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Technical Memorandum on Innovative Contracting Methods Implementation Studies

November 2008

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Abstract:

The main objective of this study is to determine the effectiveness of alternative contracting strategies on aspects of project performance such as schedule and cost, in order to promote ways to apply the strategies effectively. A quantitative analysis that draws on 1,372 infrastructure improvement projects recently completed in California from 2000 to 2008 was conducted to achieve the objective. According to the analysis, alternative projects contracted with I/D and A+B represented 7% of all project establishments and 23% of all project allotment costs. The results of one-way ANOVA analyses show that I/D projects held a decisive schedule-saving advantage over A+B and conventional projects, but that I/D also increased project costs significantly more than the others because of a higher frequency of contract change orders. The results of statistical analyses reveal a severe effectiveness problem with use of the A+B contracting strategy. When compared with conventional projects, A+B not only included extreme severe 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 growth for utilizing I/D was recouped by reduced construction time, but this tradeoff was not seen in A+B projects.

Keywords: alternative contracting; effectiveness, schedule performance; cost growth; change orders; hypothesis testing; decision-support model

Proposals for implementation:

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A New Decision-Support Model for Innovative Contracting Strategies through a Quantitative Analysis on Aspects of Project Performance, by K. H. Choi. PhD dissertation. Fall 2008.

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PROJECT OBJECTIVES

This research project has the following major objectives:

1. To investigate whether use of incentive/disincentive (I/D) provisions affects construction duration.
2. To determine whether use of alternative contracting methods on infrastructure improvement projects significantly shortened their duration compared to conventional projects.
3. To examine whether I/D projects increase project costs above the levels seen in A+B and conventional projects.

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Since much of the transportation infrastructure in the U.S. has substantially deteriorated and is in need of large-scale renewal, many state highway agencies (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 incentive/disincentive (I/D) and cost-plus-time (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. The objectives of this study are to address these shortcomings by determining the effectiveness of these strategies and to promote ways to apply them effectively.

To achieve the objectives, a quantitative analysis was conducted that drew on 1,372 infrastructure improvement projects completed in California from 2000 to 2008. According to the analysis, alternative projects contracted with I/D and A+B represented 7% of all project establishments and 23% of all project allotment costs. 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 also increased project costs significantly more than the others because of a higher frequency of contract change orders. The results of planned comparisons and post-hoc tests performed with trend analyses revealed a severe effectiveness problem with use of the A+B contracting strategy. When compared with conventional projects, A+B not only included extreme severe schedule overruns, it also increased project costs far above the levels seen in conventional projects; both of these resulted from the 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 findings and results of this study can help Caltrans make better-informed decisions in choosing an appropriate contracting strategy.

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1 PROBLEMS, DELIVERABLES, AND CONTRIBUTIONS

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 project performance components such as schedule and cost. A special Texas DOT commission held July 18, 2007, 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."

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. The 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 I/D rates. 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. Competitive contractors can also easily earn an incentive bonus without extra commitments for fast-track construction.

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. On the other hand, according to Herbsman et al., A+B is more effective and less expensive than the I/D strategy because (a) schedule compression can be achieved prior to construction through competition rather than incentive payments and (b) bidding on cost and time enables the contractor to devise better schedules and plans.

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 systematic studies hinders agencies' ability to determine whether to use I/D and/or A+B contracting.

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 and that neither standard computer tools nor a calculation procedure for determining I/D dollar amounts exists.

1.4 Research Objectives and Deliverables

The objectives and deliverables of this study are defined in Table 1. (Note that the table includes objectives completed as part of PPRC SPE 4.14 where indicated.)

Table 1: Summary of Objectives and Deliverables

Objective	Deliverables
1. Literature review	Literature survey of U.S. practice. Problems and needs in current practice. (Completed in 4.14)
2. Data collection	I/D, A+B, and conventional contracting projects (Completed in 4.14)
3. Effectiveness analysis	Evaluation of alternative projects on schedule performance, cost growth, and contract changes over conventional projects.
4. Interim report	Report documenting the literature, data analysis, and framework.
5. Prototype computer tool	Spreadsheet-based implementation of framework.
6. Computer tool	A tool for determining the daily I/D amounts and I/D caps.
7. Final report	Report summarizing all of the work completed and documenting features and implementation plan of the computer model.

