arditi and

Yasamis, 1998). To be considered for an I/D clause, the following conditions are taken into account: (1) substantial road user cost savings are expected; (2) total additional user costs are expected to be at least 5% of the project cost, with a daily incentive of $5,000 for major projects; and (3) by implementing an I/D provision the duration of lane closure can be shortened by at least 15 days (Gillespie, 1998).

3.6.4 Other States

In Illinois from 1989–1993, all twenty-eight highway construction projects that used time-based I/D provisions were completed ahead of schedule. About 79% of the contractors for these twenty-eight projects received the maximum incentive payment. The average incentive amount paid per project was 4.71% of the contract amount (Arditi et al., 1997).

In Kentucky from 1999 to 2002, approximately thirty-two highway construction projects were implemented with time-based I/D provisions. For these thirty-two highway projects, about $10.8 million was paid out in incentive bonuses and $21,500 was collected as disincentives (Rister and Wang, 2004).

According to a survey conducted by Iowa Department of Transportation, thirty-five states responded that they had adopted I/D provisions for their highway rehabilitation/reconstruction projects. Of these thirty-five states, thirty-two said that contractors had received an incentive payment and twenty-two states responded they had paid the maximum incentive amount (Plummer et al., 1992).

3.7 CHAPTER SUMMARY

The existing literature, as summarized above, provides information about current industry practice on time-based I/D provisions and their effects on project acceleration and operations. These general themes emerged from the review of pertinent literature:

- Methods to determine daily I/D amount and contract time have advanced over the years, but they still have many limitations.
- Engineers' overestimation of contract time is noticeable in the studies to date and impedes the effective application of the time-based I/D contracting method.
- The existing literature is outdated and insufficient. Besides, methodical research has not been conducted to examine the effectiveness of using time-based I/D provisions.

4 DATA COLLECTION AND ANALYSIS

4.1 INTRODUCTION

Historically, cost has been regarded as the major component for determining the winning contract bid; that is, in the conventional project delivery mechanism, the contractor who turns in the lowest-cost bid wins the contract. However, in the early 1990s, some innovative states begun to think about alternative ways that have the potential to deliver projects faster and to limit the negative traffic impact on the traveling public. The State of California stands as a leader when it comes using alternative contracting strategies, primarily selecting either A+B bidding or the I/D technique as an alternative contracting strategy, especially for emergency-type projects.

In 1990, FHWA initiated the Special Experimental Projects Program to evaluate project-specific innovative contracting techniques with the goal of reducing project delivery times and life cycle cost without sacrificing project quality. In 1995, after conducting five-year study, the FHWA declared that A+B was no longer experimental. FHWA also recommended experimenting with new innovative approaches that have the potential to shorten construction time, such as incentives/disincentives (Caltrans, 2000).

In response, Caltrans implemented its Long-life Pavement Rehabilitation Strategies (LLPRS) program in 1998. Since that time, approximately 2,800 lane-km of highly deteriorated pavements have been rebuilt to last more than thirty years with minimal maintenance. In general, LLPRS projects involve accelerated methods, often combining A+B bidding and time-related I/D provisions, and their successful implementation has validated them. In June 12, 2000, the Caltrans Director's Office authorized promotion of A+B bidding and I/D contracts to respond to the public's desire for rapid project delivery with minimal traffic inconvenience.

4.2 DATA COLLECTION

A quantitative study drawing on 1,372 infrastructure improvement projects completed in California between 2000 and 2008 was conducted to quantify likely impacts of I/D on project schedule and cost compared with A+B and conventional contracting strategies. The original project data were received from the Caltrans Division of Construction and Caltrans Office of Project Engineers. The data covers three main areas: project summary, schedule, and cost (see Table 4.1).

Initial project schedule and contract amount estimates are often adjusted due to contract changes in project scope resulting from frequently occurring contract change orders. Consequently, project data used for quantitative analyses must contain this contract change order information. The data used here include the adjusted days and contract amounts so that the impact of contract and schedule changes can be quantified. The data also contain daily I/D and incentive cap rates.

4.3 DATA CLASSIFICATION

Results of this quantitative data analysis could be biased if samples of varied project types and sizes are compared, so to perform an unbiased analysis, project data were sorted by project type and by project size. Three major project types were identified through the classification procedure:

- So-called "3R" types of roadway renewal projects: resurfacing (maintenance), reconstruction, and rehabilitation of existing roadways;
- Bridge projects: replacement, repair, and rehabilitation of existing bridges; and
- Capacity-added projects: the addition of lanes or the widening existing lanes, often accompanied by 3R types of renewal work.

Table 4.1 Nature of Project Data

	No.	Value type	Description
Project Summary	1	EA number	6 digit unique project ID
	2	District	
	3	County	
	4	Route	
	5	Postmiles	lane-miles rebuilt
	6	Location description	
	7	Project description	work description (project type)
	8	Name of contractor	
	9	Contracting type	
Time	11	Origianl contract time	originally scheduled duration of project
	12	CCO days	times adjusted due to contract change orders
	13	Amended contract time	equals 11+12
	14	Actual project time	days spent to complete the project
	15	Project time change	equals 12/11
Cost	16	Original contract amount	initial bid amount
	17	Engineer's estimate amount	project cost estimates done by agency engineers
	18	CCO amount	all costs adjusted due to contract change orders
	19	Amended contract amount	equals 16+18
	20	Final project cost	final project cost actually spent for the project
	21	Project cost change	equals 18/16
	22	Daily I/D rate	
	23	Incentive cap amount	Maximum incentive amount allowed for the project

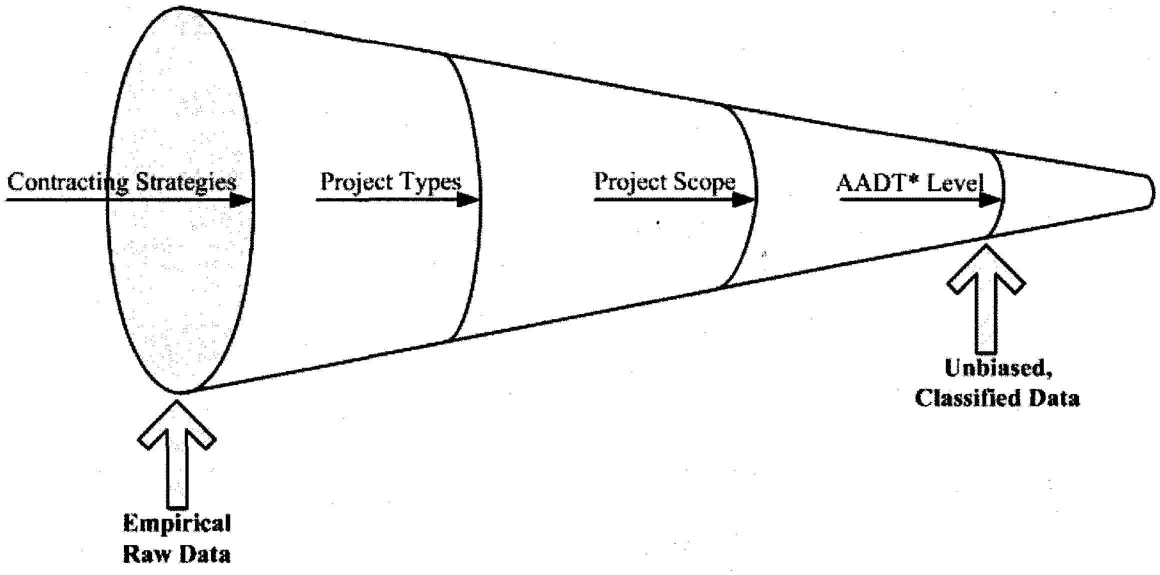


Figure 4.1 Data Classification Procedure (*AADT: Annual Average Daily Traffic)

Figure 4.1 shows the data classification procedure undertaken in this study. Recall that the major objective of the quantitative analysis is to examine the likely impact and effectiveness of I/D projects compared with A+B and conventional projects in terms of schedule and cost. All 1,372 projects were classified by their contracting strategy: I/D, A+B, or conventional. The projects were then sorted by project type and in doing this they were further identified as either major or minor projects (Table 4.2). In this part of the procedure, some minor projects were excluded, such as work on shoulders, lighting, and bike paths/trails, bridge painting, access/drainage improvement, tree planting, etc.

In the second classification round, projects already sorted by type and contracting strategy were classified by project size, in terms of the original contract amount. In the third classification round, hundreds of conventional contracting projects were excluded due to the low construction work zone traffic volumes (based on AADT). This was done because low traffic level at a construction work zone can directly affect both project planning and construction practice, so it is relatively easy for contractors to define project scope on rurally situated projects. These projects are likely to result in fewer contract change orders during construction, subsequent lower cost growth, and a higher likelihood of on-time project delivery.

Table 4.2 Data Classification by Project Type

	Project Type	Project Description	Acronym	Incentive/Disincentive		A+B		Conventional		Overall			
				# of Ests	% of Tot Ests	# of Ests	% of Tot Ests	# of Ests	% of Tot Ests	# of Ests	% of Tot Ests	Project Size	% of Tot Cost Allotments
MAJOR	Roadway (3R)												
		Maintenance (Resurfacing)	RS	4	13.8%	22	37.9%	292	56.4%	318	52.6%	$708,151,145	19.2%
		Reconstruction/Rehabilitation	RH	6	20.7%	5	8.6%	86	16.6%	97	16.0%	$826,179,855	22.4%
	Bridge	Replacement, repair, rehabilitation	BR	5	17.2%	4	6.9%	31	6.0%	40	6.6%	$184,888,422	5.0%
	Capacity-Added	Adding or widening lanes (w/ 3R)	CA	6	20.7%	10	17.2%	90	17.4%	106	17.5%	$1,233,150,626	33.5%
	Subtotal			21	72.4%	41	70.7%	499	96.3%	561	92.7%	$2,952,370,048	
MINOR	New Road		NR	2	6.9%	3	5.2%	12	2.3%	17	2.8%	$462,082,154	12.5%
	New Bridge	including widening projects	BN	0	0.0%	1	1.7%	5	1.0%	6	1.0%	$58,777,484	1.6%
	Other		IN	6	20.7%	13	22.4%	2	0.4%	21	3.5%	$213,093,135	5.8%
	Subtotal			8	27.6%	17	29.3%	19	3.7%	44	7.3%	$733,952,773	
				29		58		518		605		$3,686,322,821	

4.4 RESEARCH DATA STUDIED

4.4.1 Current Trend of Infrastructure Improvement Projects

Figure 4.2 displays the current trend of infrastructure improvement projects and it shows that the three major project types represent approximately 67.4% of all project establishments. Viewed as a percentage of all contract cost allotments, it becomes even clearer that the three major types (83.0%) are forming an ever-greater portion of the recent infrastructure improvement projects. This number also suggests that major types had larger project size than other types.

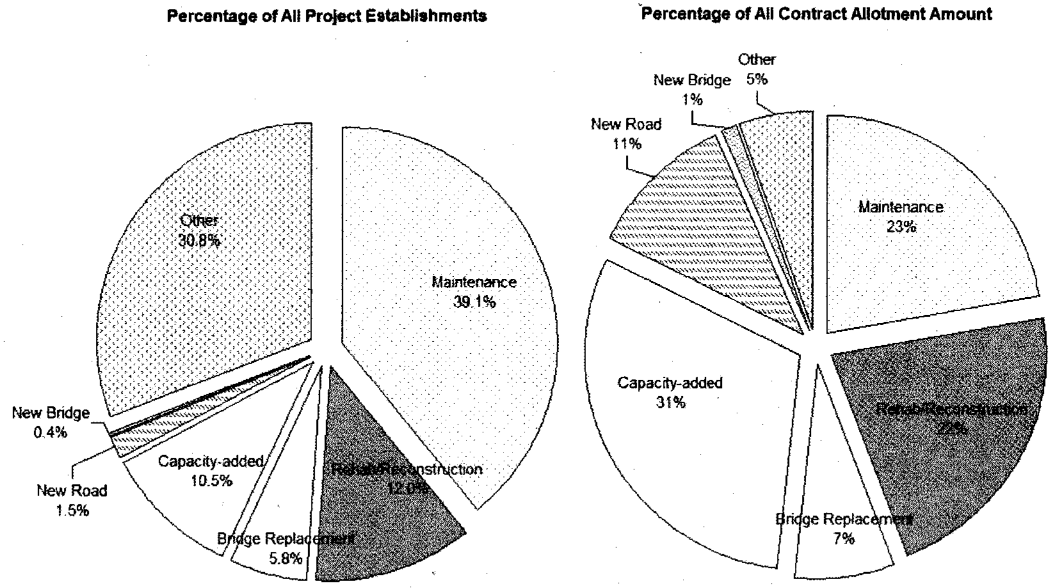


Figure 4.2 Current Trend of Infrastructure Improvement Projects (2001–2006)

It is noteworthy that among the three major types, roadway construction (3R: resurfacing, reconstruction, and rehabilitation) represents 51.1% of all project establishments. The emphasis on the roadway 3R types reinforces the observation that the trend of infrastructure improvement projects has started to shift from development and construction of new facilities to maintenance and renewal of existing facilities. This high percentage of renewal projects on existing roadways and the increased potential for the growth of these projects in the near future implies that alternative (I/D and A+B) contracting strategies will play an important role in shortening the duration of projects in high-profile urban areas to lessen the impact of traffic on the traveling public.

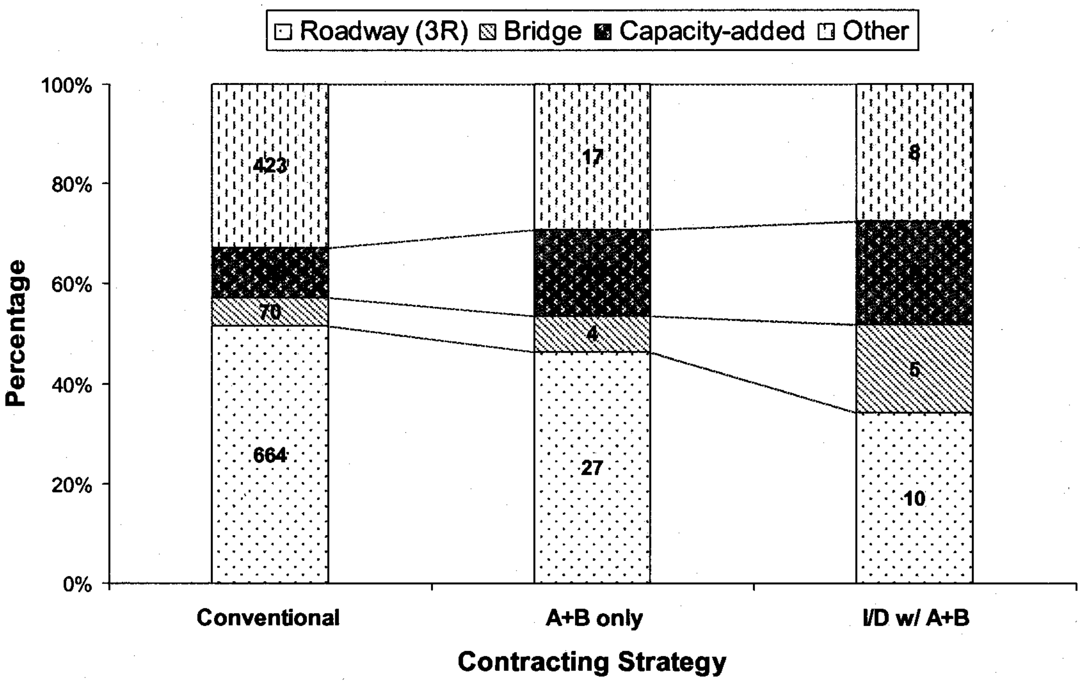


Figure 4.3 Adoption of Alternative Contracting Strategies versus Project Type

Figure 4.3 displays the tendency for adoption of alternative contracting strategies more frequently for capacity-added projects, such as widening of existing lanes or the addition of new lanes under live traffic conditions. These capacity-added projects, which are usually of relatively large-scale, are typically undertaken in heavily-trafficked urban areas to meet ever-growing traffic demand. At the same time, the large size of these projects requires agencies to close construction work zones longer. These apparently conflicting constraints have brought the fore the need for an alternative contracting method such as I/D to hasten project completion while minimizing the impacts of traffic disruption on the traveling public.

4.4.2 Project Size Issues

From Figure 4.4, it can be seen that alternative contracting strategies (I/D and A+B together) were applied in 6.47% of all the department's projects completed over the study years, 2000 to 2008. When this number was compared to the total project allotment costs, the percentage using I/D and A+B rose to 22.9%, which means that alternative contracting projects were used more often in larger-than-conventional projects.

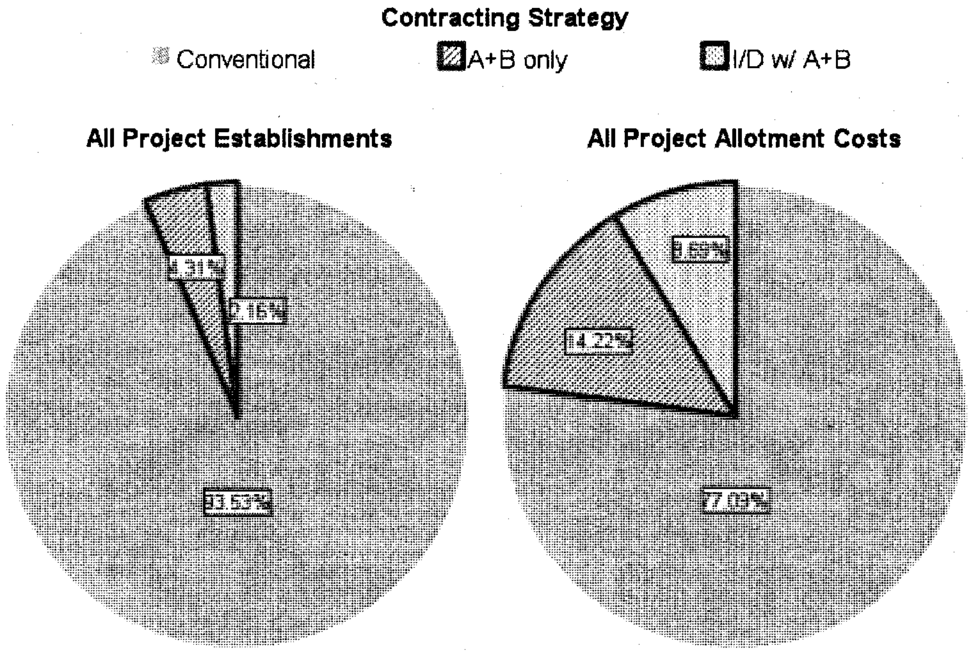


Figure 4.4 Percentage Comparison of Three Contracting Strategies (2000–2008)

Figure 4.5 confirms the fact that I/D and A+B projects are much bigger than conventional projects when it comes to the average project size on the original contract amount. Figure 4.5 and Figure 4.6 contain important information about the characteristics of an I/D project:

- I/D projects ($16.3 million) had the largest average project size in terms of the original contract amount, followed by A+B (13.4 million) and conventional ($4.1 million) projects.
- The large size of I/D projects implies that I/D strategy has primarily been applied to large-scale projects where time is of essence.
- The majority of projects contracted in I/D and A+B were between $5 million and $15 million, whereas conventional projects were around $5 million (Figure 4.6).
- Projects of the capacity-added type had the largest project size according to their original contract amount.

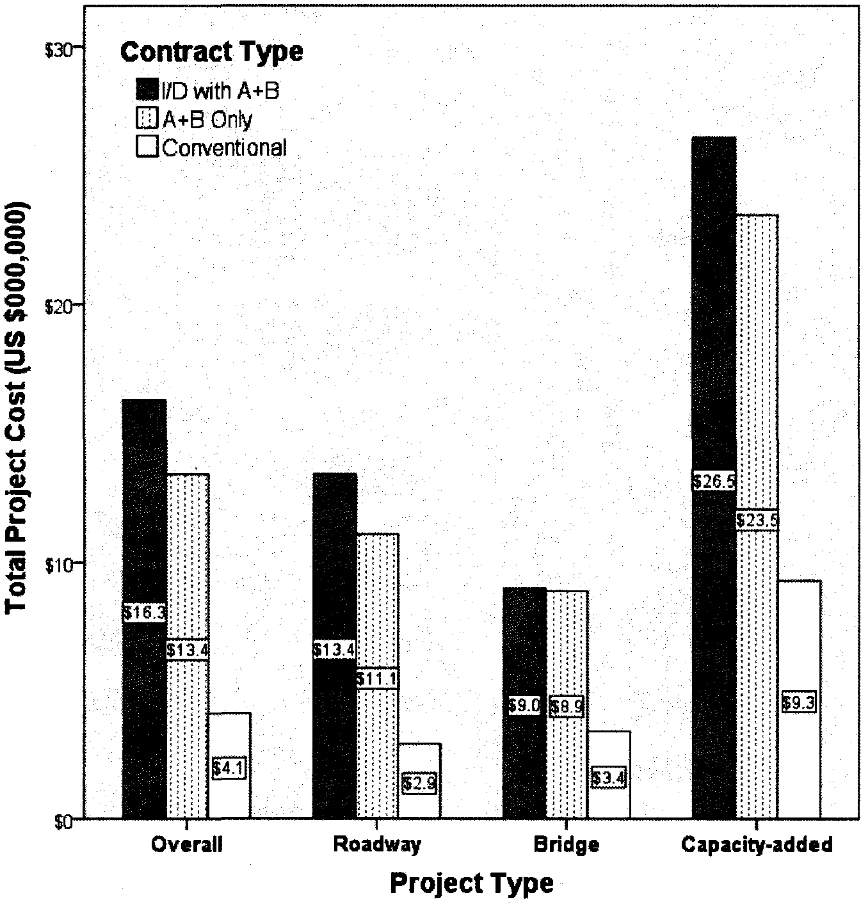


Figure 4.5 Average Project Size versus Contracting Strategy

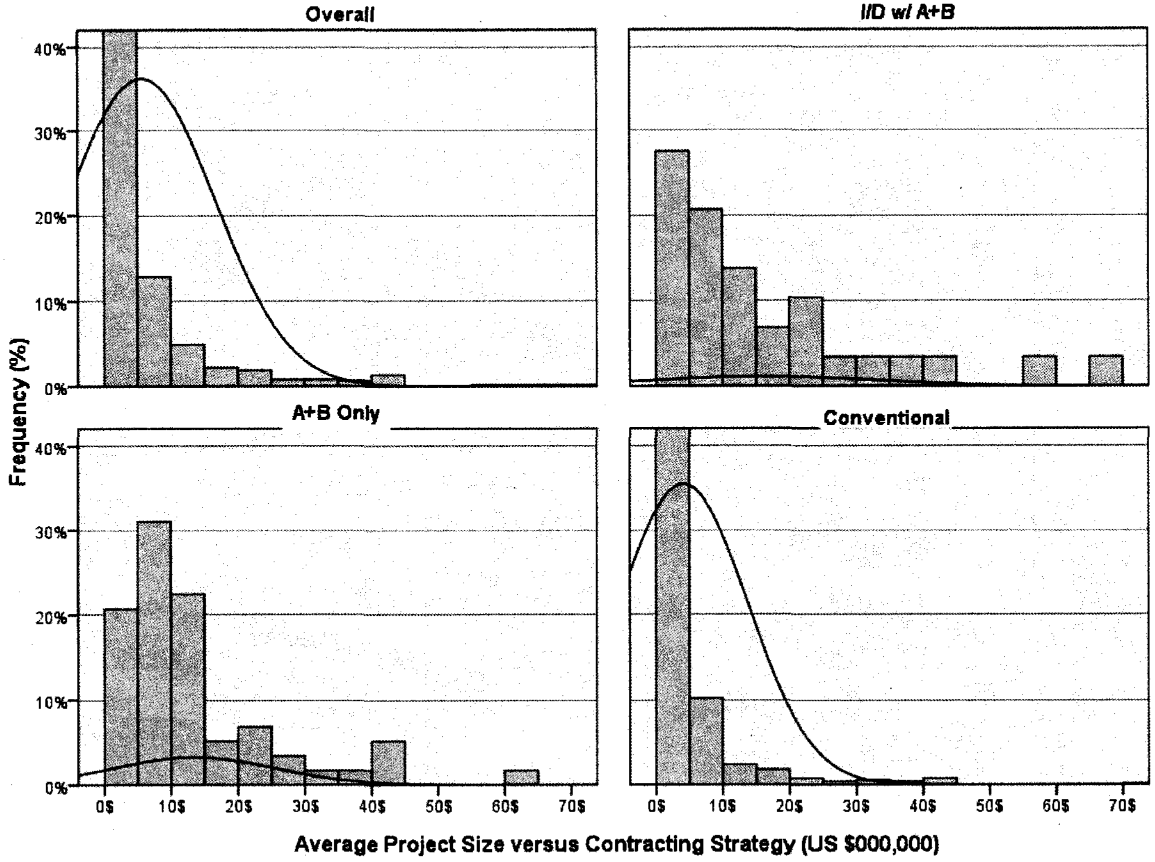


Figure 4.6 Comparison of Project Size by Contracting Strategies

Figure 4.7 displays daily contract dollar values for three contracting strategies. It was noted earlier that I/D corresponded to use in larger-size projects than A+B in terms of contract dollar value per project establishment. As Figure 4.7 shows, it is noticeable that the daily project size of A+B ($68,380) is larger than that of I/D ($63,512) in terms of contract dollar value per day, which results from the relatively shorter duration of A+B projects compared to I/D projects of similar project scope and size (A+B received 196 days on average, while the I/D's average was 257 days). Taken together, A+B projects seem to be subject to large contractor underestimations of contract times in bidding on the 'B' portion so they can be rewarded. This will be further explored in the next chapter.

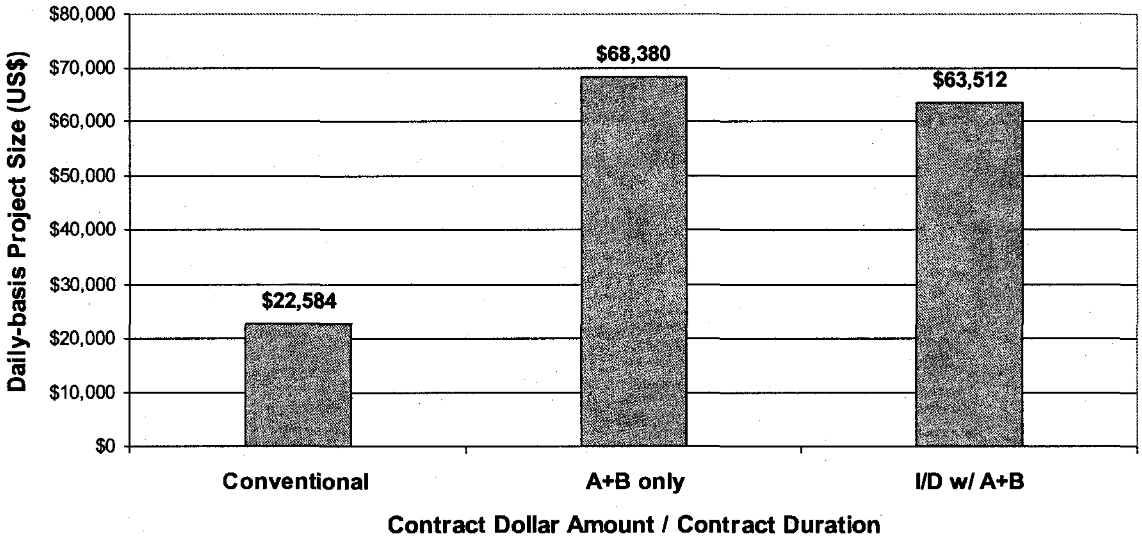


Figure 4.7 Average Project Size per Day versus Contracting Strategy

4.4.3 I/D Project Characteristics

General findings that emerged from data analysis are summarized as follows:

- I/D has always been used in conjunction with an A+B contract.
- Among 29 I/D projects, the average daily I/D amount was $17,009, with the largest amount being $30,000 and the smallest $5,000. Based on the literature review, the average I/D amount (per day) has been accrued over time; $1,000 to $5,000 in 1991, $2,500 to $5,000 in 1995, and $5,000 to $20,000 in 2000.
- Among 29 I/D projects, the maximum incentive amount (incentive cap) was $1.3 million on average, ranging from $135,000 to $5 million.
- The maximum incentive amount takes on average 8.84% of the original contract amount, which exceeds the 5% incentive cap recommended by FHWA.

