

Systematic Procedures to Determine Incentive/Disincentive Dollar Amounts for Highway Transportation Construction Projects



MTI Report 11-22



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REPORT 11-22

SYSTEMATIC PROCEDURES TO DETERMINE INCENTIVE/ DISINCENTIVE DOLLAR AMOUNTS FOR HIGHWAY TRANSPORTATION CONSTRUCTION PROJECTS

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EXECUTIVE SUMMARY

RESEARCH BACKGROUND AND OBJECTIVES

The Federal Highway Administration (FHWA) has encouraged state transportation agencies (STAs) to implement Incentive/Disincentive (I/D) contracting provisions to reduce traffic disruption during highway construction. I/D provisions for early project completion have been widely used in the United States. More than 35 STAs including Caltrans have implemented I/D contracting.

The FHWA recommended that a daily I/D amount be calculated on a project-by-project basis using established construction engineering inspection costs, state-related traffic control and maintenance costs, detour costs, and road user costs. Although general guidelines to determine the I/D dollar amount for a project have been published by STAs, there is no systematic tool in use to determine I/D dollar amounts for I/D projects. Therefore, an understanding of the effect of I/D dollar amounts under different project situations would be very useful to refine and stimulate the use of I/D contracting. A systematic procedure to assist project planners and engineers in determining an appropriate I/D dollar amount is essential to optimizing the use of I/D contracting techniques.

In order to develop a systematic procedure to determine an appropriate I/D amount for a project, it is necessary to learn from previous I/D project experience. In addition, more research efforts need to be undertaken to evaluate the outcome of a proposed I/D dollar amount used for early project completion. Therefore, the objectives of this research are:

- To evaluate the effect of I/D amounts in order to improve the effectiveness of I/D contracting, and
- To develop a systematic procedure for determining the I/D dollar amount to assist district project planners and engineers in their decision-making process.

RESEARCH APPROACHES

First, the research team performed a literature review related to the determination of daily I/D dollar amounts and up-to-date information on current practices to set up I/D amounts. Second, the research team collected I/D project data, including: project type and location, construction time and cost information, average daily traffic (ADT), project length, I/D daily dollar amounts, and maximum incentive cap amounts. Third, the project data obtained were evaluated using project performance indices. Project performance data were analyzed and evaluated with regard to project outcomes in two key areas: project time and project cost. Statistical analyses were performed to identify the impact of ID dollar amount on project time and cost performance. Fourth, using Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software, Caltrans I/D projects were used to introduce three different levels of CA4PRS implementations to calculate the I/D dollar amounts. Finally, using CA4PRS software, daily road user cost was calculated and used to determine a daily I/D amount that took into consideration road user cost, agency cost, contractor's additional cost, and contractor's cost savings. By incorporating the results of

CA4PRS analysis into the systematic procedures to determine an appropriate I/D amount, the researchers proposed an improved procedure to assist transportation project planners and engineers in their decision-making process.

DATA ANALYSIS AND RESEARCH OUTCOMES

A total of 48 I/D projects awarded between 2003 and 2010 were collected from Caltrans. Of these, 43 I/D projects completed in 11 Districts were used for data analysis. A majority of projects were 3R (resurfacing, rehabilitation, and reconstruction) and widening projects. Approximately 54 percent of the projects had high traffic volumes measured in excess of 100,000 ADT. In addition, the project data showed a median project length of 3.8 miles. The I/D projects had an average contract award amount of approximately \$40 million and an average of 515 working days. The incentive cap amount proposed for each project ranged from \$15,000 to \$5.3 million, with an average cap amount of \$1,137,635 per project. Approximately 50 percent of the projects proposed an incentive cap amount between \$100,000 and \$600,000.

A number of correlation analyses were performed to identify any relationship between: 1) the incentive amount and original time performance index (OTPI); 2) the incentive amount and original cost performance index (OCPI); 3) the incentive amount and project award amount; and 4) the incentive amount and ADT. The results of correlation analysis showed that there are positive relationships for OTPI, project award amount, and ADT. On the other hand, the incentive amount showed a negative relationship with OCPI. A range of approximately 27 percent to 40 percent correlation between two variables was found from four correlation analyses.

A relatively small sample size of I/D data has been used for statistical analysis. The results of nonparametric analysis showed that only the comparison between ADT and project time performance was significant. This result indicates that improving project time performance in a high-ADT work zone is more difficult than in a low-ADT work zone.

In order to understand Caltrans' I/D amount decision-making practices, four Caltrans I/D projects were investigated and three different levels of CA4PRS implementations for the I/D dollar amount calculation were introduced. In addition, the findings of I/D project case studies are summarized to provide a framework for developing more comprehensive and systematic procedures for I/D amount calculation.

Based on the results of the I/D project case studies, the systematic procedures to determine appropriate I/D dollar amounts were developed using the CA4PRS schedule-traffic integration process for new I-5 southbound rehabilitation project in Kern County. The systematic procedures to determine I/D dollar amounts utilizing CA4PRS analysis are briefly summarized in the following steps:

- STEP 1: Set up a schedule baseline based on CA4PRS schedule analysis.
- STEP 2: Evaluate the impact of work zone on the traveling public, especially road user cost based on CA4PRS traffic analysis.

- STEP 3: Estimate contractor's cost for additional resources for I/D acceleration and contractor's saving from schedule compression. Also, estimate the contractor's savings in their field operation cost with the project duration reduction results from the schedule acceleration.
- STEP 4: Estimate agency's cost savings from schedule compression.
- STEP 5: Determine reasonable value of discount factors to split I/D benefits and costs between the contractor and the agency with some sensitivity analysis.
- STEP 6: Make a decision on the I/D implementation based on the comparison of additional acceleration cost and field operation cost savings for the contractor and benefits to road users and the agency from schedule compression.
- STEP 7: Set up daily incentive amount and maximum incentive amount based on the above-described procedure and parameters and project budget constraints.
- STEP 8: Set up daily disincentive amount and maximum disincentive amount based on the above-described procedure and parameters.

In summary, this research provides a better understanding of the relationship between the I/D dollar amount and project time and cost performance. In addition, the proposed procedures to determine an appropriate I/D dollar amount for a highway construction project will provide systematic guidelines and procedures to improve I/D contracting strategies for Caltrans project engineers and managers.

FUTURE STUDIES FOR IMPLEMENTATION

The I/D framework process introduced in this study was applied to a typical highway pavement rehabilitation project using HMA materials. A similar case study is needed for a typical concrete pavement rehabilitation using the project's own resource inputs for schedule acceleration. More study is needed to apply the concept to other types of highway projects, with adjustment for the type of project. For example, the proposed I/D calculation process can be used for a roadway widening project with relevant schedule baselines and resource inputs for acceleration. The CA4PRS new version (V3.0) released in early 2012 has a new module for roadway widening schedule analysis that can produce the schedule baseline for the I/D calculation.

Once the logic and input/output configurations of the systematic I/D calculation process are confirmed, the current prototype, which is running on an Excel spreadsheet, should be converted into a more professional program for practical implementation. Meanwhile, more collaboration between the contractor and the transportation agency is needed to test and implement the new I/D system. After a small number of I/D implementation demonstration projects are completed, outreach efforts and end-user training are needed to introduce and encourage adoption of the new I/D system.

I. INTRODUCTION

BACKGROUND

Highway construction projects in urban corridors with high traffic volume have represented a long-time challenge (NCHRP 2011). In particular, management of traffic during the construction of congested highway rehabilitation/reconstruction projects has always been an issue in the United States. Thus, the Federal Highway Administration (FHWA) has encouraged state transportation agencies (STAs) to implement Incentive/Disincentive (I/D) contracting provisions to reduce traffic disruption during highway construction.

I/D provisions for early project completion have been widely used in the United States (NCHRP 2010). More than 35 STAs, including Caltrans, have implemented I/D contracting and have reported substantial project time savings on many projects (Herbsman et al. 1995, Arditi and Yasamis 1998, Ellis and Pyeon 2005, Pyeon et al. 2009, and Pyeon and Park 2010). The implementation of I/D contracting has played an important role in improving project time performance, in that substantial project time savings have been reported for numerous projects in many states.

The FHWA provided general guidelines and recommendations for STAs. However, each project is unique. Thus, it is recommended for each STA to develop its own guidelines for implementing I/D contracting. In particular, the FHWA requires that each STA should calculate I/D dollar amounts for each I/D project (FHWA 1989). Obviously, the I/D dollar amount should be large enough to motivate the contractor to complete the project ahead of schedule. This could be accomplished by working extra hours/days and/or using innovative equipment and techniques.

The FHWA recommended that a daily I/D amount be calculated on a project-by-project basis using established construction engineering inspection costs, state-related traffic control and maintenance costs, detour costs, and road user costs (FHWA 1989). Many studies have emphasized that the determination of the appropriate I/D dollar amount per day is one of the most important issues in the use of I/D contracting (FHWA 1989, Jaraiedi et al., and Gillespie 1997).

Although general guidelines to determine the I/D dollar amount for a project have been published by STAs, there is no systematic tool in use to determine optimal I/D dollar amounts for I/D projects. Therefore, an understanding of the effect of I/D dollar amounts under different project situations would be very useful in refining and stimulating the use of I/D contracting. A systematic procedure to assist project planners and engineers in determining an appropriate I/D dollar amount is essential to optimizing the use of I/D contracting techniques.

OBJECTIVES

In order to develop a systematic procedure to determine an appropriate I/D amount for a project, it is necessary to learn from previous I/D project experience. In addition, more

research efforts need to be undertaken to evaluate the outcome of a proposed I/D dollar amount used for early project completion. Therefore, the objectives of this research are:

- To evaluate the effect of I/D amounts in order to improve the effectiveness of I/D contracting and
- To develop a systematic procedure to determine the I/D dollar amount to assist district project planners and engineers in their decision-making process.

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

1. Collect transportation construction project data;
2. Evaluate the effect of I/D dollar amounts in terms of project time and cost performance;
3. Perform data analysis for I/D projects completed;
4. Perform I/D project case studies using CA4PRS; and
5. Develop a systematic procedure implementing CA4PRS to determine I/D dollar amounts to assist district project planners and engineers.

RESEARCH APPROACHES

An overview of the research methodology is illustrated in Figure 1. Three major functions described in the figure are data collection, data analysis, and model development. The following five-step process to develop systematic procedures to determine I/D dollar amounts describes in detail the research methodology shown in Figure 1.

First, the research team performed a literature review related to determining daily I/D dollar amounts and up-to-date information on current practices to set up I/D amounts. Second, the research team collected I/D project data, including project type and location, construction time and cost information, average daily traffic (ADT), project length, I/D daily dollar amounts and maximum incentive cap amounts. Third, project data obtained were evaluated using project performance indices. Project performance data were analyzed and evaluated with regard to project outcomes in two key areas, project time and project cost. Statistical analyses were performed to identify the relationship between I/D dollar amount and project time and cost performance. Fourth, using Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software, Caltrans I/D projects were investigated to introduce three different levels of CA4PRS implementations for the I/D dollar amount calculation. Finally, using CA4PRS software, daily road user cost was calculated and used to determine a daily I/D amount, taking into consideration road user cost, agency cost, contractor's additional cost and contractor's cost savings. By incorporating the results of CA4PRS analysis into the systematic procedures to determine an appropriate I/D amount, the researchers proposed an improved procedure to assist transportation project planners and engineers in their decision-making process.

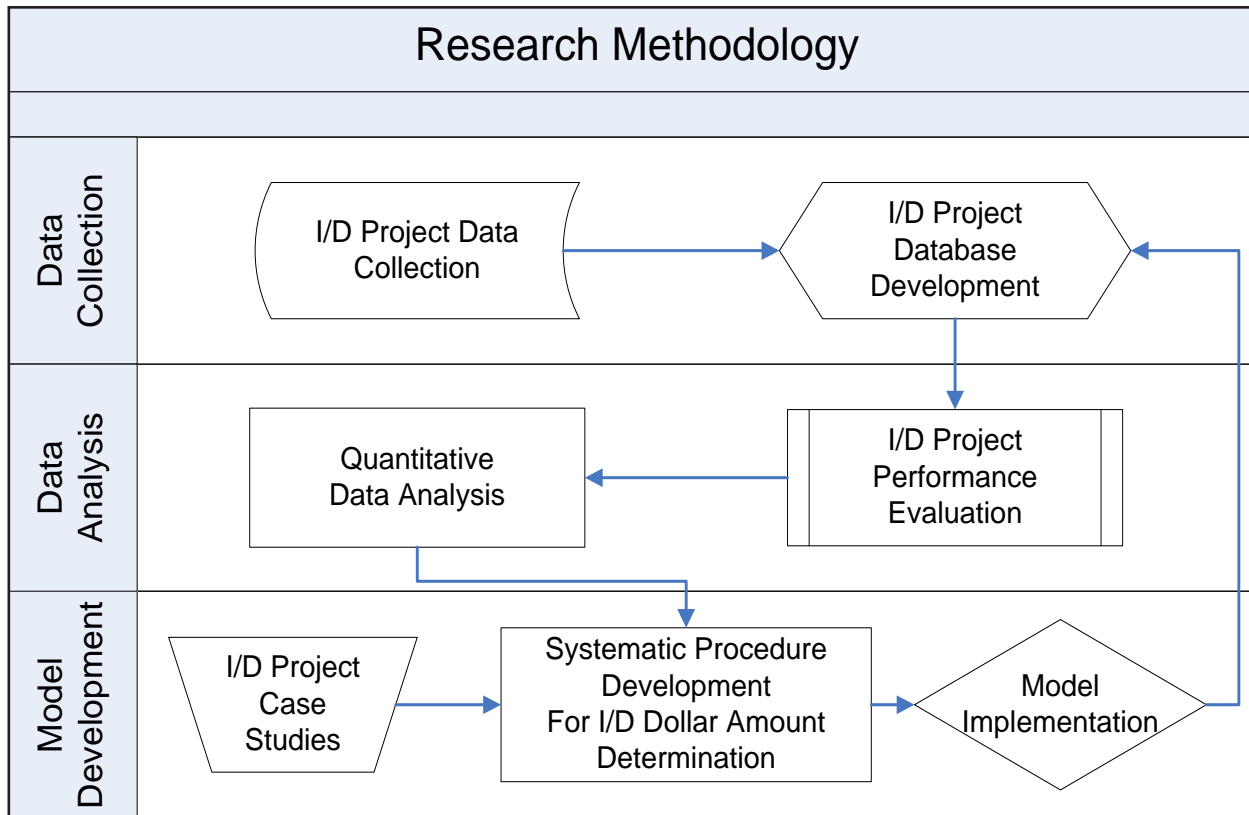


Figure 1. Overview of Research Methodology

II. LITERATURE REVIEW

The research team reviewed published papers and reports related to I/D contracting dollar amount determination and evaluation, and obtained up-to-date information on current practices of I/D contracting with regard to determining I/D amounts.

GUIDELINES FOR DETERMINING I/D AMOUNTS

In 1984, the FHWA's old policy prohibiting extra payments for early completion was officially withdrawn. FHWA (1989) reported that the present FHWA policy regarding bonus payments is based in part on an assessment of the National Experimental and Evaluation Program (NEEP) that showed that the use of early completion payments could be valuable. The current FHWA policy includes I/D provisions that result in significant benefits to the traveling public. FHWA provided STAs with general guidance for the approval of I/D provisions as follows: "The approval of I/D provisions will be reserved only for critical projects or phases of projects where traffic inconveniences and delays must be minimized. States should develop guidelines for selection of projects" (FHWA 1989).

FHWA (1989) recommended projects that are appropriate for I/D provisions should include the following characteristics: high traffic volume in urban areas, lengthy detours created by the project, major bridges out of service, and major reconstruction or rehabilitation on an existing facility that would severely disrupt traffic. Thus, I/D provisions should be limited to the projects that severely disrupt highway traffic or highway services, significantly increase road user costs, have a significant impact on adjacent neighborhoods or businesses, or close a gap, thereby providing a major improvement in the highway system.

The determination of the appropriate dollar amount has been one of the most important issues in the use of I/D provisions (FHWA 1989, Jaraiedi et al. 1995, Gillespie 1997). For the determination of the I/D amount, FHWA (1989) clearly stated, "The dollar amount must be of sufficient benefit to the contractor to encourage his/her interest, stimulate innovative ideas, and increase the profitability of meeting tight schedules so as to be effective and accomplish the objectives of I/D provisions." It is also mentioned that the incentive payment should be sufficient to cover the contractor's cost for the extra work to produce the intended results (FHWA 1989).

FHWA (1989) provided the following guidelines for determining the I/D amount:

- A daily I/D amount is calculated on a project-by-project basis using established construction engineering inspection costs, state-related traffic control and maintenance costs, detour costs, and road user costs. Costs attributed to disruption of adjacent businesses should not be included in the daily I/D amount. Engineering judgment may be used to adjust the calculated daily amount downward to a final daily I/D amount. A daily I/D amount should provide a favorable benefit/cost ratio to the traveling public and be large enough to motivate the contractor.
- Accepted State Highway Agency's procedures for estimating road user costs may be used.