This technical memorandum summarizes the research results and findings from Objectives 1 to 3.

1.5 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). Responses to problems and contributions of this research are defined in Table 2.

Table 2: 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.

2 DATA ANALYSIS

2.1 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 3).

2.2 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 3. Nature of Project Data

	No.	Value Type	Description
Project Summary	1	EA number	Six-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	Original 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 project cost (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	Amended project cost due to CCOs (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

2.3 Initial Data Analysis

The following shows a summary of the findings through initial data analysis:

- Three major project types represented 83.0% of all Caltrans' project allotment costs over the eight years, 2000 to 2008 (Figure 1).
- 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 2).

- 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 3).
- Projects of the capacity-added type had the largest project size according to their installed original contract amount (Figure 4).
- I/D projects had the largest project size, followed by A+B and conventional projects, conveying the fact that the I/D strategy has primarily been applied to large-scale projects (Figure 4).
- Among 29 I/D projects, the average daily I/D amount was \$17,009. 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.

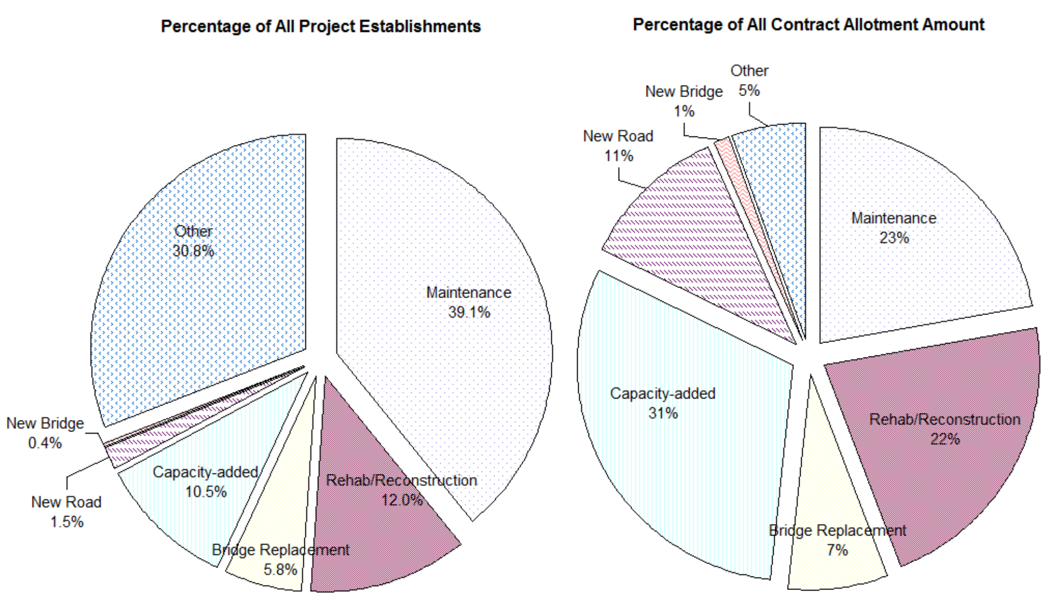

Figure 1: Current trend of infrastructure improvement projects (2001–2008).