4.5 STATISTICAL HYPOTHESES TESTING

In order to make a scientific inference about population or to determine a population characteristic, hypothesis testing is commonly used to assess whether (1) the means of two (or more) independent groups are statistically different from each other (two-tailed) or (2) the means of one group are significantly higher than other groups (one-tailed).

The main purpose of hypothesis testing is to test the validity of the null hypothesis. The null hypothesis (H_0) is a counter-hypothesis to the research hypothesis that the experimenter believes to be true (H_a). If there is statistically significant evidence to show that the null hypothesis is false, then the null hypothesis is rejected in favor of an alternative hypothesis.

This process is determined by setting an error threshold, called a significance level, α. The significance level is defined as "the probability that the researcher is willing to take of incorrectly rejecting a true null hypothesis" (Gerstman, 2003). For instance, in the significance level of 0.01, the researcher is willing to take one percent probability of incorrectly rejecting a true null hypothesis.

The predetermined significance level (α=.05 or .01) is then compared to a p value computed through a test statistics. If the p value is less than or equal to the alpha level, the null hypothesis is rejected. If the p value is larger than the alpha level, the null hypothesis is retained.

4.6 DEFINITION OF TERMS

4.6.1 Schedule Performance Ratio

The schedule performance ratio is the ratio of the difference between the actual final completion time and the original contract time to the original contract time.

Schedule performance ratio =

[(final completion time – original (and amended) contract time) / original (and amended) contract time]

A negative value implies that the project was completed sooner than originally scheduled. A positive value implies that the project took longer than originally scheduled. If the ratio equals zero, that implies the project was completed on time.

The schedule performance ratio was computed on two different thresholds; that is, original contract time versus amended contract time. The final completion time is defined as the time that the contractor completes all (or any designated portion) of the work called for under the contract, which allows unrestricted traffic on the CWZ. The original contract time is the originally scheduled project duration. The amended contract time reflects time adjustments, required by the imposition of contract change orders including contractor initiated changes, agency directed changes, and contingency changes.

Using the schedule performance ratio, whether the actual project duration was affected by the presence of I/D contracts was mainly examined. In other words, it was used to investigate if I/D projects offer a decisive time-saving advantage over A+B and conventional projects.

Conventional contracting projects are defined as projects contracted in a traditional lump sum contract under the design-bid-build project delivery system (lowest bidder is the winning bidder). Regardless of contracting strategy, the contractor would have a reason to complete the project on time to avoid a penalty imposed by liquidated damages, which are routinely assessed against them when they do not meet the completion date specified. Generally, liquidated damages are assessed separately from disincentives.

4.6.2 Cost Changes Ratio

The *cost changes ratio* was used to examine the level of cost growth for I/D projects over A+B and conventional projects. It is defined as the ratio of difference between the final project cost and the original contract amount to the original contract amount.

The cost change ratio =

[(final project cost – original (and amended) contract amount) / original (and amended) contract amount]

A positive ratio implies cost growth and a negative one means a reduction.

The calculation was repeated on the amended contract amount. The original contact amount consists of the costs of the bid items that the contractor proposes. The amended contract amount is the total cost adjusted on the installed original contract amount due to contract change orders. The final cost is the final project cost expended for the bid items at the end of the project, including total contract adjustments (e.g., incentive payments to contractors).

4.7 CHAPTER SUMMARY

This chapter mainly presents the procedure of data classification and findings through initial data analysis. The following shows a summary of the findings through initial data analysis:

- Roadway renewal, bridge, and capacity-added projects represented 83.0% of all Caltrans' project allotment costs over the eight years, 2000 to 2008 (Figure 4.1).
- I/D projects had the largest project size, followed by A+B and conventional projects, conveying the fact that I/D strategy has primarily been applied to large-scale projects (Figure 4.5).
- The majority of projects contracted in I/D and A+B were between $5 million and $15 million, whereas conventional projects were around $5 million.
- I/D was chosen more frequently for capacity-added projects (Figure 4.3).
- Projects of the capacity-added type had the largest project size according to their installed original contract amount (Figure 4.5).
- Among 29 I/D projects, the average daily I/D amount was $17,009.
- Among 29 I/D projects, the maximum incentive amount (incentive cap) was $1.3 million on average, ranging from $135,000 to $5 million.

- The maximum incentive amount allocated takes on average 8.84% of the original contract amount.

5 EFFECT OF I/D CONTRACT ON PROJECT SCHEDULE

5.1 INTRODUCTION

Although historically, I/D contracting has primarily been applied to emergency-type projects, it can also be an effective means to accelerate construction time on non-emergency projects usually bid by conventional methods. In particular, the I/D contracting strategy aims to encourage contractors to accomplish an internal milestones sooner and/or to complete entire projects faster than originally scheduled.

A+B is known as an effective means to eliminate inefficient contractors from the bidding process. It is valuable for the agency to compare the schedule effectiveness of an I/D project with an A+B project. To evaluate their effectiveness, I/D projects were compared with: (1) projects contracted solely with an A+B contract; and (2) projects contracted conventionally. As a methodology, a one-way ANOVA analysis was used with a planned comparison and post-hoc tests to achieve the following objectives:

- To examine whether the actual contract duration was affected by the presence of an I/D contract.
- To determine whether alternative contracting projects (A+B and I/D) shortened the project duration below the levels observed in the conventional projects.
- To determine whether I/D projects reduced construction times more significantly than A+B and conventional projects.

Based on the data used in this study, I/D provisions have always been used in conjunction with A+B contracts, while A+B has been applied as a standalone or with accompanying

I/D provisions. Each state (of an approximate total of 35 using I/D) has a different practice for using I/D. For example, in Florida A+B has always been used with I/D, while I/D has also been used as a standalone or in a hybrid form.

5.2 EXISTING STUDIES ON I/D SCHEDULE EFFECT

The research study of Herbsman and Ellis indicates that 99% of the contractors in thirty-five states who contracted with I/D provisions on infrastructure improvement projects received an incentive bonus (Herbsman and Ellis, 1995). The work of Arditi (Arditi et al., 1997) and Jaraiedi (Jaraiedi et al., 1995) reported that I/D contracting reduced construction time by up to 50%. More specifically, 93% of I/D contracting projects were completed on time or earlier while 41% of non-I/D contracting projects were completed on time or ahead of schedule. However, these results are out-of-date and might be obsolete as I/D has become increasingly popular in the intervening decade. At the time of these studies, I/D was deemed experimental, and was thus applied in a limited way.

5.3 SUBSTANTIAL COMPLETION VERSUS FINAL COMPLETION

Substantial completion and final completion are the two benchmarks used to determine project completion time for paying incentives or charging disincentives. Substantial completion is defined as the time when parts of lanes are opened to traffic under minor construction work being performed, such as site cleanup, planting, and lane marking (Arditi et al., 1997). On the other hand, final completion is defined as the time that the contractor completes all (or any designated portion) of the work called for under the contract and allows unrestricted traffic on the construction work zone. In practice, the selection of the benchmarks varies from one state highway agency to another; some states (e.g., Illinois) adopt the former as a baseline for setting an I/D amount and other states, such as California, accept the latter. Therefore, the actual project time used for the analyses presented in this study is the final completion time.

5.4 A+B BIDDING MECHANISM AND EFFECTIVENESS

In A+B contracting, the winning bidder is the one who turns in the lowest combined bid for cost (A) and time (B) required to complete the project. In symbols (Herbsman et al., 1995),

$$\mathrm{BCT} = \mathrm{TPC} + (\mathrm{DRUC} \times \mathrm{TPT}) \qquad \textbf{(1)}$$

where BCT = bid on cost and time;

TPC = total project cost for the project representing the "A" portion;

DRUC = daily road user cost; and

TPT = total project time for completing the project representing the "B" portion.

The value of daily road user cost (DRUC) is established by the contracting agency for the contractor to incorporate it into the "B" portion in A+B bidding. The Caltrans guidelines for use of A+B bidding provisions specify that the "daily road user cost should not be more than the liquidated damages; otherwise it might prove to be more economical to pay liquidated damages rather than plan to finish within the bid project duration" (Caltrans, 2000). In Caltrans practice, the real DRUC will typically range from 50 to 100 percent of the calculated daily road user cost. This percentage is determined by the project engineer after seeking input from the Office of Traffic Operations regarding traffic delay significance.

Recently, A+B bidding has become one of the most widely used alternative contracting techniques for shortening construction time. This form of bidding takes advantage of contractors' ingenuity by utilizing their realistic estimates of construction schedule and cost; it is also generally acknowledged that this bidding process eliminates unqualified contractors. However, A+B implementation experiences to date indicate that the effectiveness of A+B contracting is debatable largely due to inherent inaccuracy in letting contractors specify project duration during the bidding. To bridge the gap between these conflicting notions, this chapter aims to resolve this conflict by exploring which alternative contracting strategy more effectively reduces construction time, compared with conventional contracting projects.

5.5 IMPACT OF AN I/D CONTRACT ON OVERALL PROJECT SCHEDULE

The impact of I/D on project schedule compared with A+B and conventional projects was measured by the schedule performance ratio defined in Chapter 4. It was noted that 58.6% of I/D projects were completed earlier than originally scheduled, while just 12% of A+B projects and 32.4% of conventional projects were completed ahead of schedule. I/D contracting reduced construction time by up to 57%.

Figure 5.1 shows that I/D projects reduced construction time by compressing the "original" contract schedule by an average of 4.16%, while A+B and conventional projects increased the construction time by 31.55% and 18.58%, respectively. A similar trend was observed when the schedule impact is viewed in terms of "amended" contract time, which includes time extensions forced by contract change orders; I/D projects still led to a positive schedule change (15.85% compression), and conventional and A+B projects showing negative schedule changes.

According to the analysis, I/D contracting projects showed much better schedule performance on both schedule baselines (original and amended) than other contracting projects; 22.74% and 35.71% better than those of conventional and A+B projects, respectively.

An unusual, unforeseen pattern was observed in A+B projects. It was initially expected that A+B projects provided schedule-saving performance similar to I/D projects. However, in reality, A+B projects underwent a fairly negative schedule change (31.55% overruns), which reveals a severe schedule reliability problem in letting the contractor specify contract time in the bidding process.

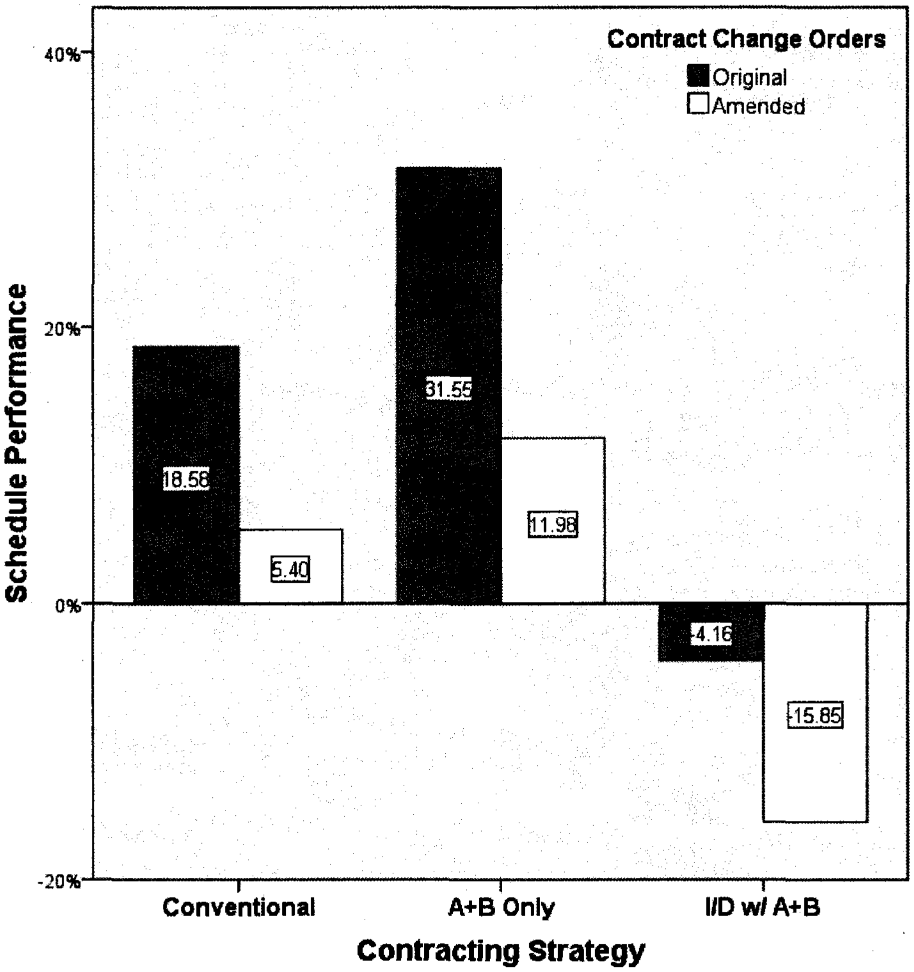


Figure 5.1 Overall Schedule Performance versus Contracting Strategy

Figure 5.2 displays a box-and-whisker plot of project schedule performance on the three contracting strategies, indicating five-number summaries such as minimum, lower quartile, median, upper quartile, and maximum. The middle line in the box depicts the median, which is more representative of the central tendency since it limits the impact of extreme cases known as outliers. When the level of schedule performance was analyzed by looking at the median value, the same trend was observed; I/D projects produced the best schedule performance, followed by conventional and A+B projects. When the degree of project dispersion for schedule performance (the length of boxes labeled "original") was considered, it is seen that the schedule performance of A+B projects varied highly from one project to another. This might convey the fact that A+B projects did not start with a well-defined project scope.

Figure 5.2 also indicates that the conventional contracting strategy had many outlier projects. This means that the schedule performance result for conventional projects could be dramatically affected by those outlier projects. To scientifically verify the aforementioned results, a one-way ANOVA analysis was conducted to compare the means of three contracting project groups (see Section 5.7). To further examine where the schedule changes (positive or negative) occurred, a detailed analysis was undertaken on three major project types.

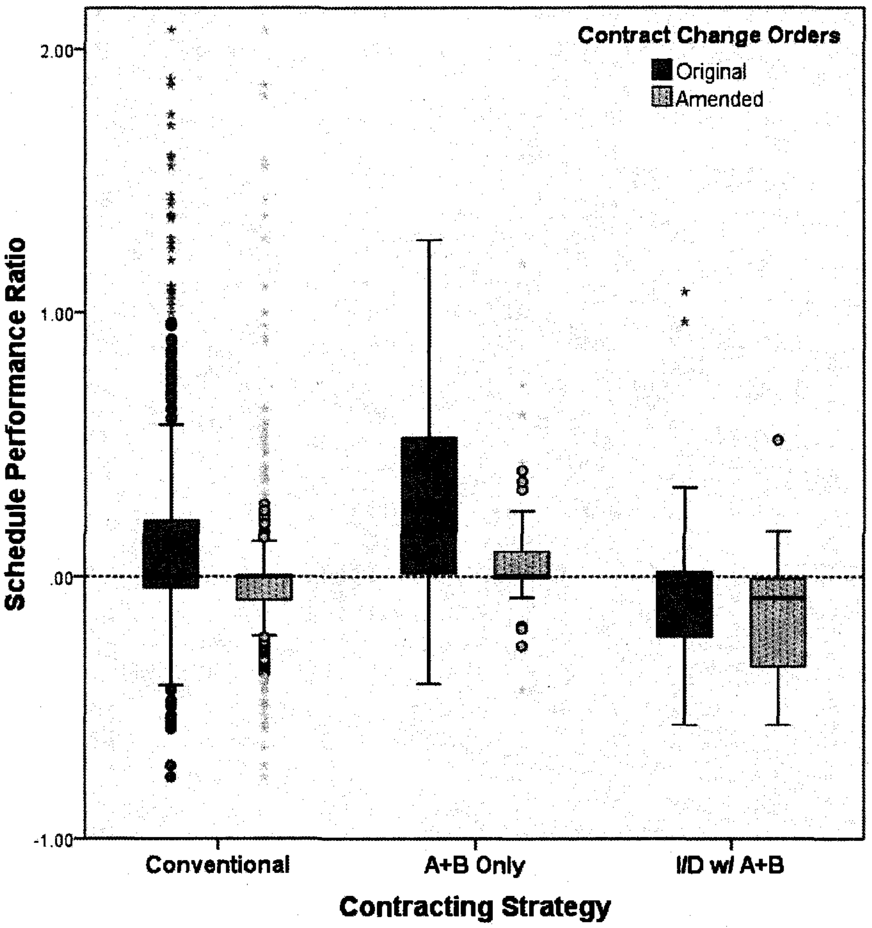


Figure 5.2 Schedule Performance Box Plot of All Projects

5.6 SCHEDULE PERFORMANCE VERSUS PROJECT TYPES

5.6.1 Roadway 3R Projects

During the eight year study period, 2000 to 2008, roadway projects including maintenance (resurfacing), reconstruction, and rehabilitation of existing facilities represented approximately 50% of all project establishments and 45% of all project cost allotments. These percentages indicate that improvement and renewal of existing roadways has been the central focus of recent infrastructure projects. By this reasoning, knowing how the scheduling effectiveness of alternative contracting strategies varies with roadway type and comparison with the conventional strategy is important for contracting agencies; this knowledge can help agencies uncover the problems with the alternative contracting strategies in current practice so they can plan better in the future.

On the selected roadway projects, 40.0% of the I/D projects were completed sooner than initially scheduled. By comparison, 33.6% of conventional projects were completed ahead of schedule, and 14.8% of A+B projects were completed earlier. As shown in Figure 5.3, I/D projects produced schedule overruns on average by 7.72% on the original contract time, while A+B projects underwent schedule delays of 31.85%, and conventional projects led to schedule overruns of 20.47%. When schedule extensions resulting from contract change orders are considered, it appears that while A+B and conventional projects led to schedule delays, I/D projects shortened construction time by 7.18% (see Figure 5.3).

In summary:

- Even if I/D projects had a negative change (schedule delay) on original contract time, they showed far better time-saving performance than any other contracting strategy.
- A+B projects experienced significant schedule delays and their schedule performance ratios are highly dispersed (see Figure 5.4 to compare the degree of dispersion of A+B projects with that of I/D projects).
- The composition of schedule performance on I/D and A+B projects conveys the facts that the contracting agency benefited by significant time savings using the

I/D contracting strategy, and that A+B projects have a crucial problem with the inaccuracy of contractors' original schedule estimates, which were underestimated.

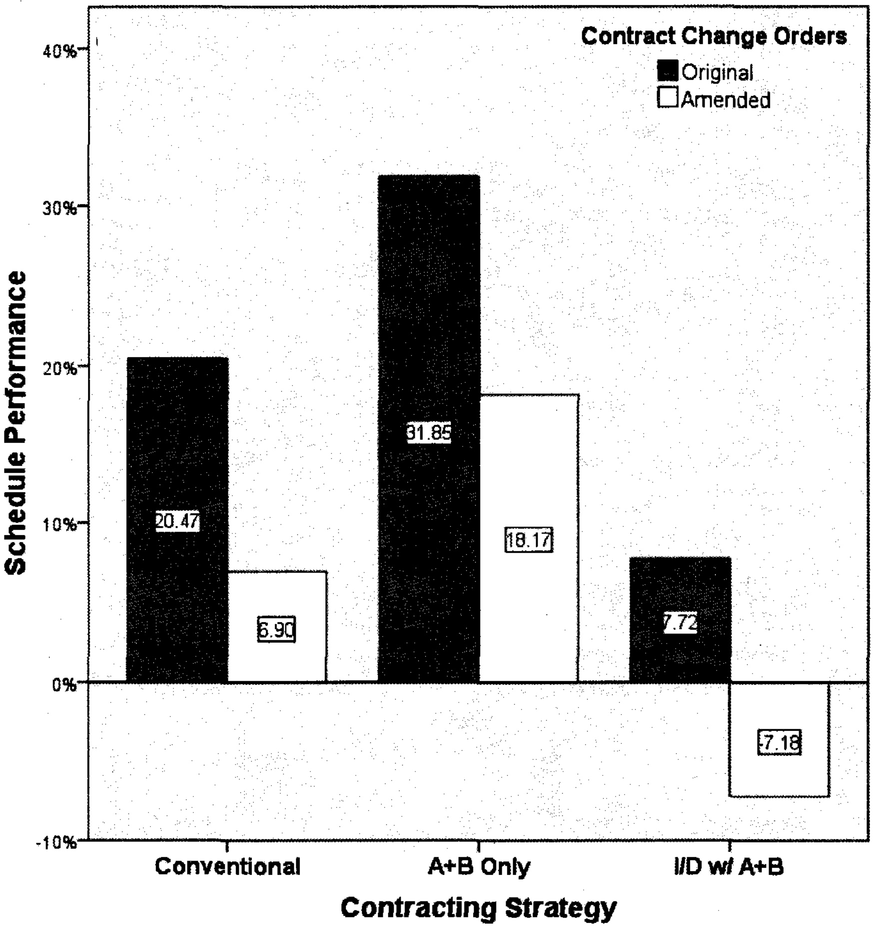


Figure 5.3 Schedule Performance on Roadway Projects versus Contracting Strategy

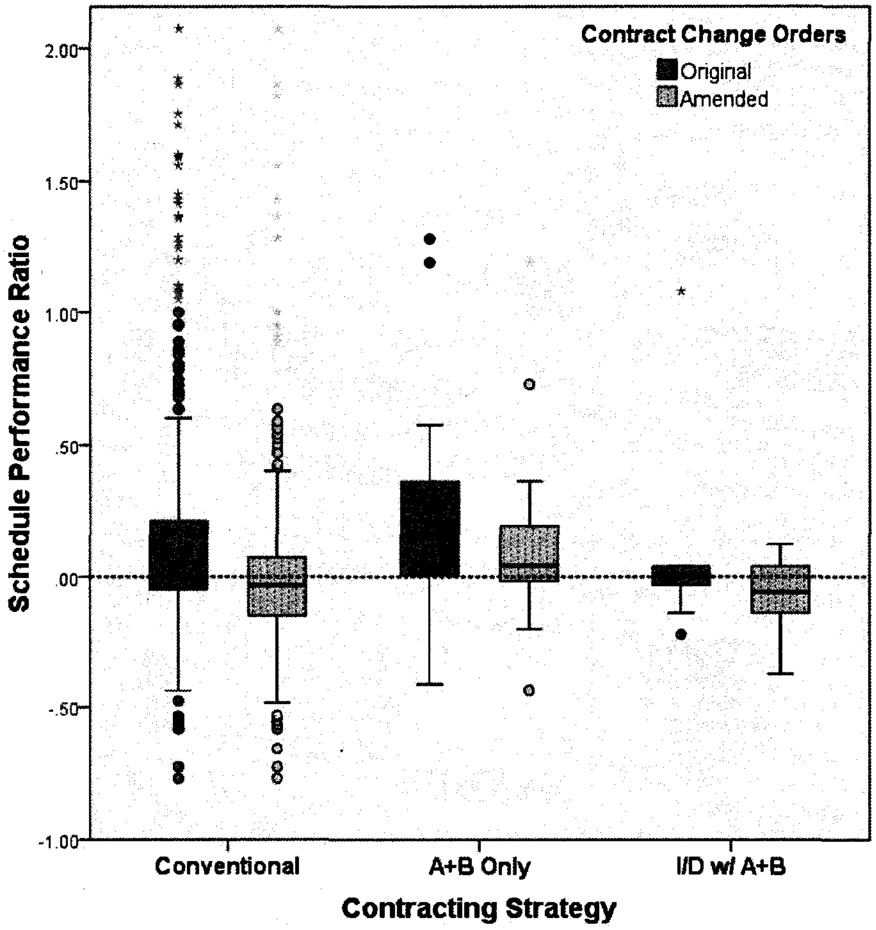


Figure 5.4 Schedule Performance Box Plot of Roadway Projects

5.6.2 Bridge Projects

Bridge projects presented in this study include replacement, repair, and rehabilitation of existing bridges, which represents 5.8% of all project establishments and 7.0% of all project cost allotments over the study year period, 2000–2008. It is striking that 100% of all I/D bridge projects were completed sooner than projected, while 38.7% of conventional projects were completed ahead of schedule. As pointed out in the roadway type, A+B projects on the bridge type also reveal a severe schedule delay problem;

namely, 50% of the project produced a schedule overrun (only one project among four was completed sooner than the schedule called for).

Figure 5.5 indicates that I/D projects on bridges type resulted in a decisive schedule saving advantage over conventional and A+B projects; I/D projects reduced construction time significantly (45.77%) on the installed original contract time, while A+B and conventional projects had schedule delays (17.54% and 13.43%, respectively). It is also seen that all six I/D projects were located in heavily populated and trafficked urban areas; 33 percent within the Los Angeles basin, and 67 percent in the San Francisco Bay Area.

When schedule extensions resulting from contract change orders are considered, all of three contracting groups provided schedule savings, unlike other project types (Figure 5.5 and Figure 5.6). A likely reason that all the bridge projects shortened construction times from their contract times amended due to contract change orders was increased public pressure on the agencies to open the bridges early or on time, regardless of contracting strategy, to re-establish critical services (such as emergency services) to the adjacent communities. In addition, construction work on the existing bridges resulted in direct and indirect environmental impacts on the adjoining communities, another spur to project completion.

Findings that emerged on bridge type are summarized as follows:

- I/D projects that were situated in highly urbanized areas showed a definitive schedule-saving advantage.

- A+B projects showed the worst schedule compression effect.
- Based on amended contract time reflecting contract change orders, all three contracting projects produced some degree of schedule compression.