- The vehicle operating costs should be based on the most recent information available.
- Generally, the incentive daily rate should equal the disincentive daily rate. If different rates are selected, the incentive daily rate should not exceed the disincentive daily rate.
- A cap of 5 percent of the total contract amount has been recommended as the maximum incentive payment. The 5 percent was based on the NEEP study average of incentive payments made on experimental I/D projects. However, no cap was recommended on maximum disincentive amounts.

FHWA (1989) provided STAs with the general requirement for the determination of I/D amounts as follows:

The determination of I/D amount and time should be documented and retained in the project records. The I/D amount and time determination with supporting data should be submitted and concurred with by the FHWA Division Administrator prior to the State's request for approval of the plans, specifications, estimate, and authorization to advertise.

EVALUATION OF I/D AMOUNTS

According to the report Primer on Contracting for the Twenty-first Century, Michigan DOT reported I/D project time and cost evaluation results based on the evaluation of 26 projects completed in 1998 and 1999. The summary results showed that the average I/D amount rate for all projects was \$18,500 and the average road user delay savings were \$610,500 (AASHTO 2006). In addition, it was reported that the use of I/D provisions indicated an average increase of 1.5 percent in the contract amount.

In Florida, Ellis et al. (2007) performed a comprehensive quantitative evaluation on FDOT construction projects. A total of 144 I/D projects were evaluated and compared with traditional design-bid-build, non-I/D contracting projects. The quantitative project cost and time evaluation results indicated that I/D projects showed average time savings of 16.5 percent but average cost overruns of 3.3 percent. These results indicated that there was a trade-off effect between project cost and time. They also found that contractors on I/D projects achieved full or partial incentives approximately 51 percent of the time.

Pyeon (2005) collected 63 alternative contracting projects, including I/D and "No-Excuse Bonus" from FDOT and performed a statistical analysis to identify the impact of project time performance on incentive amount variables. Interestingly, he reported that the project time performance in a group where maximum incentive projects of less than \$50,000 was generally better than in groups where the maximum incentive was more than \$50,000. However, projects with larger maximum incentive amounts typically had high traffic impact in areas with high congestion. Therefore, the value of time savings on those high-traffic-impact projects was considered to be more valuable than those of low-traffic-impact projects in areas with less congestion.

Appropriate Choice of Incentive Amounts

FDOT District 6 (Miami-Dade and Monroe Counties) has been the most active in implementing I/D contracting in Florida. Based on their I/D contracting experience, the district engineers analyzed construction time and cost performance and found the results indicated that the department does not need to offer an exorbitant incentive in order to attract a contractor's interest (Ellis and Pyeon 2005). It was also found that a relatively low amount, such as \$10,000 or \$20,000, was frequently proposed in order to motivate contractors for early project completion.

Appropriate incentives are usually based on road user cost analysis. At one time, the road user cost was calculated using various methods and software, such as MicroBENCOST, Quewz, QuickZone, and so on. Frequently, the user cost could become a very high number. The daily road user cost may rise to \$100,000 a day if there are 100,000 vehicles a day on an interstate. In this instance, the district engineers were required to review the project to decide what a reasonable incentive amount will be. Eventually, they had to use their judgment and justify the incentive amount.

I/D Amount Calculation Methods

In order to determine the optimum I/D amount and duration, the I/D amount paid by the agency and the contractor's actual cost for expediting the work should be identified. For many STAs, the incentive amount provided is usually equal to the amount the owners save in daily road user cost. Generally speaking, the contractor's daily cost for a project increases over time, but the exact daily cost is unknown and can vary from one project to another.

Jaraiedi et al. (1995) introduced an algorithm that determines whether the I/D contract for a project is necessary or not. In this algorithm, the authors defined the contractor's extra costs to complete a project ahead of schedule as follows: "A is a fixed, one-time cost for marshaling extra crews and equipment to expedite the work and ordering of materials for early delivery; B is a variable cost per day of using the additional crews and equipment to expedite the project." If X is the number of days expedited, then, $A + BX$ will be the total cost to the contractor for expediting the work. The authors recommended that the contracting agency examine the contractor's past experience with bidding in order to determine a range of values that could be used to represent both fixed and variable costs to the contractor.

The Alternative Contracting Draft User's Guide (FDOT 1997) introduced two different methods for calculating daily I/D amount. In the linear method most commonly used in the United States, the contractor receives the same daily incentive amount regardless of the number of days completed early, and is charged the same way if the project is completed late. In the non-linear method, which escalates I/D that the failure-to-work provision applies to incentive, "the earlier a work is completed, the greater the daily amount paid to the contractor, or the later a project is completed, the more the daily amount is assessed against the contractor." The linear method was most frequently implemented in determining I/D amounts.

Recently, Jiang and Chen (2010) developed cost-time equations for various highway construction projects to estimate road user costs in highway work zones and evaluated the effect of road user costs on I/D values. Then they calculated the maximum incentive amounts and days with daily I/D amounts based on 20, 25, 30, 35, and 40 percent of the daily road user cost.

Need for I/D Amount Calculation Model

In Florida, the determination of incentives and bonus amount was based on the following factors: “road user cost, CEI, and other relevant factors, such as business impacts, importance to the public, etc.” FDOT found that sample incentive amounts ranged from \$8,000 (2.9 percent) to \$475,000 (13.1 percent) of the awarded contract amount. However, no standard formula for calculating incentives was available for use by the FDOT districts.

The FDOT Office of Inspector General recommended that the Department should develop standardized formulas for Bonus and Incentives/Disincentives in order to improve the Department’s alternative contracting program. They also reported: “Without consistent standards for determining bonus amounts, incentives, lane rentals, and road user costs, it is difficult for the Department to evaluate particular alternative contracting methods from district to district” (FDOT 2000).

Sillars (2007) evaluated the Oregon DOT’s I/D contracting practices with 18 I/D contracting projects between 1996 and 2005. There was a large variation of project cost among I/D projects, ranging from \$300,000 to \$65,200,000. Although no result of in-depth analysis was provided, Sillars (2007) emphasized that developing standardized methods for the use of I/D contracting is necessary for more frequent and effective use of I/D contracts.

Sillars’s Incentive Determination Model

For the determination of I/D dollar amounts on the Oregon Department of Transportation (ODOT) projects, Sillars and Leray (2007) developed a two-stage process. In Stage I, a project’s cost and schedule for the proposed incentivized portion of work is established and the costs and profits are broken down into percentages of direct costs, indirect costs, and markup.

In Stage II, specific characteristics of the project are considered to modify the Stage I cost breakdowns. The modified cost breakdowns are used to calculate the dollar values of each breakdown element. The effects of acceleration, like overtime and additional shifts and equipment, are estimated and the cost of acceleration (CA) is calculated. An incentive “profit” is added to the CA to establish the baseline incentive value, which can be further adjusted based on significant intangibles in the project environment.

The addition of “profit” ensures the amount is truly an incentive to the contractor so that sincere efforts will be made toward accelerating the project. Finally, the incentive amount established is compared to the road user cost to make sure the cost to the public of accelerating the project do not exceed the benefits. An Incentive Determination Model worksheet for each of the steps in the two-stage process is illustrated in Figure 2.

CALTRANS CURRENT PRACTICE TO DETERMINE I/D AMOUNTS

The use of I/D provisions is primarily intended for critical projects where it is essential that traffic inconvenience and delays be held to a minimum. Based on the Caltrans Conceptual Guidelines for Use of Incentive and Disincentive Provisions (Caltrans 2000), determining the I/D amount for any given Caltrans project is largely up to the discretion of the project planner. The District/Regional Director and the District Division Chiefs of Design and Construction then approve the I/D provisions.

Stage I

Project: **Example** Worksheet

Type: **A**

Market Cond.: **CC**

Date: **8/1/2000**

Project portion: **INTERCHANGE**

Total project estimate: \$ **20,000,000**

Total project direct cost estimate: \$ **15,200,000**

Total I/D portion direct cost estimate \$ **2,000,000** 13%

Reasonable acceleration target (Days) **10**

Estimated RUC/Day for I/D portion (\$) **35,000**

Project Types:	Market Cond's:
A Roadway	AA Busy
B Interchange	BB Normal
C Bridge	CC Slow
D Complex	

Element	Sub-element	Stage I Value (%)	Project specific value (%)	Notes	Portion specific value (\$)	Acceleration impact (+/- %)	Acceleration cost (+/- \$)
Direct cost		81%	78%	<Stated as % of total	2,000,000	7%	133,000
	Labor	75%	25%	<Stated as % of Direct Cost	500,000	20%	100,000
	Materials	45%	45%	(Must sum to 100%, values incorrect if this square is read)	900,000	5%	45,000
	Equipment	30%	30%		600,000	-2%	(12,000)
	Subcontract	0%	0%			0%	
Indirect Cost		8%	8%	<Stated as % of total	220,000	1%	3,500
	Supervision	2%	2%		40,000	10%	4,000
	Time-related facilities	1%	1%		20,000	-5%	(1,000)
	Non-time-related facilities	1%	1%	<Stated as % of Direct Cost	30,000	0%	
	Mobilization/demobilization	3%	5%		100,000	0%	
	Insurance and taxes	1%	2%		40,000	0%	
Markup		12%	18%	<Stated as % of total	406,000	1.2%	50,000
	Risk	3%	5%		100,000	50%	50,000
	Home Office G&A	8%	10%	<Stated as % of Direct Cost	300,000	0%	
	Profit	4.3%	5.3%		106,000	See below	See below
Total			100%		2,626,000	7%	186,000
Estimated Total Project Profit			\$ 697,312				
Acceleration cost per day							\$ 18,600
I/D Incentive profit per day (to be added to above Acceleration cost per day)					Professional value = \$705		\$ 3,000
Net I/D daily amount							\$ 21,600
Total I/D profit incentive for period							\$ 30,000
Total I/D amount for period							\$ 216,000
Total I/D profit incentive as a % of Total Project profit							3.7%
Total RUC amount for period							\$ 350,000
Incentivized portion							\$ 2,812,000

Stage II

Figure 2. Incentive Determination Model User Screen (Sillars 2007)

Caltrans requires that the project engineer obtain road user delay estimates and potential accident rate from Traffic Operations. Other impacts, such as social/economic, percentage of truck traffic, length and type of detour, safety concerns and public relations, should also be taken into account when estimating feasible I/D amount. A supporting cost/benefit calculation must also be provided and funding availability must be assured.

Caltrans provides guidelines on performing the road user cost analysis, which is required for projects above a specified amount. Essentially, the RUC for a project is calculated as a function of Work Zone Delay, Queue Delay, and Detour Delay. Work Zone Delay is defined as the additional time cars and trucks need to travel the work zone at a lower speed to accommodate the road work conditions. Queue Delay represents the additional time needed to travel the work zone because of work zone induced queues. A capacity

analysis for all times of the day comparing expected traffic to reduced work zone capacity is required to calculate Queue Delay. Detour Delay represents the additional time it takes for vehicles to travel a detour route to avoid queue delays. After calculating RUC considering all of the delays described above, Caltrans recommends the RUC be further reduced by 50 percent. This is to account for potential variations in traffic volumes, work conditions and other factors.

The guidelines for determining the I/D amount provided by Caltrans are based on daily user cost, which consists of road user delay costs and construction engineering cost estimates. In addition, the incentive payment should be greater than the contractor's additional cost to accelerate the project plus a reasonable profit. However, Caltrans does not provide any guidance on how to estimate the additional cost of acceleration or how to determine a reasonable profit. Caltrans states that the disincentive amount usually be equal to the incentive amount, although it could be higher if justified. The disincentive amount should also be equal to or higher than the liquidated damage amount. As a general guideline, minimum daily user cost should be at least \$5,000 to justify I/D provisions (Caltrans 2000).

SUMMARY OF LITERATURE REVIEW

In summary, it was found that FHWA provides general guidelines about determining I/D dollar amount and each STA generally develops similar guidelines for the use of I/D contracting. Many STAs implemented various RUC calculation methods with a variety of discount factors for determining I/D dollar amounts. However, only a few highway agencies have established standard procedures or specific policies to set up a reasonable amount of I/D with given project constraints.

It was also found that there were few case studies and data analyses to determine I/D dollar amount. Sillars' incentive determination model is relatively mature and considers historical costs, project type, and market conditions. However, there was no systematic method considering critical information of agency cost, contractor cost, and Transportation Management Plan (TMP) cost for the calculation of I/D amount. Thus, a more comprehensive approach, which considers the costs/benefits to the agency, contractor and users, should be adopted to determine an appropriate I/D amount for early project completion.

In conclusion, more research efforts should be made to develop a systematic procedure for determining I/D dollar amounts, with a focus on the following tasks:

- Historical I/D project data analysis to identify the impact of the I/D dollar amount;
- Case studies to analyze the usage of I/D dollar amount determination; and
- Systematic procedure development considering important cost savings, such as agency cost savings, contractor cost savings, and TMP cost savings.

III. I/D PROJECT DATA COLLECTION AND EVALUATION

CALTRANS I/D PROJECT DATA COLLECTION

The research team contacted Caltrans' Division of Construction and collected comprehensive construction project data, such as contract number, district, project length, project location, description, contractor name, critical dates, number of change orders, weather days, project award amount, and other construction cost and time information. A screenshot of raw project data collected from Caltrans' Division of Construction is shown in Figure 3. The research team also contacted Caltrans' Office of Project Engineer and collected additional contract-related information.

The data covered more than 4,000 construction projects awarded and finally accepted in 12 districts during a period from 2003 to 2010. Among all projects examined during the study period, only 43 I/D projects were completed and finally accepted in 11 districts (D1, D2, D3, D4, D5, D6, D7, D8, D10, D11, and D12). An example of I/D project sample data obtained from Caltrans is shown in Table 1. Each project contained necessary project information: critical dates, project location, project length, work description, contract amounts, and contract duration; however, the following critical project information for this research either was not available in a single database or was not retrievable from a single source:

- Average Daily Traffic
- Maximum Incentive Cap Amount
- Daily I/D Amount

ADT Data Collection

The most recent traffic data (2009) provided by the Caltrans traffic division was used to identify typical ADT for the I/D projects. As the Caltrans ADT data was typically measured at two locations on the route nearby an interchange, i.e., "Before" (off-ramp) and "After" (on-ramp), the average of the two locations ADT was mathematically calculated. When the ADT measured interchange did not exactly match with the I/D project location, the nearest location was used. If the I/D project covered several ADT data interchanges, an average of the multi-locations was used as the representative ADT. Figure 4 shows a screenshot example of I/D No. 39 project (EA 07266704) on Route 11 in LA County (PM 27.0–32.5), showing multiple locations of the Caltrans ADT data.

1	Dist_EA	Contract Key	District	Ea	County	Rte Prj	Postmil e Ahead	Postmil e Back	Resident Engineer Name	Desc Of Work	Location Desc	Contractor Name
2	014293U4	27645	01	4293U4	MEN	101	69.6	69.4	TIMMONS, KELLY	CURVE IMPROVEMENT	IN MENDOCINO COUNTY A ARGONAUT CONSTR	
3	02355604	14701	02	355604	SHA	299	7.2	0	TORRES, SAL	ASPHALT CONCRETE OVERLAY	IN SHASTA COUNTY ABOU J F SHEA CO INC	
4	023259U4	18230	02	3259U4	PLU	70	46.3	41.5	BLINE, JEFF	ROADWAY AND BRIDGE REHABIN	PLUMAS COUNTY AT AN BALDWIN CONTRACT	
5	02370704	28597	02	370704	TEH	5	7.7	7.2	ROGERS, JIM	RECONSTRUCT INTERCHANGE	IN TEHAMA COUNTY IN AN KNIFE RIVER CONST	
6	032E0504	27867	03	2E0504	NEV	80	0	28.4	DEVER, ALAN	REPLACE BRIDGE DECK	IN NEVADA COUNTY NEAR C C MYERS INC	
7	032C8604	29182	03	2C8604	PLA	80	66.3	56.1	ZINK, PHIL	RECONSTRUCT ROADWAY	IN PLACER AND NEVADA C TEICHERT CONSTRU	
8	040435V4	19870	04	0435V4	SF	80	5.9	4.9	OBEROI RAJESH	SEISMIC RETROFIT	IN THE CITY AND COUNTY TUTOR-SALIBA CORP	
9	041S2304	15433	04	1S2304	SM	1	0	20.8	BOOSHEHRI, FRED	STORM DAMAGE REPAIR	IN SAN MATEO COUNTY AER.M. HARRIS	
10	040120K4	26448	04	0120K4	SF	80	8.8	8.2	MOHAN AYADURAI	INSTALL ELECTRICAL SUBMARI	IN SAN FRANCISCO AND AL MANSON CONSTRU	
11	044A4104	26875	04	4A4104	ALA	580	46.9	46.5	SARGISS, RAMSES	EMERGENCY BRIDGE REPAIR	IN ALAMEDA COUNTY IN O C C MYERS INC	
12	04163734	29031	04	163734	SF	101	9.8	9.2	SHARMA, JYOTSNA	RECONSTRUCT IC. CONSTRUCT	IN CITY AND COUNTY OF S C C MYERS INC	
13	04163744	29232	04	163744	SF	101	9.2	8.8	YAN, ANDREW	CONSTRUCT TUNNEL	IN THE CITY AND COUNTY R & L BROSAMER, INC	
14	05129104	24829	05	129104	SCR	1	17.6	15.8	SIOBHAN SAUNDERS	WIDEN TO 6 LANES	IN SANTA CRUZ COUNTY IN PAVEX MYERS J V	
15	05447804	27699	05	447804	SB	101	12.8	10.8	KAUSI AMUTH	RECONSTRUCT TWO INTERCH	IN SANTA BARBARA COUN SECURITY PAVING CO	
16	06350704	24549	06	350704	FRE	99	7.4	0.7	WOODS, JOHN A	WIDEN AND REHABILITATE FRE	IN FRESNO COUNTY IN ANIFCI CONSTRUCTION	
17	07195904	23343	07	195904	LA	405	32.2	29.5	TANJUAQUIO, ALLAN	WIDEN EXISTING FREEWAY	IN LOS ANGELES COUNTY DIABLO CONTRACTO	
18	071384U4	15791	07	1384U4	LA	710	9.7	6.8	AKBARIAN, MASSOD	RESURFACE EXISTING FREEWA	IN LOS ANGELES COUNTY EXCEL PAVING COMP	
19	07181804	17217	07	181804	LA	1	0	40.8	TRUJILLO, GILBERT EXT	SLOPE REPAIR	IN LOS ANGELES COUNTY PKB CONSTRUCTION	
20	07201204	23099	07	201204	LA	405	39.4	38.7	PATEL, JAGDISH	REALIGN AND WIDEN EXISTING	IN LOS ANGELES COUNTY STEVE P RADOS INC	
21	07166104	18732	07	166104	LA	1	0	41.7	TRUJILLO, GILBERT EXT	RECONSTRUCT TIMBER RETAIN	IN LOS ANGELES COUNTY JOHN S. MEEK COMP	
22	071X8404	27380	07	1X8404	LA	5	46.1	45.8	OBEID, AMJAD	REPAIR FIRE DAMAGE TO TRUC	IN LOS ANGELES COUNTY SECURITY PAVING CO	