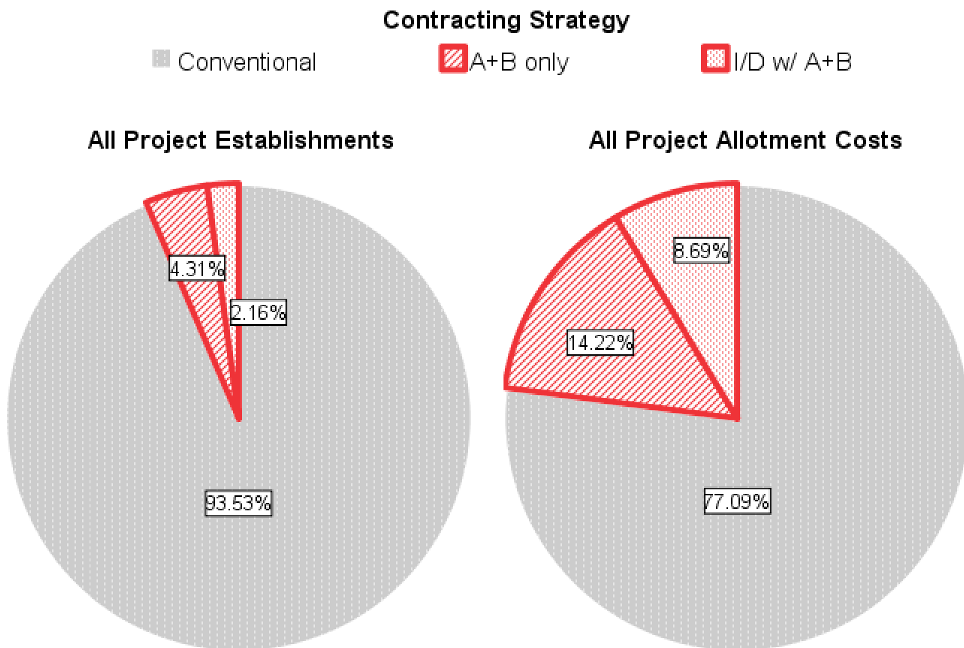

Figure 2: Percentage comparison of three contracting strategies (2000–2008).

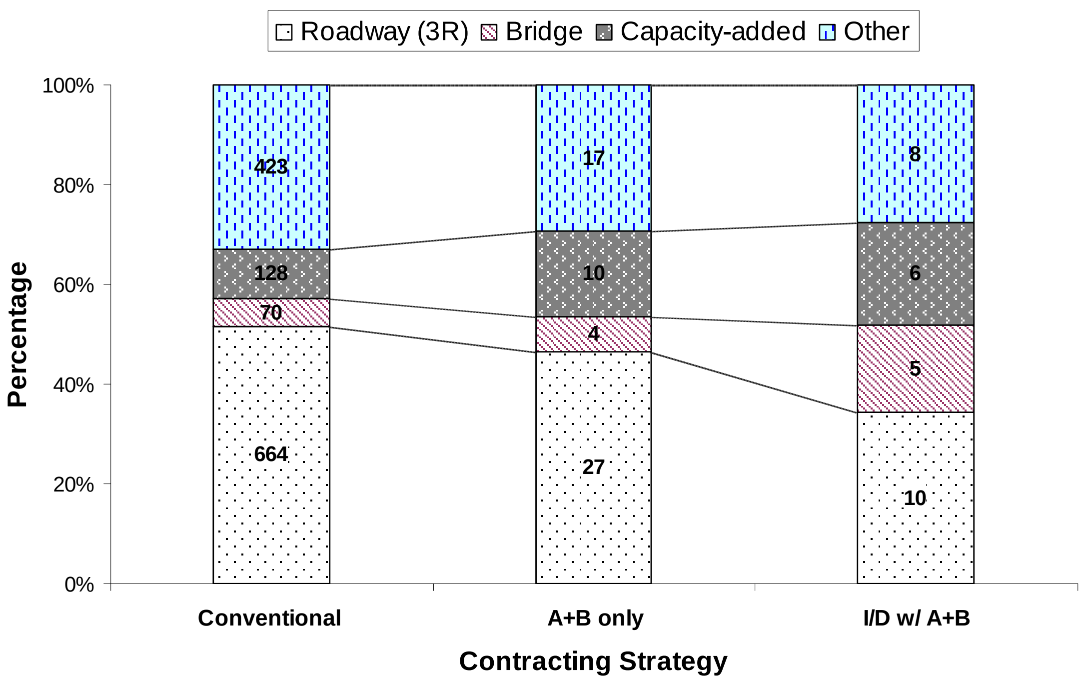

Figure 3: Adoption of alternative contracting strategies versus project type.