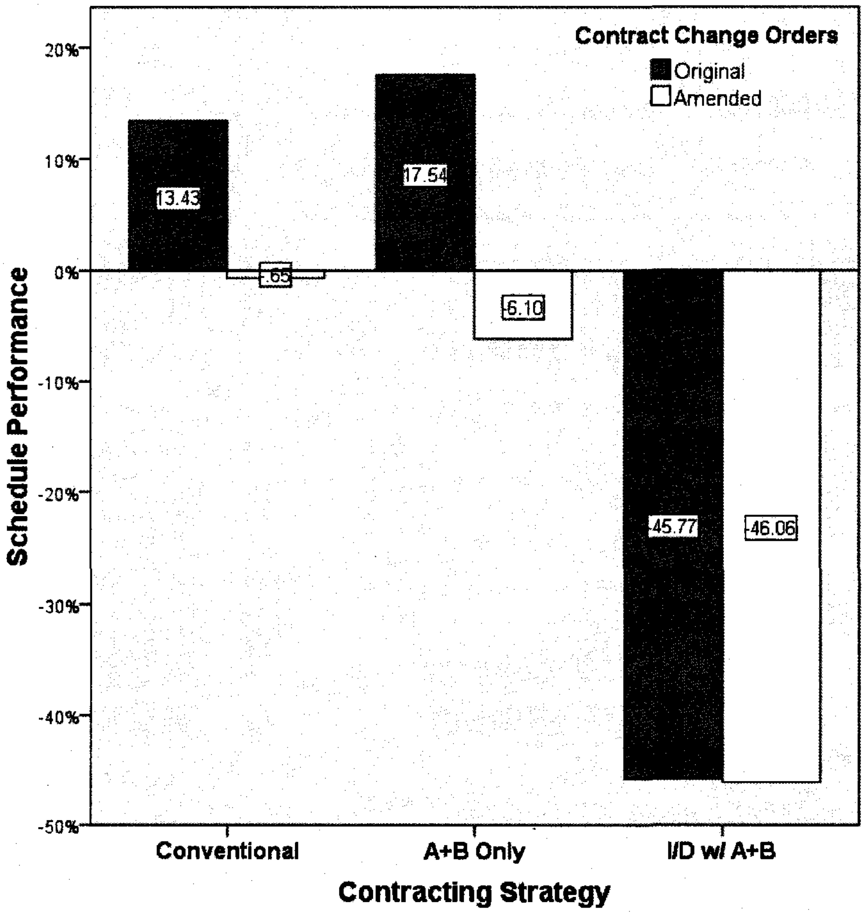


Figure 5.5 Schedule Performance on Bridge Projects versus Contracting Strategy

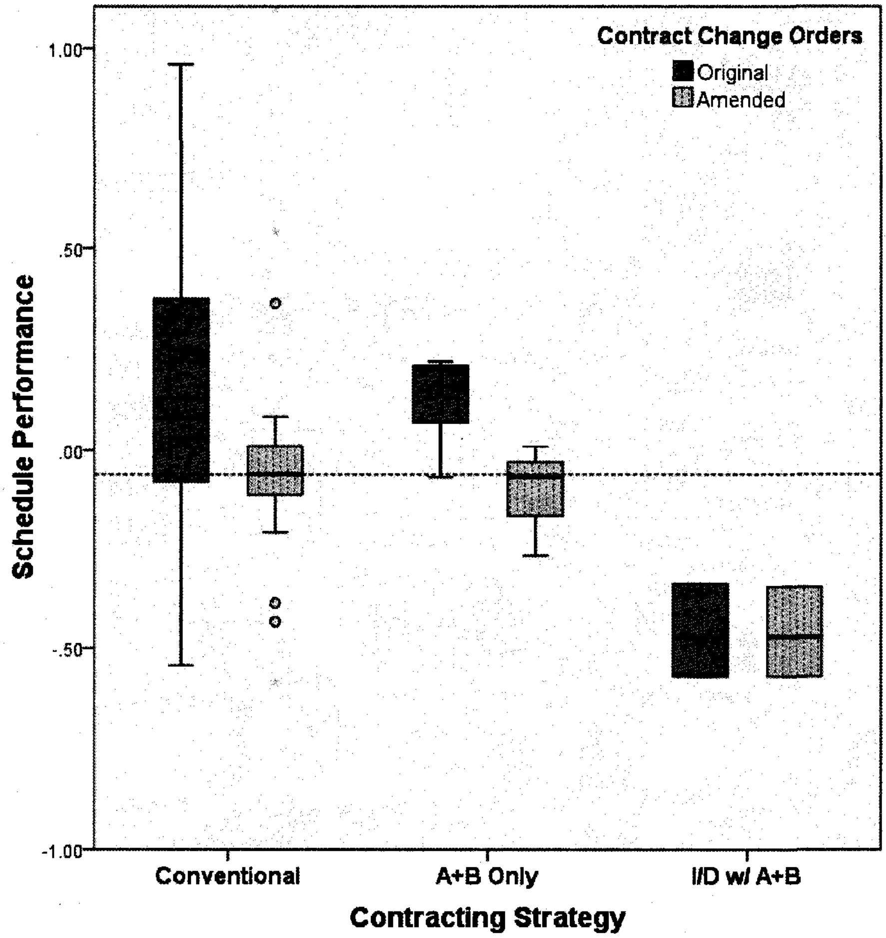


Figure 5.6 Schedule Performance Box Plot of Bridge Projects

5.6.3 Capacity-added Projects

The capacity-added projects presented in this study include adding or widening lanes performed concurrently with some renewal work on existing lanes, such as resurfacing, reconstruction, or rehabilitation. This project type represents 10.5% of all project establishments over the study year period, 2000 to 2008, and 31.0% of all project cost allotments. It appears that this type of project received the largest investment among all the project categories. Owing to their large size, projects of the capacity-added type create major negative impacts on the traveling public. Therefore, it is especially worthwhile for agencies to know the percentages of schedule performance for this project type.

Fifty percent of the capacity-added I/D projects were completed earlier than originally planned, while 24.4% of the conventional projects were completed ahead of schedule. Significantly, 100% of capacity-added A+B projects did not meet their scheduled completion dates. In addition, Figure 5.7 shows that A+B projects also underwent significant schedule delays by 37.0%, whereas I/D projects reduced construction time on average by 2.5%. The same trend was seen when compared with median values; I/D projects showed the greatest schedule-saving performance, followed by conventional, and A+B projects (see Figure 5.8).

These summarized findings emerged from this analysis on the capacity-added projects:

- I/D projects held a definitive schedule-saving advantage over other contracting strategies.
- A+B projects showed a severe problem with schedule delays.
- Figure 5.8 shows a higher degree of dispersion of ratios on A+B projects, suggesting that they did not start with well-defined project scope.

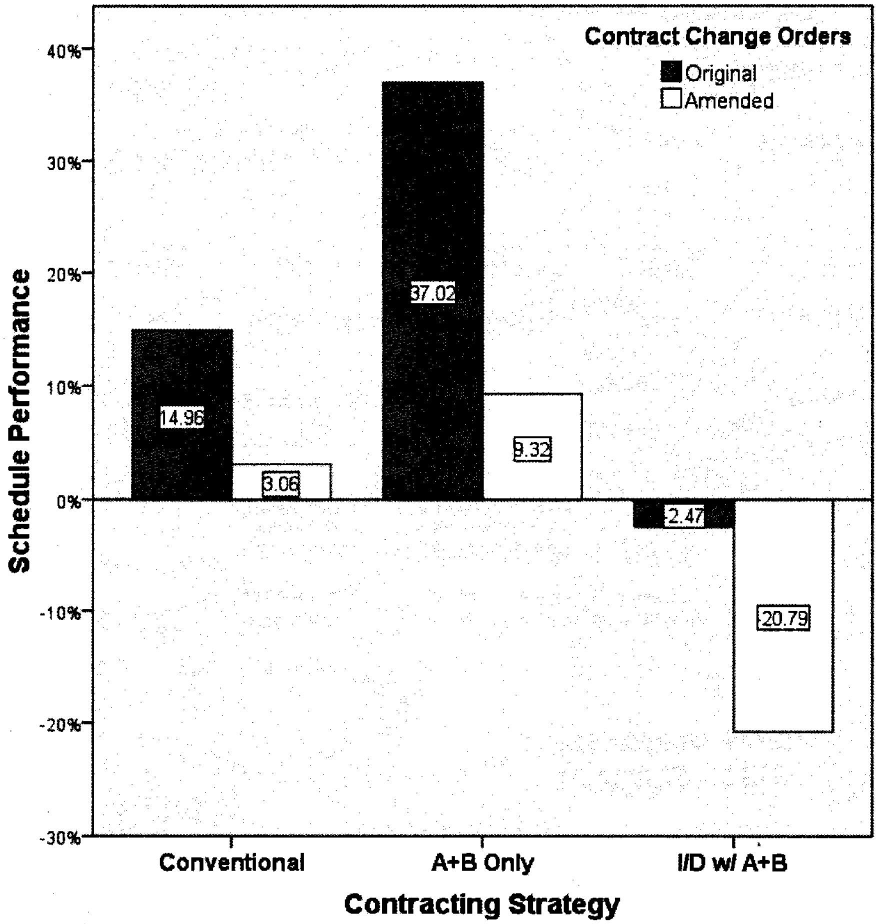


Figure 5.7 Schedule Performance on Capacity-Added Projects

versus Contracting Strategy

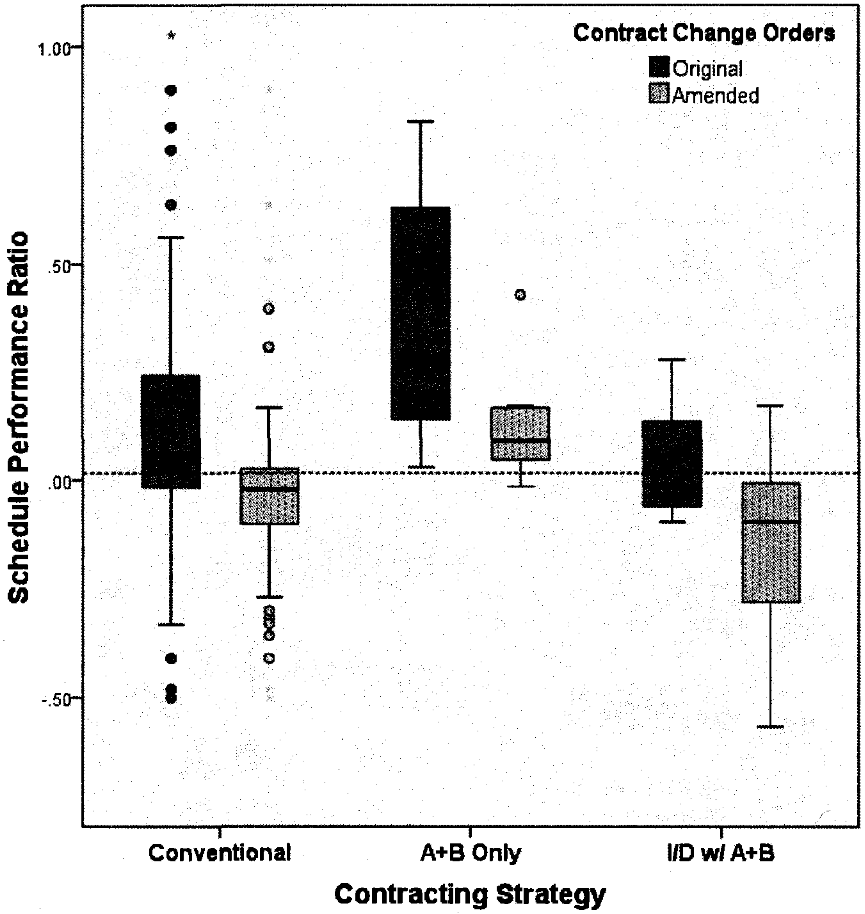


Figure 5.8 Schedule Performance Box Plot of Capacity-Added Projects

5.6.4 Other Projects

Other projects include minor construction works, such as median barriers, guard rails, seismic retrofit, etc. This project type represents 30.8% of all project establishments, but represents only 5.0% of all project cost allotments due to its small size.

The same trend is observed on this type; (1) I/D projects held a relative schedule-saving advantage over other contracting projects (Figure 5.9), (2) A+B projects had severe schedule delays, and (3) a higher degree of dispersion of ratios on A+B projects also appeared (Figure 5.10).

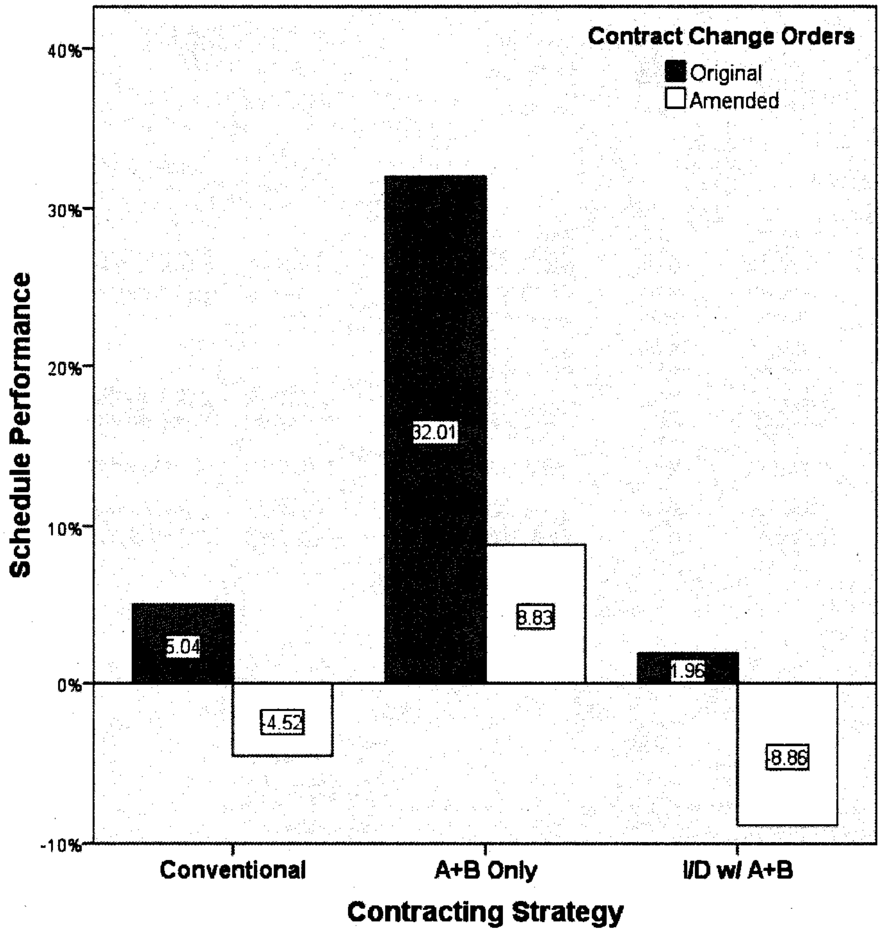


Figure 5.9 Schedule Performance on Other Projects versus Contracting Strategy

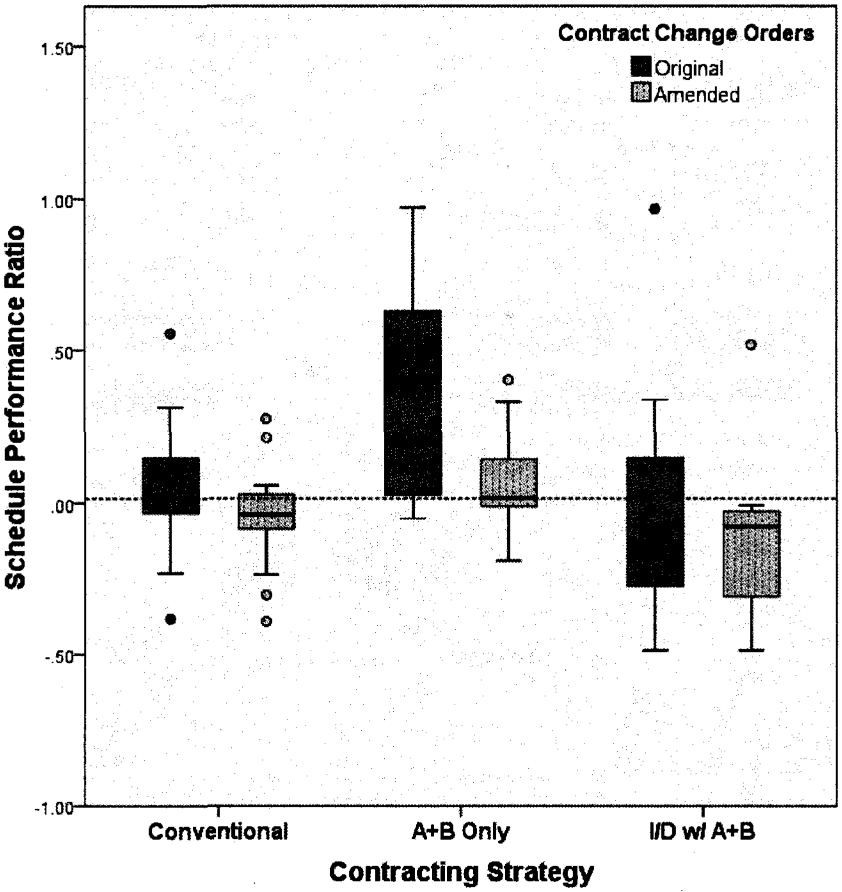


Figure 5.10 Schedule Performance Box Plot of Other Projects

5.7 RESEARCH HYPOTHESIS TESTING

5.7.1 Design of Research Hypotheses

Based on the analyses performed in this chapter, it was known that I/D projects were more effective than A+B and conventional strategies in reducing construction time. They held a relative time-saving advantage over other contracting strategies. The analyses also showed that use of A+B did not result in much better schedule performance than conventional projects. To further explore this case, a one-way ANOVA analysis for comparing means of three contracting groups was conducted to test the following research hypotheses:

- Actual contract duration is affected by the presence of an I/D provision.
- Alternative contracting (A+B and I/D) strategies shorten the duration of projects significantly more than the conventional method does.
- For shortening completion time, the I/D contracting strategy is preferable to the other two strategies.

It is assumed that contractors' individual production performance and work experience are identical. Contractor productivity during daytimes and nighttimes is also assumed to be equivalent.

5.7.2 Validation of Assumptions

When conducting a one-way ANOVA analysis, the data should satisfy the following three assumptions for a test variable (i.e., schedule performance ratios):

1. Normality: The test variable should be normally distributed.
2. Homogeneity of variances: The population distributions have the same variances.
3. Independence: Three contracting project groups are independent of one another.

It is known that ANOVA is quite robust over moderate violations of the first assumption. Normality of the data was first checked by the Shapiro-Wilk test to examine whether the project data is significantly different from a normal distribution. It is recommended that the Shapiro-Wilk test be used if the sample size is between 3 and 2,000 and the

Kolmogorov-Smirnov test be used if the sample size is greater than 2,000 (Rice, 1995). Table 5.1 shows that the project data of schedule performance ratios are normally distributed because the significance value (.521) generated by the Shapiro-Wilk test is greater than .05.

Table 5.1 Normality test of Schedule Performance Ratios

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Transformed	.053	477	.534	.989	477	.521

a. Lilliefors Significance Correction

Because the Shapiro-Wilk test can produce a misleading result, normality of the project data was confirmed by a graphical plot, quantile-quantile (Q-Q) plot, and there was no evidence to show that the data was not normally distributed (Figure 5.11).

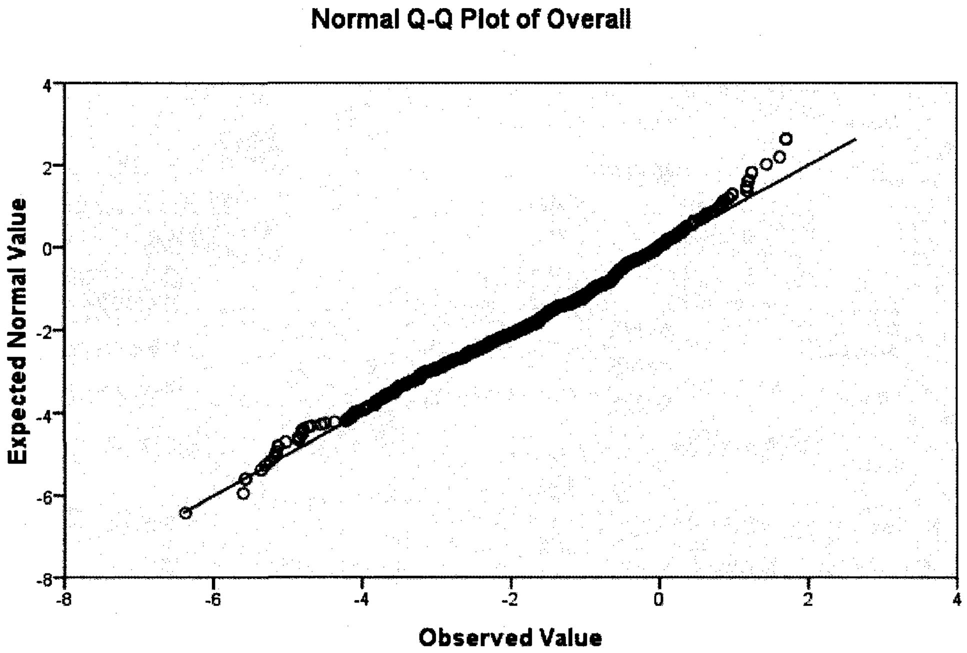


Figure 5.11 Normal Q-Q Plot of Schedule Performance Ratios

In Figure 5.11, the test variable is represented by circles plotted along a straight line. The straight line represents an ideal normal distribution line and circles represent our data; that is, the closer the circles are to the straight line, the more normally distributed (Rice, 1995). The Q-Q plot suggests that the test variable is normally distributed except for few outliers. The second assumption that the variances of samples are statistically equal was examined by the Levene's *F* test (test of homogeneity of variances). The results of Levene's *F* test statistics for the equality of variances are 0.986 (*p*=.374). This suggests that the variances of schedule performance ratios are equal.

A project could be affected by some externalities (e.g., inclement weather conditions and schedule delays due to unexpected equipment breakdowns during construction), but there should not be correlation between projects because all projects were independently implemented and completed at different locations in different times. Therefore, it is reasonable to assume that all projects are statistically independent.

5.7.3 Analysis of Testing Results

Table 5.2 presents the summary statistics of schedule performance for three contracting groups with regard to all projects. Standard deviations show that the variability of I/D projects is much lower than that of other contracting project groups. The fact that I/D projects usually start with a better definition of project scope could be evidenced by their relatively lower variability in schedule performance.

Table 5.2 Average Schedule Performance versus Contracting Strategy

Descriptives

Overall

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Conventional	518	.1858	.61838	.02717	.1324	.2392	-.77	5.49
A+B Only	58	.3155	.45770	.06010	.1952	.4359	-.41	2.67
I/D w/ A+B	29	-.0416	.36939	.06859	-.1821	.0990	-.57	1.08
Total	605	.1873	.59791	.02431	.1396	.2351	-.77	5.49

Table 5.3 shows the summary of the main ANOVA analysis, which is divided into *between-group effects* (i.e., effects due to the implementation of different contracting strategies) and *within-group effects* (i.e., unsystematic variation in the data). The between group effect is further divided into a linear and quadratic term for a trend analysis. The test of whether the mean difference of three contracting project groups is statistically significant is represented by the F-ratio (3.488) for the combined between-group effect. The significance value ($df = 2, p = .031$) suggests that the likelihood that an F-ratio of this

size would have occurred by chance is less than 5%. Hence, it is concluded that there is sufficient evidence to show that the mean difference of three contracting project groups is significant.

Table 5.3 also displays the results of the trend analysis to examine the schedule effect between a linear relationship and a quadratic relationship. From Table 5.3, it is seen that the schedule effect is better explained by the quadratic relationship (*F* = 6.343, *P* = .012). The quadratic relationship among three contracting project groups implies that there is a negative change in schedule performance as the contracting strategy has changed from a conventional to an A+B, and the negative change is shifted to a positive change as the contracting strategy has changed from an A+B to an I/D. To further investigate this trend, planned comparison and post-hoc tests were followed.

Table 5.3 Summary of ANOVA Analysis on Schedule Performance

ANOVA

Overall

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		2.474	2	1.237	3.488	.031
	Linear Term	Unweighted	1.420	1	1.420	4.004	.046
		Weighted	.225	1	.225	.634	.426
		Deviation	2.249	1	2.249	6.343	.012
	Quadratic Term	Unweighted	2.249	1	2.249	6.343	.012
		Weighted	2.249	1	2.249	6.343	.012
	Within Groups		213.458	602	.355		
	Total		215.931	604			

To examine the difference in schedule performance of three contracting project groups, four planned comparisons were conducted with the following one-tailed hypotheses (see Table 5.4);

1. Alternative contracting projects would shorten construction time significantly more than conventional projects (Contrast 1: alternative versus conventional).
2. Conventional projects would reduce the duration of projects significantly more than A+B projects (Contrast 2: conventional versus A+B).
3. I/D projects would cut the length of project duration significantly more than conventional projects (Contrast 3: I/D versus conventional).
4. Use of incentives/disincentives would make a difference to schedule performance in comparison to A+B projects (Contrast 4: I/D versus A+B).

Table 5.4 shows the results of the planned comparisons. The *p*-values in the table need to be divided by two to obtain the one-tailed probability. The upper part of the table, titled "Assume equal variances," should be referred to because the second assumption of equal variance was not significant. The *t*-statistic of -.673 (df = 602, p = .502/2 = .251) for Contrast 1 indicates that there is no significant evidence to show that alternative contracting projects would reduce construction time significantly more than conventional projects. The significance of Contrast 2 (df = 602, p = .116/2 = .058) shows that there is no significant evidence to prove that conventional projects (0.1858) performed much better than A+B projects (0.3155). The significance (p<.05) of Contrast 3-4 proves that I/D performed much better than other contracting projects.

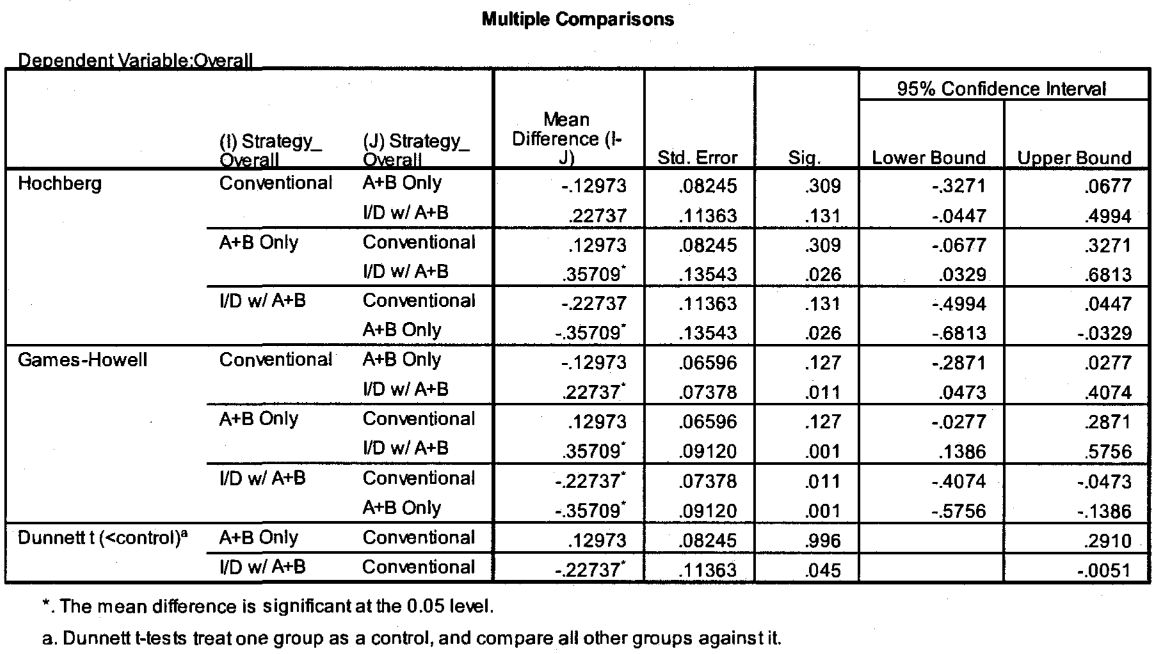
Table 5.4 Results of Planned Comparison Test on Schedule Performance

Contrast Tests

		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
Overall	Assume equal variances	1	-.0976	.14518	-.673	602	.502
		2	-.1297	.08245	-1.573	602	.116
		3	.2274	.11363	2.001	602	.046
		4	.3571	.13543	2.637	602	.009
	Does not assume equal variances	1	-.0976	.10616	-.920	122.551	.360
		2	-.1297	.06596	-1.967	82.302	.053
		3	.2274	.07378	3.082	37.426	.004
		4	.3571	.09120	3.916	67.848	.000

Some post-hoc tests were followed to further identify which contracting strategy is significantly better than other strategies in shortening the duration of projects. The post-hoc tests are for further investigation after a significant effect among testing variables has been found through a one-way ANOVA analysis (Rice, 1995). The post-hoc analysis was needed to determine which contracting groups performed significantly better in shortening construction times. Table 5.5 shows the results of Hochberg's test, Games-Howell, and Dunnett's test. The Hochberg's test was chosen due to the fact that the sample sizes of the three contracting groups are very different. Along with the Hochberg's test, the Games-Howell procedure was chosen to confirm the research hypothesis that I/D projects had a significantly better schedule compression effect than other contracting projects. The Dunnett's test was selected to compare alternative contracting projects against the conventional project (Garson, 2008). For each pair of contracting strategies in the post-hoc tests described above, the difference between the average schedule performance of two contracting strategies, the standard error of that difference, and the significance level of that difference are presented in Table 5.5. When conventional projects were compared to A+B and I/D projects, a similar result with the planned comparisons was observed, which confirms that I/D contracting strategy is preferable to the other two strategies for shortening completion time.

