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Setting Maximum Incentive for Incentive/Disincentive Contracts for Highway Projects

Jin-Fang Shr, M.ASCE,[1] and Wei Tong Chen[2]

Abstract: An increasing number of State Highway Agencies (SHAs) are utilizing Incentive/Disincentive (I/D) bidding for highway construction. The I/D bidding concept is designed to shorten the total contract time by giving the contractor an incentive for early completion and a disincentive for late completion of a project. SHAs are then presented with the problem of determining the maximum incentive that may be awarded to the contractor. This maximum incentive amount is affected by construction cost, time, and the incentive/disincentive formula. Many SHAs use a fixed amount or fixed percent of construction cost as a maximum incentive amount. However, overestimation of the maximum incentive amount may waste public money and underestimation will reduce the effectiveness of the incentive. This research offers a quantifying model to determine a reasonable maximum incentive amount and uses projects from the Florida Department of Transportation (FDOT) to illustrate this model that is only suitable for linear I/D. A functional relationship between the construction cost and time duration is developed from the FDOT's data. The curve with the functional relationship between the construction cost and time duration is then combined with the incentive/disincentive line to determine the optimum maximum days for incentive and incentive amount. Finally, several projects completed by the FDOT will be used to illustrate the validity of this model.

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Introduction

Incentive/disincentive (I/D) contracts are used not only to provide an incentive to the contractor for early completion, but also to provide a disincentive for late completion of a project. Generally, I/D contracts are limited to those projects whose construction would severely disrupt highway traffic or highway services, significantly increase road users' costs, considerably affect adjacent neighborhoods or businesses, or close a gap thereby providing a major improvement in the highway system. I/D is assessed on a daily basis and can be used to achieve specific milestones within a project or to encourage timely completion of the total contract (FDOT 1996–1997, 1997–1998).

Currently most State Highway Agencies (SHAs) use a fixed amount or fixed percents of construction cost as the maximum incentive. As shown in Table 1, some states set the limits (also referred to as the "caps") as a percentage of the total construction cost; the caps are set mainly by using a value of 5% of the total construction cost. Other states set a flat-rate dollar amount to restrict the maximum amount of I/D fees; the New Jersey Department of Transportation (DOT) is one of the examples. Only one state (Arizona) had a limiting cap defined by time duration (±30 days) rather than dollar amount. Several states varied their cap amounts depending on the project. Some states even did not have any restrictions on the cap rates.

Although the basic concept of using the I/D is simple, there is variation. The bottom line of determining I/D rates is that the rates should be able to reflect the cost of saving/delay to the public and the saving/extra administration cost to the SHAs (Herbsman et al. 1995). According to Jaraiedi et al. (1995), the I/D amount should include various costs such as (1) safety of the users; (2) loss of user time due to the construction; (3) the increase in gasoline consumption; and (4) the increased administrative and monitoring associated with the use of an I/D contact. Most SHAs employ the daily road user cost (DRUC) as a basis for determining appropriate I/D amount (Herbsman et al. 1995) that is generally accepted, while some states count on other parameters. Similar to the calculation of the I/D rate, the DRUC is based on construction engineering inspection costs, traffic-control costs, detour costs, accident costs, and administrative costs (FHWA 1989; Jaraiedi et al. 1995). In Florida, the DRUC is calculated using the computer programs *Quewz* or *MicroBENCOST* that are available from the McTrans Center at the University of Florida.

In order to ensure the effectiveness of the incentive, SHAs would like to allocate a more accurate incentive budget. Overestimation of the maximum incentive may waste public money while underestimation will reduce the effectiveness of the incentive. Only considering a project's construction cost as the parameter to compute the current incentive estimation is incapable of addressing each individual project's specific traits.

This study develops a quantified model of the cost-time bidding contract. A functional relationship (equation) of the construction cost versus time duration is developed from the Florida De-

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Table 1. Incentive/Disincentive Cap Rates for Various State Highway Agencies (Herbsman et al. 1995; L. Rouen, CalTrans, J. Brewer, Kansas DOT, Personal Communication, Jan., 2002)

State	Cap
Alabama	None
Arizona	±30 days
Arkansas	None
California	Dollar amount[a]
Colorado	None
Delaware	None
Florida	Varies
Georgia	None
Idaho	Varies
Illinois	N/A
Indiana	Dollar amount[c]
Iowa	None
Kansas	Dollar amount[a]
Maine	Dollar amount[c]
Maryland	5%
Massachusetts	None
Michigan	5%
Minnesota	None
Missouri	10%
Montana	Varies
Nevada	Varies
New Hampshire	None
New Jersey	Dollars 100,000
New York	10%
North Carolina	Varies
North Dakota	5%
Ohio	5%
Pennsylvania	5%
South Dakota	None
Tennessee	None
Utah	Dollar amount[c]
Virginia	Dollar amount[b]
Washington	5%
Wisconsin	Varies
Wyoming	6–8%

[a]Fixed.
[b]Fixed except the A+B contracts.
[c]Fixed or negotiated not available.

partment of Transportation's (FDOT's) data. The equation is then combined with the I/D line to determine the optimum maximum incentive and duration. Finally, several projects completed by the FDOT will be used to illustrate the validity of this model.