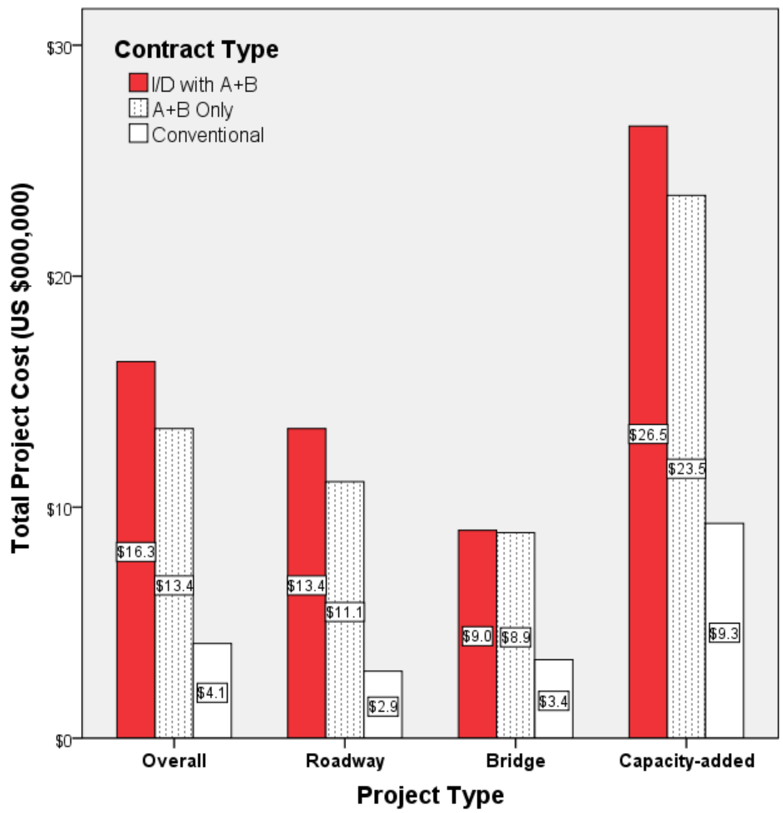

Figure 4: Average project size versus contracting strategy.

3 EFFECT OF I/D CONTRACT ON PROJECT SCHEDULE

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 (a) projects contracted solely with an A+B contract and (b) 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.

3.1 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:
[(final completion time – original (or amended) contract time) / original (or amended) contract time].

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 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 is 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 showed negative schedule changes (18.58% and 31.55% overruns, respectively).

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.

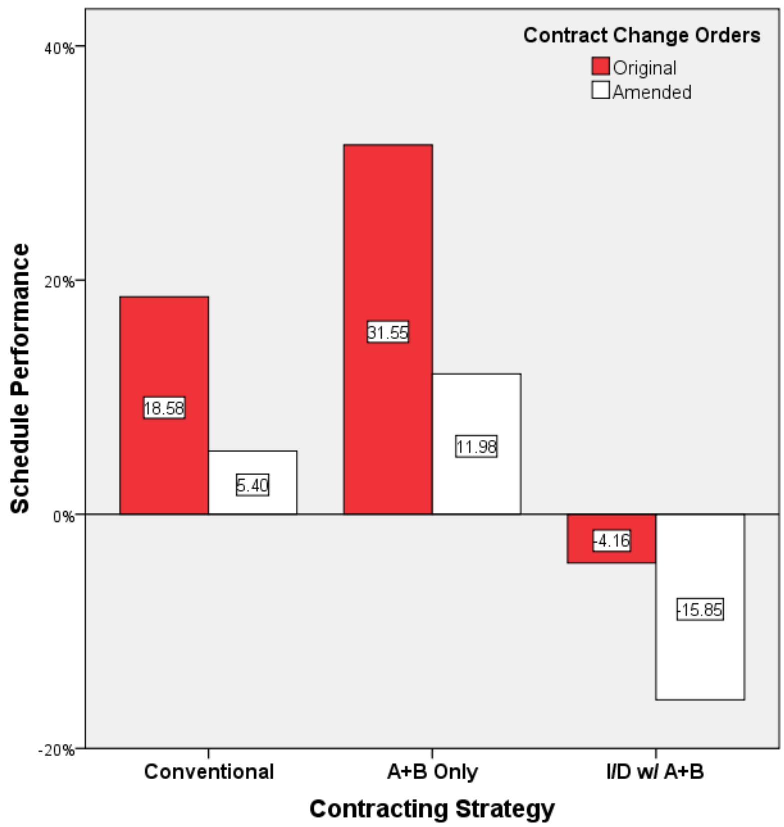

Figure 5. Overall schedule performance versus contracting strategy.
(Note that a negative value implies schedule compression.)

To scientifically verify the aforementioned results, a one-way ANOVA analysis was conducted to compare the means of three contracting project groups.

3.2 Research Hypothesis Testing

3.2.1 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, and that they held a relative time-saving advantage over other contracting strategies. The analyses also included a case in which use of A+B did not result in much better schedule performance than conventional projects did. 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.