Table 5.5 Results of Post-Hoc Tests on Schedule Performance



Multiple Comparisons

Dependent Variable:Overall

	(I) Strategy_Overall	(J) Strategy_Overall	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Hochberg	Conventional	A+B Only	-.12973	.08245	.309	-.3271	.0677
		I/D w/ A+B	.22737	.11363	.131	-.0447	.4994
	A+B Only	Conventional	.12973	.08245	.309	-.0677	.3271
		I/D w/ A+B	.35709*	.13543	.026	.0329	.6813
	I/D w/ A+B	Conventional	-.22737	.11363	.131	-.4994	.0447
		A+B Only	-.35709*	.13543	.026	-.6813	-.0329
Games-Howell	Conventional	A+B Only	-.12973	.06596	.127	-.2871	.0277
		I/D w/ A+B	.22737*	.07378	.011	.0473	.4074
	A+B Only	Conventional	.12973	.06596	.127	-.0277	.2871
		I/D w/ A+B	.35709*	.09120	.001	.1386	.5756
	I/D w/ A+B	Conventional	-.22737*	.07378	.011	-.4074	-.0473
		A+B Only	-.35709*	.09120	.001	-.5756	-.1386
Dunnett t (<control)[a]	A+B Only	Conventional	.12973	.08245	.996		.2910
	I/D w/ A+B	Conventional	-.22737*	.11363	.045		-.0051

*. The mean difference is significant at the 0.05 level.

a. Dunnett t-tests treat one group as a control, and compare all other groups against it.

5.8 CHAPTER SUMMARY

The major goal of utilizing alternative contracting strategies is to complete critical project work as quickly as possible by motivating and challenging contractors to either complete an internal milestone within a certain time period or to complete the entire project sooner. However, California presents a case in which A+B contracting did not perform better than conventionally contracted projects. It is seen that A+B projects suffered severely from contractors' underestimations of contract times in their bids on the "B" portion in A+B bidding. Under the presumption that schedule compression can be achieved by competition at the outset of a project, A+B bidding is used so that contractors will reasonably shorten their bids on duration (the "B" portion in the A+B contracting strategy). However, based on the analysis results, it seems that contractors often manipulated the duration of project downward to win contracts, and this ultimately resulted in significant schedule overruns. Meanwhile, projects that applied the I/D contracting strategy demonstrated the power of including an incentive/disincentive clause: many of these I/D projects achieved or even surpassed the agency's goal of early project completion. Therefore, under the assumption that A+B and I/D projects are equivalent in terms of size, complexity, and other factors, it is concluded that the I/D strategy is favorable to the A+B strategy to shorten construction times.

6 EFFECT OF I/D CONTRACT ON INSTALLED PROJECT COST

6.1 INTRODUCTION

Chapter 5 focused on the promise that the I/D strategy holds for shortening project duration and lessening the impact of projects on motorists, and as noted, few studies examining the impact of I/D strategy on project scheduling have been undertaken. However, although implementation of the strategy also involves additional agency costs, information about this cost aspect of the decision to use I/D remains obscure to date. The single existing study on this subject (Arditi et al., 1997) reported that the time savings resulting from use of I/D contracts also seem to result in increased project costs to the contracting agency.

The effort to use the I/D strategy effectively—and the development of sound project contract packages such as PS&E—has been hampered by a lack of data on incentives and by the absence of quantitative studies on the measurement and interpretation of the likely impact of using I/D provisions on aspect of project cost changes. On July 18, 2007, a special Texas DOT commission addressed the issue directly: "one of the issues we have faced is we tried to look at what's the percentage when you make the incentive/disincentive contract, and there's really no data out there" (Texas DOT, 2007).

To address this problem, this chapter examines:

1) How much project cost is affected by the presence of an incentive contract;
2) How much I/D actually increased project cost; and,

3) Whether there is significant evidence to prove the research hypothesis that incentive projects increase project costs significantly compared to A+B and conventionally contracted projects.

To achieve these objectives, a one-way ANOVA analysis was conducted to compare I/D projects with:

- Projects that were contracted solely with A+B contracts.
- Projects that were contracted with conventional contracts.

6.2 COST DYNAMICS ASSOCIATED WITH SCHEDULE VARIATION

A well-known trade-off effect exists between construction cost and schedule. As Figure 6.1 shows, there is a normal point beyond the tradeoff between cost and schedule. For example, to shorten the duration of a project by as much as ΔT (from t_0 to t_1), a contractor would need to make an additional cost commitment of ΔC (from c_0 to c_1). The additional cost increase for shortening construction time involves an increase of direct project costs, such as the use of (1) extra crews (regular plus overtime) and equipment, (2) faster-setting materials, and (3) adoption of methods to expedite delivery of construction materials.

Meanwhile, a delay in the project schedule from the normal point also increases the project cost due largely to increased indirect costs, such as office overhead, overtime payments, running rental equipment longer than originally contracted, etc. (Plummer et al., 1993).

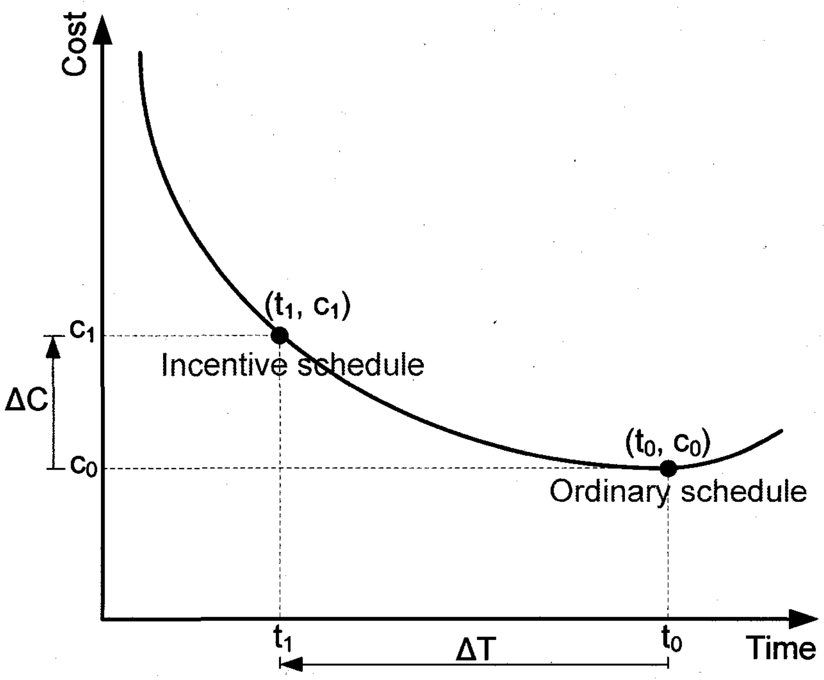


Figure 6.1 Theoretical time-cost tradeoff curve (Adapted from Shr and Chen, 2004)

Figure 6.2, which was drawn using data from actual roadway I/D projects, shows a strong tradeoff relationship between schedule and cost: cost increases as a function of schedule compression. Figure 6.2 justifies the presence of the normal point, which means that from that point, schedule delays also cause project cost increases. This indicates that as a schedule change increases from approximately the 20% schedule change point, project costs also increase. While the intersections of project schedule and cost certainly lay off the regression curve from negative to positive around the 20% schedule change point, an R-squared value of 0.81 indicates a very strong reasonable fit, indicating that schedule compression begets an increase in project cost until a schedule delay arrives at a 20% time extension of the originally planned schedule. When repeated on other types of projects, a similar curve was drawn.

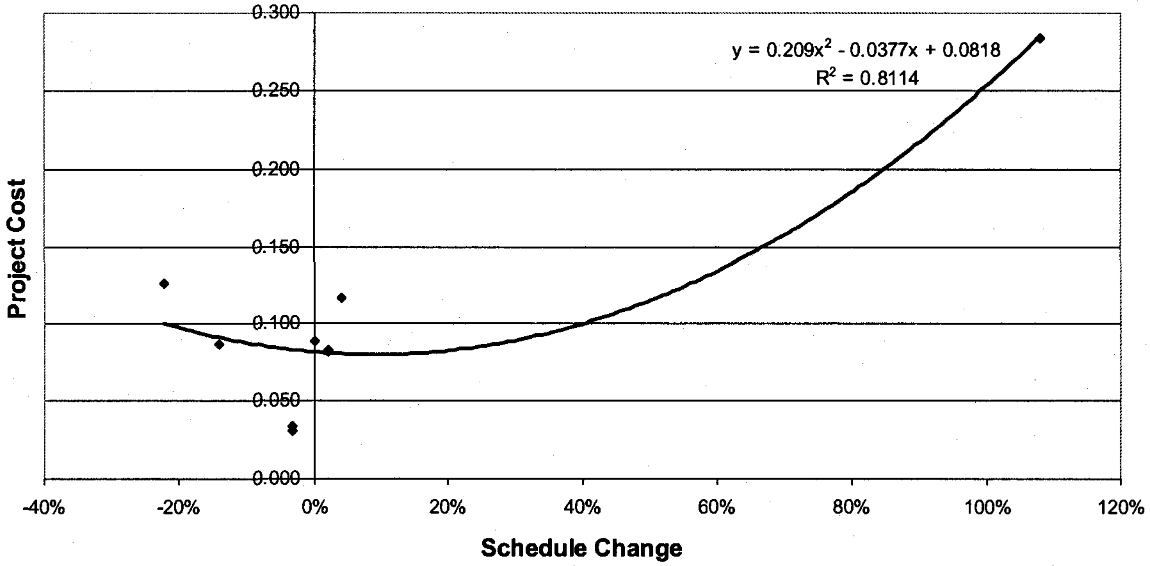


Figure 6.2 As-built Time-Cost Tradeoff Curve Observed on Roadway I/D Projects

6.3 IMPACT OF AN I/D CONTRACT ON OVERALL PROJECT COST

The level of cost growth was measured by the cost change ratio described in Chapter 4. Two different benchmarks were used to assess cost growth: the *original* contract amount versus the *amended* contract amount. The "original" cost change ratio is the ratio of the difference between the final cost and the original contract amount to the original contract amount. The "amended" cost change ratio is the ratio of the difference between the final cost and the amended contract amount to the amended contract amount, and reflects cost changes on the original contract amount due to contract change orders.

Figure 6.3 shows that among the three contracting strategies, I/D contracting projects had the largest cost growth, approximately 14%, on the installed original contract amount, which is roughly 7.5% and 3.6% higher than that of conventional and A+B contracting projects, respectively. This cost growth can be explained by the cost expended for contract change orders (CCOs). It appears that I/D projects involved a relatively large number of CCOs during construction, which is supported by the numbers: I/D projects led to the highest frequency of CCOs (17.66% on the original contract amount), followed by A+B projects (9.92%) and conventional projects (7.96%). Due to the large size of I/D projects, it was initially anticipated that CCOs would occur less frequently in I/D contracting projects, in that these are usually awarded to major contractors who generally have more experience and a higher level of expertise in project control and management. However, the results of the analysis indicate that once a project has started, pressures to shorten its duration lead to uncertainties that result in a higher frequency of CCOs.

A different situation was observed with regard to the amended cost change ratio that takes CCOs into account. I/D projects produced positive cost changes (-2.77% savings) on average while A+B projects had negative cost changes (+0.56%) (Figure 6.3). It is not yet possible to interpret this result, however the positive change produced by I/D projects might be due to their higher frequency of CCOs. It is reasonable to focus more on the "original" contract values because the measurement and interpretation of cost growth based on the amended contract values cannot represent the nature and performance of projects.

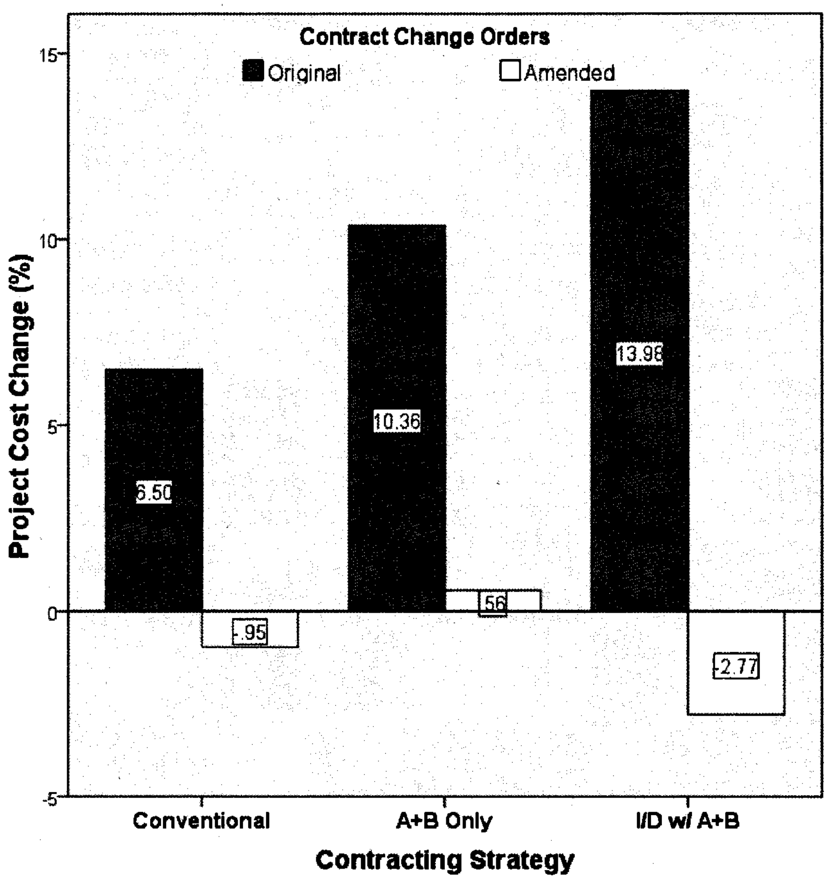


Figure 6.3 Average Cost Growth of All Projects versus Contracting Strategy

Figure 6.4 shows a box-and-whisker plot of project cost changes for the three selected contracting project groups. When the cost growth level was examined in the median value rather than the average value, the same trend is seen for I/D projects over A+B and conventional projects: I/D projects had the largest cost growth, followed by A+B and conventional projects. When the dispersion level of cost growth on the three selected contracting groups was taken into account by looking at the length of each box, it is seen that each contracting strategy has a similar degree of cost growth variation, and the level of cost growth varied from project to project. Meanwhile, Figure 6.4 indicates that A+B and conventional contracting projects have outliers, and that their average values could have been affected by those outliers. To rule out this case, a statistical analysis known as one-way ANOVA analysis was conducted in Section 6.5.

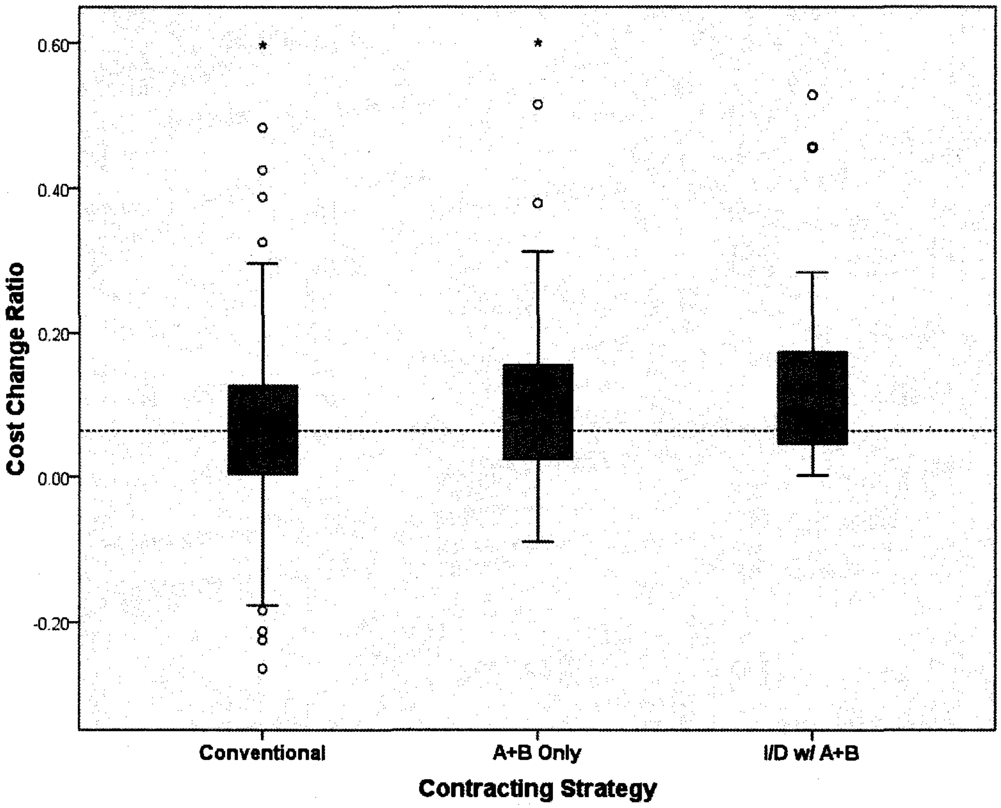


Figure 6.4 Box Plot of Project Cost Growth versus Contracting Strategy

6.4 COST GROWTH VERSUS PROJECT TYPES

Figure 6.5 displays information about how the contracting strategies differed on project cost growth by project type. From the figure, it can be seen that the same trend of cost growth level was observed on the major project types, with the exception of the "capacity-added" project type, where A+B projects underwent the highest cost growth.

On the roadway type representing approximately 50% of all project establishments over the years 2000 to 2008, I/D projects underwent a 4.8% higher cost growth than conventional projects and a 1.27% higher cost growth than A+B projects. The same situation was observed when the median values were looked at (Figure 6.6). The figure shows that the level of cost growth in I/D contracting projects is relatively similar (least variation) to the other contracting projects.

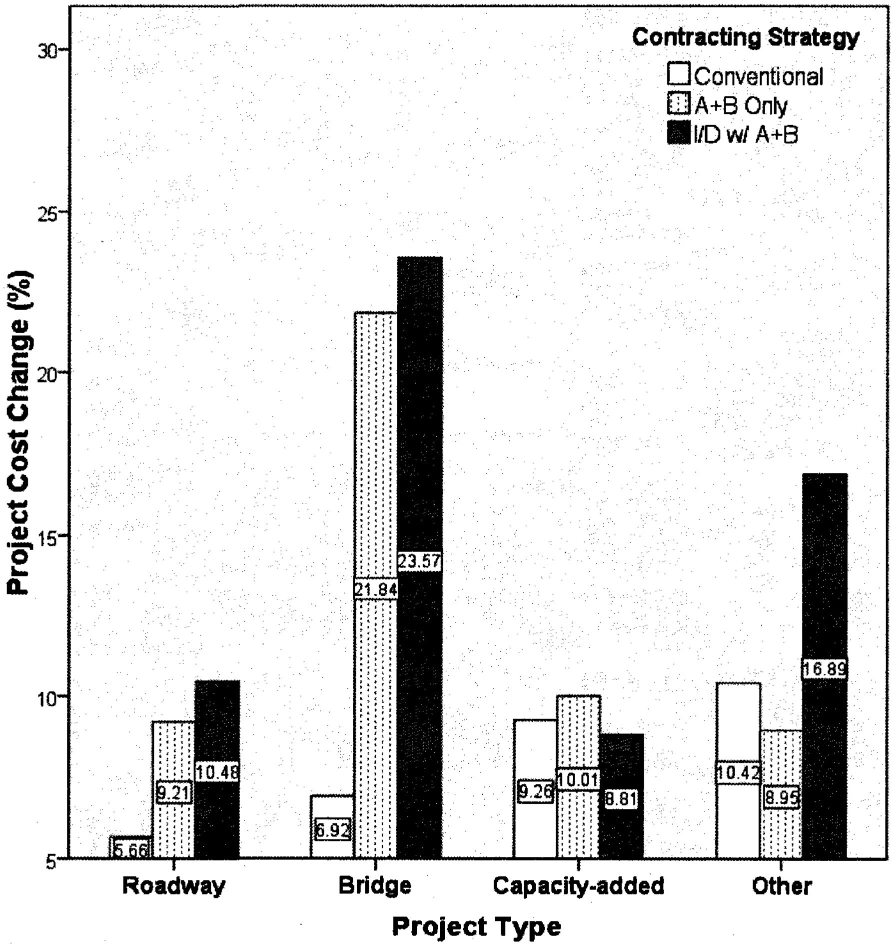


Figure 6.5 Project Cost Growth of Alternative Contracting Strategies Sorted by Project Type

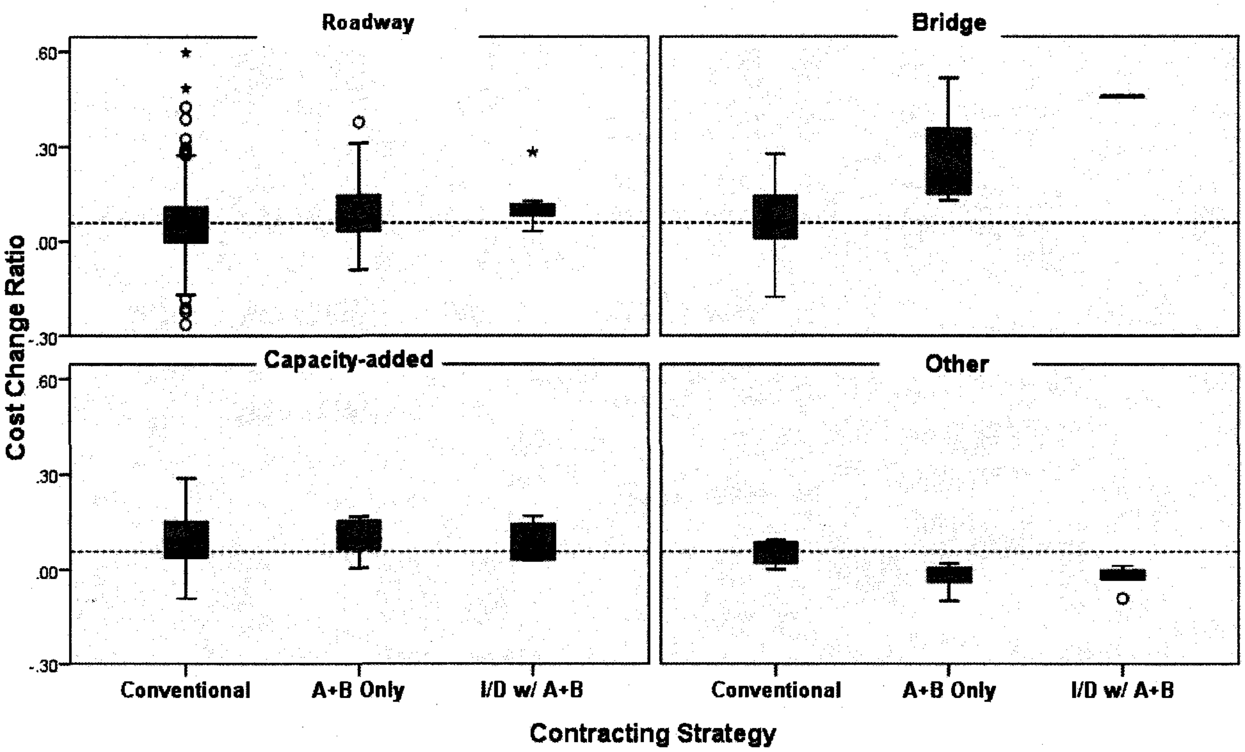


Figure 6.6 Box Plot of Project Cost Growth

On the bridge replacement/repair/rehabilitation projects, which represent about 6% of all project establishments, it is noteworthy that while I/D projects produced substantial cost growth (23.57%), they reduced construction time by 45.77% on average on the installed original contract duration. The same trend was observed on the median values, as shown in Figure 6.6. The reason that I/D bridge projects had a severe tradeoff between construction time and cost was because there were urgent needs to complete the projects as quickly as possible due to high road user delay costs; it was found that all six bridge projects contracted with an I/D clause were situated in heavily trafficked urban areas. Aside from the location issue, the contracting agency had to pursue expedited project delivery despite substantial cost increases because bridge project delays can cause severe disruptions of vital emergency services. From a time-cost tradeoff perspective, the substantial cost increase was recouped by considerable savings in construction time and road user cost, and by the minimized inconvenience to the bridge users.

In contrast to the significant time-cost tradeoff effect of I/Ds, A+B projects led to substantial cost growth (21.84%) on the bridge-type projects (Figure 6.5), increasing project duration by 17.54% on average (see Figure 5.5). In addition, as seen in Figure 6.6, A+B projects had the largest variation of cost growth ratios, which reveals a critical problem in allowing the contractor bid on cost and time. A similar situation was seen for conventional projects, which had 6.92% cost growth and 13.43% schedule overruns on bridge projects.

From Figure 6.5, it is seen that on the capacity-added type, A+B projects had the largest cost growth (+10.01%), followed by conventional (+9.26%), and I/D projects (8.81%), respectively. This represents the smallest percentage difference in cost changes among the three major project types. A similar trend was observed on the capacity-added type when comparing with median values (Figure 6.6). A possible reason for the small percentage difference among the three contracting project groups is their relatively large project sizes. Typically, capacity-added projects involve one of 3R construction works (resurfacing, reconstruction, or rehabilitation) coinciding with the widening or addition of a lane. Owing to its large project size and the direct traffic impact on the public, it is reasonable to believe that the agency needs to utilize additional resources to minimize unfavorable traffic impact regardless of contracting type.

6.5 RESEARCH HYPOTHESIS TESTING

6.5.1 Design of Research Hypotheses

A one-way ANOVA analysis was conducted to test the overall effect of I/D on project cost growth compared with A+B and conventional projects. The cost effect was examined by testing the validity of the following research hypotheses:

- Alternative contracting projects (i.e., A+B and I/D projects) increase project cost above the levels seen in conventional projects; and,
- I/D projects would cause project cost growth significantly more than A+B and conventional projects.

6.5.2 Validation of Assumptions

As mentioned in the previous chapter, research data should satisfy three assumptions before a one-way ANOVA analysis can be performed. The three assumptions are normality, homogeneity of variances, and independence. ANOVA is known to be quite robust over moderate violations of the first assumption, which was examined by the Shapiro-Wilk test and a normal Q-Q plot (see Figure 6.7).

Table 6.1 shows that the project data of cost change ratios are normally distributed, based on the Shapiro-Wilk test (significance value p=.521).

Table 6.1 Normality Test of Cost Change Ratios

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Overall	.071	605	.200	.918	605	.146

a. Lilliefors Significance Correction

Normality of the project data was confirmed by a Q-Q plot, and there was no evidence to show that the data was not normally distributed (Figure 6.7).

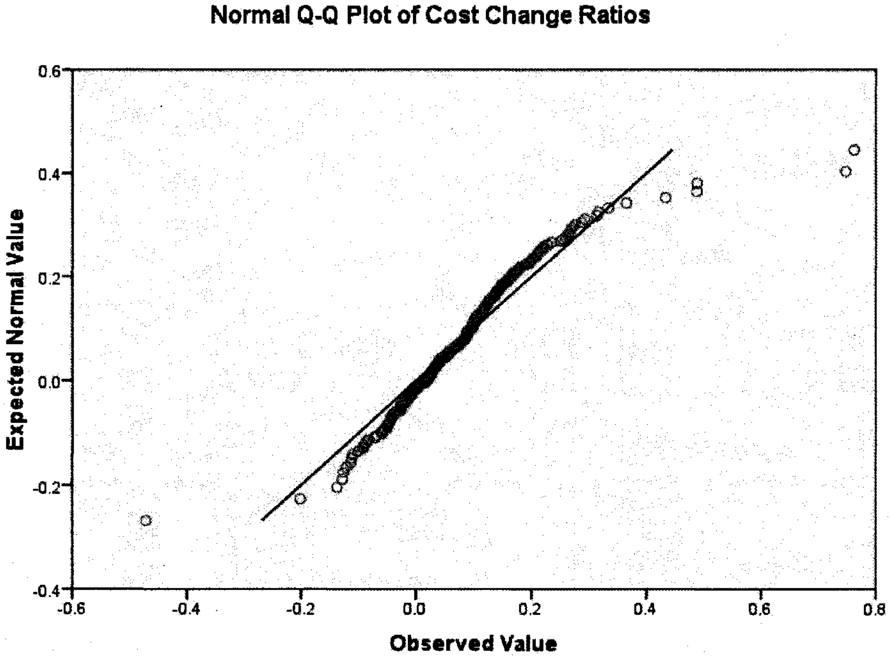


Figure 6.7 Normal Q-Q Plot of Cost Change Ratios

The second assumption of equal variance was tested by the Levene's *F* test. The results of Levene's *F* test statistics were 8.695 (p=.001), which suggests that the variances are very dissimilar. This means the violation of the assumption of homogeneity of variance.