Figure 3. Screenshot of the List of Projects Collected from Caltrans' Division of Construction

Table 1. Project Data Sample Obtained from Caltrans' Division of Construction

Column Name	Data
District	04
EA	4A4104
County	ALA
Route Project	580
Postmile Ahead	46.9
Postmile Back	46.5
Average Daily Traffic	218,000
CCOs Total No. of Days	7
Original No. of Working Days	70
Actual No. of Days Worked	37
Change Order Days	0
Other Days	0
Weather Days	0
Award Date	05/07/07
Work Must Start Date	05/08/07
Acceptance Date	06/19/07
Engineers Estimate Amount	\$5,140,070
Original Contract Allot Amount	\$19,750,000
Current Contract Allot Amount	\$19,750,000
Contractor Paid to Date Amount	\$6,573,408
Total Amt. All Contract CCO's	\$5,839,621
Daily I/D Amount	\$200,000
Maximum Incentive Amount	\$5,000,000
Contractor Name	CC Meyers
Description of Work	Emergency Bridge Repair
Location Description	In Oakland at the Route 580 and 880 Separation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	District	Route	Rte Suf	County	Pre	Postmile		Description	Back Peak Hour	Back Peak Month	Back AADT	Ahead Peak Hour	Ahead Peak Month	Ahead AADT
4830	04	116	SON			44.84		ARNOLD DR	1,050	14,500	13,900	1,200	16,600	15,900
4831	04	116	SON			46.755		JCT. RTE. 121	1,200	17,100	15,900			
4832	07	118	VEN			0.516		VENTURA, JCT. RTE. 126, SANTA PAULA FRWY				4,350	41,000	36,000
4833	07	118	VEN	R		1.019		TELEPHONE RD	4,350	41,000	36,000	4,400	43,500	37,500
4834	07	118	VEN			2.2		JCT. RTE. 232, VINEYARD AVE	4,000	41,500	35,000	2,400	25,500	23,400
4835	07	118	VEN			4.16		SANTA CLARA AVE	2,400	25,500	23,400	1,350	13,900	12,800
4836	07	118	VEN			10.92		JCT. RTE. 34, SOMIS RD	1,100	11,900	11,000	1,650	18,700	17,500
4837	07	118	VEN			14.686		GRIMES CANYON RD	1,650	18,700	17,500	1,800	20,100	18,900
4838	07	118	VEN			17.494		MOORPARK, WEST JCT. RTE. 23, MC	3,150	38,000	32,500	3,450	42,000	36,000
4839	07	118	VEN	R		17.905		MOORPARK, EAST JCT. RTE. 23, AT	3,450	42,000	36,000	7,200	78,000	77,000
4840	07	118	VEN	T		19.127		MOORPARK, PRINCETON AVE INTER	7,200	78,000	77,000	7,400	82,000	81,000
4841	07	118	VEN	T		19.981		MOORPARK, COLLINS DR INTERCHAI	7,400	82,000	81,000	7,300	79,000	77,000
4842	07	118	VEN	R		23.022		SIMI VALLEY, MADERA RD INTERCHA	7,300	79,000	77,000	8,800	96,000	93,000
4843	07	118	VEN	R		23.821		SIMI VALLEY, FIRST ST INTERCHANG	8,800	96,000	93,000	9,800	106,000	103,000
4844	07	118	VEN	R		24.808		SIMI VALLEY, ERRINGER RD INTERCH	9,800	106,000	103,000	11,100	116,000	112,000
4845	07	118	VEN	R		25.813		SIMI VALLEY, SYCAMORE DR INTERC	11,100	116,000	112,000	10,500	115,000	113,000
4846	07	118	VEN	R		27.304		SIMI VALLEY, TAPO CANYON RD INTE	10,500	115,000	113,000	10,800	115,000	112,000
4847	07	118	VEN	R		28.815		SIMI VALLEY, STEARNS ST INTERCHA	10,800	115,000	112,000	11,100	118,000	115,000
4848	07	118	VEN	R		29.563		SIMI VALLEY, YOSEMITE ST INTERCH	11,100	118,000	115,000	11,100	118,000	115,000
4849	07	118	VEN	R		30.521		SIMI VALLEY, KUEHNER DR INTERCHA	11,100	118,000	115,000	11,300	116,000	113,000
4850	07	118	VEN	R		32.427		SIMI VALLEY, ROCKY PEAK RD INTER	11,300	116,000	113,000	11,500	118,000	115,000
4851	07	118	VEN	R		32.6		VENTURA/LOS ANGELES COUNTY LIN	11,500	118,000	115,000			
4852	07	118	LA	R		0		VENTURA/LOS ANGELES COUNTY LINE				11,500	118,000	115,000
4853	07	118	LA	R		1.799		LOS ANGELES, JCT. RTE. 27, TOPAN	11,500	118,000	115,000	12,500	129,000	126,000
4854	07	118	LA	R		2.68		LOS ANGELES, DE SOTO AVE INTERI	12,500	129,000	126,000	14,000	150,000	147,000
4855	07	118	LA	R		3.864		LOS ANGELES, PORTER RANCH DRA	14,000	150,000	147,000	15,400	164,000	162,000
4856	07	118	LA	R		4.639		LOS ANGELES, TAMPA AVE INTERCH	15,400	164,000	162,000	17,700	191,000	188,000

Figure 4. Screenshot of a Caltrans Construction Project (EA 07266704) on Route 11 in LA County (PM 27.0 – 32.5)

Maximum Incentive Amount

In order to collect the above project information, the research team contacted Caltrans’ Office of Project Engineer and obtained a list of I/D projects including the maximum incentive amount, district number, and EA number. Then, two project information sources were joined based on contract numbers (district and EA numbers) to construct an I/D contracting project database. A total of 43 I/D contracting projects were collected. As a result of this process, the maximum incentive amount for the sample project (Contract No. 04-4A4104) in Table 1 was found to be \$5 million.

Daily I/D Dollar Amount

The research team also made contact with Caltrans’ Office of Project Delivery and requested additional I/D project information. The Office of Project Delivery provided special provisions for several recent I/D contracting projects. It was found that the daily I/D amount for the same example project is \$200,000 per day. This information was added to the I/D contracting database. However, this information had to be collected manually from contract files and the research team was able to obtain the daily I/D amount for only eight I/D projects from Caltrans during this study period.

EVALUATION OF PROJECT PERFORMANCE

Time and cost parameters are the most commonly used project performance indices (CII 2003). Using the time parameter, a project time performance index (TPI) for each project was determined based on the following formula:

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

where a positive value of TPI means time savings and a negative value of TPI means time overruns. For example, a value of TPI = 0.10 indicates a 10 percent project time savings, while a value of TPI = - 0.10 means a 10 percent time overrun.

Furthermore, a detailed TPI was developed to estimate project time performance more accurately. TPI was measured using such details as a time performance index based on original contract duration (OTPI), which did not include time extensions and supplemental agreement days. For example, the OTPI index can be calculated as:

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

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

$$CPI = \frac{\text{Contract Cost} - \text{Final Cost}}{\text{Contract Cost}} \quad (3)$$

where a positive value of CPI means cost savings and a negative value of CPI means cost overruns. For example, a value of CPI = 0.10 means project cost savings of 10 percent, while a value of CPI = - 0.10 means a 10 percent cost overrun.

The CPI was also refined using such details as a cost performance index based on original contract cost (OCPI) and did not include total work order amount, supplemental agreement amount, incentives paid, and other contract adjustments. This index was calculated as:

$$OCPI = \frac{\text{Original Contract Cost} - \text{Final Cost}}{\text{Original Contract Cost}} \quad (4)$$

I/D PROJECT DATABASE CONSTRUCTION

The Caltrans I/D contracting project database was constructed by combining project information obtained. A descriptive statistical summary tool was developed to automatically retrieve I/D contracting project data with performance indices as shown in Figure 5. Dialog boxes for variable selection such as project type, contract type, project location, and project size are shown in Figures 6 and 7. The developed interactive tool was used for data analysis and can quickly combine and compare I/D contracting project time and cost performance data.