Formulation of the Model

Construction Cost as a Function of Duration

Construction cost and time for undertaking a specific construction project are interrelated. Literature (Callahan et al. 1992; Munzer 1998) on construction project scheduling has reported that, for a specific construction company, there is an optimum cost-time balancing point for every construction contract without considering I/D. At this point, the contractor would have the lowest construction cost. In general, the interrelationship between cost and time for a construction project is expressed as the curve shown in Fig.

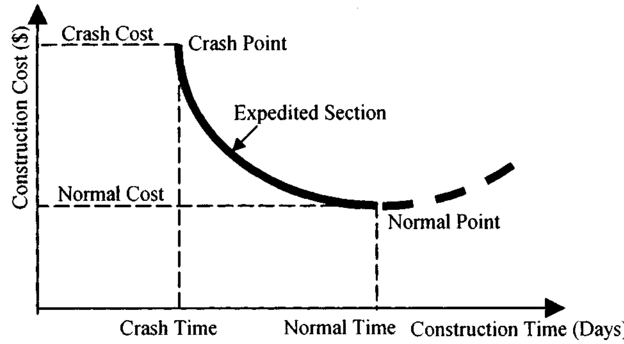

Fig. 1. Relationship between construction time and cost without considering incentive/disincentive

1. On this curve, the ''normal point'' represents the construction duration where construction cost (normal cost) is the lowest (Cusack 1991) without considering I/D. Any variation in time from the normal point may result in a corresponding increase in construction cost. For example, to shorten construction time may increase project direct cost due to the use of multiple shifts, overtime work, or other costly measures. An increase in the construction duration from the normal point may obviously incur an increase in general indirect cost (Shen et al. 1999).

Model Framework

Generally a contractor will complete the project in accordance with the contract time. However, when there is an incentive for the early completion of the project, the contractor may attempt to shorten the construction time so that the incentive can be earned. Referring to Fig. 2, SHAs can use the following steps to determine the maximum days for incentive and maximum incentive of a project:

1. The SHA estimates construction cost (C_0) and determine the corresponding contract time (D_0) (referring to Line 1);
2. Develop the functional relationship between the construction cost and time duration (CC);
3. Develop the incentive/disincentive equation (I/D) based on the linear I/D daily amount;
4. Add both equations (CC+I/D) to form the total project cost equation (TPC);
5. Locate the minimum TPC (C′) and the corresponding duration (B′) that is the SHA's optimized (allowable maximum) days for incentive. The SHA will pay more to the contractor to expedite the project for durations shorter than B′; and
6. Use I/D equation to calculate the maximum incentive (referring to Line 3) at the duration B′.

Model Formulation for Florida Department of Transportation Projects

Building an Equation for Construction Cost as a Function of Duration

In 1987, the Florida legislature passed the alternative contracting statute F.S. 337.025; the Time-Plus-Money contracting statute F.S. 337.11(04), and the Incentive/Disincentive statute F.S.337.18(4), along with a modified Design/Build statute F.F. 337.11(7) in response to the increasing demands on Florida highways by an ever-growing number of road users. The alternative

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Table 2. Florida Department of Transportation (FDOT) Project Progress Report — A+B Projects (1996/07/01–1999/04/16)

Financial management number	Start date	Work description	FDOT construction cost estimate (k) ($)	Award bid (k) ($)	Final construction cost (k) ($)	Bid days (d)	Final contract time[a] (d)	Days used (d)	FDOT maximum allowable days (d)	Incentive/ disincentive ($/d)	Incentive paid (k) ($)
210623	7/17/97	Replace	9,213	9,424	9,718	300	381	311	650	6,000	234.9
210897	3/1/98	Widen	3,359	3,101	3,151	101	162	145	Not applicable	2,694	43.1
217902	2/3/97	Replace	15,378	14,325	14,612	429	468	460	739	2,200	0
250164	10/2/98	Miscellaneous	1,775	1,551	1,601	199	199	142	Not applicable	2,000	100
257017	11/1/97	Resurface	3,119	2,945	2,991	120	142	135	135	5,000	35
257060	7/13/98	Resurface	1,432	1,700	1,800	150	160	97	Not applicable	3,000	150

[a]Final contract time means the contract time at the end. Because of the change order or other factors, the final contract time is different from the initial contract time.

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contracting techniques prompted by FDOT recently have been applied in a variety of ways, either as a single method or in combination with other methods.