The Brown-Forsythe and Welch's version of the *F*-ratio, which should be accurate when homogeneity of variance is not true, indicate whether the test is still robust to this violation. Table 6.2 was produced in the main ANOVA analysis.

Table 6.2 Robust Tests of Equality of Means

Robust Tests of Equality of Means

CCR Overall

	Statistic[a]	df1	df2	Sig.
Welch	3.961	2	53.154	.025
Brown-Forsythe	3.533	2	49.935	.037

a. Asymptotically F distributed.

The results on both test statistics are still highly significant (p<.05). This implies that there was a significant cost growth effect of the contracting strategies, which suggests that the test is still robust.

6.5.3 Analysis of Testing Results

Table 6.3 shows that the cost growth of I/D projects (I/D with A+B) was highest and the variability (standard deviation) amongst the three contracting project groups was lowest.

Table 6.3 Descriptive Statistics on Cost Growth

Descriptives

CCR Overall

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Conventional	518	.0650	.10381	.00456	.0560	.0740	-.61	.60
A+B Only	58	.1036	.12917	.01696	.0697	.1376	-.09	.60
I/D w/ A+B	29	.1398	.21661	.04022	.0574	.2222	-.65	.53
Total	605	.0723	.11546	.00469	.0631	.0815	-.65	.60

Table 6.4 shows the main ANOVA summary table. The table is divided into *between-group effects* and *within-group effects.* The between-group effect is further divided into a linear and quadratic component for trend analyses. The test of whether the means of three contracting project groups are the same is represented by the F-ratio (8.321) for the combined between-group effect. The significance value (*p*=.000) suggests that the likelihood that an F-ratio of this size would have occurred by chance is close to 0%. Hence, it is concluded that there was a significant effect of alternative contracting strategies on project cost growth. However, what the effect of utilizing alternative contracting strategies over the conventional contracting method (i.e., which contracting strategies differed on project cost growth) is unknown at this analysis stage. Results of planned comparison test and post-hoc test (Table 6.5 and Table 6.6) justify the validity of research hypotheses set in the earlier section.

Table 6.4 shows the result of trend analysis, which breaks down the cost growth effect into linear and quadratic terms. For the linear trend, the F-ratio is 11.796 and this value is significant at a .001 level of significance, suggesting that there exists a liner relationship among the three contracting project groups. In other words, as the contracting strategy has changed from a conventional to an A+B to an I/D, project cost increases proportionately. Meanwhile, the F-ratio for the quadratic trend is not significant.

Table 6.4 ANOVA Analysis Summary Table on Cost Growth

ANOVA

CCR_Overall

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		.217	2	.108	8.321	.000
	Linear Term	Unweighted	.154	1	.154	11.796	.001
		Weighted	.217	1	.217	16.637	.000
		Deviation	.000	1	.000	.005	.946
	Quadratic Term	Unweighted	.000	1	.000	.005	.946
		Weighted	.000	1	.000	.005	.946
	Within Groups		7.836	602	.013		
	Total		8.052	604			

To examine which contracting strategies differed on project cost growth, two planned comparisons were conducted; one to test whether the conventional projects were different from the alternative contracting projects (i.e., Contrast 1: conventional versus A+B and I/D projects), and one to examine whether the use of incentives/disincentives would make a difference to project cost growth (i.e., Contrast 2: A+B versus I/D). Table 6.5 shows the results of the planned comparisons. As mentioned, Contrast 1 compares the conventional contracting projects over the two alternative contracting project groups, and Contrast 2 compares the A+B projects with the I/D projects.

The *t*-statistic of 2.543 (*df*=42, *p*=.015/2=.0075 for one-tailed analysis) for Contrast 1 indicates that alternative contracting projects would increase project cost above the levels seen in the conventional projects (since the second assumption of equal variance was significant, the lower part of the table subtitled "Does not assume equal variances" should be used). The significance of Contrast 2 (*df*=38, *p*=.413/2=.207 for one-tailed analysis) shows there is no significant evidence to prove the research hypothesis that I/D projects would cause project cost growth significantly more than A+B projects.

Table 6.5 Results of Planned Comparison Test on Cost Growth

Contrast Tests

		Contrast	Value of Contrast	Std. Error	t	df	Sig. (2-tailed)
CCR_Overall	Assume equal variances	1	.1134	.02782	4.077	602	.000
		2	-.0361	.02595	-1.392	602	.164
	Does not assume equal variances	1	.1134	.04460	2.543	41.655	.015
		2	-.0361	.04365	-.828	38.248	.413

Table 6.6 shows the results of Hochberg's test and Dunnett's test. Hochberg's test was selected largely because of the fact that sample sizes of the three contracting groups are very different. Along with Hochberg's test, the Dunnett's test was selected to confirm the research hypothesis that the A+B and I/D projects underwent greater cost growth than the conventional projects. For each pair of contracting strategies in the Hochberg's test, the difference between average cost growth rates of two contracting strategies, the standard error of that difference, and the significance level of that difference are presented in Table 6.6. For instance, the conventional project group was compared to the A+B and I/D contracting project groups, which revealed a significant difference ($p<.05$). However, when the A+B project group was compared to the I/D project group (or vice versa), there was a non-significant difference ($p>.05$). These results were consistent with the results of planned comparison analysis. The Dunnett's test produced the same result.

Table 6.6 Results of Post Hoc Tests on Cost Growth

Multiple Comparisons

Dependent Variable:CCR_Overall

	(I) Contracting_Strategy	(J) Contracting_Strategy	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Hochberg	Conventional	A+B Only	-.03864*	.01580	.043	-.0765	-.0008
		I/D w/ A+B	-.07477*	.02177	.002	-.1269	-.0226
	A+B Only	Conventional	.03864*	.01580	.043	.0008	.0765
		I/D w/ A+B	-.03613	.02595	.416	-.0983	.0260
	I/D w/ A+B	Conventional	.07477*	.02177	.002	.0226	.1269
		A+B Only	.03613	.02595	.416	-.0260	.0983
Dunnett t (>control)[a]	A+B Only	Conventional	.03864*	.01580	.015	.0077	
	I/D w/ A+B	Conventional	.07477*	.02177	.001	.0322	

*. The mean difference is significant at the 0.05 level.

a. Dunnett t-tests treat one group as a control, and compare all other groups against it.

In summary, it is seen that there is a significant overall effect of alternative contracting strategies on project cost growth. Moreover, the planned contrast analysis revealed that utilizing alternative contracting strategies significantly increases project cost compared to a conventional strategy. Yet, there is no significant evidence to prove that the I/D contracting strategy increases project cost significantly more than A+B.

6.6 CHAPTER SUMMARY

The project size analysis indicated that I/D projects were relatively large-scale. It was initially anticipated that I/D projects underwent relatively small cost growth under the belief that I/D projects were started with a clearer definition of project scope due to their large project size. However, this analysis showed the opposite results. I/D contracting projects had the largest cost growth overall. It was seen that projects contracted solely in an A+B contract underwent similar level of cost growth with I/D's. When the considerably different project sizes (contract dollar values) between alternative and conventional projects are emphasized, the real value (difference) of cost growth for each is significant.

The statistical analyses have revealed that utilizing alternative contracting strategies significantly increases project cost compared to a conventional strategy. Yet, there was no significant evidence to prove that the I/D contracting strategy increases project cost significantly more than the A+B strategy. It was seen that the cost growth effect is closely tied to the frequency of contract change orders.

7 FRAMEWORK OF DECISION-SUPPORT MODEL

7.1 INTRODUCTION

When this study was initially undertaken, it was noted that there was disagreement about the effectiveness of adopting the I/D contracting strategy because of (1) a lack of data and (2) a corresponding lack of standardized methods and analytical tools to determine the I/D amounts. The quantitative analysis performed through Chapters 4 to 6 provided insight of the effectiveness for using them on aspects of project performance such as project schedule and cost. The major objective of this chapter is to address the second problem by developing the systematic analysis framework of a new decision-support model for the I/D contracting strategy in order to promote a way to apply it more effectively.

The model attempts to determine the most realistic, economical I/D dollar amounts that fall within an agency's budget and are sufficient to motivate a contractor to complete the project ahead of schedule. The model can help contracting agencies make better-informed decisions when choosing an appropriate contracting strategy, and facilitate agencies' creation of more realistic incentive budgets, which will result in more favorable cost-benefit ratios and better use of public funds.

7.2 LIMITATIONS OF CURRENT ANALYTICAL TOOLS

Over the years, computer tools for determining daily I/D amounts and maximum incentive amounts have advanced but these tools still have crucial limitations insofar as they cannot concurrently account for project-specific peculiarities, road user costs, and reasonable adjustments of road user costs. All the tools currently available have these critical limitations:

- None of the tools provide reliable estimates of the number of days that can be saved by using an incentive schedule, even though this quantity is crucial for determining the daily I/D amount and the maximum incentive amount. In general, the time-saved estimate is manually input by an agency engineer who bases it on judgment and personal experience rather than on a validated method.
- None of tools consider a discount factor to adjust initial RUCs in the course of determining the daily I/D amount and the maximum incentive amount, i.e., how effectively the initial estimate can be adjusted downward to the final daily I/D amount is not taken into consideration.

According to the Florida Department of Transportation (FDOT), there are neither computer tools nor standard procedures to compute I/D dollar amounts, which leads to misapplication of I/D (FDOT, 2000). These limitations prevent state highway agencies from budgeting accurately and realistically for time-based I/D provisions.

7.3 MAIN FRAMEWORK OF THE I/D DECISION-SUPPORT MODEL

Recognizing the above mentioned limitations, the model employs an integrated analysis of (1) construction schedule, (2) total time value savings, and (3) cost growth—with appropriate discounting factors—resulting from contractors expediting construction.

Figure 7.1 depicts the main inputs and outputs of the decision-support model. The main analysis framework is divided into three categories in algorithmic order consisting of (1) a Schedule Module that estimates the probable number of days that can be saved by using an incentive schedule, (2) a Time-Value Saving Module that computes total savings by accounting for the monetary value of the time saved by road users and the agency, and (3) a Time-Cost Tradeoff Module that quantifies the level of additional contractor's cost growth in order to arrive at accurate I/D fees and realistic maximum incentives by applying appropriate discount factors. The model produces two types of incentives, closure I/Ds and daily I/Ds, along with the maximum incentives.

The primary applications of the model proposed in this study are limited to urban highway pavement maintenance and renewal projects, which according to the data analysis, represent 51% of all project establishments over the past eight years in California.

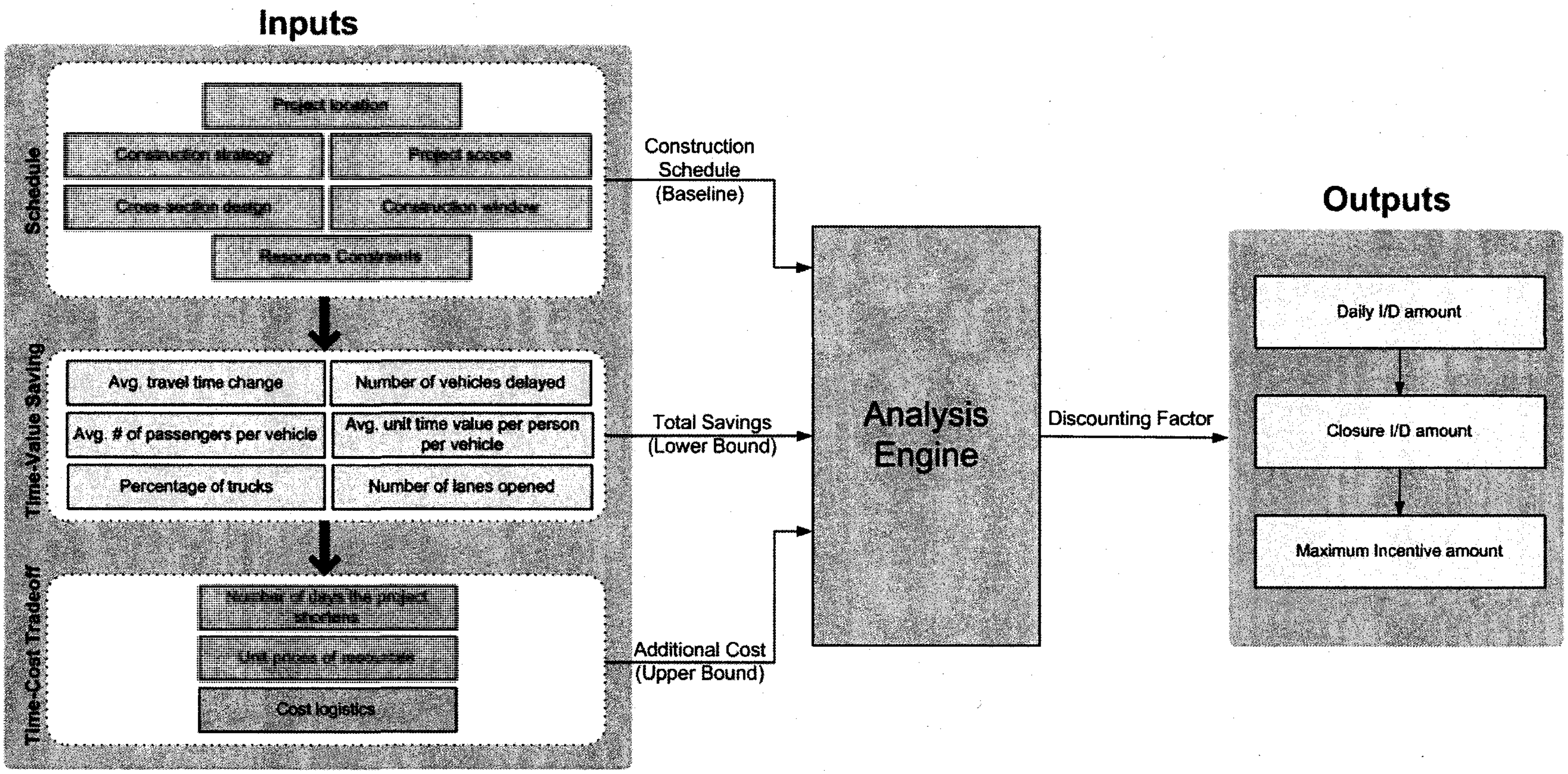


Figure 7.1 Main Framework of the I/D Decision-Support Computer Model

7.4 USE OF CA4PRS FOR BUILDING BASELINE DATA

Agency efforts to deliver projects in a timely manner have been furthered by use of innovative software analysis programs and scheduling techniques like *CPM* (Critical Path Method) or *PERT* (Program Evaluation and Review Technique). A more recent tool arising from these efforts is a state-of-the-art tool called *CA4PRS* (Construction Analysis for Pavement Rehabilitation Strategies), which has come into use because of its ability to analyze schedules, costs, and work zone traffic impacts (Figure 7.2).

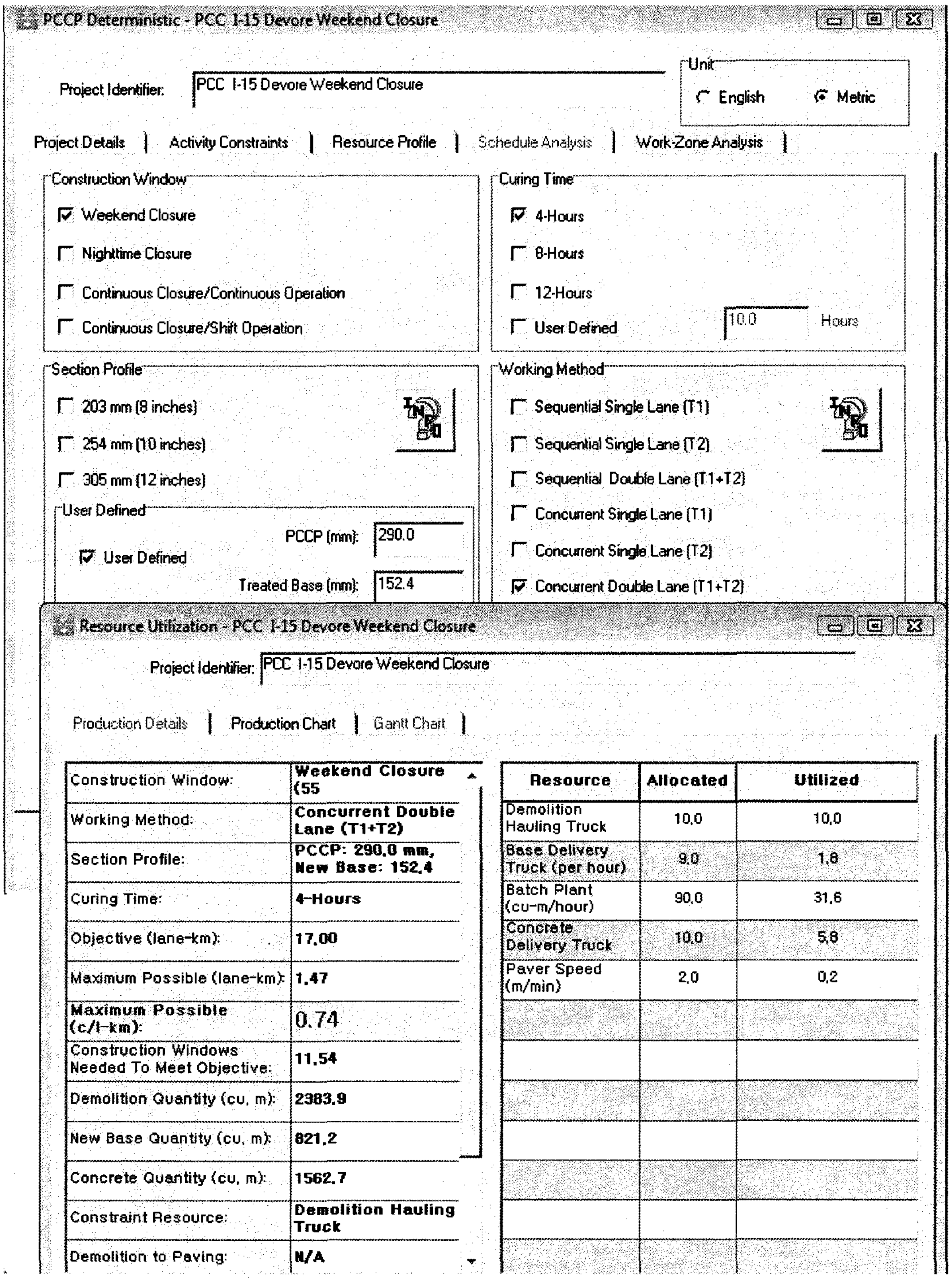
CA4PRS was developed under the FHWA (Federal Highway Administration) pooled research fund with a multistate consortium (California, Minnesota, Texas, and Washington). The software has three main functions, schedule, cost, and work zone estimates. *CA4PRS*'s schedule analysis estimates the duration of highway rehabilitation project in terms of total number of closures by considering the following critical factors that affect project duration: project scope (lane-mile to be rebuilt), construction strategies (e.g., concrete, asphalt concrete, milling, etc), cross-section designs, construction windows (e.g., nighttime, weekend, extended 24/7 operations), and contractor logistics and resource constraints (Lee and Ibbs, 2005). *CA4PRS*'s work zone analysis, which is based on the Highway Capacity Manual demand capacity model, quantifies the impact of construction work zone closures on the traveling public in terms of road user cost and time spent in queue (Lee et al., 2008).

CA4PRS has been widely used in California and in four other states. Validation studies on several major highway rehabilitation projects in states including California, Washington, and Minnesota proved the scheduling reliability and accuracy of the software (Lee et al., 2008) and as a result, there has been nationally growing acceptance of the program, including recent arrangement by FHWA of free group licenses for all fifty states.

CA4PRS played a pivotal role in this research in generating the baseline data for integration of schedule/time value savings/additional cost growth. It was used to estimate:

- How many closures the project would take;
- How much road user costs could be reduced by shortening construction time; and
- How many closures (days) a contractor can reasonably eliminate under four given resource levels.

Since the scheduling reliability and accuracy of *CA4PRS* was validated with numerous highway renewal projects, it was assumed that the program's use would provide reliable baseline data.



Project Identifier: PCC I-15 Devore Weekend Closure

Unit
○ English
● Metric

Construction Window
☑ Weekend Closure
☐ Nighttime Closure
☐ Continuous Closure/Continuous Operation
☐ Continuous Closure/Shift Operation

Curing Time
☑ 4-Hours
☐ 8-Hours
☐ 12-Hours
☐ User Defined 10.0 Hours

Section Profile
☐ 203 mm (8 inches)
☐ 254 mm (10 inches)
☐ 305 mm (12 inches)

User Defined
☑ User Defined
PCCP (mm): 290.0
Treated Base (mm): 152.4

Working Method
☐ Sequential Single Lane (T1)
☐ Sequential Single Lane (T2)
☐ Sequential Double Lane (T1+T2)
☐ Concurrent Single Lane (T1)
☐ Concurrent Single Lane (T2)
☑ Concurrent Double Lane (T1+T2)

Project Identifier: PCC I-15 Devore Weekend Closure

Construction Window:	**Weekend Closure (55**
Working Method:	**Concurrent Double Lane (T1+T2)**
Section Profile:	**PCCP: 290,0 mm, New Base: 152,4**
Curing Time:	**4-Hours**
Objective (lane-km):	**17,00**
Maximum Possible (lane-km):	**1,47**
Maximum Possible (c/l-km):	0.74
Construction Windows Needed To Meet Objective:	**11,54**
Demolition Quantity (cu, m):	**2383,9**
New Base Quantity (cu, m):	**821,2**
Concrete Quantity (cu, m):	**1562,7**
Constraint Resource:	**Demolition Hauling Truck**
Demolition to Paving:	**N/A**

Resource	Allocated	Utilized
Demolition Hauling Truck	10,0	10,0
Base Delivery Truck (per hour)	9,0	1,8
Batch Plant (cu-m/hour)	90,0	31,6
Concrete Delivery Truck	10,0	5,8
Paver Speed (m/min)	2,0	0,2

Figure 7.2 Input and Output Screen Example of the *CA4PRS* Schedule Estimate

7.5 SCHEDULE MODULE

As noted, use of the *CA4PRS* Schedule Module is the basis for proceeding to the next levels of analysis. The module quantifies the number of closures and working days by which the project can be shortened with use of an incentive-based accelerated schedule—with an expectation that the accelerated project will use 15 to 20 percent more resources than a conventional schedule.

Many researchers have reported that competitive highway construction contractors possess adequate resources (e.g., extra labor and equipment) to meet incentive-based schedules (Herbsman et al., 1995). Further, because schedules are usually overestimated by the contracting agencies in current practice, it is believed that contractors easily perform expedited work and received an incentive bonus without additional effort. For these reasons, it is essential to accurately estimate project duration in order to arrive at the most realistic I/D amount.

It has been reported that *CA4PRS* provides accurate schedule estimates of highway renewal projects (Lee et al., 2008), therefore the program was used to develop a database of schedule estimate lookup tables by considering five critical factors that significantly affect project schedule (Tables 7.1−7.5):

- Rehabilitation strategy: concrete, asphalt, and milling
- Project scope: lane-miles to be rebuilt
- Pavement design: cross-section design
- Construction window: nighttime versus weekend closures

- Resource constraints.

The Schedule Module incorporates the database to produce reliable schedule estimates--including the number of closures and working days that can be saved--by comparing the effort required to use a conventional schedule strategy and an incentive schedule strategy. The estimated difference between the number of closures necessary to complete a project by using a conventional schedule and an incentive schedule determines the maximum probable number of closures and working days that can be saved by using an incentive schedule. This schedule estimate is essential in that the daily I/D and maximum incentive amounts are determined as a function of the time the project can save. This new approach using state-of-the-art *CA4PRS* software should reduce the number of contractors who receive incentives without committing additional effort.

The computational procedure of this module is shown in Figure 7.3, which describes how the module arrives at the maximum probable number of working days that can be saved. Figure 7.3 and Table 7.1 together show how *CA4PRS* estimates two different contracting strategies, first estimating the number of closures required for completing a given project with the specified scope (lane-miles). The conventional schedule was estimated on the basis of competitive contractors' average resource usage levels, average resource capacity, and average labor productivity. The incentive schedule reflects an accelerated construction schedule that commits additional resources, namely, 15% more for a strategy that uses concrete and 20% more for strategies that use asphalt concrete and milling. Labor productivity for the incentive and conventional schedules were assumed to be equivalent. Second, the estimated number of closures on the 55-hour weekend window was converted into working days because current Caltrans practice calls for use of working days rather than calendar days when determining I/D project completion times. The number of weekend closures was multiplied by 2.29 for the conversion to working days. Lastly, the maximum probable number of days that can be saved was then calculated using the difference in the number of days required to complete the project with a conventional schedule and with an I/D schedule (Tables 7.1−7.5).