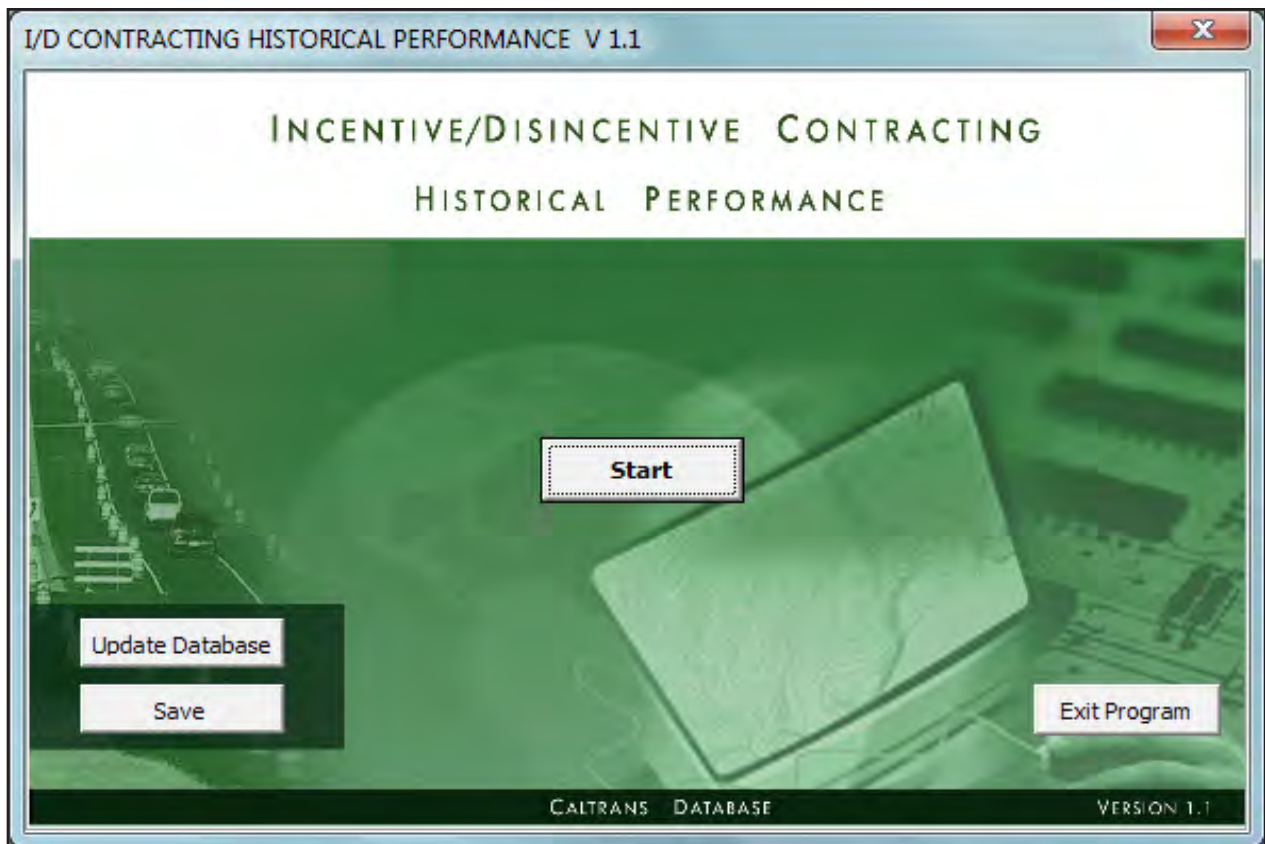


Figure 5. Main Page of Caltrans I/D Project Time and Cost Database

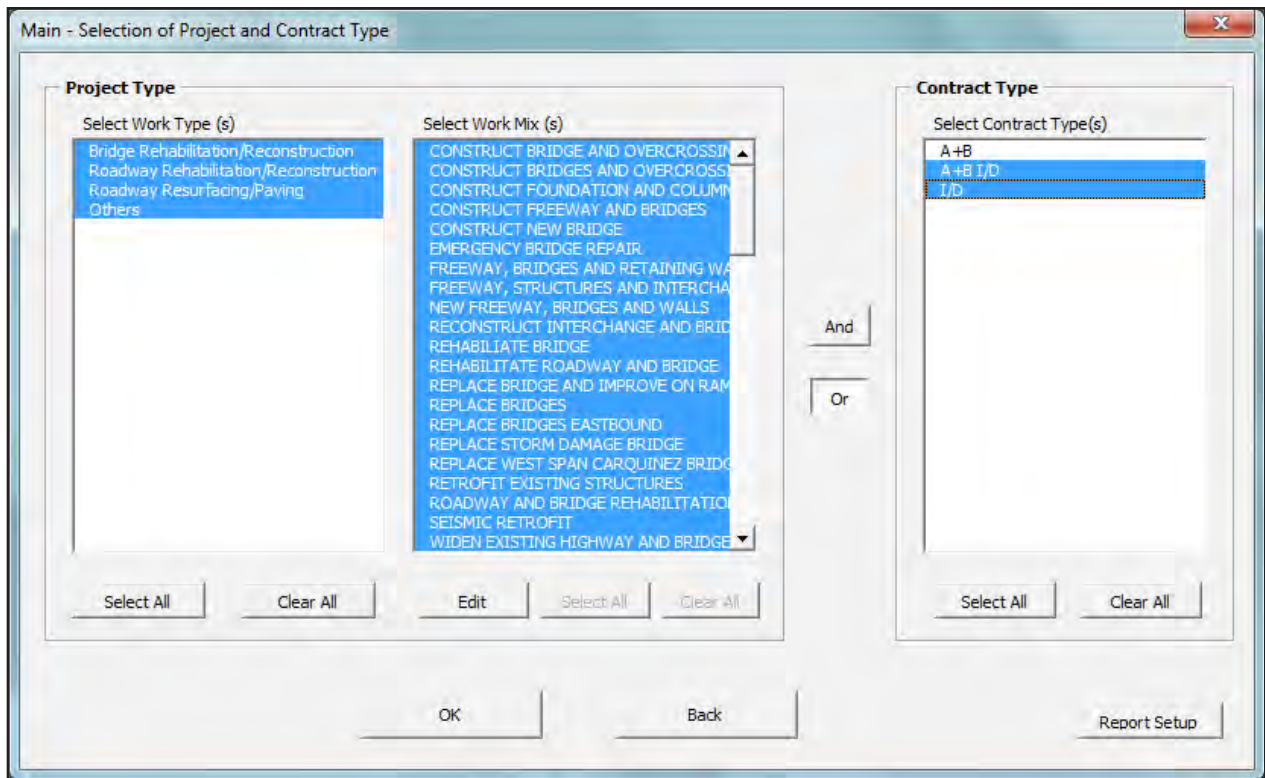


Figure 6. Variable Selection Dialog Box: Project Type and Contract Type

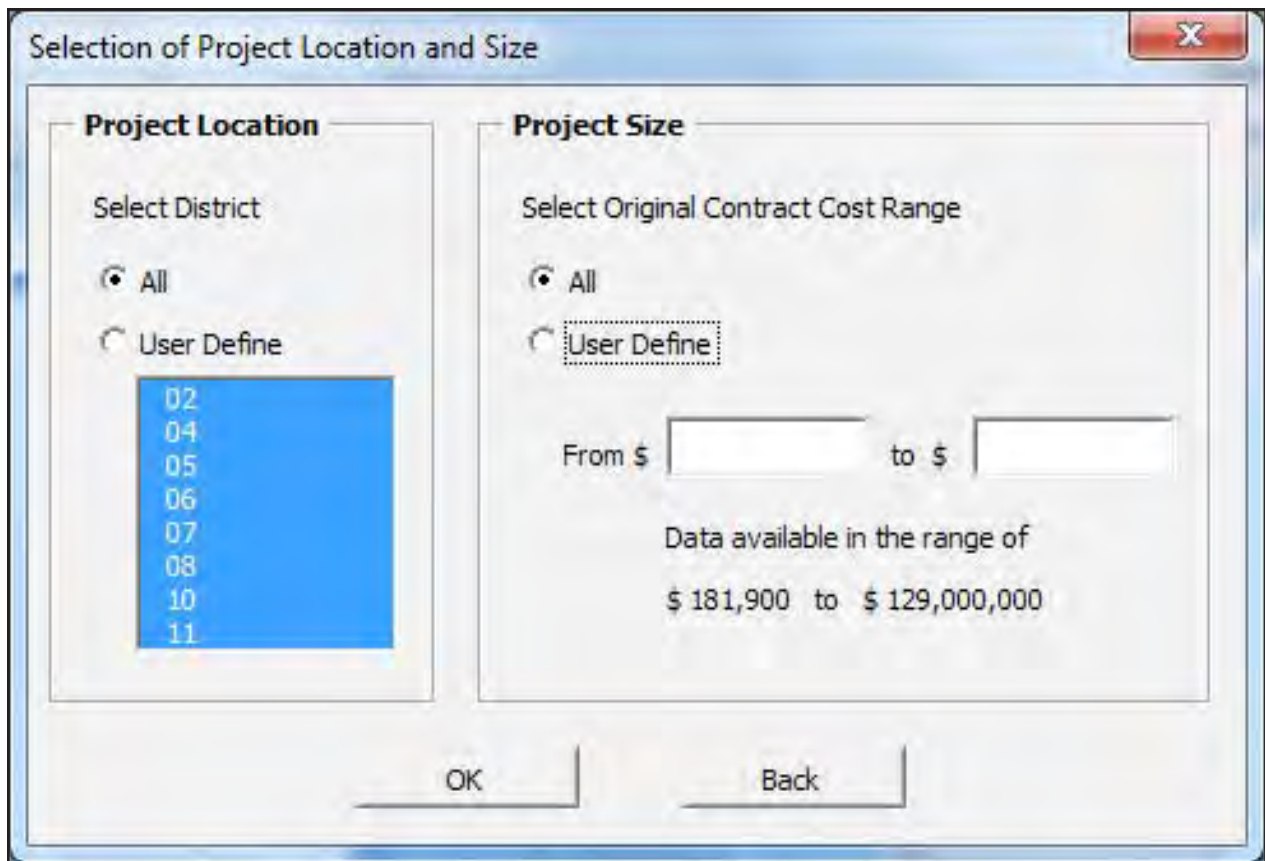


Figure 7. Variable Selection Dialog Box: Project Location and Size

IV. ANALYSIS OF CALTRANS I/D PRACTICES

I/D project data obtained were evaluated using project performance indices. Project performance data were analyzed and evaluated. Statistical analysis was performed to identify the relationship between the I/D dollar amount and project time and cost performance. The impact of I/D dollar amounts on project time and cost performance is quantified below.

SUMMARY STATISTICS OF I/D PROJECT DATA

A total of 48 I/D projects awarded between 2003 and 2010 were collected from Caltrans. Only 43 I/D projects completed in 11 districts were used for data analysis. The number of projects per district ranged from one to 16. Five districts completed five or more I/D projects during the study period. A summary of I/D project data by district and project type with ADT, incentive cap amount (maximum incentive amount), original budget, and original contract duration is shown in Table 2.

I/D provisions have been used for various project types, as shown in Table 2. However, a majority of projects are 3R (resurfacing, rehabilitation, and reconstruction) and widening projects. These projects usually have a high impact on traffic. The number of ADT ranged from 3,850 to 285,000 with an average of 134,004. Although the variation in ADT was relatively high, approximately 54 percent of the projects had more than 100,000 ADT. In addition, the project data showed an average project length of 9.54 miles and a median project length of 3.8 miles. Approximately 75 percent of the I/D projects had less than a 10-mile-long project length.

The average contract award amount of I/D projects was approximately \$40 million. The contract amount of the projects ranged from \$144,480 to \$185,995,000. Only two projects had project award of less than \$1 million, and four projects had a project award of more than a \$100 million. Project contract duration ranged from 33 to 1,824 working days with an average of 515 working days. To calculate the project daily cost, the project award amount was divided by the contract duration. The project daily cost ranged from \$1,605 to \$334,235 with an average of \$81,613 per day.

The incentive cap amount proposed for each project ranged from \$15,000 to \$5.3 million and the average cap amount was \$1,137,635 per project. The most commonly used cap amount was \$500,000, and approximately 50 percent of the projects proposed an incentive cap amount between \$100,000 and \$600,000. Only seven I/D projects proposed more than \$2,000,000 as an incentive cap amount. Figure 8 shows the average incentive cap amount by district.

Table 2. Summary of I/D Project Data by District and Project Type

District	Project Type	ADT	Incentive Cap Amount	Original Contract Allocation Amount	Original Working Days
01	Curve improvement	6,500	\$24,000	\$2,196,000	330
02	Resurfacing	3,850	\$35,300	\$1,443,000	50
	Road reconstruction	26,250	\$80,000	\$4,528,000	120
	Roadway and bridge rehabilitation	6,292	\$30,000	\$8,404,200	306
03	Bridge replacement	22,077	\$140,000	\$2,797,000	45
	Road reconstruction	18,188	\$90,000	\$105,160,000	360
04	Construct tunnel	79,750	\$5,300,000	\$95,706,000	725
	Emergency bridge repair	218,000	\$5,000,000	\$19,750,000	70
	Install electrical submarine cable	252,000	\$300,000	\$11,538,340	330
	Road reconstruction	99,250	\$3,000,000	\$79,469,000	540
	Seismic retrofit	252,000	\$5,100,000	\$214,640,000	1824
	Storm damage repair	6,100	\$350,000	\$4,090,000	120
05	Road reconstruction	51,000	\$841,000	\$51,804,000	650
	Road widening	82,000	\$300,000	\$47,720,000	850
06	Road widening	64,333	\$258,000	\$61,890,000	320
07	Construct approach slab	228,800	\$15,000	\$231,500	90
	Construct concrete barrier	94,650	\$500,000	\$17,480,000	360
	Long-life pavement rehabilitation	208,667	\$1,000,000	\$47,120,000	750
	Place rubberized hot mix asphalt	223,333	\$420,000	\$35,270,000	550
	Realign and widen existing highway	280,000	\$1,200,000	\$27,058,000	484
	Reconstruct interchange and bridges	155,000	\$135,000	\$36,020,000	1510
	Reconstruct timber retaining wall	47,680	\$200,000	\$1,826,000	95
	Repair fire damage to truck tunnel	195,000	\$3,500,000	\$20,000,000	33
	Resurfacing	159,500	\$500,000	\$21,120,000	450
	Road rehabilitation	199,000	\$2,000,000	\$79,350,000	600
		206,875	\$2,000,000	\$162,920,000	1340
		224,250	\$1,800,000	\$151,310,000	770
	Road widening	94,650	\$180,000	\$15,468,000	500
		285,000	\$600,000	\$36,310,000	420
	Slope repair	103,750	\$290,000	\$4,092,000	240
	Widen off-ramp	103,750	\$150,000	\$10,535,000	360
08	Bridge replacement	15,600	\$3,000,000	\$10,780,000	180
		228,800	\$3,000,000	\$10,910,000	165
	Pavement rehabilitation	169,000	\$600,000	\$16,380,000	100
		228,800	\$500,000	\$26,300,000	100
	Road rehabilitation	204,167	\$900,000	\$62,440,000	410
	Road widening	152,200	\$1,000,000	\$210,650,000	845

District	Project Type	ADT	Incentive Cap Amount	Original Contract Allocation Amount	Original Working Days
	Widen roadway and bridges	72,000	\$2,000,000	\$115,000,000	705
10	Construct freeway and bridges	53,000	\$600,000	\$74,350,000	550
11	Bridge widening	57,435	\$200,000	\$4,252,000	465
	Construct managed lanes	219,000	\$1,000,000	\$46,876,285	540
	Widen roadway and bridges	176,666	\$500,000	\$129,000,000	1350
12	Road widening	188,000	\$280,000	\$206,968,000	1530

Most I/D projects proposed an incentive cap amount in the range of 1 percent to 15 percent of the original contract amount. Only six projects proposed less than 1 percent, and four projects proposed more than 15 percent of the original contract cost. An average incentive cap amount proposed by the Caltrans Districts was 4.62 percent of the original contract amount. Figure 9 shows the average incentive cap percentages of the original contract amount by district.

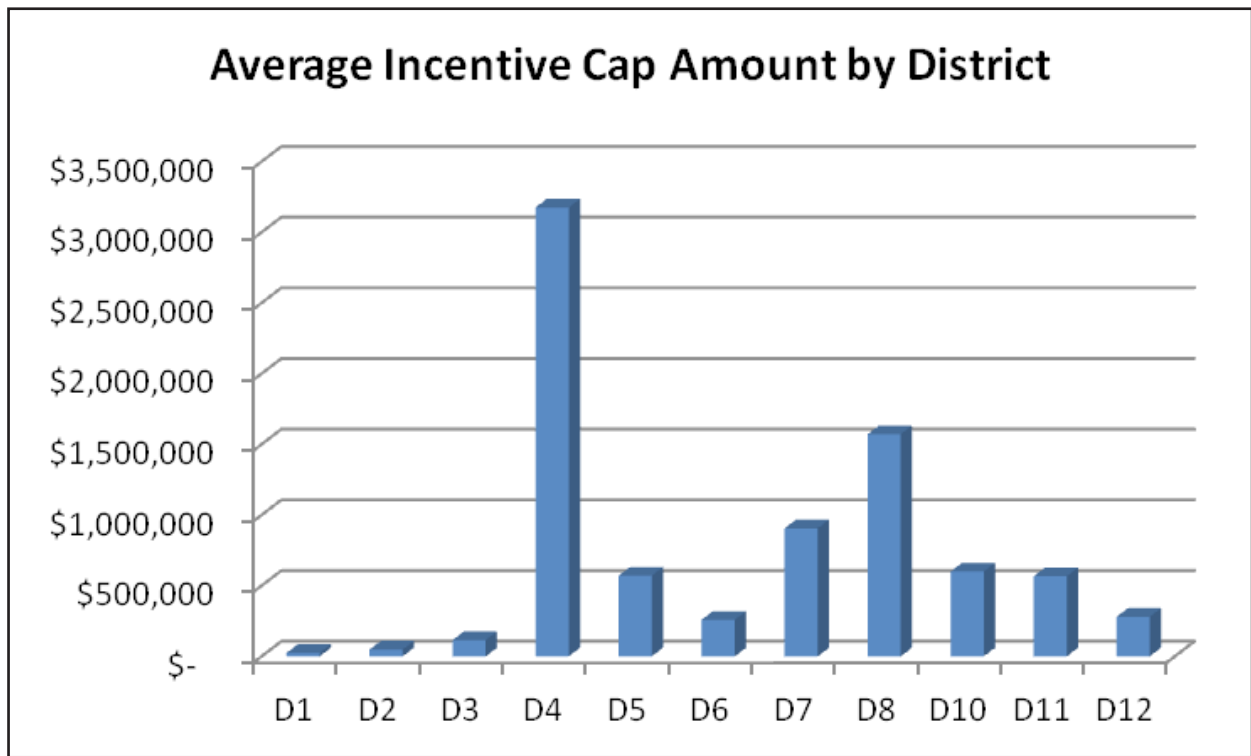


Figure 8. Average Incentive Cap Amount by District

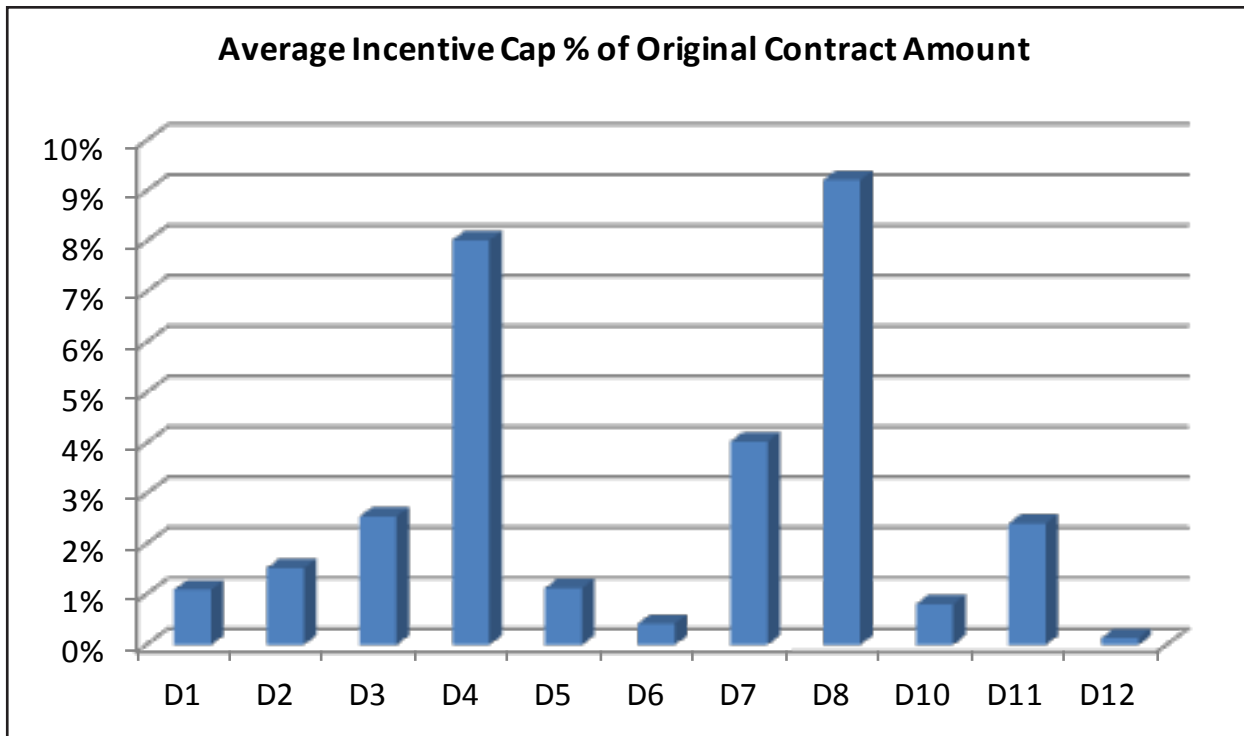


Figure 9. Average Incentive Cap Percent of Original Contract Amount by District

STATISTICAL ANALYSIS OF I/D PROJECT DATA

The purpose of the I/D project data statistical analysis was to identify the impact of the I/D dollar amount on construction project time and cost performance. The obtained I/D project data were evaluated using time and cost performance indices. Two performance indices were developed and used for analysis: 1) A Time performance index based on original contract duration (OTPI) and 2) A Cost performance index based on original contract cost (OCPI). Then, statistical analyses were performed to identify any differences on project performance among I/D project variables.

Statistical Analysis Process

The I/D amount variables such as incentive cap amount, project award amount, and ADT are quantitative variables. For the quantitative variables, correlation analysis was performed to identify the relationship between the I/D amount and the project variables and performance indices. In further analysis, the I/D amount data were classified using an appropriate categorization process. Then, statistical analyses were performed to identify any differences among project variables.

Since each project was completed at a different location and at a different time, each project was assumed to be independent. If the sample size is not large enough or the sample data are not normally distributed, a nonparametric test would be more appropriate for small sample sizes and does not require any assumptions about the type of underlying distribution. Thus, the Mann-Whitney nonparametric procedures were used to test the null hypothesis that two samples are generated by the same probability distribution.

Correlation Analysis

A number of correlation analyses were performed to identify any relationship between: 1) the incentive cap amount and project time performance index; 2) the incentive cap amount and project cost performance index; 3) the incentive cap amount and project award amount; and 4) the incentive cap amount and ADT.

Original Project Time Performance Index (OTPI)

A correlation analysis between the incentive amount and original project time performance was performed. The result was 0.273 and showed a positive relationship between two variables. Since a positive value of OTPI means time savings, it indicated that the maximum incentive amount proposed to the contractor had a positive impact on improving project time performance.

Original Project Cost Performance Index (OCPI)

A correlation analysis between the incentive amount and project cost performance was performed. The result was -0.399 and showed a negative relationship between two variables. Since a negative value of OCPI means cost overruns, it indicated that the maximum incentive amount proposed to the contractor had a negative impact on improving project cost performance.

Project Award Amount

A correlation analysis between the incentive amount and project award amount was performed. The result was 0.335 and showed a positive relationship between two variables. It indicated that the greater project award amount had a positive impact on increasing the maximum incentive amount proposed to the contractor. That is, larger projects tended to lead to larger incentive cap payments.