The following statistical information is from the projects that were awarded by the FDOT using different contracting methods including the A+B contract, the I/D contract, and the No Excuse Bonus method during fiscal years 1996–1997 and 1997–1998. The A+B contract awards a project to the low bidder based on a monetary combination of all work to be performed (A) and the time needed to complete the project (B). The project time estimated by the low bidder thus becomes the project contract duration. Under the No Excuse Bonus method, the SHA gives the contractor a ‘‘special time frame date (or an incentive date)’’ for the completion of a phase or a project. The contractor will receive a bonus if the work is completed earlier than that day. However, when the contractor is incapable of meeting the incentive date, no excuse is acceptable, including inclement weather. Then the normal contract administration processes will be applied.

The projects examined for building the formula for construction cost as a function of duration are described in Tables 2–4. The six projects in Table 2 used the A+B contract method, the four projects in Table 3 used the I/D contracts, and the five projects in Table 4 adopted the No Excuse Bonus method. These projects from the FDOT were 100% finished before 04/16/99. Obtaining the actual construction durations of the projects is critical because these durations, literally serving as the inputs of the equations developed in this research, will directly affect the results.

From Tables 2–4, four columns of data were extracted for the analysis of variance for investigating the relationship between cost and time, followed by the regression analysis for fitting an appropriate model. These columns were Award bid, Final construction cost, Final contract time, and Days used. The Award bid is the price that the contractor bid. The Final construction cost is the final construction cost excluding incentive/disincentive. The Final contract time is the final contract time that is determined by FDOT and is adjusted for the weather or additional work. Days Used is the number of days that the contractor actually used. For each project, days used is a variation in time from the normal point (contract time) that results in a corresponding cost that is the construction cost.

Because the scopes of the projects were different, we employed two formulas to transform the data so that further analysis could be performed as shown in Table 5 which are (days used—final contract time)/(final contract time) and (final construction cost—award bid)/(award bid), then performed the analysis of variance for investigating the relationship between costs and time, determining whether or not the effect of the independent variable (days used—final contract time)/(final contract time) on the dependent variable (final construction cost—award bid)/(award bid) is significant. In conjunction with the last step (if significant), we use regression analysis to fit an appropriate model, to establish the internal relationship between cost and time.

Regression results and their variances are shown in Table 6. The statistical significance of the independent variable is given by the probability (Pr)-value which is defined in this work to be significant when it is smaller than 0.05 and mildly significant when it is between 0.05 and 0.20. Since the Pr-value of the variance is 0.002, this research concludes that the effect of the independent variable (days used—final contract time)/(final contract time) on the dependent variable (final construction cost—award bid)/(award bid) is significant. This conclusion reveals that there is a very strong link between these two variables. Based on this conclusion, we use regression analysis to fit the data for obtaining a suitable model. Because the corresponding Pr-values of the intercept, day, and day$\times$day are 0.0003, 0.1681, and 0.0072, we

Table 3. Florida Department of Transportation (FDOT) Project Progress Report—Incentive/Disincentive Projects (1996/07/01–1999/04/16)

Financial management number	Start date	Work description	FDOT contract estimate (k) ($)	Award bid (k) ($)	Final construction cost (k) ($)	FDOT contract time estimate (d)	Final contract time[a] (d)	Days used (d)	Incentive/ disincentive ($/d)	Incentive paid (k) ($)
195578	4/13/98	Resurface	2,598	2,914	2,972	200	233	301	Not applicable	0
237453	11/17/97	Add lane	3,356	3,437	3,534	245	327	297	Not applicable	162
242633	8/6/97	Resurface	13,764	14,136	14,617	440	575	515	Not applicable	475
258638	8/26/98	Resurface	328	273	290	120	120	81	Not applicable	10

[a]The final contract time means the contract time at the end. Because of the change order or other factors, the final contract time is different from the initial contract time.

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Table 4. Florida Department of Transportation (FDOT) Project Progress Report—No Excuse Bonus Projects (1996/07/01–1999/04/16)

Financial management number	Start date	Work description	FDOT contract estimate (k) ($)	Award bid (k) ($)	Final construction cost (k) ($)	FDOT contract time estimate (d)	Final contract time[a] (d)	Days used (d)	Incentive paid (k) ($)
200704	7/7/97	Bridge	1,285	1,172	1,305	185	185	84	100
240843	3/4/97	Add lane	4,169	4,333	4,415	340	401	401	300
251240	8/25/97	Add lane	6,676	4,220	4,300	400	400	397	300
251280	1/29/98	Add lane	4,243	3,177	3,323	400	400	266	400
257074	5/26/98	Resurface	1,210	1,280	1,330	175	192	172	0

[a]Final contract time means the contract time at the end. Because of the change order or other factors, the final contract time is different from the initial contract time.

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conclude that the intercept, day, and day×day are significant, mildly significant, and significant effects of the regression, respectively. The fitted model is

$$\left[\frac{C-C_0}{C_0}\right]=0.03214+0.10481\left[\frac{D-D_0}{D_0}\right]+0.46572\left[\frac{D-D_0}{D_0}\right]^2 \tag{1}$$

where C=final construction cost; D=days used; C_0=award bid; and D_0=final contract time.