3.2.2 Analysis of Testing Results

Table 4 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 4: 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 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 a 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 also displays the results of the trend analysis, which breaks down the schedule effect into that which can be explained by a linear relationship and that which can be explained by a quadratic relationship. From Table 5, 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 changes from an A+B to an I/D. To further investigate this trend, planned comparison and post-hoc tests were followed.

Table 5: 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 6);

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 6 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 6: 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.

Table 7 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 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. 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 7. 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 7: 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	95% Confidence Interval 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.

4 EFFECT OF I/D CONTRACT ON INSTALLED PROJECT COST

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.

4.1 Cost Dynamics Associated with Schedule Variation

A well-known trade-off effect exists between construction cost and schedule. As Figure 6 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_1 to t_0), a contractor would need to make an additional cost commitment of ΔC (from c_1 to c_0). 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. (12).

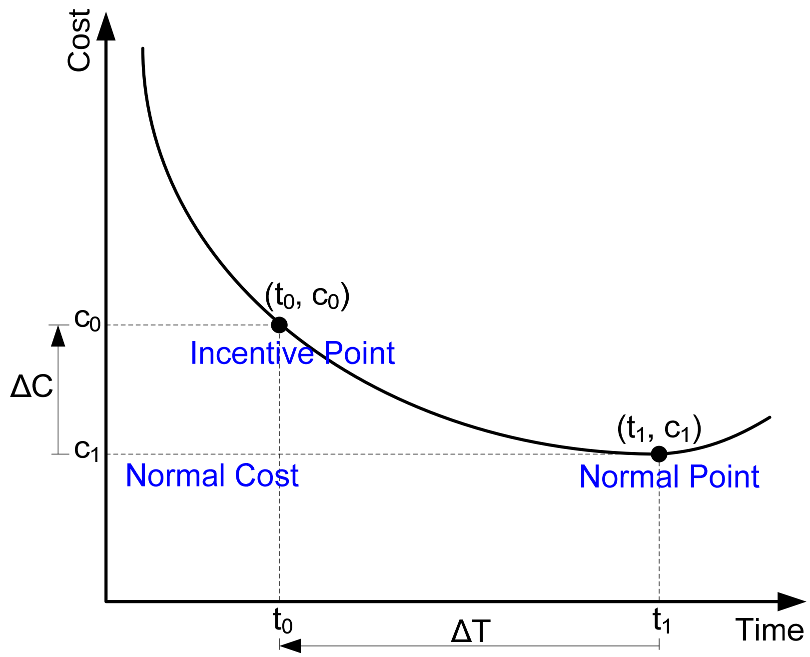

Figure 6: Theoretical time-cost tradeoff curve.

Figure 7, 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 7 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.