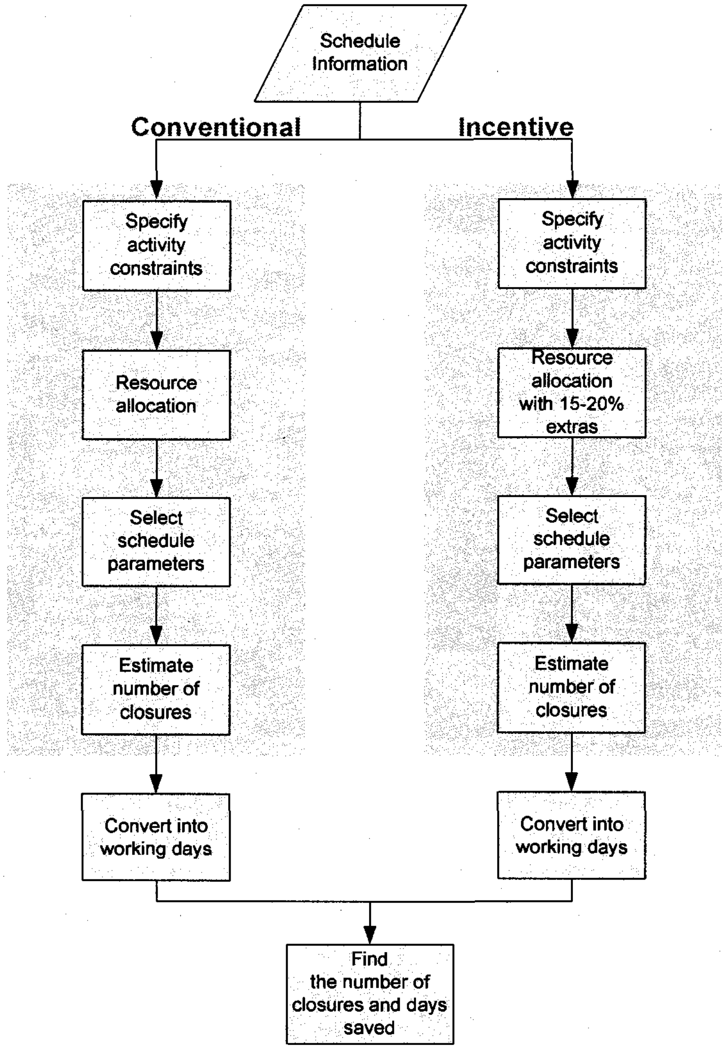


Figure 7.3 Computational Algorithm of the Schedule Module Using *CA4PRS*

Table 7.1 *CA4PRS*-based Schedule Estimate of Concrete Rehabilitation Strategy with Nighttime Construction

Scope (lane-mi)	Ordinary Schedule 8-hours window		Incentive Schedule 8-hours window		Number of Closures Saved	
	8" (1)	12" w/6" base (2)	8" (3)	12" w/6" base (4)	8" (5)	12" w/6" base (6)
1	19	28	17	24	2	4
2	38	56	33	49	5	7
3	57	83	50	73	7	10
4	76	111	66	97	10	14
5	94	139	82	121	12	18
6	113	166	99	145	14	21
7	132	194	115	169	17	25
8	151	222	131	193	20	29
9	170	249	148	217	22	32
10	188	277	164	241	24	36
11	207	305	180	265	27	40
12	226	332	197	289	29	43
13	245	360	213	313	32	47
14	264	388	229	337	35	51
15	282	415	246	361	36	54
16	301	443	262	385	39	58
17	320	470	278	409	42	61
18	339	498	295	433	44	65
19	358	526	311	457	47	69
20	376	553	327	481	49	72

(a)Column 5 = Column 1 - Column 3

(b)Column 6 = Column 2 - Column 4

Table 7.2 *CA4PRS*-based Schedule Estimate of Concrete Rehabilitation Strategy with 55-hour Weekend Construction

Scope (lane-mi)	Ordinary Schedule 55-hours window				Incentive Schedule 55-hours window				Probable Number of Closures and Days Saved			
	8"		12" w/ 6" base		8"		12" w/ 6" base		8"		12" w/ 6" base	
	Closures (1)	Days (2)	Closures (3)	Days (4)	Closures (5)	Days (6)	Closures (7)	Days (8)	Closures (9)	Days (10)	Closures (11)	Days (12)
1	0.8	2	1.6	4	0.7	2	1.4	3	0.1	0	0.2	0
2	1.5	3	3.1	7	1.3	3	2.7	6	0.2	0	0.4	1
3	2.3	5	4.7	11	2.0	5	4.1	9	0.3	1	0.6	1
4	3.0	7	6.3	14	2.6	6	5.4	12	0.4	1	0.9	2
5	3.8	9	7.8	18	3.3	8	6.8	16	0.5	1	1.0	2
6	4.6	11	9.4	22	4.0	9	8.2	19	0.6	1	1.2	3
7	5.3	12	10.9	25	4.6	11	9.5	22	0.7	2	1.4	3
8	6.1	14	12.5	29	5.3	12	10.9	25	0.8	2	1.6	4
9	6.8	16	14.1	32	5.9	14	12.2	28	0.9	2	1.9	4
10	7.6	17	15.6	36	6.6	15	13.6	31	1.0	2	2.0	5
11	8.4	19	17.2	39	7.3	17	15.0	34	1.1	3	2.2	5
12	9.1	21	18.8	43	7.9	18	16.3	37	1.2	3	2.5	6
13	9.9	23	20.3	47	8.6	20	17.7	41	1.3	3	2.6	6
14	10.6	24	21.9	50	9.2	21	19.0	44	1.4	3	2.9	7
15	11.4	26	23.4	54	9.9	23	20.4	47	1.5	3	3.0	7
16	12.2	28	25.0	57	10.6	24	21.7	50	1.6	4	3.3	8
17	12.9	30	26.6	61	11.2	26	23.1	53	1.7	4	3.5	8
18	13.7	31	28.1	64	11.9	27	24.5	56	1.8	4	3.6	8
19	14.4	33	29.7	68	12.6	29	25.8	59	1.8	4	3.9	9
20	15.2	35	31.3	72	13.2	30	27.2	62	2.0	5	4.1	9

[a] Column 9 = Column 1 - Column 5
[b] Column 10 = Column 2 - Column 6
[c] Column 11 = Column 3 - Column 7
[b] Column 12 = Column 4 - Column 8

Table 7.3 *CA4PRS*-based Schedule Estimate of Concrete Rehabilitation Strategy with 72-hour Weekday Construction

Scope (lane-mi)	Ordinary Schedule 55-hours window				Incentive Schedule 55-hours window				Probable Number of Closures and Days Saved			
	8"		12" w/ 6" base		8"		12" w/ 6" base		8"		12" w/ 6" base	
	Closures (1)	Days (2)	Closures (3)	Days (4)	Closures (5)	Days (6)	Closures (7)	Days (8)	Closures (9)	Days (10)	Closures (11)	Days (12)
1	0.3	1	0.7	2	0.3	1	0.6	2	0.0	0	0.1	0
2	0.7	2	1.4	4	0.7	2	1.2	4	0.0	0	0.2	1
3	1.0	3	2.2	7	1.0	3	1.8	5	0.0	0	0.4	1
4	1.3	4	2.9	9	1.3	4	2.4	7	0.0	0	0.5	2
5	1.6	5	3.6	11	1.6	5	3.0	9	0.0	0	0.6	2
6	2.0	6	4.3	13	2.0	6	3.6	11	0.0	0	0.7	2
7	2.3	7	5.1	15	2.3	7	4.2	13	0.0	0	0.9	3
8	2.6	8	5.8	17	2.6	8	4.8	14	0.0	0	1.0	3
9	3.0	9	6.5	20	2.9	9	5.4	16	0.1	0	1.1	3
10	3.3	10	7.2	22	3.3	10	6.0	18	0.0	0	1.2	4
11	3.6	11	7.9	24	3.6	11	6.6	20	0.0	0	1.3	4
12	3.9	12	8.7	26	3.9	12	7.2	22	0.0	0	1.5	5
13	4.3	13	9.4	28	4.3	13	7.8	23	0.0	0	1.6	5
14	4.6	14	10.1	30	4.6	14	8.4	25	0.0	0	1.7	5
15	4.9	15	10.8	32	4.9	15	9.0	27	0.0	0	1.8	5
16	5.3	16	11.5	35	5.2	16	9.6	29	0.1	0	1.9	6
17	5.6	17	12.2	37	5.6	17	10.2	31	0.0	0	2.0	6
18	5.9	18	13.0	39	5.9	18	10.8	32	0.0	0	2.2	7
19	6.2	19	13.7	41	6.2	19	11.4	34	0.0	0	2.3	7
20	6.6	20	14.4	43	6.5	20	12.0	36	0.1	0	2.4	7

Table 7.4 CA4PRS-based Schedule Estimate of Asphalt Concrete Rehabilitation Strategy: Nighttime versus Weekend

Scope (lane-mi)	Ordinary Schedule				Incentive Schedule				Probable Number of Closures and Days Saved			
	Nighttime		55-hours		Nighttime		55-hours		Nighttime		55-hours	
	Closures (1)	Days (2)	Closures (3)	Days (4)	Closures (5)	Days (6)	Closures (7)	Days (8)	Closures (9)	Days (10)	Closures (11)	Days (12)
5	71	71	1.5	3	60	60	1.3	3	11	11	0.2	0
10	142	142	3.1	7	119	119	2.6	6	23	23	0.5	1
15	213	213	4.6	11	178	178	3.8	9	35	35	0.8	2
20	284	284	6.1	14	237	237	5.1	12	47	47	1.0	2
25	355	355	7.7	18	296	296	6.4	15	59	59	1.3	3
30	426	426	9.2	21	355	355	7.7	18	71	71	1.5	3
35	497	497	10.7	25	415	415	8.9	20	82	82	1.8	4
40	568	568	12.3	28	473	473	10.2	23	95	95	2.1	5
45	639	639	13.8	32	533	533	11.5	26	106	106	2.3	5
50	710	710	15.3	35	592	592	12.8	29	118	118	2.5	6
55	781	781	16.8	39	651	651	14.0	32	130	130	2.8	6
60	852	852	18.4	42	710	710	15.3	35	142	142	3.1	7
65	923	923	19.9	46	770	770	16.6	38	153	153	3.3	8
70	994	994	21.4	49	829	829	17.9	41	165	165	3.5	8
75	1065	1065	24.5	56	888	888	19.1	44	177	177	5.4	12
80	1136	1136	25.0	57	947	947	20.4	47	189	189	4.6	11

Table 7.5 *CA4PRS*-based Schedule Estimate of Milling and Asphalt Concrete Overlay Rehabilitation Strategy: Nighttime versus Weekend

Scope (lane-mi)	Ordinary Schedule				Incentive Schedule				Probable Number of Closures and Days Saved			
	Nighttime		55-hours		Nighttime		55-hours		Nighttime		55-hours	
	Closures (1)	Days (2)	Closures (3)	Days (4)	Closures (5)	Days (6)	Closures (7)	Days (8)	Closures (9)	Days (10)	Closures (11)	Days (12)
5	18	18	2.3	5	16	16	2.1	5	2	2	0.2	0
10	35	35	5.0	11	32	32	4.2	10	3	3	0.8	2
15	52	52	6.9	16	48	48	6.3	14	4	4	0.6	1
20	70	70	9.2	21	64	64	8.4	19	6	6	0.8	2
25	87	87	11.5	26	80	80	10.4	24	7	7	1.1	3
30	104	104	13.8	32	96	96	12.5	29	8	8	1.3	3
35	121	121	16.1	37	111	111	14.6	33	10	10	1.5	3
40	139	139	18.4	42	127	127	16.7	38	12	12	1.7	4
45	156	156	20.7	47	143	143	18.8	43	13	13	1.9	4
50	173	173	22.9	52	159	159	20.9	48	14	14	2.0	5
55	190	190	25.2	58	175	175	23.0	53	15	15	2.2	5
60	208	208	27.5	63	191	191	25.1	58	17	17	2.4	5
65	225	225	29.8	68	207	207	27.1	62	18	18	2.7	6
70	242	242	32.1	74	222	222	29.2	67	20	20	2.9	7
75	260	260	34.4	79	238	238	31.3	72	22	22	3.1	7
80	277	277	36.7	84	254	254	33.4	77	23	23	3.3	8

7.6 TIME-VALUE SAVING MODULE

The Schedule Module provides information needed to proceed to the next step because the project duration and the maximum probable numbers of closures and days that can be saved provide the basis for estimating the total time value savings to road users and to the agency. The Time-Value Saving Module takes the schedule information and then quantifies the total monetary value of the time saved by use of I/D.

7.6.1 Time-Value Saving to Road Users

7.6.1.1 Factors Affecting Road User Costs

The Time-Value Saving Module incorporates the concept of demand-capacity model to determine Road User Costs (RUC), based on the *Highway Capacity Manual 2000* (HCM, 2000). *Demand* is defined as hourly traffic volumes at a certain point of interest, which is unknown and thus requires the logical quantification presented in this section. *Capacity* is defined as the maximum possible traffic service flow, which can be selected from the manual. In general, it is assumed that in normal conditions capacity ranges from 2,200 to 2,300 pcphpl (passenger car per hour per lane) and that in construction conditions it ranges from 1,500 to 1,600 pcphpl. Using a passenger car equivalent (PCE) factor, it is generally assumed that a truck is equal to 1.5 passenger vehicles (2.5 for a rolling setting and 4.5 for a mountain setting). Capacity varies because of the following factors:

- Project location where the project is taken place.
- Percentage of heavy vehicles (H): H = 100 / [100 + P(PCE−1)], where P = percentage of trucks.
- Width of lanes (W): W=1.00 if width is 12.0 feet, W=0.95 if width is 11.0 feet, and W=0.90 if width is 0.90.
- Shoulder and lateral clearance (S): S=1.00 if both shoulders are available, S=0.95 if one shoulder is available, and S= 0.90 if now shoulder is available.
- Number of lanes opened to traffic (N).

Adjusted capacity can be calculated by taking into account the above mentioned factors:

- *Adjusted capacity = basic capacity x H x W x S x N.*

The RUC is not tangible, but when considering the concept of *opportunity cost* that motorists could be spent doing something else for recreation or work, its value as time saved by completing the project early becomes important to road users. The four major factors to account for when estimating RUC are: (1) additional travel time (time lost due to construction lane closures), (2) the average number of motorists per vehicle, (3) the monetary value of time to motorists in the vehicle, and (4) the percentage of trucks at a construction work zone. The travel-time changes arise from differences in average travel time at the CWZ in two different traffic conditions, i.e., traffic conditions before construction and its predicted condition during construction, when normal flow is disrupted by lane closures for construction. The value of motorists' wasted time (cost per hour) on the roadway should be considered as a key parameter in the calculation of RUC. Different pay rates should also be applied to passenger cars and trucks.

7.6.1.2 Computational Procedure for Estimating Road User Cost

Based on the understanding of the major RUC components listed above, the Time-Value Saving Module computes the RUC using the following procedure:

1. Input the average travel time in normal traffic conditions.
2. Input the average travel time in conditions with construction-induced traffic disruption.
3. Calculate the difference in the average travel time at the CWZ in two different traffic conditions.
4. Convert the predicted travel time delay into a monetary value using Table 7.6.
5. Apply Equation (2) (below) to come up with the initial daily RUC.

Table 7.6 Time Value Comparison versus State (updated from Ibarra et al., 2002)

State	Average Time Value Automobiles	Average Time Value Trucks
California	$11.51	$27.83
Florida	$11.12	$22.36
Georgia	$11.65	N/A
New York	$9.00	21.14
North Carolina	$8.70	N/A
Ohio	$12.60	$26.40
Oregon	$16.31	$29.00
Pennsylvania	$12.21	$24.18
Texas	$11.97	$21.87
Virginia	$11.97	$21.87
Washington	$12.51	$50.00

As Table 7.6 shows, the hourly time value varies among states. In California, the hourly value of time to road users is $11.51 per passenger vehicle and $27.83 per truck. These travel time values are based on those established by the Caltrans Division of Transportation Planning and the Division of Traffic Operations. An adjustment factor based on an average vehicle occupancy rate of 1.1 persons per passenger vehicle is applied to passenger vehicles.

As noted above, the first procedure for estimating RUC is to measure the difference in average travel time at the CWZ in two different traffic conditions. Most of the state highway agencies that use I/D provisions perform a preconstruction traffic sensitivity analysis to estimate expected traffic delay times, as part of transportation management plans. Subsequently, the expected average travel delay time is directly input or selected by the agency engineers who will use the model.

The Time-Value Saving Module will convert the predicted travel time delay into a monetary value per passenger (per hour), taking account of the project location and the rate of inflation at the time of construction. The module uses the dollar value of time to road users that is described in Table 7.6. For example, if a thirty-minute delay is predicted at a one-lane highway rehabilitation project undertaken in California in the year 2008, the hourly value of time is cut to half, about \$5.76 per passenger car and \$13.92 per truck.

Next, the following equation is applied to calculate the time value to road users:

$$RUC = [(VIQ * P_n * P_s) * P_p) + ((VIQ * T_s * PCE) * T_p] \qquad (2)$$

where, VIQ = anticipated number of vehicles in queue due to a construction delay (vehicles per hour per lane)

P_n = average number of passengers per passenger vehicle

P_s = monetary time value per passenger for passenger vehicles

P_p = percentage of passenger vehicles driving through the CWZ

T_s = average pay rate per hour for trucks

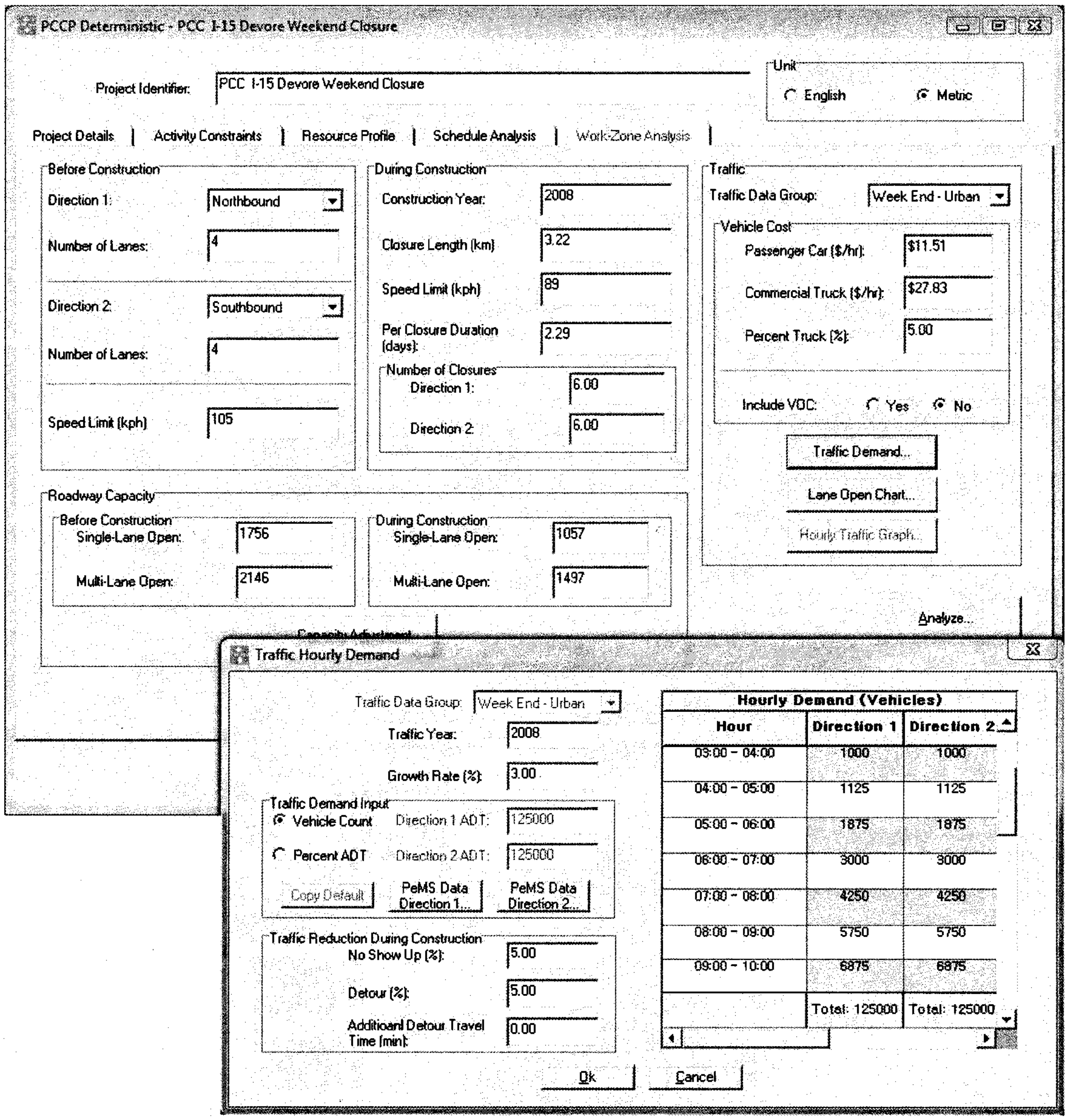
PCE = passenger car equivalent factor

T_p = percentage of trucks driving through the CWZ

Due to the budget limitations of SHAs, the time value to road users should be adjusted downward by applying a realistic discount factor in an economically rational manner under the appropriate circumstances as is considered in the Time-Cost Tradeoff Module.

7.6.1.3 Road User Cost Calculation with CA4PRS

As Figure 7.4 depicts, the most recent version (version 2.0) of *CA4PRS* has capability of doing work zone analysis in terms of road user cost and time spent in queue. The work zone analysis module of *CA4PRS* is also based on the demand-capacity model described in the previous two sections.



Project Identifier: PCC I-15 Devore Weekend Closure
Unit: ○ English ● Metric

Before Construction
Direction 1: Northbound
Number of Lanes: 4
Direction 2: Southbound
Number of Lanes: 4
Speed Limit (kph): 105

During Construction
Construction Year: 2008
Closure Length (km): 3.22
Speed Limit (kph): 89
Per Closure Duration (days): 2.29
Number of Closures
Direction 1: 6.00
Direction 2: 6.00

Traffic
Traffic Data Group: Week End - Urban
Vehicle Cost
Passenger Car ($/hr): $11.51
Commercial Truck ($/hr): $27.83
Percent Truck (%): 5.00
Include VOC: ○ Yes ● No

Roadway Capacity
Before Construction
Single-Lane Open: 1756
Multi-Lane Open: 2146
During Construction
Single-Lane Open: 1057
Multi-Lane Open: 1497

Traffic Data Group: Week End - Urban
Traffic Year: 2008
Growth Rate (%): 3.00
Traffic Demand Input
● Vehicle Count Direction 1 ADT: 125000
○ Percent ADT Direction 2 ADT: 125000
Traffic Reduction During Construction
No Show Up (%): 5.00
Detour (%): 5.00
Additional Detour Travel Time (min): 0.00

Hourly Demand (Vehicles)		
Hour	Direction 1	Direction 2
03:00 - 04:00	1000	1000
04:00 - 05:00	1125	1125
05:00 - 06:00	1875	1875
06:00 - 07:00	3000	3000
07:00 - 08:00	4250	4250
08:00 - 09:00	5750	5750
09:00 - 10:00	6875	6875
	Total: 125000	Total: 125000

Figure 7.4 Input Screens of the *CA4PRS* Work Zone Analysis

Using the latest version of *CA4PRS,* lookup tables of road user costs were developed for use as a database in the Time-Value Saving Module. It is believed that this alternative way of using *CA4PRS* can considerably reduce the effort, time, and future development costs of a prototype computer software system.

As Table 7.7–Table 7.9 show, the lookup tables are designed to account for the following important factors when estimating RUC: (1) levels of traffic (AADT: Annual Average Daily Traffic), (2) construction working windows (nighttime versus extended), (3) percentage of trucks (5%, 10%, and 15%), and (4) lane closure scheme (partial closure versus full closure). However, this current RUC lookup tables are limited to urban highway renewal projects where the project scope is rebuilding of a portion of a typical four-by-four lane freeway in both directions.

The following assumptions in the *CA4PRS* analysis to develop a RUC lookup database were used:

- Number of lanes opened to traffic during lane closures: Four-by-two lane closures were assumed for the partial closure scheme, and counter-flow traffic that closed one direction completely was assumed for the full-closure scheme.
- Changes in roadway capacity: In normal conditions capacity was assumed as about 2,150 pcphpl and in conditions with construction-induced traffic disruption it was assumed to be approximately 1,500 pcphpl.

- Passenger car equivalent (PCE) factor: A PCE of 1.50 was assumed, which means that a truck is equivalent to 1.5 passenger vehicles.
- Traffic pattern: It was assumed for the weekend construction project that both directions have the same level of traffic volume because most I/D projects have this type of traffic pattern. Further, it turns out that changing a traffic pattern produces similar values of RUC. Traffic patterns assumptions made on weekday and weekend lane closures are depicted by Figure 7.5.
- Motorists travel pattern adjustments: Three percent no-shows (detour reduction) were assumed for the nighttime construction with partial-closures and five percent no-shows and five percent detours were assumed for the weekday and weekend construction with full-closures.
- Motorists' additional travel time for diversions: This was not taken into consideration because the detour routes can flow freely even during peak commute hours.
- Lane width: It was assumed that the width of lane is reduced to 11 feet from 12 feet due to the lane closures.
- Externalities: Vehicle operating cost (e.g., fuel, tires, and mileage-dependent depreciation) resulting from construction work being performed was not taken into consideration due to its complexity in measurements.

Regarding motorists travel pattern adjustments, a research study concluded that demand around the construction work zone can be reduced by 10% to 20% with implementation of a public outreach program, which has now become an essential part of a transportation management plan (Lee and Choi, 2006).

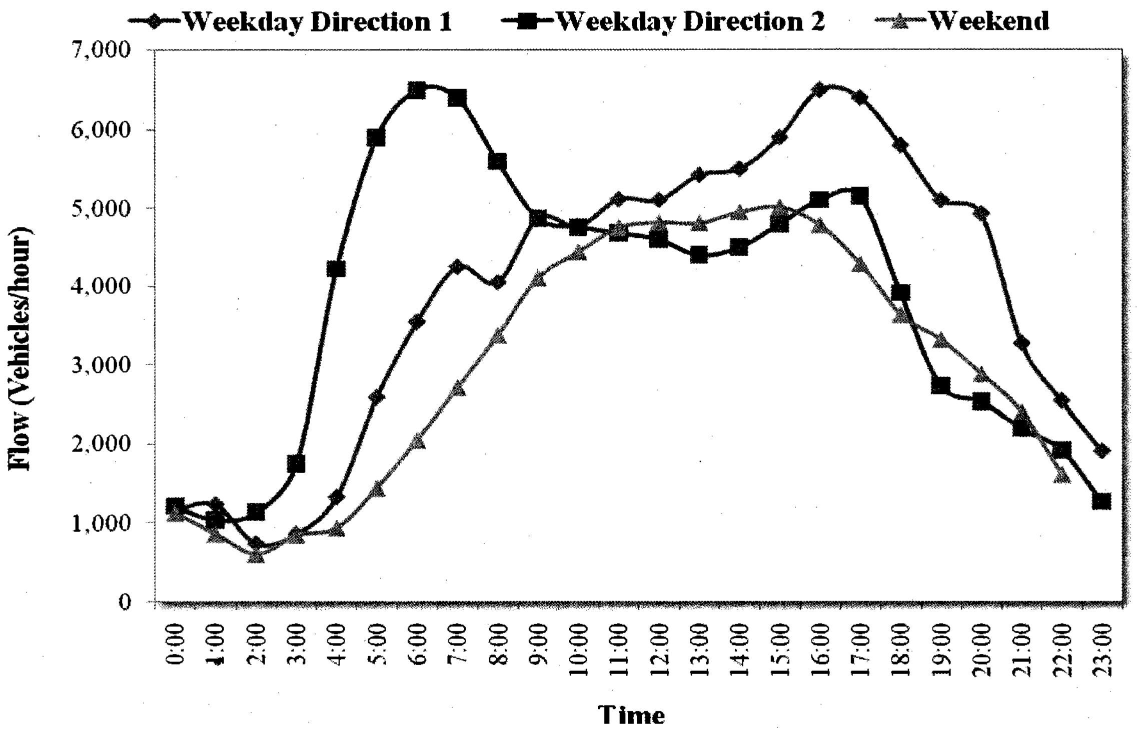


Figure 7.5 Typical Weekday and Weekend Traffic Patterns Based on *CA4PRS* Hourly Traffic Distribution Tables

Under the assumptions listed above, the following factors significantly affecting the value of RUC were incorporated as *CA4PRS* inputs:

- Average number of passengers in passenger vehicles: 1.10
- Monetary value of time to road users: $11.51 for passenger cars and $27.83 for trucks
- Percentage of trucks: 5%, 10%, and 15% conditions
- Closure tactics: 8-hour nighttime closures versus 55-hour one roadbed continuous closures on weekends

- Number of lanes opened to traffic: sequential single lane versus concurrent double lane.

Table 7.7 RUC Calculation for a 4-by-4 Urban Freeway Nighttime Construction Project with Partial-Closure

Partial-Closure*: 8-hour Nighttime Construction Two lane closed in one direction		
AADT	**5% Trucks**	**10% Trucks**
50,000	549	590
55,000	605	649
60,000	660	709
65,000	714	767
70,000	769	826
75,000	824	886
80,000	879	945
85,000	934	1,003
90,000	990	1,063
95,000	1,044	1,122
100,000	1,099	1,181
105,000	1,154	1,240
110,000	1,209	1,299
115,000	1,264	1,358
120,000	1,318	1,418
125,000	1,374	1,476
130,000	1,429	1,535
135,000	1,484	1,595
140,000	1,539	1,653
145,000	1,593	1,712
150,000	1,648	1,772
155,000	2,084	2,770
160,000	2,814	3,587
165,000	3,590	4,462
170,000	4,421	5,408
175,000	5,319	6,439
180,000	6,297	7,575
185,000	7,375	8,844
190,000	8,577	14,466
195,000	14,330	23,215
200,000	22,632	38,727

*Sequential single lane closure scheme is assumed.