Equation Shifting

As showing in Fig. 1, the "normal point" represents the construction plan where the construction cost is the lowest at a specific construction time without taking project I/D into account. Any variation in time from the normal point may result in a corresponding increase in construction cost. Eq. (1) expresses the interrelationship between construction cost and construction time. After C_0 and D_0 are decided, the curve is determined.

If the contractor's estimates are exactly the same as C_0 and D_0, his construction cost and time estimates should be at the normal point in Fig. 1. Since the interrelationship equation is from regression, usually C_0 and D_0 will not necessarily locate at the lowest point (the normal point). Because the research assumes C_0 and D_0 is at the normal point, some mathematical adjustment is needed to shift Curve 1 to let its lowest point (D_1,C_1) match the normal point as shown in Fig. 3. Here, C_1 is the minimum cost and D_1 is the corresponding duration. On Curve 2, the normal point represents the construction plan where construction cost is the lowest associated with a specific construction time without considering project I/D. The adjustment will not change the scale of the curve, but will move the lowest point of Curve 1 (D_1,C_1) to the normal point of Curve 2 (D_0,C_0). The shifting procedures from Curve 1 to Curve 2 can be summarized as follows:

1. Determine (D_0,C_0);
2. Use the set of (D_0,C_0) and Eq. (1) to determine the functional relationship between the construction cost and time duration of Curve 2 in Fig. 3;
3. Locate the point of minimum construction cost (D_1,C_1) of Curve 1 in Fig. 3;
4. Calculate the distance between (D_0,C_0) and (D_1,C_1); and
5. Shift the functional relationship between the construction cost and time duration using the distance from Step 4 and let (D_1,C_1) to match (D_0,C_0) in Fig. 3 (shifting Curve 1 to Curve 2).

After the adjustment (referring to Appendix I), the equation for Curve 2 in Fig. 3 is developed as shown below

$$C=1.0059C_0+0.1048C_0\left(\frac{D-1.1125D_0}{D_0}\right)+0.4657C_0\left(\frac{D-1.1125D_0}{D_0}\right)^2 \tag{2}$$

Eq. (2) assumes that every project has an internal relationship between the construction cost and time. Once (D_0,C_0) is decided, the functional relationship between construction cost and time is determined. When using Eq. (2), C and D are variables. Each D_0 has a corresponding C_0. C_0 and D_0 may be engineer's or contractor's estimates as will be illustrated later.

Listed in Table 2, the project FM210623 (bid days=300 days and award bid=$9,424,000) is used to illustrate this model. It isassumed that bid days and award bid are at the normal point. When applying this to Eq. (2), bid days is D_0 and award bid is C_0. The functional relationship between construction cost and time duration is

$$\begin{aligned}C&=1.0059\times 9{,}424+0.1048\times 9{,}424\times[(D-1.1125\times 300)/300]\\&\quad+0.4657\times 9{,}424\times[(D-1.1125\times 300)/300]^2\\&=9{,}475.6+987.63\times[(D-333.75)/300]+4{,}388.76\\&\quad\times[(D-333.75)/300]^2\\&=9{,}475.6+3.2921\times(D-333.75)+0.048764\times(D-333.75)^2\end{aligned} \tag{3}$$

Table 5. Data Correction for Regression Analysis

Financial management number	(Days used—final contract time)/final contract time (independent variable: DAY)	(Final construction cost—award bid)/award bid (dependent variable: COST)
210623	−0.1837	0.0312
210897	−0.1049	0.0161
217902	−0.0171	0.0200
250164	−0.2864	0.0322
257017	−0.0493	0.0156
257060	−0.3938	0.0588
229622	0.0133	0.0683
237453	−0.0917	0.0282
242633	−0.1043	0.0340
258638	−0.3250	0.0623
200704	−0.5459	0.1135
240843	0.0000	0.0189
251240	−0.0075	0.0190
251280	−0.3350	0.0460
257074	−0.1042	0.0391

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Table 6. Analysis of Variance Procedure

Source	DF	Sum of squares	Mean square	F value	Probability$>F$
Model	2	0.00739	0.00370	18.07	0.0002
Error	12	0.00246	0.00020		
Corrected total	14	0.00985			

R-Square=0.75071 C.V.=35.56890 Root mean square error=0.01431
COST Mean=0.04022 C.V.=Root mean square error/COST Mean

Parameter	Estimate	T	Probability$>\|T\|$	S.E.
Intercept	0.03214	5.06	0.0003	0.00635
DAY	0.10481	1.47	0.1681	0.07144
DAY*DAY	0.46572	3.23	0.0072	0.14407

Note: Since the model P value 0.0002 is quite small, the equation is adoptable. R-Square 0.75071 means 75% of total variation about the mean COST explained by the regression. Dependent variable: COST=(final construction cost—award bid)/award bid independent variable: DAY=(days used—final contract time)/final contract time. C.V.=coefficient of variation; and S.E.=standard error.

$$C=9{,}476+3.29\times(D-334)+0.05\times(D-334)^2$$

Based on Eq. (3), if D is 300 days, C will be \$9,424,000 that matches with C_0. Since the research assumes (C_0,D_0) is at the normal point, (C,D) should be at the normal point as well.