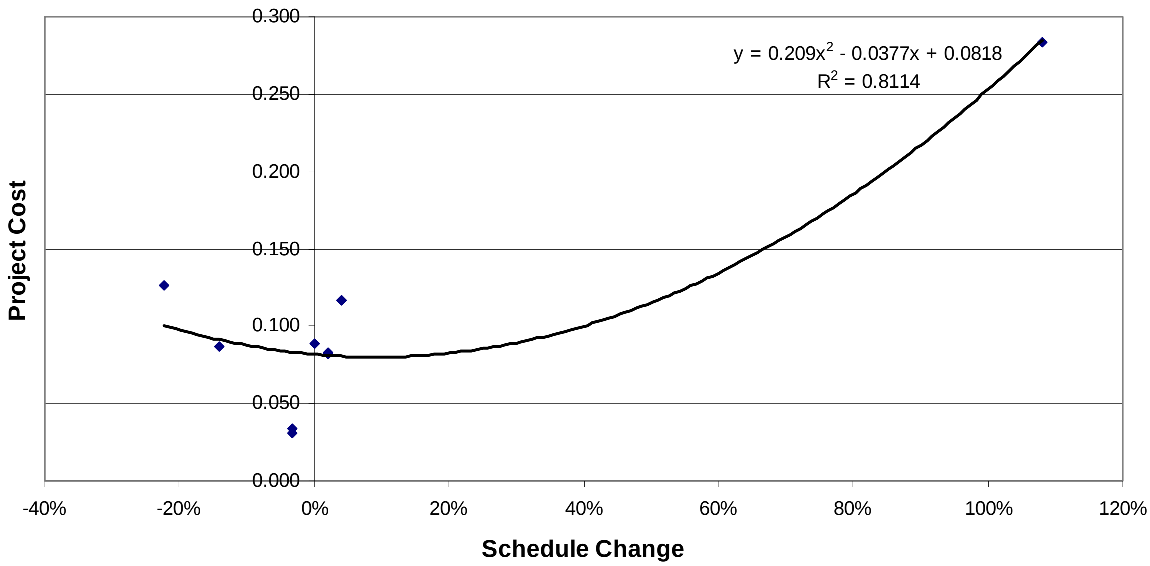

Figure 7: As-built time-cost tradeoff curve observed on roadway I/D projects.

4.2 Impact of an I/D Contract on Overall Project Cost

The level of cost growth was measured by the *cost change ratio:*

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

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 8 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 accelerate its schedule and 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 8). It is not yet possible to interpret this result, although 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.

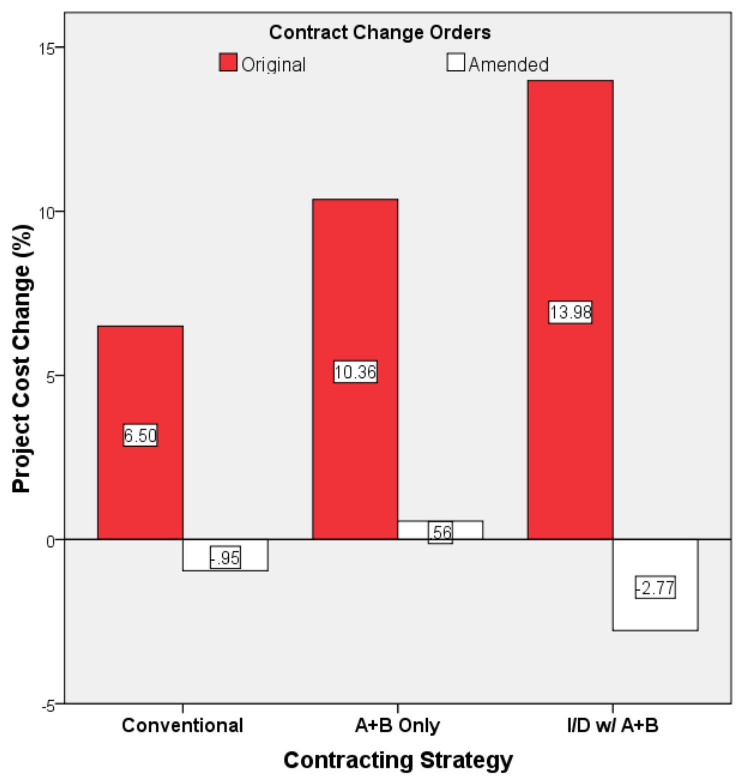

Figure 8: Average cost growth of all projects versus contracting strategy.

Figure 9 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 9 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.