Average Daily Traffic

A correlation analysis between the incentive amount and ADT was performed. The result was 0.277 and showed a positive relationship between two variables. It indicated that the greater ADT had a positive impact on increasing the maximum incentive amount proposed to the contractor.

Summary of Correlation Analysis

The incentive amount showed positive relationships with OTPI, project award amount, and ADT. On the other hand, the incentive amount showed a negative relationship with OCPI. This matches the literature review findings. A range of approximately 27 percent to 40 percent correlation between two variables was found from four correlation analyses. The results of correlation analyses are summarized in Table 3.

Table 3. Correlation Analysis Results

Correlation Analysis	Project Award Amount	ADT	OTPI	OCPI
Mean	\$39,755,821	128,951	-0.108	-0.240
Median	\$16,743,677	152,200	0.000	-0.090
Minimum	\$144,480	3,850	-1.369	-6.581
Maximum	\$185,955,000	285,000	0.570	0.879
Correlation with incentive cap amount	0.335	0.277	0.273	-0.399

Mann-Whitney Test

There were 43 I/D contracting projects used for correlation analysis in each project variable. For further analysis, a grouping process is required. After the grouping process, each sample includes approximately 10 to 20 I/D projects, which are a small sample size for statistical analysis. Therefore, Mann-Whitney nonparametric procedures were used to test the null hypothesis that two samples are generated by the same probability distribution. A number of statistical analyses were performed to investigate the possible differences on project performance between two samples within a project variable.

There were positive or negative relationships on project performance among incentive cap amount and project award amount variables. However, no categorized sample within both variables showed a statistically significant difference on project performance. All possible cases were tested and only the ADT variable case was statistically significant.

Average Daily Traffic

A correlation analysis between the maximum incentives proposed and ADT was performed and the result was 0.277. This indicated that there was a positive relationship between the two variables. For further analysis, a categorization process was followed. Considering the distribution of the dataset, ADT data was divided by the mean value (128,951) of ADT. The two groups of ADT variables were: (1) ADT below average (Low ADT; <128,951) and (2) ADT above average (High ADT; >128,951). Summary statistics of ADT variables are shown in Table 4.

In this case, both sample sizes were small and their distributions were not normal. Therefore, Mann-Whitney nonparametric procedures were used to test the null hypothesis that two samples are generated by the same probability distribution. Two possible cases were tested and one conclusive case is summarized in Table 5. The results showed that the probability distributions of High ADT tended to yield smaller OTPI values than Low ADT. This result means that improving project time performance in a High ADT work zone is more difficult compared to a Low ADT work zone. This indicated that ADT has a significant impact on original project time performance.

Table 4. Summary Statistics of ADT Variables

Summary	Low ADT	High ADT
Categorized Range	< 128,951	> 128,951
Size	13	16
Mean	0.057	-0.242
Std. Dev.	0.317	0.519
Variance	0.101	0.269

Table 5. Mann-Whitney U-test Results for ADT Effect

Sample 1	Sample 2	p-value	Significance Levels
High ADT	Low ADT	0.066	0.1

FINDINGS OF I/D PROJECT DATA ANALYSIS

The results of correlation analyses showed that there is a negative or positive relationship between variables. This provides useful information to understand the connection of the incentive cap amount with OTPI, OCPI, ADT, and project award amount.

A relatively small sample size of I/D data has been used for statistical analysis. The results of nonparametric analysis showed that the comparison between ADT and project time performance was only significant. This result indicates that improving project time performance in a High ADT work zone is more difficult compared to in a Low ADT work zone.

For more effective analysis of I/D contracting, it is recommended that more completed I/D project data be collected and the historical I/D project database be updated periodically for analysis of project performance evaluation. In addition, the effectiveness of the I/D amount proposed should be evaluated on a project-by-project basis to refine the use of I/D contracting. As more data become available, in-depth statistical analyses can be performed to identify the impact of daily and/or maximum I/D dollar amounts on project time performance. Eventually, the proposed process will help to assist transportation project planners and engineers and to develop systematic I/D amount calculation procedures.

V. CASE STUDIES OF CALTRANS I/D PROJECTS

On a project-by-project basis, the I/D amount was calculated for Caltrans construction projects. In order to understand Caltrans' I/D amount decision-making practices, it is useful to perform case studies on specific Caltrans I/D projects. In this chapter, four Caltrans I/D projects were investigated to introduce three different levels of CA4PRS implementation for the I/D dollar amount calculation. In addition, the findings of I/D project case studies are summarized to provide a framework for developing more comprehensive and systematic procedures for I/D amount calculation.

I/D PROJECTS WITH CA4PRS SCHEDULE ANALYSIS

The analytical functionality of CA4PRS has evolved along with Caltrans implementation, especially for their long-life pavement rehabilitation strategy (LLPRS) pilot projects. For example, the construction staging plans and lane closure plans for the I-10 Pomona project, Caltrans' first concrete LLPRS project, were based on the CA4PRS schedule analysis. When the CA4PRS schedule module was developed, the 55-hour weekend closure (nonstop construction) on the I-10 project, the first in California, in combination with traditional nighttime construction was verified using CA4PRS schedule analysis.

The Caltrans first asphalt LLPRS, the I-710 Long Beach project, utilized the CA4PRS schedule analysis recommendation to implement a total of eight repetitive 55-hour weekend closures. The schedule baseline for the I/D provisions on the I-710 project was also confirmed using the CA4PRS schedule analysis.

I-10 Pomona Project

Caltrans demonstrated a long-life concrete pavement rehabilitation project in Pomona (near Los Angeles) on Interstate 10 using Fast-setting Hydraulic Cement Concrete (FSHCC), which developed the flexural strength of 2.8 MPa (400 psi) needed to be open to traffic in four hours. Twenty lane-km were successfully rebuilt on I-10 with one weekend (Friday 10 PM – Monday 5 AM) closure for 2.8 lane-km and repeated 7- and 10-hour nighttime closures for the remaining distance. The highway segment with four lanes in each direction was built in the early 1960's and had a high concentration of deteriorated concrete pavement due to traffic volumes of 240,000 ADT with approximately 9 percent heavy trucks.

Although the traditional low bid concept was used for the I-10 project, incentive and disincentive conditions were applied to encourage the contractor to achieve the rehabilitation production objective for the segment being built during the weekend closure. An incentive payment would 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. 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. A liquidated damage clause was provided in the contract to ensure the closure was open to traffic on Monday morning (\$10,000 liquidated damages per each 10 minute period). Under the Caltrans I/D provisions in the contract, the contractor was awarded a \$500,000

incentive bonus payment for completion of the 2.8 lane-km stretch of rehabilitation over the weekend closure.

I-710 Long Beach Project

Based on the success of the I-10 Pomona's 55-hour weekend closures, Caltrans undertook the long-life asphalt concrete pavement rehabilitation on I-710 in Long Beach (South of Los Angeles). Opened in 1952, this stretch of I-710 with three lanes in each direction, carries more than 164,000 ADT, including 13 percent heavy trucks on weekdays. Approximately 26.4 lane-km of existing PCC pavement was rehabilitated or reconstructed with AC during eight 55-hour weekend closures using around-the-clock construction operations and counterflow traffic.

The project's special provisions included a monetary incentive/disincentive clause to encourage earlier project completion and reopening of the freeway on time. The contractor was entitled to an incentive amount of \$100,000 per weekend closure if the main rehabilitation work was completed in fewer than ten weekend closures. Conversely, the contractor was subjected to a disincentive penalty of \$100,000 if more than ten weekends were required for the designated work. The total amount of incentive or disincentive was limited to \$500,000. Eventually, the contractor earned a \$200,000 incentive payment for project completion two weekends earlier than the planned ten weekends.

I/D PROJECT WITH CA4PRS TRAFFIC ANALYSIS

The I-15 Devore (Phase 1) project utilized both CA4PRS schedule and traffic modules' outputs to develop the lane closure schedule (adopted as two nine-day continuous closures), as well as the baseline of the I/D amount calculations. This was the first Caltrans project to adopt CA4PRS schedule and traffic analysis since the CA4PRS traffic module was developed.

I-15 Devore Project

The I-15 Devore project rebuilt a 4.5-km stretch of the two truck lanes from roughly 20 km north of the I-15/I-10 junction to just south of the I-15/I-215 junction near San Bernardino (Fig. 1). The I-15 freeway is one of California's most heavily traveled routes, carrying an ADT of approximately 110,000 vehicles (with about 10 percent truck traffic), with a peak hourly volume of 5,500 vehicles per direction during weekdays. The existing pavement cross-section has a 1970s-era Caltrans design; i.e., 210-230 mm of (undowelled, plain jointed) concrete slabs over 100-150 mm of cement-treated base.

The reconstruction scope was to replace the damaged concrete pavement with a new cross-section of 290 mm doweled slabs using rapid strength concrete and a 150 mm asphalt concrete (AC) base on top of the remaining aggregate base or native subgrade. The construction work, estimated to take ten months using traditional nighttime closures, was completed in two nine-day continuous closures with around-the-clock (about 210 hours for each direction) operations. This "Rapid Rehab" project adopted state-of-practice technologies to accelerate construction, mitigate traffic disruptions, and propagate project

information. As a result, traffic demand through the construction work zone was reduced by 20 percent and the maximum peak-hour delay was reduced by 50 percent.

Traditional Caltrans practice for rapid highway rehabilitation projects has been to rely on ad hoc estimates in developing incentives/disincentives to promote the production objective, often without quantitative calculations. The I-15 Devore project incorporated the unique approach of using the additional cost associated with road user traffic delay to develop the incentives/disincentives requirement. The assessment of I/D was based on the schedule estimate and work zone traffic analysis using CA4PRS. Due to high demand of traffic volume during closures and the public's desire for early completion of the reconstruction, Caltrans decided to apply two types of incentives/disincentives provisions on I-15 to encourage the contractor to complete the closure earlier or on time. The primary provision paid incentives to minimize the duration of each roadbed closure. The secondary provision paid incentives to minimize the total closure days of the entire main reconstruction.

The project's road user cost using the CA4PRS work zone module based on the demand capacity model (in the Highway Capacity Manual) was used as the baseline of the incentives/disincentives calculation for the one-roadbed continuous closures. However, only one-third of the road user cost was factored into the I/D calculation, a commonly used practice in other states. The incentives were limited by the realities of the budget limitations of the State, and a value of \$500,000 was used for the incentive cap.

The contractor would be eligible for a closure incentive bonus of \$300,000 if one-roadbed continuous closure was completed in equal or less time than two units of time segment (111 hours per unit), or be subjected to a closure disincentive penalty without a limit if the closure took longer than three units of time segment (one extra was given for realistic flexibility). In addition to this closure incentives requirement, the contractor would be eligible to receive a daily incentive bonus of \$75,000 if the entire major reconstruction was completed in fewer than 19 days (total 456 hours), or be subjected to a daily disincentive penalty (without a limit) if the reconstruction took longer.

I/D PROJECT WITH CA4PRS SCHEDULE-TRAFFIC-COST ANALYSIS

The I-80 Sacramento project, currently under construction, utilizes CA4PRS cost output when the cost module was added as its enhancement. This project implemented Caltrans life-cycle cost comparison based on the outcomes of CA4PRS schedule-traffic-cost integration analysis. The CA4PRS traffic analysis provided basic guidelines for the I/D amount calculation on the I-80 project.

I-80 Sacramento Project

The purpose of this project is to rehabilitate about 8.6 miles of the existing roadway on I-80 in the City of Sacramento. The need for the project is that the concrete pavement had deteriorated in both directions. The No. 2 and 3 lanes are currently at first- and third-stage cracking and are beyond regular maintenance repair. The outside shoulder is spalling and separating from the mainline roadway. Current average daily traffic on I-80 with three lanes in each direction is approximately 140,000, which is expected to increase to approximately

200,000 by 2030, with roughly 10 percent trucks. Total project costs for all elements of the project are currently estimated at \$93.1 million.

The median is to be widened 17 feet with asphalt concrete pavement (or alternatively concrete pavement) in both directions, designated for future HOV lanes, in order to shift traffic during construction as primary detours. Various random failed concrete slabs in the No. 1 lane will be replaced. The No. 2 and 3 lanes will be replaced completely utilizing jointed, plain concrete pavement (JPCP) with about 14-inch concrete slabs and 4-inch AC base. The No. 3 lane is to be paved 14 feet wide where feasible, which will provide lateral support for that lane.

Approximately ten lane-mile segments on the mainline near off- and on-ramp areas at seven interchanges are selected for weekend work (non-stop construction) using 12-hour-curing-time, rapid-strength concrete, whereas the majority of pavements in other areas are rebuilt using normal concrete with daytime-shift work behind K-rails with shifted detour traffic to the median side.

The first step in the I/D amount decision is to set up a schedule baseline, i.e., total number of weekend closures needed for the pavement rehabilitation, estimated from the CA4PRS schedule module. The CA4PRS schedule analysis indicates that the pavement rehabilitation of I-80 for the seven interchange areas requires approximately 20 55-hour weekend closures in total. This total closure number in the construction schedule is mathematically derived (in the CA4PRS schedule module) from the total rehabilitation scope of about 10.6 lane-miles and the typical rehabilitation progress of about a half-mile (0.53 lane-miles) per weekend closure. Figures 10 and 11 illustrate the CA4PRS schedule analysis input screens, and Figure 12 shows the CA4PRS output screen. Based on Caltrans' experience on similar previous pavement rehabilitation projects (listed above), it recommends adding about four weekend closures for schedule contingencies. That is, an incentive could be paid for each weekend closure that is eliminated. It might be practical to utilize these four extra weekend closures as the source of the maximum incentive closures.

The second step in the I/D amount calculation is to estimate the impact of the work zone on the traveling public, i.e., road user cost (\$) per weekend closure using the Caltrans standard hourly time value (\$11.51 per car and \$27.83 per truck). The CA4PRS Traffic Module shows that each 55-hour weekend closure causes an impact of about \$300,000 (as a sum of about \$60,000 for the eastbound traffic and about \$220,000 for the westbound traffic). This means that if the contractor reduces one weekend closure, it will save about \$333,000 in road user costs. Figures 13 and 14 illustrate the input and output screens, respectively, for the CA4PRS work zone traffic analysis.

The third step in the I/D amount is to use a factor to discount the value of the road user cost to match with agency cost. The researchers' understanding through literature reviews is that state DOTs usually adjust the value of the road user cost downward to the value of their incentive cost. A discount factor might be used to convert the closure road user cost to the closure incentive (or disincentive) payment to the contractor. The discount factor is usually in the range of 1 to 5, depending on the project situation, such as lane closure impacts and political priorities of the project's completion. In the case of the I-15 Devore

project, a discount factor of 4 is used in the conversion. If “3” is used as the discount factor for the I-80 Sacramento project, then the closure incentive/disincentive amount should be one-third of the closure road user cost of about \$300,000, which results in \$100,000 incentive/disincentive amount for one weekend closure. If the discount factor 4 is used, then the I/D amount is \$75,000 per weekend closure, i.e., $\$300,000/4 = \$75,000$.

For the final step of the I/D calculation, the maximum incentive amount can be set up using the closure incentive bonus and the achievable maximum number of closures. If the total of weekend closures is four (added on top of the baseline closure number of 20 weekends for a contingency purpose), the maximum incentive amount (as a cap) can be limited to \$400,000 (\$100,000 per closure with the discount factor 4 x 4 closures) or \$300,000 in the case of discount factor 4 (\$75,000 per closure). Usually, an I/D contract recommends not limiting maximum disincentives amounts (penalties) to assure that the project completion is not out of the agency’s control. The total of potential incentive payments should be set to keep the project within budget limits.