Incentive/Disincentive Equation

There are two types of I/D (linear I/D and escalating I/D) adopted by FDOT. For the linear I/D, contractor receives or is charged thesame daily amount regardless of the number of days completed early or late. For the escalating I/D, the earlier or later a job is completed, the greater the daily amount paid to or assessed against the contractor (FDOT 1996–1997, 1997–1998). Only the linear I/D that is determined by FDOT is discussed in this study. The anticipated maximum I/D amount (T) is equal to the linear I/D (I) multiplied by the difference in construction time (D) and contract time (D_1). It follows:

$$T=(I)\times(D-D_1) \tag{4}$$

In Eq. (4), every D that can earn incentive should be less than D_1. When D is smaller than D_1, T becomes negative and the total price to bid will be reduced by the anticipated incentive. This situation is beyond the scope of this study.

Minimize Total Project Cost

Adding Eqs. (2) and (4), the TPC is obtained as the following:

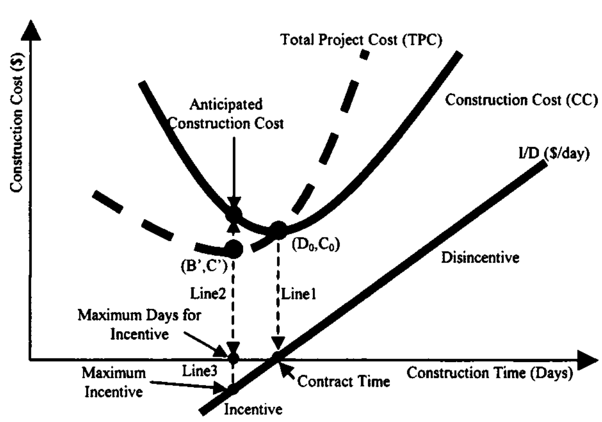

Fig. 2. Solution for state highway agencies to determine maximum days for incentive and maximum incentive

$$C=1.0059C_0+0.1048C_0\left(\frac{D-1.1125D_0}{D_0}\right)+0.4657C_0\left(\frac{D-1.1125D_0}{D_0}\right)^2+(I)\times(D-D_1) \tag{5}$$

In Eq. (5), D_0 is construction cost estimate and D_1 is contract time estimate. D_0 does not have to equal to D_1 in reality. Since there is no access to obtain D_0 before the bid, this research assumes that D_0 equals to D_1. Take the derivative of C in Eq. (5) with respect to D to find the minimum value of C. The value of D to minimize C is [the procedure of optimizing Eq. (5) is shown in Appendix II]

$$\text{Construction time } (D)=D_0-1.0736\times\left(\frac{I\times D_0^2}{C_0}\right) \tag{6}$$

The anticipated maximum days for incentive and the anticipated maximum incentive will be

$$\text{Anticipated maximum days for incentive}=(D_1-D) \tag{7}$$

$$\text{Anticipated maximum incentive}=I(D_1-D) \tag{8}$$

The determination of the maximum incentive is not an easy job. If the maximum incentive were not set high enough by the SHA, contractors would not be motivated to shorten the project duration. If the maximum incentive is higher than the anticipated maximum incentive calculated by using the model, the contractor might not be able to obtain as much incentive as possible. Even if the contractor achieves the maximum incentive, the TPC subtotal (construction cost plus incentive) would be higher than the lowest

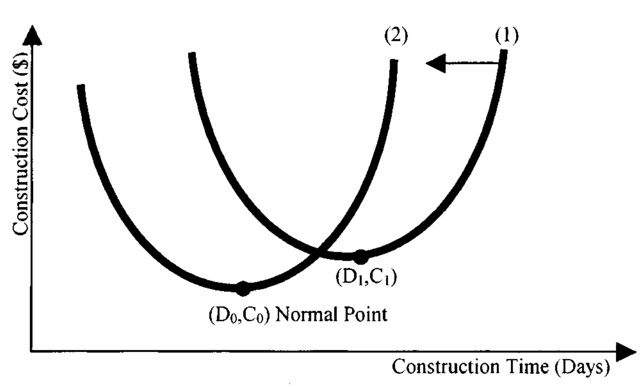

Fig. 3. Equation shift for construction cost as function of duration

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Table 7. Analysis Result—Project Set 1 (A+B+I/D Contract Type)