Table 7.8 RUC Calculation for a 4–by-4 Urban Freeway

Weekend Construction Project with Full-Closure

Extended Full-Closure: 55-hour Weekend Construction* Counter-flow traffic (closed one direction completely)				
AADT	5% Trucks		10% Trucks	
	Per Day	Per Closure	Per Day	Per Closure
50,000	5,208	11,935	5,584	12,797
55,000	5,730	13,131	6,142	14,075
60,000	6,250	14,323	6,250	14,323
65,000	6,772	15,519	7,250	16,615
70,000	7,292	16,711	7,818	17,916
75,000	7,813	17,905	8,376	19,195
80,000	8,334	19,099	8,934	20,474
85,000	8,854	20,290	9,492	21,753
90,000	9,375	21,484	10,051	23,034
95,000	9,896	22,678	10,609	24,312
100,000	13,788	31,598	22,965	52,628
105,000	38,298	87,766	67,217	154,039
110,000	112,762	258,413	201,051	460,742
115,000	280,932	643,803	425,126	974,247
120,000	526,347	1,206,212	725,545	1,662,707
125,000	823,566	1,887,339	1,065,467	2,441,695
130,000	1,148,759	2,632,573	1,419,503	3,253,028
135,000	1,489,249	3,412,862	1,792,609	4,108,062
140,000	1,840,156	4,217,024	2,180,459	4,996,885
145,000	2,211,146	5,067,210	2,580,652	5,913,994
150,000	2,587,398	5,929,454	2,993,502	6,860,109
155,000	2,980,721	6,830,819	3,421,222	7,840,300
160,000	3,382,703	7,752,028	3,852,581	8,828,831
165,000	3,788,026	8,680,893	4,287,627	9,825,812
170,000	4,196,736	9,617,520	4,726,411	10,831,359
175,000	4,608,877	10,562,010	5,178,043	11,866,349
180,000	5,037,978	11,545,366	5,661,729	12,974,796
185,000	5,492,116	12,586,099	6,149,647	14,092,941
190,000	5,950,137	13,635,731	6,641,860	15,220,929
195,000	6,412,096	14,694,387	7,138,426	16,358,893
200,000	6,878,045	15,762,186	7,639,408	17,506,977

*Around-the-clock operation is assumed.

Table 7.9 RUC Calculation for a 4-by-4 Urban Freeway

Weekday Construction Project with Full-Closure

Extended Full-Closure: 72-hour Weekday Construction* Counter-flow traffic (closed one direction completely)				
AADT	5% Trucks		10% Trucks	
	Per Day	Per Closure	Per Day	Per Closure
50,000	5,208	15,624	5,584	16,752
55,000	5,730	17,190	6,142	18,426
60,000	6,250	18,750	6,700	20,100
65,000	6,771	20,313	7,259	21,777
70,000	7,292	21,876	7,817	23,451
75,000	7,813	23,439	8,376	25,128
80,000	8,334	25,002	11,993	35,979
85,000	18,653	55,959	26,283	78,849
90,000	36,717	110,151	49,675	149,025
95,000	65,343	196,029	94,277	282,831
100,000	126,389	379,167	175,151	525,453
105,000	216,444	649,332	283,134	849,402
110,000	329,857	989,571	423,533	1,270,599
115,000	506,031	1,518,093	673,626	2,020,878
120,000	763,178	2,289,534	971,842	2,915,526
125,000	1,064,916	3,194,748	1,326,539	3,979,617
130,000	1,412,261	4,236,783	1,742,541	5,227,623
135,000	1,826,961	5,480,883	2,267,442	6,802,326
140,000	2,284,979	6,854,937	2,739,000	8,217,000
145,000	2,791,654	8,374,962	3,292,015	9,876,045
150,000	3,312,240	9,936,720	3,849,620	11,548,860
155,000	3,836,114	11,508,342	4,418,417	13,255,251
160,000	4,376,824	13,130,472	5,040,521	15,121,563
165,000	4,969,943	14,909,829	5,679,247	17,037,741
170,000	5,569,840	16,709,520	6,322,571	18,967,713
175,000	6,173,958	18,521,874	6,970,556	20,911,668
180,000	6,782,354	20,347,062	7,623,267	22,869,801
185,000	7,395,086	22,185,258	8,289,514	24,868,542
190,000	8,022,295	24,066,885	8,972,350	26,917,050
195,000	8,663,094	25,989,282	9,660,298	28,980,894
200,000	9,308,577	27,925,731	10,353,433	31,060,299

*Around-the-clock operation is assumed.

7.6.2 Time-Value Saving to the Agency

Through the I/D contracting strategy, contractors are motivated to accomplish internal milestones faster and/or to complete entire projects sooner than originally scheduled. By shortening construction times, the contracting agency can also save agency costs in proportionate to the number of days the I/D project eliminates. The savings include reductions in the costs of construction zone enhanced enforcement program (COZEEP), agency engineering cost (AEC), and moveable concrete barrier (MCB) rental. Agency cost savings were quantified by adding up the aforementioned three major reduction factors. Table 7.10 shows a list of agency cost saving factors and displays methods to quantify their monetary value. The daily rates and methods in Table 7.10 are imported directly from the *CA4PRS* cost estimate outline. Table 7.11 shows monetary time values saved to the agency, made in the basis of the *CA4PRS* cost estimate outline.

Table 7.10 *CA4PRS* Agency Cost Saving Calculation Factors and Methods

Factors	Rates	Methods
COZEEP	▪ \$700/day/officer ▪ Number of officers - 2.5/day for nighttime - 4.5/day for extended closure ▪ Overtime rate of 1.2	▪ CHP cost/day x # of officers/day x number of days saved x overtime rate x 3 shifts for extended closure
Agency Engineering Cost (AEC)	▪ \$320/day/staff ▪ Number of staff - 3/day for nighttime - 4/day for extended closure with 3 shifts ▪ Overtime rate - 1.1 for nighttime - 1.5 for extended closure	▪ Staffing cost/day x # of staff/day x number of days saved x overtime rate x 3 shifts for extended closure
MCB*	▪ Barrier cost - \$60/meter for the first month - \$11/meter for the second month ▪ Transformer cost - \$30,000 for the first month - \$15,000 for the second month	▪ Center-lane-meter to set up x appropriate monthly rates

*MCB cost applies to the extended closure only.

Table 7.11 Calculation of Agency Cost Savings

Days Saved (1)	Nighttime Construction		Total Savings ($) (4)	Extended Construction		Total Savings[c] ($) (7)
	COZEEP[a] ($) (2)	AAC[b] ($) (3)		COZEEP ($) (5)	AAC ($) (6)	
1	2,100	1,056	3,156	11,340	5,760	17,100
2	4,200	2,112	6,312	22,680	11,520	34,200
3	6,300	3,168	9,468	34,020	17,280	51,300
4	8,400	4,224	12,624	45,360	23,040	68,400
5	10,500	5,280	15,780	56,700	28,800	85,500
6	12,600	6,336	18,936	68,040	34,560	102,600
7	14,700	7,392	22,092	79,380	40,320	119,700
8	16,800	8,448	25,248	90,720	46,080	136,800
9	18,900	9,504	28,404	102,060	51,840	153,900
10	21,000	10,560	31,560	113,400	57,600	171,000
11	23,100	11,616	34,716	124,740	63,360	188,100
12	25,200	12,672	37,872	136,080	69,120	205,200
13	27,300	13,728	41,028	147,420	74,880	222,300
14	29,400	14,784	44,184	158,760	80,640	239,400
15	31,500	15,840	47,340	170,100	86,400	256,500
16	33,600	16,896	50,496	181,440	92,160	273,600
17	35,700	17,952	53,652	192,780	97,920	290,700
18	37,800	19,008	56,808	204,120	103,680	307,800
19	39,900	20,064	59,964	215,460	109,440	324,900
20	42,000	21,120	63,120	226,800	115,200	342,000
21	44,100	22,176	66,276	238,140	120,960	359,100
22	46,200	23,232	69,432	249,480	126,720	376,200
23	48,300	24,288	72,588	260,820	132,480	393,300
24	50,400	25,344	75,744	272,160	138,240	410,400
25	52,500	26,400	78,900	283,500	144,000	427,500
26	54,600	27,456	82,056	294,840	149,760	444,600
27	56,700	28,512	85,212	306,180	155,520	461,700
28	58,800	29,568	88,368	317,520	161,280	478,800
29	60,900	30,624	91,524	328,860	167,040	495,900
30	63,000	31,680	94,680	340,200	172,800	513,000

[a] COZEEP: COnstruction Zone Enhanced Enforcement Program

[b] AAC: Agency Administrative Cost

[c] Column 7 = column (5) + column (6)

Note: if days saved are greater than 30 days, add $96,000/mile for barrier + $30,000 for transformer to the column 7.

7.7 TIME-COST TRADEOFF MODULE

7.7.1 Importance of Time-Cost Tradeoff Module

Even though the construction work zone has a high RUC, the majority of state highway agencies are unwilling to spend an amount equivalent to it as an incentive fee largely because of budget constraints. In fact, most states set a maximum incentive and they hold additional funds for contingencies. However, in most cases (depending on how critical a project is), incentive amounts should be adjusted downward for time-based I/D provisions to be used effectively.

The Time-Cost Tradeoff Module has been designed accordingly to help planners determine an appropriate discount rate that can be validated in an economically rational way, in which states can offer incentives that will also motivate contractors to complete projects ahead of schedule.

A new approach was undertaken to determine the optimal I/D amount that will motivate contractors to pursue accelerated construction. Using *CA4PRS,* simulation-based contractors' time-cost tradeoff data were created based on four different resource usage levels. A linear regression analysis with the data was conducted to predict the contractors' additional cost growth rate and how it interacts with the agency's specified schedule goal (compression).

7.7.2 Underlying Principles for Setting an I/D Amount

To properly encourage contractors to complete projects earlier, incentive fees paid should be larger than increases in the contractor's additional costs for expediting construction, which are defined as the lower bound in this study. If the incentive amount is smaller than the contractor's added costs, this will not only keep competitive contractors from submitting a bid, it could also create a "winner's curse" for small-scale contractors.

In addition, to be economically valid, incentive fees should be less than a portion of the decrease in total time savings to road users and the agency, defined as the upper bound in this study.

In summary, incentive fees should satisfy the following relationship:

- *Contractors additional cost increases ≤ Incentive ≤ Portion of the decrease in total savings to road users and the contracting agency*

Using information on cost dynamics discussed in Chapter 6, it is known that cost growth can be projected by a quadratic equation as a function of schedule compression (see Figure 6.1). As verified by Figure 6.2 with as-built data from completed I/D projects, cost can be calculated as a function of time, using the following quadratic equation:

$$Cost = \beta_0 + \beta_1(Time) + \beta_2(Time)^2 \qquad (3)$$

Because the Time-Value Saving Module produces an initial estimate of the upper bound, a major focus of the Time-Cost Tradeoff Module was on determining the lower bound, which was a challenging task due to the extremely limited data about contractors' additional costs and their final construction costs.

7.7.3 Determining Contractor's Additional Cost Growth

Estimating the level of contractors' additional cost growth in exchange for shortened construction times is extremely difficult largely because such data is nonexistent. Not only is this because contractors are reluctant to disclose data that contains information about profits, but also it is because it is extremely difficult for a contracting agency to keep track of information about contractors' additional cost growth. Even though few researchers reported that they obtained contractors' final construction cost data--in an attempt to estimate the level of contractors' additional cost commitments--the final cost was most likely to be the final cost paid at the end of construction, which includes increases to the original contract bid amount due to contract change orders issued during construction.

To overcome the limitation stemming from the absence of required data, this study developed a method to quantify the level of contractors' additional cost growth for using additional resources by conducting a *CA4PRS* schedule analysis. The analysis was derived from contractors' production performance data that has been tested and validated on numerous highway rehabilitation projects throughout California. It is reasonable to assume that a contractor will need to use additional resources in an I/D contract if it is planned well to provide sufficient motivation. By this reasoning, as Table 7.12 shows, four different resource usage levels were considered to quantify the contractors' additional cost growth rates in the following procedures:

1. Identify critical factors affecting rehabilitation production performance;
2. Perform schedule estimates using *CA4PRS* simulation with four different resource usage levels (Table 7.12);
3. Determine the unit price ($/hour) of all resources used;
4. Calculate contractors' additional costs using Equation (4);
5. Quantify the interaction between contractors' additional cost growth rates and specified schedule compression rates (Table 7.13);
6. Draw a scatter plot of contractors' additional cost growth rates over schedule compression rates to confirm that the regression data is fit into a quadratic shape (which was observed in Chapter 6);
7. Conduct a linear regression analysis to determine coefficients (β_0, β_1, and β_2);
8. Derive a quadratic equation to reflect contractors additional cost growth as a function of the schedule compression the agency sets; and
9. Develop a final quantifying equation by plugging the coefficients into the quadratic equation developed in Step 8.

7.7.3.1 Contractor's Schedule Compression versus Resources

Table 7.12 shows the results of the *CA4PRS* schedule estimates. Because construction strategies, cross-section design, construction window, and contractor's resource constraints turned out to be four of the most important factors directly affecting rehabilitation production (Lee and Ibbs, 2005), these four factors were taken into account when conducting schedule estimates using *CA4PRS* simulation. Table 7.12 displays information about changes in project schedule at four different levels of resource usage. It indicates that the duration of project is shortened as the contractor uses more resources.

Table 7.12 *CA4PRS* Schedule Estimate versus Additional Resource Usage

Strategies	Cross-Section Profile	Construction Window	Schedule Estimate Versus Additioanl Resource Usage							
			Ordinary Usage		5%		15%		25%	
			Closures	Days	Closures	Days	Closures	Days	Closures	Days
PCCP	8 inches	Nighttime	142.00	142.00	136.00	136.00	118.00	118.00	113.00	113.00
		Weekend	6.88	15.76	6.55	14.99	5.98	13.69	5.50	12.59
		Extended	3.13	25.04	2.98	23.81	2.72	21.75	2.50	20.00
	12 inches with 6 inches ACB	Nighttime	227.14	227.14	216.32	216.32	197.51	197.51	181.71	181.71
		Weekend	20.06	47.17	19.41	44.91	17.91	41.01	16.48	37.74
		Extended	6.83	54.64	6.51	52.05	5.94	47.51	5.46	43.70
ACP	6 inches (3x2 lift)	Nighttime	63.32	63.32	60.30	60.30	55.06	55.06	50.66	50.66
		Weekend	5.65	12.94	5.39	12.34	5.09	11.66	5.08	11.63
		Extended	1.06	7.42	1.01	7.07	0.95	6.65	0.95	6.65
MACO	6 inches	Nighttime	126.24	126.24	120.25	120.25	109.82	109.82	101.06	101.06
		Weekend	17.92	41.04	17.07	39.09	15.67	35.88	14.77	33.82
		Extended	13.16	39.48	12.53	37.59	11.45	34.35	10.80	32.40

Each strategy shown in Table 7.12 is based on actual I/D projects where project scope (lane-miles to be rebuilt) and project size (original contract amount) were similar. Following shows a brief project overview of each strategy and summarizes all the assumptions made in conducting the schedule estimates.

- PCCP (Portland Cement Concrete Pavement) strategy is based on the Interstate 15 Devore Project where the project scope was to rebuild a 10.7 lane-mile stretch of badly damaged concrete truck lanes (project size: $18 million).
- ACP (Asphalt Concrete Pavement) strategy is based on Interstate 710 Long Beach Project where the project scope was to rehabilitate approximately 16.4 lane-mile of a six-lane highway segment (project size: $16.7 million).

- MACO (Milling and Asphalt Concrete Overlay) strategy is based on Interstate 15 Baker Project where the project scope was to rehabilitate an aging 43.5 lane-mile stretch of two lanes (project size: $20 million).
- Construction window and lane closure tactics: A sequential single lane closure with 4-hour curing time was assumed for a nighttime construction window. A concurrent double lane closure with 12-hour curing time was assumed for weekend (55-hour) and extended (24/7) construction windows.

7.7.3.2 Contractor's Cost Growth versus Resources

To estimate the cost growth rates resulting from shortening construction times with more resources, the unit price (hourly rate) information of all the major resources was needed and was found in a Caltrans publication entitled *Labor Surcharge and Equipment Rental Rates* (Caltrans, 2008). Caltrans updates the publication annually and revises changes to fuel costs, interest rates, producers' price index, sales tax, and freight rates. The following unit prices were determined:

- Truck: $75.57 with overtime rate of 0.83
- Paver: $132.79 with overtime rate of 0.83
- Milling machine: $362.59 with overtime rate of 0.87
- Batch plant: $615 with over time rate of 0.56 ($6.25/tonne).

The unit prices include the labor costs required to provide the above listed items. The labor surcharge compensates the contractor for statutory payroll items including workers' compensation, social security, Medicare, federal unemployment, state unemployment, and state training taxes (Caltrans, 2008). The surcharge rates in the year 2008 are 12% for regular time and 11% for overtime. Multiple shift hours are paid at the same rate as overtime hours. The unit prices, however, does not include the operator costs of equipment due to the lack of such data.

Contractor's expected cost growth = unit price ($/hour) x number of additional resources x labor surcharge rate x working hours per day x days needed to complete the project x overtime rate x number of shifts x overhead cost (15%) **(4)**

Contractors' additional cost growth rates were quantified based on Equation (4). Table 7.13 contains information about the dependent (cost) and independent (schedule) variables used for the regression analysis, with three different resource usage levels.

Table 7.13 Contractor's Additional Cost Growth on Extra Resource Commitments

Strategies	Cross-Section Profile	Construction Window	Time-Cost Tradeoff versus Additional Resource Usage					
			5%		15%		25%	
			Schedule Compression	Cost Growth	Schedule Compression	Cost Growth	Schedule Compression	Cost Growth
PCCP	8 inches	Nighttime	4.23	0.38	16.90	1.14	20.42	1.90
		Weekend	0.01	0.59	13.13	1.01	20.11	1.43
		Extended (24/7)	4.90	0.64	13.14	1.29	20.00	1.52
	12 inches with 6 inches ACB	Nighttime	4.76	0.41	13.04	1.17	20.00	1.89
		Weekend	4.79	0.53	13.05	1.30	19.99	1.41
		Extended (24/7)	4.74	0.70	13.05	1.47	20.02	1.72
ACP	6 inches (3x2 lift)	Nighttime	4.76	0.40	13.04	1.20	19.99	2.00
		Weekend	4.64	0.40	9.89	1.20	10.12	1.99
		Extended (24/7)	4.72	0.32	10.38	1.12	0.00	1.78
MACO	6 inches	Nighttime	4.74	1.97	13.00	5.92	19.95	9.87
		Weekend	4.75	2.31	12.57	6.92	17.59	11.54
		Extended (24/7)	4.79	2.29	12.99	6.57	17.93	11.29

7.7.4 Regression Analysis

Figure 7.6, which draws on the regression data in Table 7.13, confirms that contractors' cost growth as a function of reduced construction times can be projected by a quadratic equation.

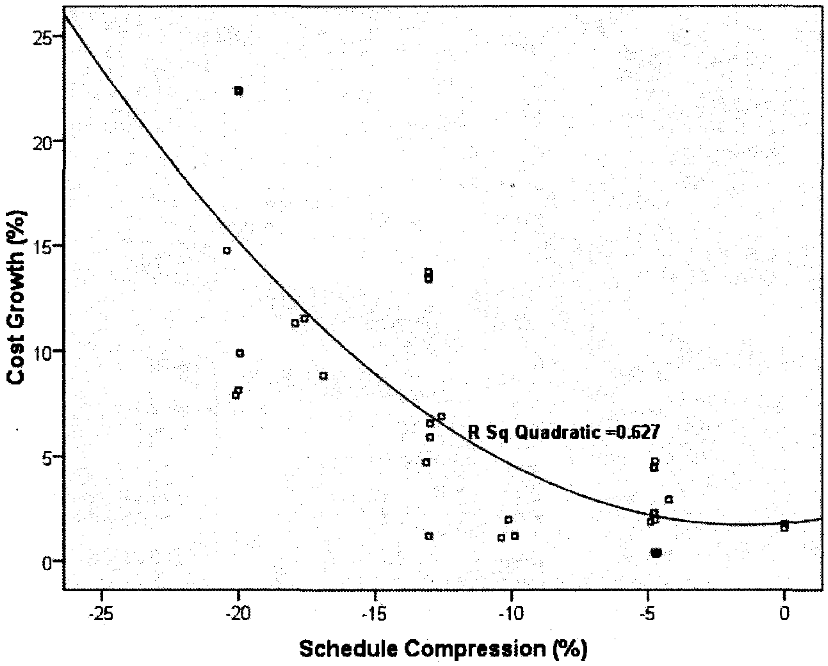


Figure 7.6 Contractor's Time-Cost Tradeoff Curve

Table 7.14 shows that the quadratic equation of contractors' cost growth rate is adequate (F-ratio = 26.005, significant at .001 level). The R-squared value of 0.63 suggests that there is a strong relationship between schedule compression and cost growth, namely, 63% of the cost variation can be explained by this regression model. Since all three coefficients are significant, the following regression equation for determining the lower bound of incentives has been generated.

$$Cost = 1.828 + .114(time) + .039(time)^2 \qquad (5)$$

Table 7.14 Summary of Regression Analysis Results

Model	Coefficient	Std. Error	Beta	t-value
Intercept	1.828	2.207		$.828^{**}$
Time	.114	.469	.115	$.244^{*}$
Time·Time	.039	.020	.903	1.917^{**}
R^2: 0.627 F ratio: 26.005^{***}				

- $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$
- The F-ratio is 26.005 and this value is significant at a .001 level, which suggests that the regression equation is adequate.
- The R-squared value of 0.627 indicates a strong reasonable fit between time and cost.

7.7.5 Equation Derivation

By performing a regression analysis, the coefficients of β_0, β_1, and β_2 were determined.

From Figure 6.1, it is seen that contractors would require committing extra costs by ΔC (i.e., $c_0 - c_1$) to shorten the duration by ΔT (from t_0 to t_1). From Equation (3), a time function can be defined as follows:

$$f = \beta_0 + \beta_1 t + \beta_2 t^2 \qquad (6)$$

Since the contractor's additional cost increase is expressed as a function of shortening time by ΔT, the following relationship can be derived from Figure 6.1:

$$C\ (\text{extra cost increase}) = f(t_1) - f(t_0) = f(t_1) - f(t_1 + \Delta T) \qquad (7)$$

where, $t_0 = t_1 + \Delta T$

The following equation is derived by combining Equations (6) and (7):

$$\text{Contractor's total additional cost increase} = -\Delta T\,(2\beta_2\, t_1 + \beta_1 + \beta_2 \Delta T) \qquad (8)$$

The minus sign means that cost decreases as time increases. In Equation (8), the symbol ΔT represents the difference in the number of days necessary to complete the project using conventional and incentive schedules. In other words, ΔT reflects the agency goal of schedule reduction. The symbol t_1 represents days necessary to complete the project by using an incentive schedule. The Schedule Module determines the values of ΔT and t_1.

To convert the total extra cost increase to a daily basis, Equation (8) needs to be divided by the number of days saved (i.e., ΔT), which cancels out ΔT. Thus, the contractor's daily additional cost growth rate equals $2\beta_2 t_1 + \beta_1 + \beta_2 \Delta T$.

Based on coefficients generated through the regression analysis, the following equations are derived to predict the level of the contractor's additional cost increase to the original contract amount:

$$\Delta C = 0.114 + 0.078t_1 + 0.039\Delta T \text{ for roadway renewal projects} \quad \textbf{(9)}$$

where, $t_1 = t_0 - \Delta T$

Using the definition of t_1, the final equation is derived:

$$\Delta C = 0.114 + 0.078t_0 - 0.039\Delta T \quad \textbf{(10)}$$

As previously stated, the daily incentive amount should range from an increase in the contractor's daily additional cost to the portion of daily road user cost savings. In symbols,

$$0.114 + 0.078t_0 - 0.039\Delta T \leq \text{Daily I/D} \leq \text{Discounted total savings} \quad \textbf{(11)}$$

7.8 OVERALL COMPUTATIONAL PROCEDURE

Figure 7.7 illustrates the overall computational procedure and framework of the model for finding a solution that (1) helps agencies make better-informed decisions about whether or not to use an I/D provision and (2) determines the most reliable, realistic daily and closure I/Ds and maximum incentive amounts. As described, the model is comprised of three main analysis modules that take into consideration the following important aspects in algorithmic order:

1) Schedule Module: the probable number of project days eliminated by use of an I/D provision.
2) Time-Value Saving Module: the monetary value of the time saved by road users and the agency.
3) Time-Cost Tradeoff Module: the appropriate dollar amount needed to properly motivate the contractor.

Using the three modules in an algorithmic order, two types of I/Ds are determined; one for completion of an internal project milestone within a specified number of closures (closure I/D), and another for completion of an entire project sooner than originally scheduled (daily I/D). The maximum incentive amount is then calculated by multiplying the maximum probable number of days the project can eliminate by the daily I/D amount. If the maximum incentive amount at the end of the analysis falls outside the agency budget, the total time savings (upper bound) and daily incentive amount should be adjusted until they are changed to an economically rational maximum incentive amount that can be offered that will still motivate the contractor to complete the project ahead of schedule.

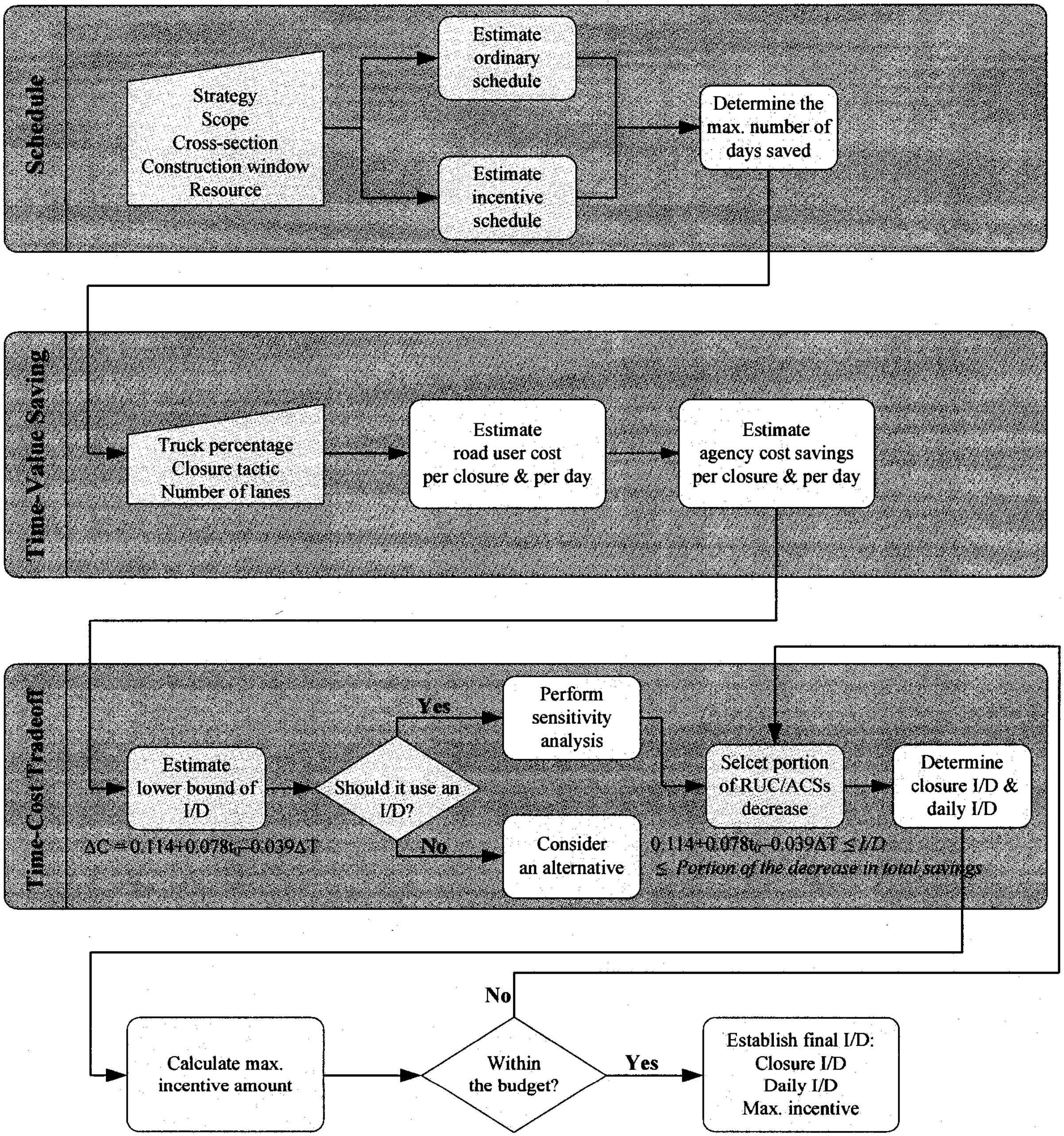


Figure 7.7 Overall Computational Procedure of the Model

7.9 PRACTICAL APPLICATION OF MODEL

Given the project information listed below, the algorithm summarized in Figure 7.7 was applied to two long-life I/D highway rehabilitation projects, recently completed in California, to check the robustness of the model in predicting the actual values of I/D amounts.