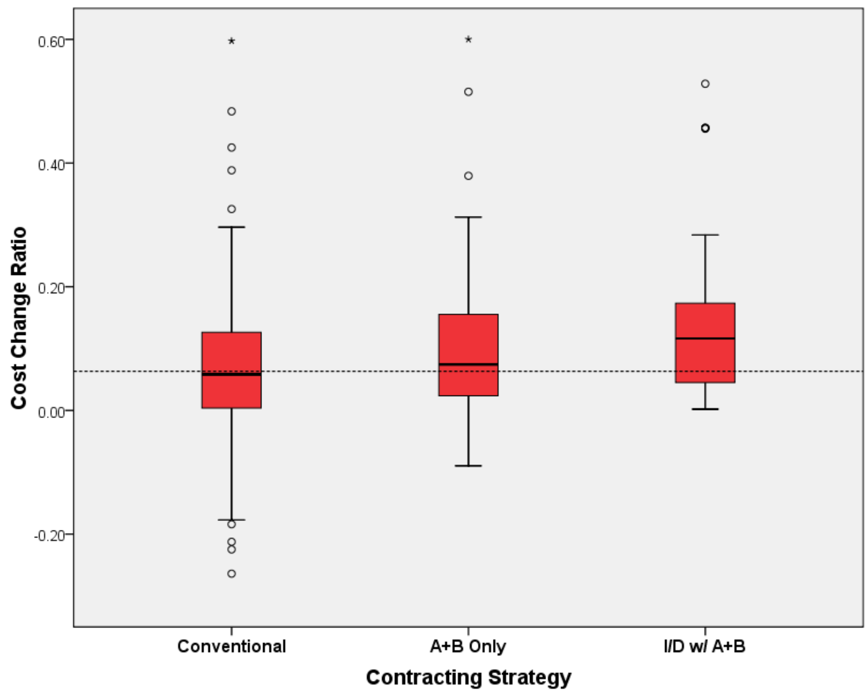

Figure 9: Box plot of project cost growth versus contracting strategy.

4.3 Cost Growth versus Project Types

Figure 10 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 cost growth level trend 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 11). The figure shows that the level of cost growth in I/D contracting projects is relatively similar (least variation) to the other contracting projects.

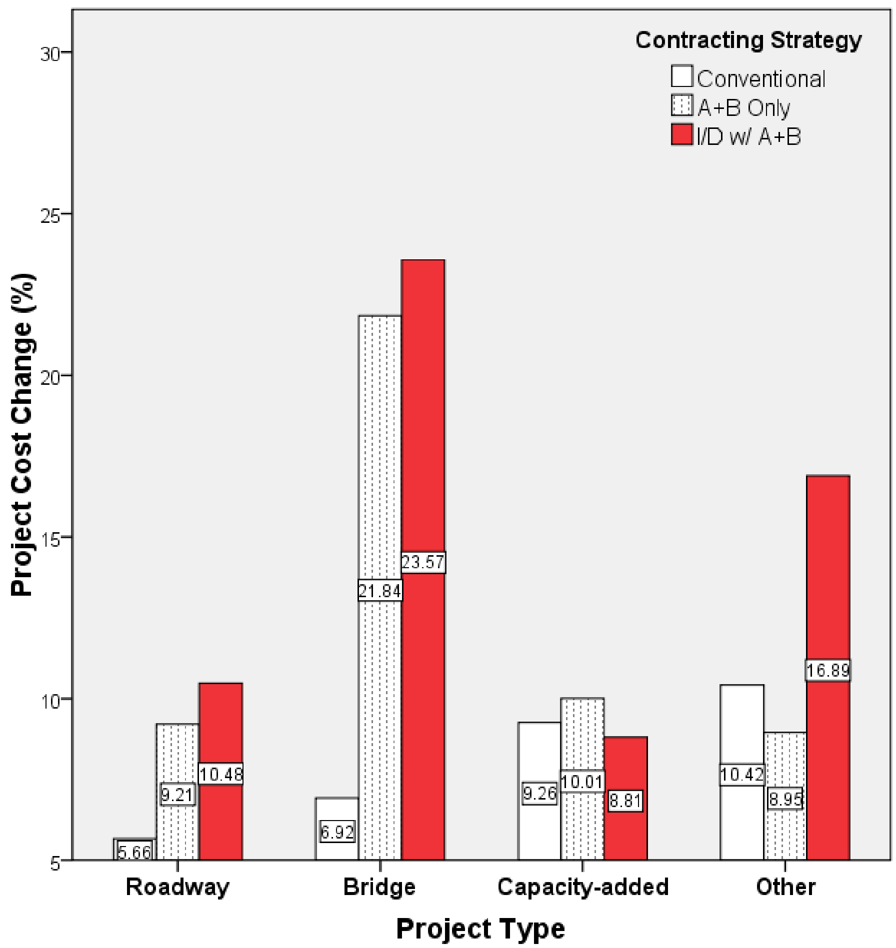

Figure 10: Project cost growth of alternative contracting strategies sorted by project type.