Financial management number	Estimator	Construction cost estimate (k) C_0 ($)	Contract time estimate D_0 ($)	Days used (d)	Days used +days of incentive[a] (d)	Incentive/ disincentive (k) ($/d)	Maximum incentive from model[b] (k) ($)	Column 9/Column 4 (%)	Maximum days for incentive from model (d)	Incentive/ disincentive paid[c] (k) ($)	I/C_0 [d] (%)	Days of incentive (d)	Contractor's contract time estimate/department of transportation contract time estimate ($)
210623	DOT	9,213	650			6	1,770	19	295				
	Contractor	9,424	300			6	372	4	62				46
	End of project	9,718	381	311	350	6				234	2.4	39	
210897	DOT	3,359	180			2.7	75.43	2	28				
	Contractor	3,101	101			2.7	26.94	1	10				56
	End of project	3,151	162	145	162	2.7				43	1	16	
217902	DOT	15,378	739			2.2	184.8	1	84				
	Contractor	14,325	429			2.2	66	0.5	30				58
	End of project	14,612	468	460	460	2.2				0	0	0	
250164	DOT	1775	N/A			2	N/A	N/A	N/A				
	Contractor	1551	199			2	110	7.1	55				N/A
	End of project	1601	199	142		2				100	6.2	50	
257017	DOT	3,119	135			5	155	5	31				
	Contractor	2,945	120			5	130	4	26				89
	End of project	2,991	142	135	142	5				35	1	7	
257060	DOT	1,432	165			3	183	13	61				
	Contractor	1,700	150			3	129	8	43				91
	End of project	1,800	160	97	147	3				150	8	50	

[a]Column 6+Column 14.
[b]Column 8×Column 11.
[c]Column 8×Column 14.
[d]Column 8/Column 14.

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Table 8. Analysis Result—Project Set 2 (A+B+I/D Contract Type)

Financial management number	Estimator	Construction cost estimate (k) C_0 ($)	Contract time estimate D_0 ($)	Days used (d)	Days used +days of incentive[a] (d)	Incentive/disincentive (k) ($/d)	Maximum incentive/ from model[b] (k) ($)	Column 9/ Column 4 (%)	Maximum days for incentive from model (d)	Incentive/disincentive paid[c] (k) ($)	I/C_0[d] (%)	Days of incentive (d)	Contractor's contract time estimate/department of transportation contract time estimate
229629	DOT	3,849	485			2.7	477.9	12	177				
	Contractor	3,643	385			2.7	318.6	9	118				79
	End of Project	3,986	478	369	369	2.7				0	0	0	
238320	DOT	7,534	485			3.5	409.5	5	117				
	Contractor	6,900	385			3.5	283.5	4	81				79
	End of Project	7,557	437	372	437	3.5				228	3	65	
242692	DOT	5,883	350			3	201	3	67				
	Contractor	4,938	214			3	90	2	30				61
	End of Project	5,070	342	342	342	3				0	0	0	

[a]Column 6+Column 14.
[b]Column 8×Column 11.
[c]Column 8×Column 14.
[d]Column 8/Column 14.

possible TPC. Unless required, the contractor would not expedite construction at the cost higher than the incentive he can obtain. In summary, it is in the SHA and contractor's best interest to have the project completed with minimum TPC and anticipated maximum incentive since the minimum TPC is the best from the public viewpoint.

Model Examples

It should be noted that the model is only suitable for predicting the maximum days for incentive or maximum incentive for linear I/D contracts. To predict the possible maximum days for incentive or maximum incentive, SHA can use the engineer's cost and time estimates to run this model. After the bid is let, SHA also can use the contractor's award bid and contract time to run this model and predict the possible maximum days for incentive or maximum incentive at the end.

Analysis of a Florida Department of Transportation Project

Both Tables 7 and 8 illustrate the analysis results of the FDOT A+B+I/D projects using the equations developed in this research. FM238320 (Table 8) is an example project from the FDOT. This example project is not used to create the model. At the bid letting, FDOT's contract time estimate was 485 days and construction cost estimate was $7,534,000. The DRUC was $3,500. Using (485,7534) as (D_0, C_0) and applying Eqs. (5) and (6), the maximum days for incentive is 117 days. From Eqs. (5) and (6), procedure of calculating the maximum days for incentive for FDOT is as follows:

$$D = D_0 - 1.0736\times(I\times D_0^2/C_0)$$

$$= 485 - 1.0736\times(3.5\times 485^2/7534)$$

$$= 485 - 117 = 368 \quad \text{(days)}$$

The maximum days for incentive

$$= D_1 - D = 485 - 368 = 117 \quad \text{(days)}$$

After the bid is awarded, the contractor's contract time is 385 days and the award bid is $6,900,000 that are placed into Eqs. (5) and (6) to calculate the maximum days for incentive. The process indicates that when (D_0, C_0) is (385,6900), the maximum days for incentive is 81 days. The contract time is 372 days, rather than the contracted 437 days. The contractor actually cut down 65 days (=437−372 days) and earned $227,500 (=65×3,500 $/day) as incentive. The procedure of calculating the maximum days for incentive for the contractor by using Eqs. (5) and (6) is as follows:

$$D = D_0 - 1.0736\times(I\times D_0^2/C_0)$$

$$= 385 - 1.0736\times(3.5\times 385^2/6900)$$

$$= 385 - 81 = 304 \quad \text{(days)}$$

The maximum days for incentive

$$= D_1 - D = 385 - 304 = 81 \quad \text{(days)}$$

From this example, FDOT's estimate of the maximum days for incentive (117 days) is higher than the contractor's estimate (81 days) that is closer to the actual days of incentive earned (65 days). It can be concluded that the contractor seems to have better prediction of the maximum days for incentive for the project.