7.9.1 Example 1: I-15 Devore Project (EA 0A4234)

The scope of I-15 Devore project, which has been selected for use as an example of the proposed model, was the rehabilitation of a heavily trafficked 2.67-mile stretch of badly damaged concrete truck lanes on I-15 in Devore in southern California. The goal of applying the model is to examine whether or not I/D provisions could have been used and, if they were, to determine the most reliable, realistic I/D amounts per day and per closure with the incentive cap. Key information about the rehabilitation project included:

- Project size : approximately $18 million;
- Lane-miles to be rebuilt: 10.7 lane-mile;
- Construction window: extended weekday closures with around-the-clock operations;
- Lane closure scheme: concurrent double-lane closure with counter-flow traffic;
- Cross-section design: 11.4-in doweled slabs of Type III Portland concrete cement and a 5.9-in asphalt concrete (AR-8000 binder) base;
- AADT: approximately 100,000 vehicles; and
- Percentage of trucks at the construction work zone: 10%.

Step 1: Schedule Module

Given the project's scope, pavement design, and construction working methods (refer to Table 7.3), the Schedule Module estimates that the project would require 7.9 72-hour weekday closures (24 working days) with a conventional contracting strategy and 6.6 closures (20 working days) in an I/D contracting strategy. Four working days (1.3 closures) is the estimated maximum probable number of days that I/D use could eliminate.

Step 2: Time Saving Module for Determining the Upper Bound

According to the RUC lookup data shown in Table 7.9, for this project's given AADT (100,000) and percentage of trucks (10%), the expected daily monetary saving to road users is estimated to be \$175,151. The expected closure-based monetary saving to road users is \$525,453, and the expected savings in agency cost by completing the project five days early is estimated to be \$68,400 (\$205,200 per closure), based on monetary value calculation in Table 7.11.

Step 3: Time-Cost Tradeoff Module for Determining the Lower Bound

Based on the construction schedule estimates generated by the Schedule Module, ΔT, schedule compression rate, is determined as -0.166 (16.6% reduction of t_0) (see Figure 7.8). The contractor's daily additional cost growth rate (ΔC) is determined as follows (Equation 10):

$0.114+0.078t_0-0.039\Delta T = 0.114+0.078(1.000)+0.039(0.166) = 0.198\% =$ \$35,640/day (\$106,920/closure).

This analysis reveals that the project is an appropriate one for use of an I/D provision because the estimated lower bound is smaller than the total time value savings in both the daily- and closure-based measurements.

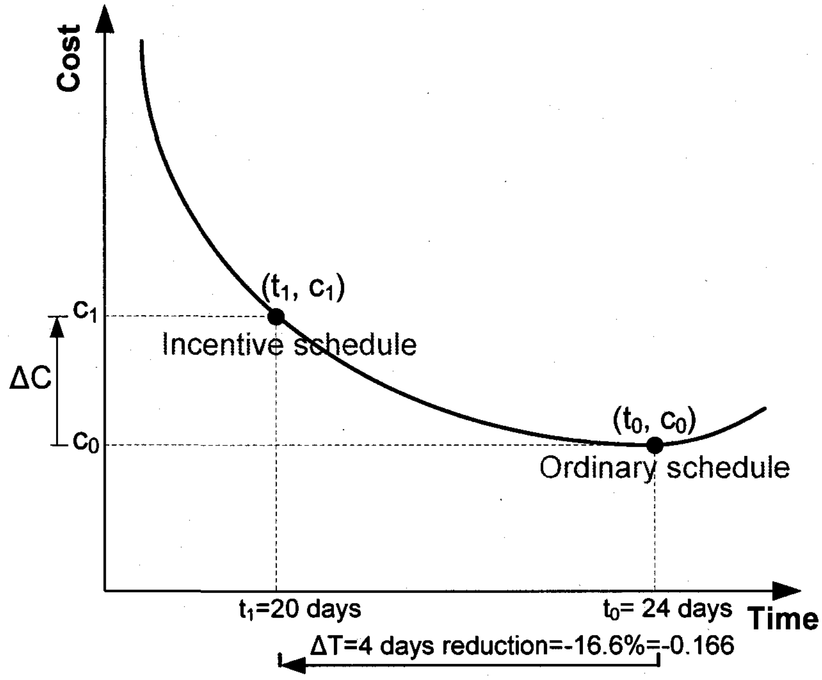


Figure 7.8 Calculation of ΔT for the I-15 Devore Project

Step 4: Sensitivity Analyses: ΔC ≤ I/D ≤ Portion of the decrease in total savings

Table 7.15 shows the lower and upper bounds for determining the most realistic I/D amount for the given project through the computational procedure shown in Figure 7.7. As stated earlier, most agencies would not want to use an amount equivalent to the total time value savings (upper bound) due to budget constraints. It would also be ineffective to set the same amount of total time value savings as the upper limit even if the agency has an adequate budget for an incentive payment. The model developed in this study provides a reasonable range-based estimate of I/D amounts between the lower and upper limits that will motivate contractors to apply their ingenuity to completing projects early while reducing the state's road user delay and agency costs.

Table 7.15 Lower and Upper Bounds of I/D before Application of a Discount Rate

	ΔC	Savings to road users	Savings to the agency	Total savings
Daily I/D	$35,640	$175,151	$68,400	$243,551
Closure I/D	$106,920	$525,453	$205,200	$730,653

As Figure 7.9 shows, one of the outputs that the decision-support model generates is a sensitivity analysis graph for finding an optimal discount rate. Figure 7.9 depicts what percentage of the calculated total time value savings would accurately represent the construction and traffic impacts for this given project. The figure indicates that discount rates smaller than 80% (20% portion of decrease in total savings in the figure) should not be considered for both the daily and closure incentives because those incentive amounts cannot properly motivate the contractor. The optimal I/D amounts are found around at 80% discount rate (20% portion of the decrease in total time value savings in the figure). By applying a 80% discount rate, the optimal I/D amounts are determined:

- Daily I/D: $35,640 ≤ I/D ≤ $48,710
- Closure I/D: $106,920 ≤ I/D ≤ $146,131
- Incentive cap: $138,996 ≤ I/D ≤ $189,969

The maximum incentive amount in this range is within 5% of the agency's budget for this project. When Caltrans actually implemented this I/D project in 2004, the agency used a daily incentive bonus of $75,000, an acceptable (at 70% discount) amount according to the procedures and results through the model developed in this study. Because this project had been deemed as a time-critical one, a smaller discount rate was applied in order to more highly motivate contractors to complete construction faster.

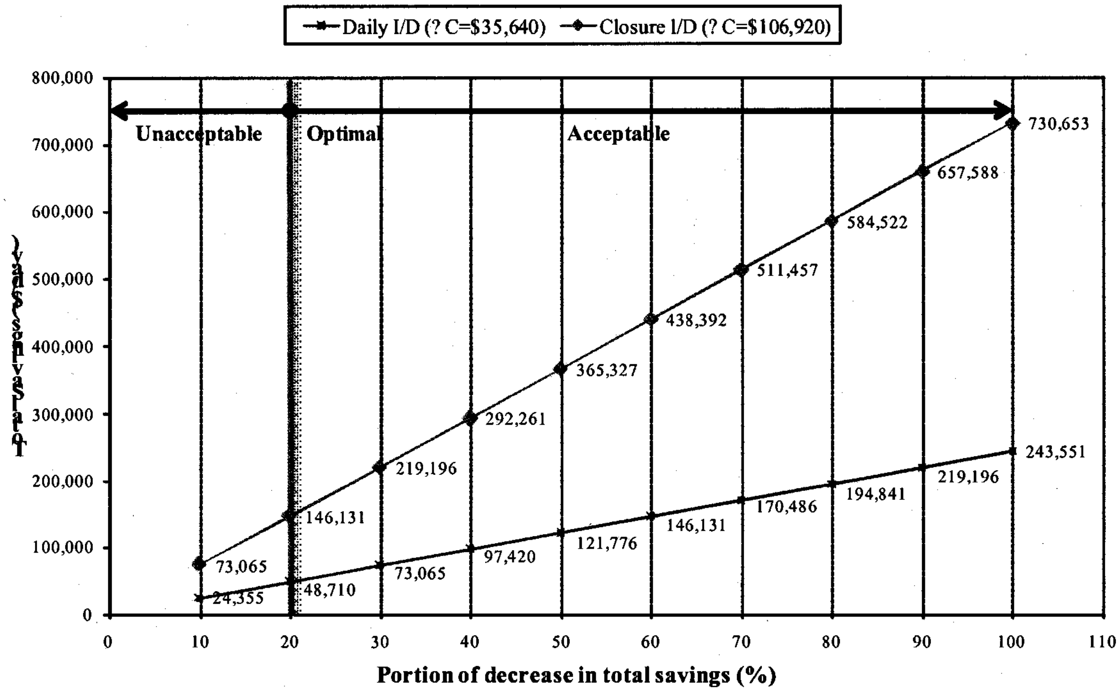


Figure 7.9 Sensitivity Analysis of the I-15 Devore Project

7.9.2 Example 2: I-710 Long Beach Project (EA 1384U4)

The scope of I-710 Long Beach project was to rehabilitate a 16.4 lane-mile section of I-710 near the Port of Long Beach during a series of fifty-five-hour weekend closures. The project consisted of three full-depth asphalt concrete (FDAC) replacement sections (1.0 mile total) under freeway overpasses, and two sections (1.7 mile total) with crack, seat, and overlay (CSOL) of existing PCC slabs with asphalt concrete (AC) (Lee et al., 2005a).

Key information about the rehabilitation project included:

- Project size : approximately $16.7 million;
- Lane-miles to be rebuilt: 16.4 lane-mile;
- Construction window: extended closures (55-hour weekend) with around-the-clock operations;
- Lane closure scheme: concurrent double-lane closure with counter-flow traffic;
- AADT: approximately 120,000 vehicles; and
- Percentage of trucks at the construction work zone: 5%.

Step 1: Schedule Module

Given the project's scope, pavement design, and construction working methods (refer to Table 7.2), the Schedule Module estimates that the project would require 10.4 extended weekend closures (24 working days) with a conventional contracting strategy and 8.6 closures (20 working days) in an I/D contracting strategy. Four working days (1.8 closures) is the estimated maximum probable number of days that I/D use could eliminate.

Step 2: Time Saving Module for Determining the Upper Bound

According to the RUC lookup data shown in Table 7.8, for this project's given AADT and percentage of trucks, the expected daily monetary saving to road users is estimated to be $526,347. The expected closure-based monetary saving to road users is $1,206,212, and the expected savings in agency cost by completing the project four days early is estimated to be $68,400 ($156,750 per closure), based on monetary value calculation in Table 7.11.

Step 3: Time-Cost Tradeoff Module for Determining the Lower Bound

Based on the construction schedule estimates generated by the Schedule Module, ΔT, schedule compression rate, is determined as -0.166 (16.8% reduction of t_0) (see Figure 7.10). The contractor's daily additional cost growth rate (ΔC) is determined as follows (Equation 10):

$0.114+0.078t_0-0.039\Delta T = 0.114+0.078(1.000)+0.039(0.166) = 0.198\% = \$33{,}066/\text{day}$ (\$75,776/closure).

One of the goals for applying this model is to examine whether or not I/D provisions could have been used and, if they were, to determine the most reliable, realistic I/D amounts per day and per closure with the incentive cap. This analysis reveals that the project is an appropriate one for use of an I/D provision because the estimated lower bound is smaller than the total time value savings in both the daily- and closure-based measurements.

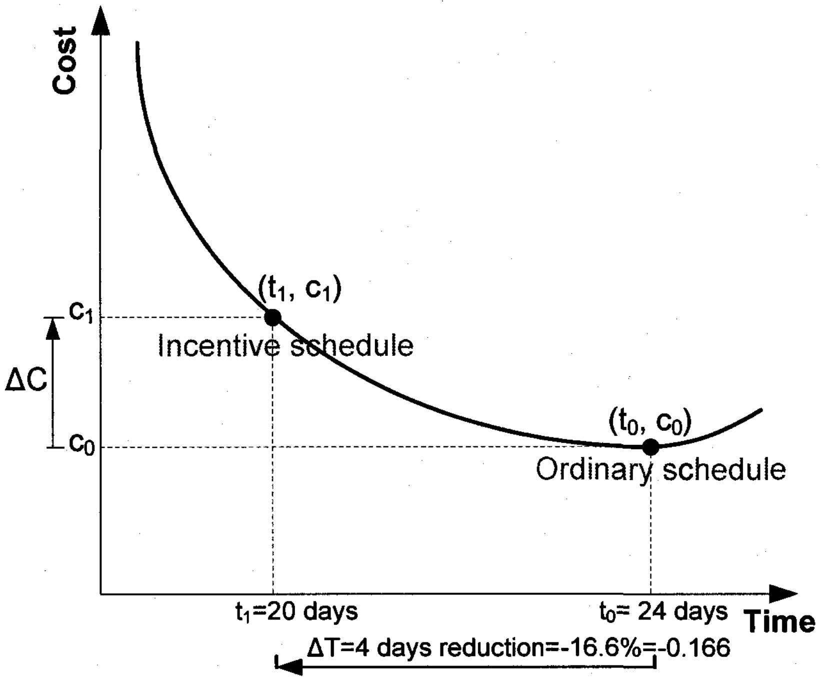


Figure 7.10 Calculation of ΔT for the I-710 Long Beach Project

Step 4: Sensitivity Analyses: ΔC ≤ I/D ≤ Portion of the decrease in total savings

Table 7.16 summarizes the lower and upper bounds for determining the most realistic I/D amount for the given project.

Table 7.16 Lower and Upper Bounds of I/D for the I-710 Long Beach Project

	ΔC	Savings to road users	Savings to the agency	Total savings
Daily I/D	$33,066	$526,347	$68,400	$594,747
Closure I/D	$75,776	$1,206,212	$156,750	$1,362,962

Figure 7.11 shows what percentage of the calculated total time value savings would accurately represent the construction and traffic impacts for this given project. The figure indicates that discount rates smaller than 90% (10% portion of decrease in total savings in

the figure) should not be considered for both the daily and closure incentives because those incentive amounts cannot properly motivate the contractor. The optimal I/D amounts are found around at 90% discount rate (10% portion of the decrease in total time value savings in the figure). By applying a 90% discount rate, the optimal I/D amounts are determined as follows:

- Daily I/D: $33,066 ≤ I/D ≤ $59,475
- Closure I/D: $75,776 ≤ I/D ≤ $136,296
- Incentive cap: $136,397 ≤ I/D ≤ $245,334

The maximum incentive amount in this range is within 5% of the agency's budget for this project. When Caltrans actually implemented this I/D project in 2003, the agency used a closure incentive bonus of $100,000, an acceptable, accurate amount based on the procedures and results through the model developed in this study.

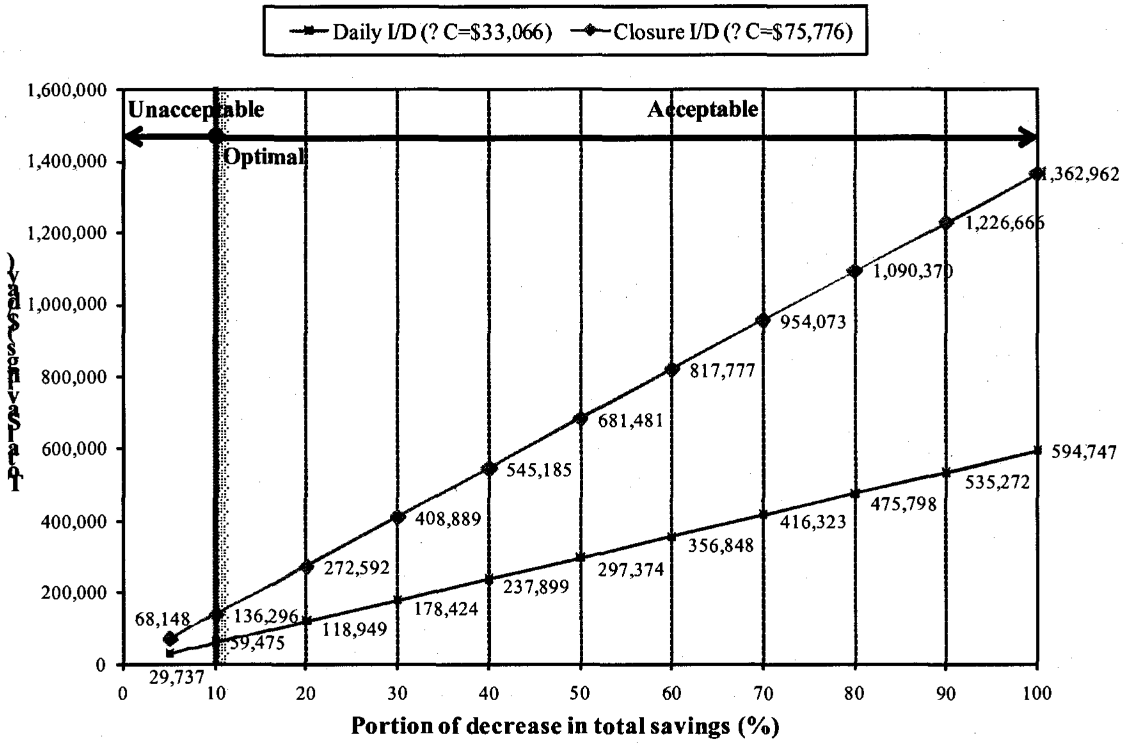


Figure 7.11 Sensitivity Analysis of the I-710 Long Beach Project

8 CONCLUSIONS

The major goal of utilizing alternative contracting strategies is for agencies to have critical project work completed by contractors as quickly as possible by motivating and challenging them either to complete an internal project milestone within a certain time period or to complete an entire project sooner. However, California presents a case in which cost-plus-time (A+B) contracting performed much worse than conventionally contracted projects. The A+B contracting strategy is used with the presumption that competition at a project's outset will encourage contractors to reasonably shorten their bids on the "B" (duration) portion of the contract. However, it was seen that A+B projects actually suffered severely from contractors' underestimations of their bids on the "B" portion in A+B bidding. Based on the analysis results, it appears that contractors often manipulated the duration of project downward to win contracts, and this ultimately resulted in significant schedule overruns. Meanwhile, projects that applied the incentive/disincentive (I/D) contracting strategy demonstrated the power of I/D clauses: many of these types of projects achieved or surpassed the agency's goal of early project completion.

When it comes to the project cost growth, it was initially believed that I/D projects underwent relatively small cost growth because they tend to be large scale and are undertaken with a clear definition of their scope. However, the analysis showed the opposite results: I/D contracting projects had the largest cost growth overall. It was also seen that projects contracted solely as A+B underwent levels of cost growth similar to that of I/D-contracted ones.

Statistical analyses revealed that use of alternative contracting strategies significantly increased the cost of projects compared to conventional strategies, under the assumption that the contracting agency's choice of A+B and I/D projects were unbiased. However, there was no significant evidence to prove that the I/D contracting strategy increases project cost significantly more than the A+B strategy. It was determined that the cost growth effect is closely tied to the frequency of contract change orders. In conclusion, it is recommended that A+B contracting be used with an I/D provision in order for contractors to be motivated to meet a scheduled completion date.

The integrated analysis framework of a new decision-support model was developed to help decision-makers choose an appropriate contracting strategy and determine the realistic incentive amounts. The model, which integrates construction schedule, total time value savings to motorists and to agencies, and contractors' expected additional cost growth, determines the I/D amounts that are higher than contractors' additional cost growth and lower than the decrease in total time savings. Using the integrated analysis, the model produces two types of incentives; one for completion of an internal project milestone within a specified number of closures (closure I/D), and another for completion of an entire project sooner than originally scheduled (daily I/D).

The current model presented in this study forms the basis for a future study to develop a prototype computer software system. It is recommended that following areas be addressed in the future study to fine-tune the proposed model's capabilities:

- Expand the model to cover other project types, such as bridges and capacity-added projects. Doing so will enhance the model's analysis capability and give contracting agencies a wider choice of construction strategies.
- Provide point-based estimates of I/D amounts by considering levels of service (LOS), which indicate levels of traffic disruption to motorists.
- Conduct a quantitative analysis similar to the one performed in this study to investigate how contract change orders impact project performance components, such as schedule and cost.

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APPENDIX A: I/D PROJECT DATA ON MAJOR TYPES

	Project ID (1)	Scope (Lane-miles) (2)	Original Contract Time (day) (3)	Amended Contract Time (day) (4)	Final Completion Time (day) (5)	Change Order Days (day) (6)	Original Contract Amount (US $ K) (7)	Engineers Estimate Amount (US $ K) (8)	Amended Contract Amount (US $ K) (9)	Final Construction Cost Paid (US $ K) (10)	Final Project Cost including incentives (US $ K) (11)	Change Order Amount (US $ K) (12)
Roadway	0A4234	2.3	100	111	102	11	$23,622	$22,217	$25,155	$25,560	$25,587	$1,534
	1760U4	1.0	1,510	1,517	1,461	7	$13,235	$10,287	$14,187	$14,431	$14,793	$952
	0A4224	2.2	100	100	104		$7,398	$7,947	$8,296	$8,334	$8,334	$898
	0A4224	2.2	100	100	104		$30,900	$45,606	$32,315	$31,945	$31,950	$1,415
	0A4234	2.3	100	111	102	11	$13,235	$10,287	$14,187	$14,431	$14,776	$952
	3259U4	4.8	306	379	238	73	$23,622	$22,217	$25,155	$25,567	$25,572	$1,534
	355604	7.2	50	50	43		$3,292	$2,768	$3,433	$3,583	$3,583	$142
	3555U4	87.1	30	30	29		$755	$675	$751	$779	$779	
	1S2304	N/A	120	146	120	26	$1,270	$1,332	$1,349	$1,380	$1,380	$79
Bridge	276004	0.4	320	387	390	67	$6,646	$8,748	$9,723	$9,682	$9,712	$3,077
	041524	1.9	70	84	84	14	$18,671	$15,140	$24,510	$6,573	$6,573	$5,840
	0J1014	17.2	180	182	119	2	$18,671	$15,140	$24,510	$6,573	$6,573	$5,840
	0J1024	17.2	165	165	71		$8,900	$6,447	$10,812	$10,700	$10,700	$1,912
Capacity-added	4874R4	0.7	550	690	498	140	$27,311	$32,184	$29,338	$28,997	$29,037	$2,027
	131244	1.2	100	231	100	131	$21,401	$22,456	$25,401	$25,075	$25,075	$4,000
	0T16U4	3.0	160	160	159		$3,674	$4,067	$3,884	$3,779	$3,779	$210
	045034	4.1	339	406	339	67	$12,122	$17,500	$13,608	$13,875	$13,875	$1,486
	350704	6.7	320	349	409	29	$37,087	$38,875	$39,188	$38,270	$38,290	$2,101
	4697V4	13.9	352	352	344		$57,673	$48,587	$60,688	$59,627	$59,674	$3,015

APPENDIX B: A+B PROJECT DATA ON MAJOR TYPES

	Project ID (1)	Scope (Lane-miles) (2)	Original Contract Time (day) (3)	Amended Contract Time (day) (4)	Final Completion Time (day) (5)	Change Order Days (day) (6)	Original Contract Amount (US $ K) (7)	Engineers Estimate Amount (US $ K) (8)	Amended Contract Amount (US $ K) (9)	Final Project Cost (US $ K) (10)	Change Order Amount (US $ K) (11)
Roadway	327204	3.3	185	221	221	36	$10,833	$10,202	$10,214	$12,051	$1,543
	207914	0.6	225	225	223		$43,223	$47,206	$47,262	$56,049	$9,957
	4874C4	1.0	930	967	547	37	$20,628	$25,200	$25,223	$22,827	$295
	0105U4	2.0	119	129	129	10	$13,637	$10,584	$10,598	$14,422	$24
	0C8604	2.1	33	33	121		$14,168	$15,891	$15,906	$15,032	$1,891
	1A6904	2.5	43	49	52	6	$22,324	$22,263	$22,289	$25,579	$2,612
	0C3504	3.6	25	33	57	8	$19,223	$17,270	$17,289	$18,543	$626
	0C9204	4.2	107	107	107		$698	$860	$861	$962	$215
	420304	5.2	236	299	239	63	$4,316	$4,603	$4,608	$4,609	$371
	0C6904	5.6	80	117	126	37	$4,229	$5,307	$5,312	$5,214	$280
	234304	6.4	200	200	195		$5,363	$5,746	$5,751	$5,433	$138
	0C9504	6.7	75	103	114	28	$5,700	$6,108	$6,114	$6,260	$252
	270514	7.6	143	173	174	30	$6,130	$5,450	$5,457	$6,507	$553
	0C7604	8.4	66	86	90	20	$15,440	$16,806	$16,824	$17,788	$12
	078304	8.5	124	124	124		$5,523	$5,277	$5,282	$5,297	$47
	0E05U4	8.7	264	310	308	46	$10,295	$8,194	$8,203	$9,373	-$872
	464104	9.1	68	75	102	7	$7,593	$12,419	$12,427	$8,000	$184
	272124	9.7	80	80	80		$11,911	$18,733	$18,748	$15,634	$773
	472004	9.9	101	101	105		$2,200	$1,949	$1,951	$2,117	$25
	213704	10.0	100	100	114		$9,161	$9,976	$9,987	$10,624	$75
	0G4004	10.1	128	131	131	3	$6,399	$7,251	$7,257	$6,258	$552
	493704	11.0	100	100	92		$9,910	$12,514	$12,526	$11,364	$40
	226204	11.5	420	462	450	42	$10,567	$12,565	$12,576	$11,547	$1,735
	0C7204	11.9	115	125	156	10	$11,318	$15,881	$15,893	$12,146	$37
	284314	12.0	140	160	163	20	$10,721	$14,495	$14,506	$11,345	$523
	077304	37.9	58	58	127		$8,342	$8,336	$8,344	$8,146	$136
	4567V4	49.1	333	450	450	117	$2,225	$3,398	$3,400	$2,346	$65
Bridge	276004	0.4	320	387	390	67	$7,820	$8,509	$8,517	$8,411	$653
	3A2604	0.5	117	117	109		$4,416	$4,605	$4,610	$4,989	$614
	2S9404	0.5	225	307	225	82	$8,900	$6,447	$6,458	$10,700	$1,912
	162004	1.1	205	306	313	101	$11,823	$20,081	$20,095	$13,823	$1,985
	041524	1.9	70	84	84	14	$10,484	$16,787	$16,803	$15,886	$7,006
Capacity-added	291004	0.4	375	506	552	131	$61,081	$92,400	$92,471	$70,567	$9,792
	281114	1.0	100	105	114	5	$21,002	$21,762	$21,786	$24,269	$1,975
	013054	1.1	800	1249	1462	449	$22,950	$28,700	$28,727	$26,539	$3,528
	228554	1.4	140	201	234	61	$4,674	$6,772	$6,777	$4,700	$183
	448504	2.5	100	100	100		$25,535	$23,316	$23,344	$27,830	$5,487
	015114	3.2	340	355	350	15	$13,899	$12,138	$12,153	$14,833	$454
	4396U4	5.1	275	310	443	35	$40,183	$46,913	$46,960	$47,005	$7,578
	125204	6.2	215	255	255	40	$28,107	$29,361	$29,392	$30,844	$2,696
	2357A4	8.3	210	340	342	130	$14,726	$13,311	$13,327	$15,867	$1,668
	472104	8.9	110	125	125	15	$2,768	$2,906	$2,909	$2,840	$80