Figure 10. I-80 Project - CA4PRS Schedule Analysis Input Screen (1)

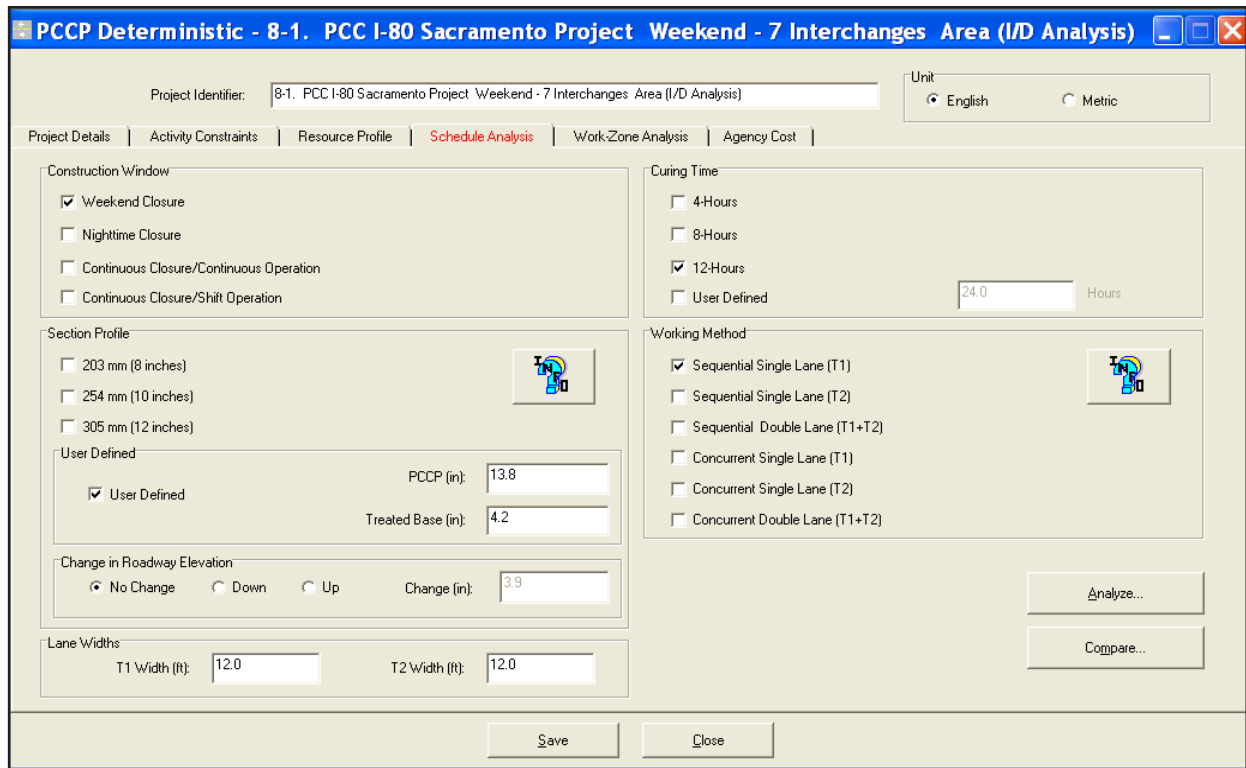


Figure 11. I-80 Project - CA4PRS Schedule Analysis Input Screen (2)

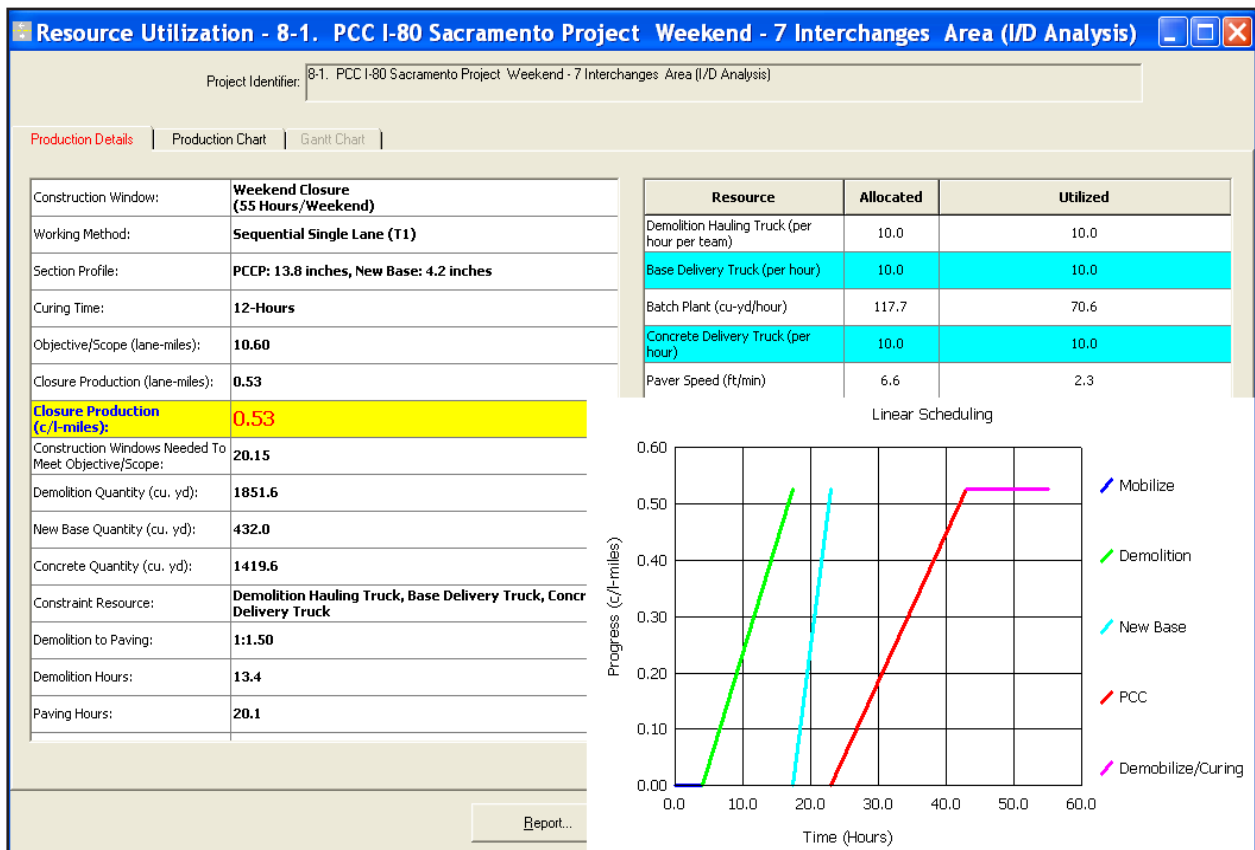


Figure 12. I-80 Project - CA4PRS Schedule Analysis Output Screen

Project Identifier: 8-1. PCC I-80 Sacramento Project Weekend - 7 Interchanges Area (I/D Analysis)

Unit: English Metric

Project Details | Activity Constraints | Resource Profile | Schedule Analysis | **Work-Zone Analysis** | Agency Cost

Before Construction:
 Direction 1: Eastbound
 Number of Lanes: 3
 Direction 2: Westbound
 Number of Lanes: 3
 Speed Limit (mph): 65

During Construction:
 Construction Year: 2011
 Closure Length(miles): 3.00
 Speed Limit (mph): 50
 Per Closure Duration (days): 2.00
 Number of Impacted Closures:
 Direction 1: 12.00
 Direction 2: 12.00

Roadway Capacity (pcphpl):
 Before Construction:
 Single-Lane Open: 1714
 Multi-Lane Open: 2095
 During Construction:
 Single-Lane Open: 977
 Multi-Lane Open: 1384

Traffic:
 Traffic Data Group: Week End - Urban
 Vehicle Cost:
 Passenger Car (\$/hr): \$11.51
 Commercial Truck (\$/hr): \$27.83
 Percent Truck (%): 10.00
 Include VDC: Yes No

Buttons: Traffic Demand..., Lane Open Chart..., Hourly Traffic Graph..., Analyze...

Bottom Buttons: Save, Close

Figure 13. I-80 Project - CA4PRS User Delay Cost Analysis Input

Work-Zone Traffic Analysis - 8-1. PCC I-80 Sacramento Project Weekend - 7 Interchanges Area (I/...

Project Identifier: 8-1. PCC I-80 Sacramento Project Weekend - 7 Interchanges Area (I/D Analysis)

Summary | Hourly Graphs

Item	Before Construction		During Construction		Difference	
	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
Direction	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
Maximum Delay (min)	0.0	0.0	4.7 @ 3:00 PM - 4:00 PM	21.3 @ 5:00 PM - 6:00 PM	4.7	21.3
Maximum Queue (miles)	0.0	0.0	1.0	5.9	1.0	5.9
Minimum Speed (mph)	65.0	65.0	13.9	13.9	51.1	51.1
Daily User Cost (\$)	\$0	\$0	\$31,522	\$111,198	\$31,522	\$111,198
Per Closure User Cost (\$)	\$0	\$0	\$63,045	\$222,395	\$63,045	\$222,395
Total User Cost per Direction (\$)	\$0	\$0	\$756,536	\$2,668,744	\$756,536	\$2,668,744
Total User Cost (\$)	\$0	\$0	\$3,425,280		\$3,425,280	

Buttons: Report..., Close

Figure 14. I-80 Project - CA4PRS User Delay Cost Analysis Output

FINDINGS OF I/D PROJECT CASE STUDIES

Most STAs use the daily I/D amount for early completion of the whole project or project milestones. However, Caltrans uses I/D provisions in various ways by setting the I/D dollar amount per day, per hour, per minute, per lane-meter, per closure, or any combination of those. For example, Caltrans set the I/D amount per lane-meter for the I-10 Pomona concrete pavement rehabilitation project. On the other hand, Caltrans set the I/D amount per weekend closure for the I-710 Long Beach asphalt pavement rehabilitation project. Caltrans requires the use of CA4PRS to determine the optimum construction schedule and cost considering various construction strategies, such as daytime or nighttime closure and weekend closure. The I/D dollar amount should be appropriately allocated across the various lane closure events that actually are set to occur in each particular project.

For these I/D project case studies, the I/D amount calculation is primarily based on a single variable, the road user cost savings. In order to develop more comprehensive and systematic procedures for the I/D amount calculation, it is necessary to broaden the I/D amount calculation criteria covering realistic cost items. Other cost items needing to be considered are the agency's administrative cost savings and contractor's overhead cost savings.

The agency cost savings resulting from the reduction in the number of closures should be included in the calculation process of I/D amount. For example, fewer closures require less Maintenance of Traffic (MOT) costs, including moveable concrete barriers and detour and advisory signs. In addition, fewer closures will reduce the TMP costs such as work zone incident management, so-called COZEEP (construction zone enhanced enforcement program). COZEEP provides California Highway Patrol (CHP) service at the cost of about \$95 per hour per officer and towing services, called freeway patrol services.

Fewer closures can also save the agency's supporting costs, such as field engineers' time (usually about five engineers and inspectors per shift at three shifts per day is needed for non-stop construction on weekends) on site and administration costs. On the other hand, the contractors might bear additional costs, triggered by the incentive bonus, to reduce the number of closures. Obviously, the contractors need to utilize such additional resources as equipment, plants, and labor on site to expedite construction and reduce the number of closures. In return for accelerating construction, the contractors are also expected to reduce their project overhead costs.

PROPOSED I/D AMOUNT ASSESSMENT PROCEDURES

Based on the findings of the case studies, more systematic procedures need to be developed to set up a reasonable amount of I/D within given project conditions considering the costs/benefits to the agency, contractor and users. Thus, an initial framework for developing systematic procedures of I/D amount calculation was performed. The proposed I/D amount assessment procedures are summarized in Table 6.

The propose procedures are developed for highway projects, especially roadway widening and renewal (resurfacing, rehabilitation, and reconstruction) construction in urban areas.

CA4PRS is incorporated into the proposed model as a simulation tool since it provides analytical capabilities for construction schedule prediction, work zone delay calculation, and agency project cost estimate. Using CA4PRS, the following systematic procedure to determine I/D dollar amount is proposed as shown in Table 7:

- Set up a schedule baseline
- Estimate the impact of work zone on the traveling public
- Use a factor to discount the value of the road user cost to match agency cost
- Set up the maximum incentive amount using the closure incentive bonus and the achievable maximum number of closures

Table 6. Proposed I/D Amount Assessment Procedures for Highway Renewal Projects

Criteria	No	Analysis Procedure	Remark
TRAFFIC IMPACT	1	Analyze work zone impact with lane closures.	
	2	Check if the benefit of construction acceleration to users with incentives is feasible.	
	3	Estimate work zone road user cost (\$RUC) per unit (like daily) lane closure.	
	4	Estimate baseline schedule (daily production) with standard resources and work-hour conditions.	
SCHEDULE ANALYSIS	5	Identify contractor's major constraining resources on critical activities.	
	6	Input (maximum) additional resources for acceleration.	
	7	Calculate maximum schedule compression (reduced closure numbers) with additional resources input.	
COST ESTIMATE	8	Estimate contractor's cost for additional resource inputs (using DOT's labor surcharge and equipment rental rate).	
	9	Estimate agency cost benefits from saving on field staff time and TMP implementation, as a result of the schedule compression.	
I/D AMOUNT CALCULATION	10	Estimate contractor's benefit (cost saving on their field operations), as a result of the schedule compression (overall shortened resources usage).	
	11	Minimum daily Incentive amount = contractor's cost for additional resources input for the acceleration.	8
	12	Baseline daily Incentives amount = Contractor's additional cost + (discounted) RUC saving + (discounted) Agency cost saving – (discounted) contractor's operational cost saving.	8+ 3* + 9* + 10*
	13	Maximum daily Incentives amount = daily RUC reduction + daily agency cost saving.	3+9
	14	Incentives cap = daily incentives x maximum possible schedule compression.	12x7
	15	Finalize incentives/disincentives amounts within the calculated range, considering project budget and profile.	

* This Indicates to use a discounted cost.

Table 7. Proposed Procedures to Determine I/D Dollar Amount Using CA4PRS

Procedures	Input	Output
Set up a schedule baseline	Closure option, section profile, lane width, curing time, and working method	Schedule analysis results: construction window types and closure hours
Estimate the impact of work zone on traveling public	Roadway capacity information (before and during construction) and traffic information (traffic demand and vehicle costs [*])	Work zone user delay cost analysis results
Use a factor to discount the value of the road user cost to match with agency cost	The discount factor ^{**} : usually in the range of 1 through 5	I/D dollar amount per closure
Set up the maximum incentive amount using the closure incentive bonus and the achievable maximum number of closures	I/D dollar amount per closure and schedule baseline	Maximum incentive amount and maximum number of closures

^{*} Caltrans standard hourly time value: \$11.51 per car and \$27.83 per truck.

^{**} Used to convert the closure road user cost to the closure I/D payment to the contractor.

VI. I/D DOLLAR AMOUNT DETERMINATION PROCESS

OVERVIEW OF THE PROPOSED PROCEDURES

In this chapter, the systematic procedures to determine appropriate I/D dollar amounts for highway construction projects are introduced based on the results of the I/D project case studies, as illustrated in Figure 15. The step-by-step procedures start with project schedule analysis in order to set up a schedule baseline in a given project situation. Then, the impact of work zone delay is evaluated. In the next step, the cost of the contractor's additional resources and agency savings caused by schedule compression are estimated. Finally, I/D dollar amounts for a project are determined.

The systematic procedure to determine I/D dollar amounts utilizing CA4PRS analysis is briefly summarized in the following steps:

- STEP 1: Set up a schedule baseline based on CA4PRS schedule analysis.
- STEP 2: Evaluate the impact of work zone on the traveling public, especially road user cost based on CA4PRS traffic analysis.
- STEP 3: Estimate contractor's cost for additional resources for I/D acceleration and contractor's savings from schedule compression. Also, estimate the contractor's savings in their field operation cost with the project duration reduction results from the schedule acceleration.
- STEP 4: Estimate agency's cost savings from schedule compression.
- STEP 5: Determine reasonable value of discount factors to split I/D benefits and costs between the contractor and agency with some sensitivity analysis.
- STEP 6: Make a decision of the ID implementation based on the comparison of additional acceleration cost and field operation cost savings for the contractor and benefits to road users and agency from the schedule compression.
- STEP 7: Set up daily incentive amount and maximum incentive amount based on the above-described procedure and parameters and project budget constraints.
- STEP 8: Set up daily disincentive amount and maximum disincentive amount based on the above-described procedure and parameters.