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Analysis of Florida Department of Transportation Projects Set 1

Table 7 illustrates the analysis results of the Projects Set 1 as shown in Table 2. In Table 7, every project was also used to create the functional relationship between construction cost and time duration [Eq. (1)]. To determine whether the model can help FDOT to predict an acceptable maximum incentive, FDOT's contract time estimate and construction cost estimate are defined as (D_0, C_0). Using (D_0, C_0) in applying the model, each project has a maximum incentive (Column 9) and maximum days for incentive (Column 11) as shown in Table 7. The contractor can also employ the same model to forecast the possible maximum incentive and maximum days for incentive on the basis of his cost and time estimates of the project.

For example, FDOT's D_0 and C_0 for Project FM210623 are 650 days and $9,213,000, respectively. FDOT can use (650,9213) in applying the model to predict the maximum days for incentive and the maximum incentive for the project. After calculation, the maximum incentive ($1,770,000) and maximum days for incentive (295 days) of Project FM210623 are obtained as shown in Columns 9 and 11 (the row of "DOT") in Table 7.

Additionally the contractor's D_0 and C_0 for Project FM210623 are 300 days and $9,424,000, respectively. The contractor can use (300,9424) to run the model to obtain the possible maximum days for incentive and the maximum incentive for the project. After calculation, the maximum incentive ($372,000) and maximum days for incentive (62 days) of Project FM210623 are obtained as shown in Columns 9 and 11 (the row of "Contractor") in Table 7.

In Table 7, the rate of maximum incentive from the model (Column 9) divided by construction cost estimate from the FDOT (Column 4) ranges from 1 to 19%. Three out of five projects are less than 5%. Three out of five projects are almost more than twice the contractor's contract time estimate (Column 15). According to Table 7, it seems that the FDOT overestimated the necessary project contract time.

Fig. 4 illustrates the FDOT's maximum days for incentive from the model, the contractor's maximum days for incentive from model, and days of incentive earned by the contractor forthe five projects listed in Table 7. Since FDOT contract time estimate of Project FM250164 listed in Table 2 is not available, there is no way to calculate FDOT maximum days for incentive by using the model. As a result, Fig. 4 includes only the five projects shown in Table 7 because Project FM250164 was dropped. As shown in Fig. 5, it is obvious that FDOT's maximum days for incentive from the model is higher than the contractor's maximum days for incentive from the model and days of incentive actually earned. The contractor's maximum days for incentive from the model are closer to days of incentive actually earned. The data from Table 7 shows the validity of the model.

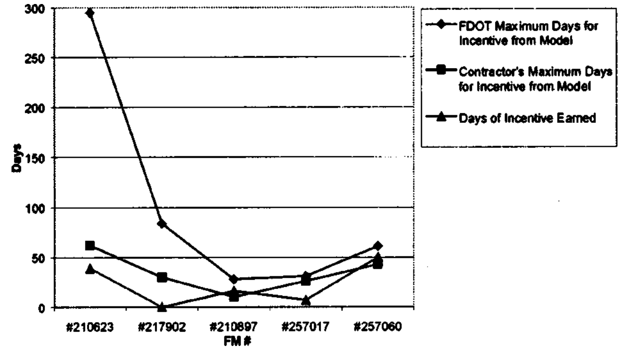

Fig. 4. Plot of maximum days of incentive for Projects Set 1

Analysis of Florida Department of Transportation Projects Set 2

In Table 8, no project was used to develop the model with the functional relationship between construction cost and time duration [Eq. (1)]. To determine whether the model can help FDOT predict an acceptable maximum incentive, FDOT's contract time estimate and construction cost estimate are defined as (D_0, C_0). Using (D_0, C_0) to run the model, each project has a maximum incentive (Column 9) and maximum days for incentive (Column 11) as shown in Table 8. The contractor can also use the same model to forecast the possible maximum incentive and maximum days for incentive on the basis of his cost and time estimates of the project.

For example, FDOT's D_0 and C_0 for Project FM229629 are 485 days and $3,849,000, respectively. FDOT can use (485,3849) to run the model to predict the maximum days for incentive and the maximum incentive for the project. After calculation, the maxi-mum incentive ($477,900) and maximum days for incentive (177 days) of Project FM229629 are obtained as shown in Columns 9 and 11 (the row "DOT") in Table 8.