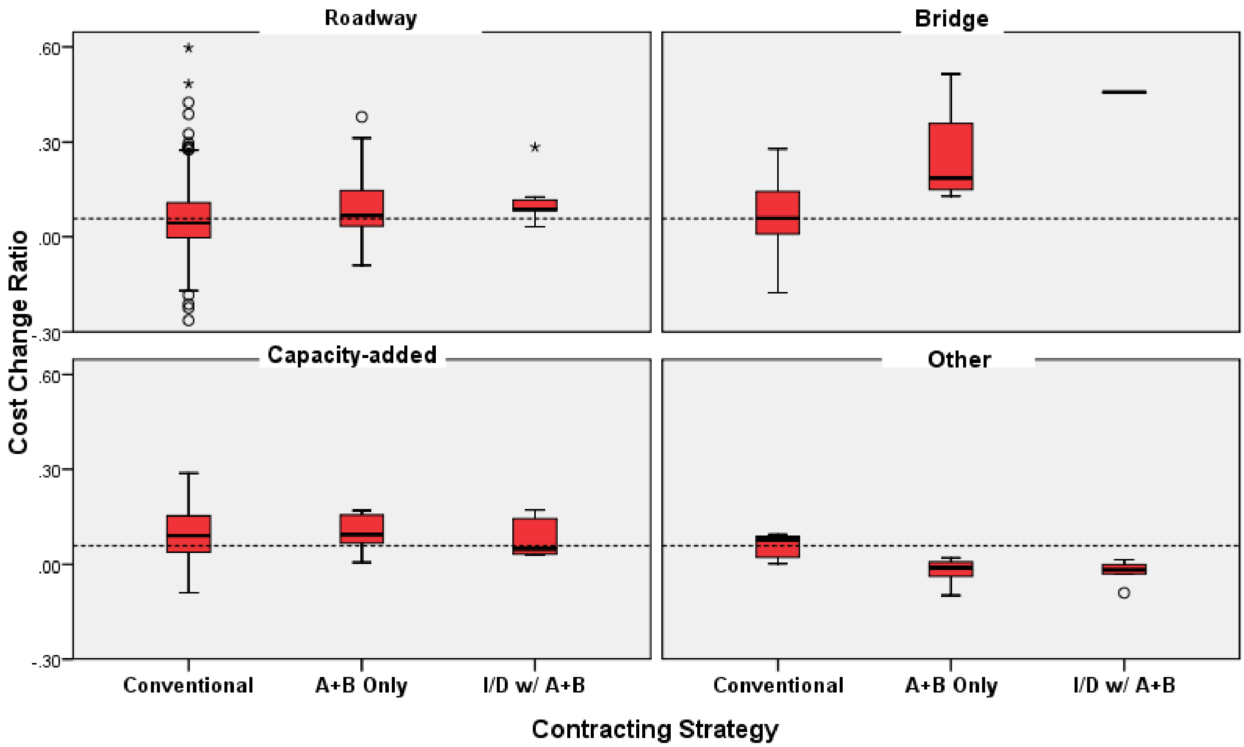

Figure 11: Box plot of project cost growth versus project type.

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 11. 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, increasing project duration by 17.54% on average (Figure 10). In addition, as seen in Figure 11, A+B projects had the largest variation of cost growth, 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 (see also Figure 11).

From Figure 10, 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 11). 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 agencies need to utilize additional resources to minimize unfavorable traffic impact regardless of contracting type.

4.4 Research Hypothesis Testing

4.4.1 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.

4.4.2 Analysis of Testing Results

Table 8 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 8: Descriptive Statistics on Cost Growth

Descriptives

CCR_Overall

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
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 9 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 a 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 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 10 and Table 11) justify the validity of research hypotheses set in the earlier section.

Table 9 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 increased proportionately. Meanwhile, the F-ratio for the quadratic trend is not significant.

Table 9: 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 10 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 10: 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 11 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 11. 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 11: 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.

5 CONCLUSIONS

The major goal of utilizing alternative contracting strategies is to complete critical project work as quickly as possible by motivating and challenging contractors to complete an internal milestone within a certain time period and/or to complete an entire project sooner. However, California presents a case in which the A+B (cost plus time) contracting strategy did not perform much better than conventionally contracted projects. It is seen that A+B projects suffered from contractors' underestimations of contract times in their bids on the "B" portion (bid duration) 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. 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.

When it comes to the project cost growth, 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 because of their large size. However, the analysis showed the opposite: I/D contracting projects had the largest cost growth overall. It was seen that projects contracted solely in an A+B contract underwent similar levels of cost growth as I/D-contracted projects. Statistical analyses revealed that utilizing alternative contracting strategies significantly increases project cost compared to conventional strategies. 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 to motivate contractors to meet scheduled completion dates.