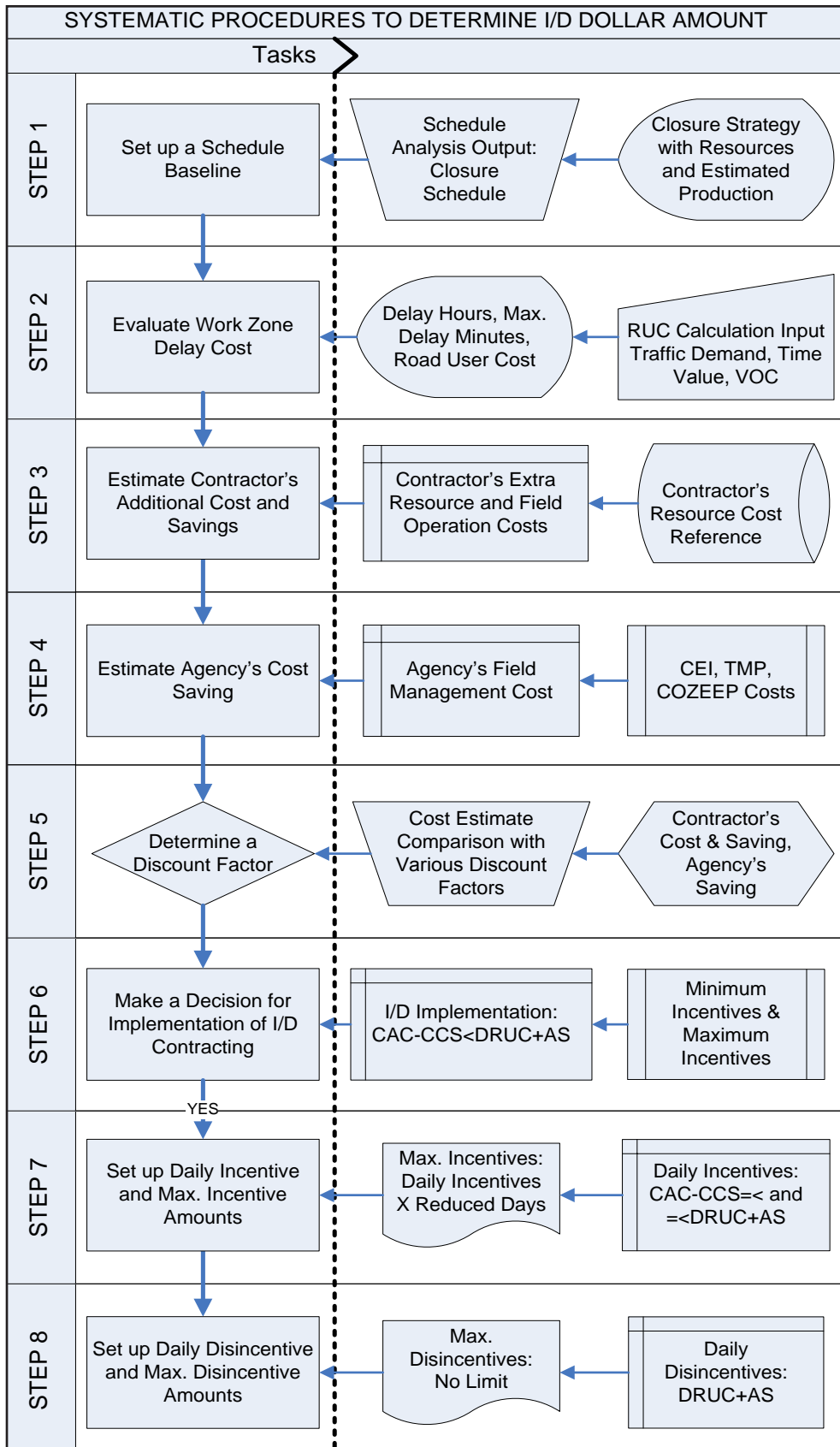


Figure 15. Flow Chart of Systematic Procedures for Determination of I/D Dollar Amount

SYSTEMATIC PROCEDURES FOR DETERMINING I/D AMOUNTS

In this section, I/D amount calculation using CA4PRS Schedule-Traffic integration process is addressed in detail. The new I-5 southbound rehabilitation project in Kern County was used for another case study with the improved procedures to determine I/D dollar amount. The length of the project is 10 miles and the number of lanes is four. The total lane-mile is 40 lane-miles with 10 feet of median width and 8 feet of shoulder width. Brief project cost estimates and asphalt quantities are shown in Table 8.

Table 8. Cost Estimate for I-5 SB Rehabilitation Project

Scope (lane-mile)	HMA Thickness (inch)	HMA Quantity (ton)	HMA Unit Cost (\$)	Milling Quantity (SY)	Milling Unit Cost (\$) / SY	Estimated COST (\$)
40	3.00	59,194	100.00	387,117	3.00	11,329,278

STEP 1: Schedule Baseline

Schedule Analysis Input

The following inputs for CA4PRS schedule analysis need to be entered to set up a baseline schedule:

1. Input project scope: 40 lane-miles (10 miles x 4 lanes on I-5 SB), as shown in Figure 16 for CA4PRS “Project Details” input screen.
2. Input construction window (lane closure hours): 8 hours nighttime construction from 9pm – 5am (see Figure 17 for CA4PRS “Activity Constraints” input screen).
3. Input standard scale of contractor’s resources mobilized without incentive trigger utilizing the resource database based on similar previous rehabilitation projects. The input screen for CA4PRS “Resource Profile” is shown in Figure 18.
4. Input pavement cross-section change for the rehabilitation project, as shown in Figure 19 for CA4PRS “Schedule Analysis” input screen.

Figure 16. CA4PRS “Project Details” Input Screen

Figure 17. CA4PRS “Activity Constraints” Input Screen

Figure 18. CA4PRS “Resource Profile” Input Screen

Figure 19. CA4PRS “Schedule Analysis” Input Screen

Schedule Analysis Output

The analysis output of the baseline schedule shows a total of 110 closures with 8-hour nighttime construction (standard resources). Other schedule analysis results are also shown in Table 9. In this table, the schedule analysis outputs show a total of 92 closures with 9-hour nighttime and 79 closures with 10-hour nighttime construction. It also shows that a total of 93 closures with 8-hour nighttime construction with extra resources.

Table 9. CA4PRS Schedule Estimate Results

Closure Strategy	Closure Hours	Resources	No. of Closures Estimated	Estimated Production (Lane-Mile)
8 hours (standard closure)	9 PM - 5 AM	8 hauling + 9 HMA trucks	110	0.36
9 hours	8 PM - 5 AM	8 hauling + 9 HMA trucks	92	0.44
10 hours	8 PM - 6 AM	8 hauling + 9 HMA trucks	79	0.51
8 hours with extra resources	9 PM - 5 AM	10 hauling (9 utilized) + 11 HMA trucks	93	0.43

Schedule Analysis for Accelerating Construction

In addition, a schedule analysis for accelerating construction with contractor's additional resources was performed that assumed that the contractor was encouraged by the incentive bonus for schedule compression. For example, demolition hauling trucks and HMA delivery trucks can be increased slightly (approximately two trucks per hour for each activity). See Figure 20 for CA4PRS "Schedule Analysis" output screen.

The schedule analysis output indicates that the construction duration due to the incentive acceleration with the additional resource inputs can be reduced to 93 x 8-hour closures, compared to 110 x 8-hour closures with the standard resource inputs. In other words, about 17 x 8-hour nighttime closures can be reduced as a result of the contractor's incentive acceleration with additional resources.

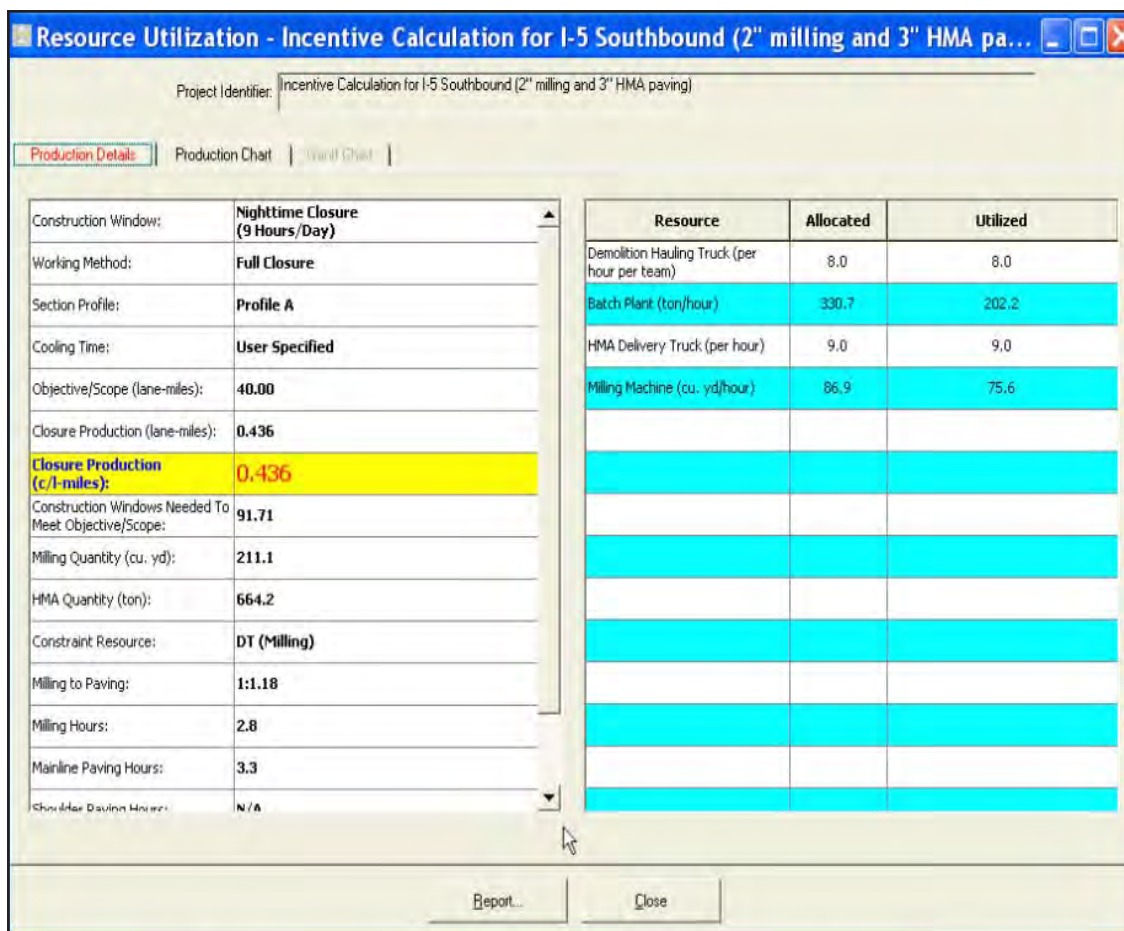


Figure 20. CA4PRS “Schedule Analysis” Output Screen

STEP 2: Road User Cost

RUC Calculation Input

To calculate RUC, the following input parameters for CA4PRS work zone analysis need to be entered:

1. Input basic traffic parameters for the work zone (see Figure 21 for CA4PRS “Work Zone Analysis” input screen).
2. Input traffic hourly demand (volume) during construction, including demand reduction during construction (no-shows and detour traffic).
3. Input lane hourly closure chart: two lanes opened to traffic during construction (8-hours, 9 pm – 5 am).
4. Adjust work zone lane capacity based on highway capacity manual procedure.
5. Input time value for traffic delay calculation: Caltrans’ guideline is to use \$11.52 per hour for a passenger vehicle and \$27.83 for a truck.

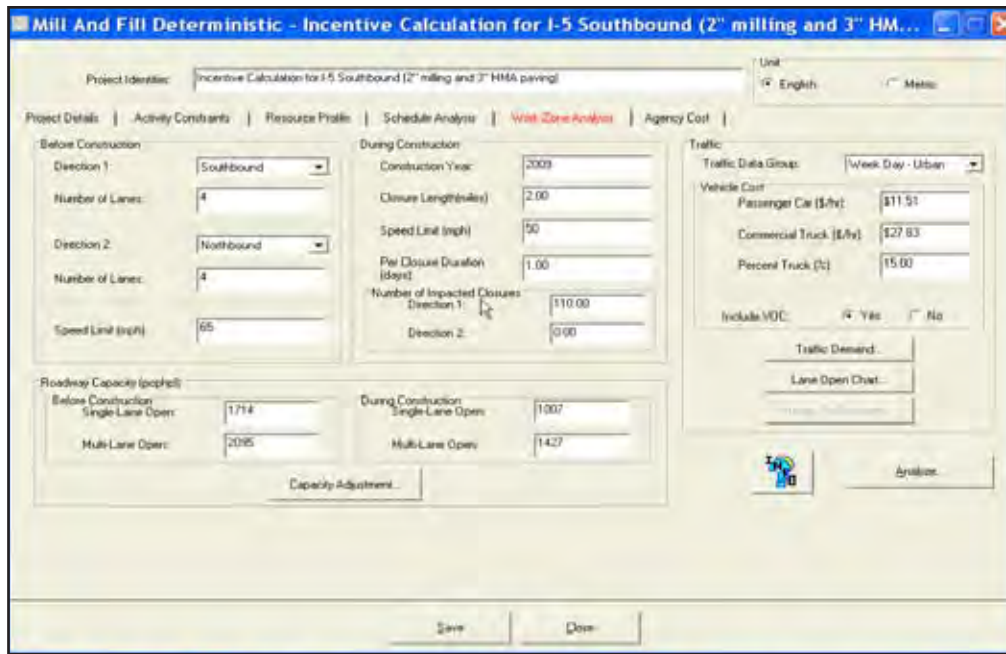


Figure 21. CA4PRS “Work Zone Analysis” Input Screen

RUC Calculation Output

As a result of the work zone analysis, the output RUC calculated is approximately \$7,350 per 8-hour closure and total RUC of approximately \$800,000 for the whole project (110 days x 8-hour closures). See Figure 22 for the CA4PRS “Work Zone Analysis” output screen. Therefore, calculated total savings in RUC from the schedule acceleration is a total of \$125,000 (\$7,350 RUC per closure x 17 closures). The complete results of CA4PRS work zone delay simulation are shown in Table 10.

Item	Before Construction	Before Construction	During Construction	During Construction	Difference
	Southbound	Northbound	Southbound	Northbound	Southbound
Maximum Delay (min)	0.0	0.0	4.0 @ 10:00 PM - 11:00 PM	0.0	4.0
Maximum Queue (miles)	0.0	0.0	0.3	0.0	0.3
Minimum Speed (mph)	65.0	65.0	5.9	65.0	59.1
Daily User Cost (\$)	\$0	\$0	\$7,316	\$0	\$7,316
Per Closure User Cost (\$)	\$0	\$0	\$7,316	\$0	\$7,316
Total User Cost per Direction (\$)	\$0	\$0	\$804,760	\$0	\$804,760
Total User Cost (\$)	\$0	\$0	\$804,760	\$0	\$804,760

Figure 22. CA4PRS “Work Zone Analysis” Output Screen

Table 10. CA4PRS Work Zone Delay Simulation Results

Closure Strategy	Delay Hours	Max Delay (Min)	RUC Per Closure	Total RUC
8 Hours	10 - 11 PM	5.0	\$7,350	\$808,500
9 Hours	9 - 10 PM	15.0	\$30,000	\$2,760,000
10 Hours	5 - 6 AM	28.0	\$86,000	\$6,794,000

STEP 3: Contractor's Additional Cost and Savings

Contractor's Additional Cost for Schedule Acceleration

Estimate additional cost to encourage and compensate the contractor to mobilize extra key resources, as identified in the above schedule compression analysis. More detailed information about the additional resources and their unit cost is listed in Table 11. Unit cost of the contractor's resources, such as equipment and labor, is based on Caltrans cost reference entitled Labor Surcharge and Equipment Rental Rates.

As the CA4PRS cost estimate module is limited to calculating project cost (agency cost) based on material volumes and bid unit price of the materials, a simplified spreadsheet is developed to estimate contractor's additional resource cost and resource cost savings (reduction) from the schedule acceleration.

The cost estimate shows that the contractor needs about \$3,762 per night to arrange a few numbers of each major key resource. Consequently, a total of \$350,000 should be paid to the contractor to keep this additional resource input for the entire duration (93 x 8-hour closure) of the construction to achieve the total of 17 days schedule compression with the additional key resources, i.e., $350,000 = \$3,762 \text{ per night} \times 93 \text{ nights}$. Table 11 lists details of the contractor's resources, including typical numbers mobilized and unit rates. Other cost items and rates, such as labor, markup, and surcharge, are shown in Table 12.

Contractor's Cost Saving from Schedule Compression

Estimated cost savings in the contractor's overall field operation costs results from the work-day reduction with the schedule acceleration. The schedule estimate indicates that each contractor might save approximately \$21,000 in its whole resource operation (equipment, labor, and site management) from one day (night) of schedule reduction. It means that the contractor can save a total of about \$360,000 operation cost from the 17 days of schedule compression with the ID acceleration.

On this particular case study project, the cost estimate comparison shows that the contractor's acceleration cost (about \$350k) with the key additional resource inputs is similar to the overall field operation cost savings (about \$360k) from the schedule reduction.

Table 11. Contractor's Cost for Additional Major Inputs for Schedule Acceleration Including Only Key Resources

Activity	Crew Resource	Equipment (E) / Laborer (L)	Resource Unit per Closure	Extra Resource	Additional Resource Cost for Acceleration	Contractor's Cost Saving per Closure
Demolition	Demolition hauling trucks	E	8	2	\$413	\$1,652
	Demolition hauling truck operator	L	8	2	\$480	\$1,919
	Demo labor	L	4	2	\$446	\$891
Paving	Asphalt delivery truck	E	9	2	\$413	\$1,859
	Asphalt delivery truck operator	L	9	2	\$480	\$2,159
	Paving labor	L	6	2	\$446	\$1,337
	Batch plant operator	L	2			\$528
General	General labor	L	4	2	\$594	\$1,188

Table 12. Other Cost Items and Rates Used

Cost Items: Labor, Markup, and Surcharge	Rates
Truck driver	\$47.04
Labor (skilled)	\$51.76
Labor (general)	\$43.68
Markup	15 percent
Surcharge (WC, social, Medicare, unemployment, training tax)	11 percent

STEP 4: Agency's Cost Savings

Agency's Cost Savings from Incentive Acceleration

As a result of schedule compression from the contractor's incentive acceleration, the agency can reduce their field management costs as well. Mainly, the agency's field engineers' time (salary) and TMP cost (including COZEEL for incident management) can be reduced when the total number of nighttime closures is reduced. For example, the cost estimate shows that about \$6,600 of agency cost can be saved per night, as itemized in Table 13.

Table 13. Agency Staff/TMP Cost

Agency Cost Items	Resource Unit per Closure	Resource Cost per Closure
Resident engineer	1	\$800
Field engineer	2	\$1,280
Inspector	2	\$1,280
Traffic engineer	1	\$640
QA & test (Mat)	1	\$640
Staff subtotal per day	7	\$4,640
Safety COZEEL (CHP) per day	2	\$1,520
TMP (PO, FSP) per day	\$500	\$500
Agency cost total (without discount)		\$6,660

STEP 5: Discount Factors

It is important to determine how to equally treat the cost and savings components involved in I/D amount calculation, especially for the following main parameters:

1. The contractor additional cost to arrange extra key resources for schedule acceleration;
2. The contractor's cost savings, especially on overall field operation cost results from the schedule reduction;
3. The agency's cost savings as a consequence of the early project completion due to the contractor's schedule compression; and
4. Savings in road user cost derived from the closure duration due to the contractor's early completion.

The basic I/D calculation process previously introduced deals with the above parameters equally. In other words, the original value of each parameter is included in the process of the I/D amount calculation. No discount factor (DF) was used for determining I/D dollar amounts. However, the RUC savings as a result of early completion is often not the same as the contractor's additional cost (CAC) for acceleration. It is generally considered that the RUC savings with high volume of traffic is much greater than the CAC for acceleration. In this case, the agency uses a discount factor to adjust the I/D amount payment. Typically, a discount factor of 2 (50 percent) is recommended by Caltrans I/D implementation guidelines. However, discount factors of 4 (75 percent) and 5 (80 percent) are also commonly used for high RUC projects.

A discount factor can be used for the RUC savings, the Agency's savings, and the Contractor's savings because the estimated costs are frequently too enormous or unrealistic. However, in this study the use of a discount factor was not recommended for the contractor's additional cost because it is estimated using the contractor's additional resources, such as equipment and labor.

Discount Factor Sensitivity

A simple sensitivity analysis was performed to assess the impact of discount factors on the conversion of the I/D costs and savings. More specifically, the I/D calculation using DFs of 1, 2, and 3 is summarized in Tables 14, 15, and 16, respectively. The sensitivity analysis shows that the I-5 case study project needed to use a discount factor of 1 for all involved parameters, such as the contractor's cost (parameter 1), their savings (parameter 2), agency savings (parameter 3), and RUC savings (parameter 4). If the discount factor is greater than 1, the benefit (RUC and AS) from the I/D implementation is smaller than the minimum incentive payment to the contractor for their additional resource arrangement. One conclusion of the discount factor sensitivity analysis for the I-5 project case study was that in the systematic I/D process it is more reasonable to use a discount factor of one, as long as all major parameters are taken into account. This is quite different from the most

commonly used traditional I/D amount calculation process that considers only RUC with some discount factors for down-adjustment to the incentive amount.

Table 14. I/D Cost Estimate Comparison with Discount Factor 1

Parameters and I/D	Items	Daily Cost	Discount Factor	Days	Total Amount
Contractor (cost savings)	Resources cost for acceleration	\$3,762	1	93	\$349,827
	Saving from schedule compression	\$21,237	1	17	\$361,022
	Cost difference				\$(11,195)
Benefit (DRUC+agency)	RUC saving	\$7,500	1	17	\$127,500
	Agency saving	\$6,660	1	17	\$113,220
	Total savings				\$240,720
Incentives	Daily incentive minimum*	\$(659)			\$(659)
	Daily incentive maximum	\$14,160			\$14,160
	Maximum incentives			17	\$240,720
Disincentives	Daily disincentives (RUC + agency)	\$14,160			\$14,160
	Max disincentives				No limit

* The negative number or zero of Daily Incentive Minimum indicates that no minimum incentive amount is necessary to motivate the contractor for early completion of the project.

Table 15. I/D Cost Estimate Comparison with Discount Factor 2

Parameters and I/D	Items	Daily Cost	Discount Factor	Days	Total Amount
Contractor (cost savings)	Resources cost for acceleration	\$3,762	1	93	\$349,827
	Saving from schedule compression	\$21,237	2	17	\$180,511
	Cost difference				\$169,316
Benefit (DRUC+agency)	RUC saving	\$7,500	2	17	\$63,750
	Agency saving	\$6,660	2	17	\$56,610
	Total savings				\$120,360
Incentives	Daily incentive minimum	\$9,960			\$9,960
	Daily incentive maximum	\$7,080			\$7,080
	Maximum incentives			17	\$120,360
Disincentives	Daily disincentives (RUC + Agency)	\$14,160			\$14,160
	Max disincentives				No Limit

Table 16. I/D Cost Estimate Comparison with Discount Factor 3

Parameters and I/D	Items	Daily Cost	Discount Factor	Days	Total Amount
Contractor (cost savings)	Resources cost for acceleration	\$3,762	1	93	\$349,827
	Saving from schedule compression	\$21,237	3	17	\$120,341
	Cost difference				\$229,486
Benefit (DRUC+agency)	RUC saving	\$7,500	3	17	\$42,500
	Agency saving	\$6,660	3	17	\$37,740
	Total savings				\$80,240
Incentives	Daily incentive minimum	\$13,499			\$13,499
	Daily incentive maximum	\$4,720			\$4,720
	Maximum incentives			17	\$80,240
Disincentives	Daily disincentives (RUC + agency)	\$14,160			\$14,160
	Max disincentives				No Limit

STEP 6: Decision to Implement I/D

In the previous steps, Contractor's Additional Cost (CAC), Contractor's Cost Saving (CCS), Road User Cost (RUC), and Agency's Saving (AS) were calculated. In order to determine an appropriate incentive dollar amount for a project, all four variables should be considered. In reality, the appropriate incentive should be large enough to compensate the contractor's actual project cost for early completion. At the same time, the incentive should not exceed the benefits.

Minimum Incentive Amount

It is obvious that extra resources need to be used for early completion of the project. However, there is a trade-off between CAC and CCS. Therefore, the contractor's actual project cost for early completion should include CAC and CCS. An appropriate incentive amount should be equal to or greater than the contractor's actual project cost for early completion. The minimum incentive amount can be calculated as follows:

$$\text{Minimum Incentive} = \text{CAC} - \text{CCS} \quad (5)$$

Maximum Incentive Amount

In addition, an appropriate incentive amount should be equal to or smaller than the benefits realized by early project completion. The benefits are quantified using the agency's actual cost savings and road user cost. For that reason, the maximum incentive amount can be calculated as follows:

$$\text{Maximum Incentive} = \text{RUC} + \text{AS} \quad (6)$$

I/D Implementation Decision

To make a go or no-go decision for I/D contracting, it is important for the agency to compare the contractor's actual project cost for early completion and the benefits, such as the

agency's actual cost savings and the road user cost. The contractor's actual project cost for early completion should not exceed the benefits. If the contractor's actual project cost for early completion exceeds the benefits, I/D contracting should not be implemented. Consequently, the minimum incentive must not exceed the maximum incentive amount as follows to implement I/D contracting:

$$\text{CAC} - \text{CCS} < \text{RUC} + \text{AS} \quad (7)$$

STEP 7: Daily Incentive and Maximum Incentive Amount

Daily Incentives

An appropriate daily incentive should be equal to or greater than the contractor's actual project cost for early completion and should be equal to or less than the agency's benefits, such as the agency's actual cost savings and the road user cost.

$$\text{CAC} - \text{CCS} \leq \text{Daily Incentive} \leq \text{DRUC} + \text{AS} \quad (8)$$

Based on the discount factor chosen in the previous step, the daily incentive amount can be decided.

Maximum Incentives

Once the daily incentive amount is decided, then the maximum incentive can be calculated by multiplying reduced days caused by acceleration. The maximum incentive amount should be equal to or smaller than the agency's benefits, such as total agency's actual cost savings and road user cost.

STEP 8: Daily Disincentive and Maximum Disincentive Amount

Daily Disincentives

Regardless of the discount factor chosen, the ideal daily disincentive amount can be calculated. The ideal amount should be equal to the benefits, including the agency's actual cost savings and road user cost.

$$\text{Daily Disincentive} = \text{DRUC} + \text{AS} \quad (9)$$

However, it is proper for an agency to use the same amount as the daily incentive calculated in the previous step as a daily disincentive amount.

Maximum Disincentives

It is not recommended to calculate or set a limit for disincentives.

VII. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Although I/D contracting has been used in many states and significant amounts of money have been spent on I/D projects, there is as yet no systematic decision-making procedure for the determination of I/D dollar amounts to assist project planners and engineers and to refine the use of the I/D contracting process. This research developed an innovative I/D assessment modeling procedure to determine appropriate I/D amounts for early completion of highway projects, considering the costs/benefits to the agency, contractor, and users in terms of both dollars and time. Based on the results of the I/D project case studies, the systematic procedures to determine appropriate I/D dollar amounts were developed using the CA4PRS schedule-traffic integration process for new I-5 southbound rehabilitation project in Kern County. The systematic procedures to determine I/D dollar amounts utilizing CA4PRS analysis are briefly summarized in the following steps:

- STEP 1: Set up a schedule baseline based on CA4PRS schedule analysis.
- STEP 2: Evaluate the impact of work zone on the traveling public, especially road user cost based on CA4PRS traffic analysis.
- STEP 3: Estimate contractor's cost for additional resources for I/D acceleration and contractor's saving from schedule compression. Also, estimate the contractor's savings in their field operation cost with the project duration reduction results from the schedule acceleration.
- STEP 4: Estimate agency's cost savings from schedule compression.
- STEP 5: Determine reasonable value of discount factors to split I/D benefits and costs between the contractor and the agency with some sensitivity analysis.
- STEP 6: Make a decision on the I/D implementation based on the comparison of additional acceleration cost and field operation cost savings for the contractor and benefits to road users and the agency from schedule compression.
- STEP 7: Set up daily incentive amount and maximum incentive amount based on the above-described procedure and parameters and project budget constraints.
- STEP 8: Set up daily disincentive amount and maximum disincentive amount based on the above-described procedure and parameters.

In summary, the research provides a better understanding of the relationship between the I/D dollar amount and project time and cost performance. In addition, the proposed procedure to determine an appropriate I/D dollar amount for a highway construction project will provide systematic guidelines and procedures to improve I/D contracting strategies for Caltrans project engineers and managers.

RECOMMENDATIONS

The use of I/D provisions for project early completion of highway projects has helped STAs to improve project time performance, potentially reducing traffic delays and other inconveniences to the traveling public. However, the implementation of I/D provisions generally increases project costs to the contracting agency, and should therefore be used sparingly, only for those critical closures where traffic inconvenience and delays are to be held to a minimum. The I/D amounts are based upon estimates of such items as primarily road user delay, traffic safety and maintenance costs, and agency cost savings or revenue benefits. In essence, I/D provisions need to be applied to lane restriction and closures and ramp/connector closures where traffic inconveniences and delays must be minimized by early completion of construction.

For a more effective analysis of I/D contracting, it is recommended that more completed I/D project data be collected and the historic I/D project database be updated periodically for analysis of project performance evaluation. In addition, the effectiveness of the I/D amount proposed should be evaluated on a project-by-project basis to refine the use of I/D contracting. As more data become available, in-depth statistical analyses can be performed to identify the impact of daily and/or maximum I/D dollar amounts on project time performance. Eventually, the proposed process will help to assist transportation project planners and engineers and to develop systematic I/D amount calculation procedures.

FUTURE STUDIES FOR IMPLEMENTATION

The I/D framework process introduced in this study was applied to a typical highway pavement rehabilitation project using HMA materials. A similar case study is needed for a typical concrete pavement rehabilitation, using its own resource inputs for schedule acceleration. More study is needed to apply the concept to other types of highway projects with some adjustment. For example, the proposed I/D calculation process can be used for a roadway widening project with relevant schedule baseline and resource inputs for acceleration. The CA4PRS new version (V3.0), scheduled to be released in early 2012 has a new module for roadway widening schedule analysis that can produce the schedule baseline for the I/D calculation.

Once the systematic I/D calculation process's logic and input/output configuration are confirmed, the current prototype, which is running on an Excel spreadsheet, should be converted into a more professional program for practical implementation. In the meantime, more collaboration with the contractor and the transportation agency is needed to test and implement the new I/D system. More outreach effort is needed to propagate the new I/D system through some training for end-users after a small number of I/D implementation demonstration projects.

Finally, for the improvement of the proposed I/D calculation process, it is important to validate whether the proposed I/D calculations have an impact on contract performance in terms of both time and budget.

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AS	Agency Saving
CA	Cost of Acceleration
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
CAC	Contractor's Additional Cost
CALTRANS	California Department of Transportation
CCS	Contractor Cost Savings
CHP	California Highway Patrol
CPI	Cost Performance Index
DF	Discount Factor
DOT	Department of Transportation
DRUC	Daily Road User Cost
EA	Expenditure Authorization; abbreviation precedes a project identification number at Caltrans
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FSHCC	Fast Setting Hydraulic Cement Concrete
HMA	Hot Mix Asphalt
I/D	Incentive or Disincentive
JPCP	Jointed Plain Concrete Pavement
LLPRS	Long-Life Pavement Rehabilitation Strategy
MnDOT	Minnesota Department of Transportation
MOT	Maintenance of Traffic
NCHRP	National Cooperative Highway Research Program
NEEP	National Experimental and Evaluation Program
OCPI	Cost Performance Index Based on Original Contract
ODOT	Oregon Department of Transportation
OTPI	Time Performance Index Based on Original Contract
RUC	Road User Cost
STA	State Transportation Agency
TMP	Transportation Management Plan
TPI	Time Performance Index

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Jae-Ho Pyeon, Ph.D., is an assistant professor in the Department of Civil and Environmental Engineering at San José State University. Dr. Pyeon received both his master's and doctoral degrees in civil and coastal engineering from the University of Florida. Currently, Dr. Pyeon is a university representative on the Transportation Research Board and a member of the Construction Research Council, American Society of Civil Engineers. Dr. Pyeon conducts research in transportation construction engineering and management and teaches undergraduate and graduate courses in construction project management, construction information technology, construction scheduling and estimating, and heavy transportation construction equipment.

Dr. Pyeon has published 22 peer-reviewed journal or conference papers in the last five years. His research interests include seeking efficient ways to improve the highway construction planning and process, assessing uncertainty in construction, and developing decision support systems to assist project planners and managers. Specific research areas are transportation construction project delivery systems, work zone road user cost, transportation management plans, project risk management, and innovative contracting methods, such as Incentives/Disincentives, No-Excuse Bonus and A+B.

Dr. Pyeon has successfully performed several federal- and/or state-funded transportation construction research projects, including Improving Transportation Construction Project Performance – Development of a Model to Support the Decision-Making Process for Incentive/Disincentive Construction Projects; Evaluation of Alternative Contracting Techniques on FDOT Construction Projects; Improving the Time Performance of Highway Construction Contracts; Development of Improved Procedures for Managing Pavement Markings During Highway Construction Projects; and Development of Procedures for Utilizing Pit Proctors in the Construction Process for Pavement Base Materials. He also serves as an external reviewer of FHWA's Work Zone Road User Cost research project and as an active reviewer of several major journals in the area of construction engineering and management.

EUL-BUM LEE, PH.D., P.E., PMP

Eul-Bum Lee, Ph.D., P.E., PMP, has more than 20 years of experience in heavy construction, mainly in the varied disciplines of transportation projects, including design and engineering, project management and control, and academic research. Currently working as an associate researcher and co-principal investigator in the Institute of Transportation Studies at the University of California, Berkeley, Dr. Lee has focused on researching and implementing innovative methods for rehabilitating transportation infrastructure.

Dr. Lee earned M.E. and Ph.D. degrees in the Engineering Project Management Program of the Department of Civil and Environmental Engineering at UC Berkeley. He earned his B.S. degree in civil engineering at Seoul National University. Before beginning his doctoral work, Dr. Lee spent 12 years with Hyundai Engineering and Construction, Inc.,

as a manager of international megaprojects in Asia, Europe, and North America. One of his greatest successes with the company was serving as the project coordinator for the engineer, contractor, and owner, for a long-span concrete, precast box girder bridge project (the Jamuna Multipurpose Bridge Project in Bangladesh), which was funded with \$1.3 billion from the World Bridge Fund, as a turnkey (design-build) project.

Dr. Lee's research led to the creation of Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software, a scheduling and traffic analysis tool developed to help decision makers at transportation agencies select the most economical strategies for highway projects. The Technology Implementation Group (TIG) of the Association of American State Highway and Transportation Officials (AASHTO) has selected CA4PRS for nationwide promotion to its state members and is considering assigning the software as a product of AASHTOWare for marketing nationwide. The Federal Highway Administration (FHWA) formally endorsed CA4PRS as a Priority, Market-Ready Technologies and Innovations Product in 2008 for nationwide deployment. In addition, the FHWA is in the process of arranging free group licenses for all states to deploy the software nationally in the United States. CA4PRS won a 2007 Global Road Achievement Award granted by the International Road Federation. Recognized nationally for his contributions to the research and implementation of new industry practices, Dr. Lee has received a number of awards, including the California Department of Transportation's 2005 Excellence in Transportation Awards (Innovation and Public Outreach).

Dr. Lee is actively involved in the academic and professional communities in construction/project management and transportation engineering. Currently, he is serving as a committee member, expert group member, or journal reviewer for the American Society of Civil Engineers (ASCE), AASHTO, FHWA, and the Transportation Research Board (TRB). He has published approximately 23 peer-reviewed journal papers and 25 conference proceedings in a variety of professional civil engineering society and transportation journals.

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