Additionally the contractor's D_0 and C_0 for Project FM229629 are 385 days and $3,643,000, respectively. The contractor can also use (385,3643) to run the model to obtain the possible maximum days for incentive and the maximum incentive for the project. The maximum incentive ($318,600) and maximum days for incentive (118 days) of Project FM229629 are obtained as shown in Columns 9 and 11 (the row "Contractor") in Table 8.

In Table 8, the rate of maximum incentive from the model (Column 9) divided by construction cost estimate from the FDOT (Column 4) ranges from 3 to 12% while that of the contractor ranges from 2 to 9%. The comparison of the three projects in Table 8 indicates that the FDOT seems consistently overestimated the necessary project contract time.

Fig. 5 illustrates the FDOT's maximum days for incentive from the model, the contractor's maximum days for incentive from the model, and days of incentive earned by the contractor for three projects listed in Table 8. From Fig. 5, the days of incentive earned are all less than the FDOT's and contractor's maximum days for incentive from the model. The contractor's maximum days for incentive from the model is also less than

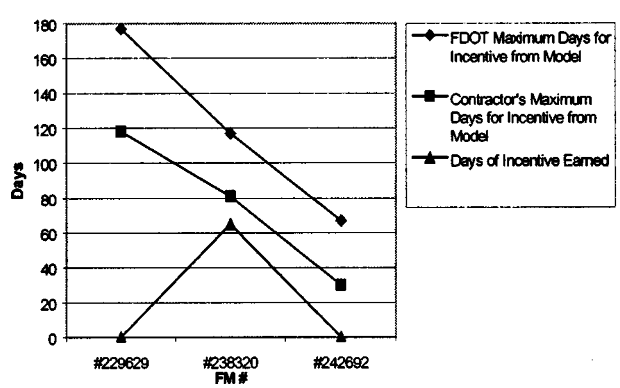

Fig. 5. Plot of maximum days of incentive for Project Set 2

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FDOT's maximum days for incentive from the model. The data from Table 8 also shows the validity of the model.

Conclusions

More and more SHAs are adopting I/D contracts because of time pressure. How to efficiently determine the maximum incentive has become a big challenge to SHAs. The overestimation or underestimation of the maximum incentive can lead to an inefficient use of public resources. Instead of using the quantifying model, most SHAs have used experience or a fixed percent of construction cost as the maximum incentive as shown in Table 1. Although more and more research reports explore related topics, most of them focus on the performance analysis or the procedure improvement.

In this study, an approach for predicting the project maximum days for incentive as well as the maximum incentive for SHAs and contractors is presented. By using data from FDOT projects, a quantified model to determine the maximum incentive values is developed and validated. The main equation used by this model is the functional relationship between the construction cost and duration. The findings of the study can be summarized in the following ways:

1. It seems that the FDOT consistently overestimated the necessary project contract time;
2. There is a need for DOT to develop a model to predict the maximum incentive;
3. The model developed by the study enables the DOT to predict acceptable maximum incentive and maximum days for incentive by using DOT's contract time and construction cost estimates;
4. The model can forecast contractor's maximum days for incentive and maximum incentive by utilizing his cost and time estimates of the project; and
5. The model developed is based on data of FDOT projects. Therefore it is only good for the prediction of FDOT projects.

Although the model is developed based on the data from FDOT projects, this model can be adopted by any SHA that plans to utilize I/D contracts. However, the functional relationship between the construction cost and duration needs to be developed by the client depending on construction type, location, and economic factors. It also should be known that the model should be project-dependent only.

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Appendix I. Deviation of Eq. (2)

$$\left[\frac{C-C_0}{C_0}\right]=0.03214+0.10481\left(\frac{D-D_0}{D_0}\right)+0.46572\left(\frac{D-D_0}{D_0}\right)^2 \tag{1}$$

$$C=1.03214C_0+0.10481C_0\left(\frac{D-D_0}{D_0}\right)+0.46572C_0\left(\frac{D-D_0}{D_0}\right)^2$$

$$\frac{\partial C}{\partial D}=0.10481\left(\frac{C_0}{D}\right)+0.93144C_0\left(\frac{D-D_0}{D_0^2}\right)^2=0$$

$$D=0.887475D_0$$

$$C=1.026246C_0$$

Minimum C Happen at $(0.887475D_0,1.026246C_0)$

Distance from (D_0,C_0) to $(0.887475D_0,1.026246C_0)$ $=(-0.11252D_0,0.026256C_0)$

Shift Eq. (1) with distance from $(0.887475D_0,1.026246C_0)$ to (D_0,C_0):

$$C+1.026256C_0=1.03214C_0+0.10481C_0\left(\frac{D-0.11252D_0-D_0}{D_0}\right)+0.46572C_0\left(\frac{D-0.11252D_0-D_0}{D_0}\right)^2$$

$$C=1.0059C_0+0.1048C_0\left(\frac{D-1.1125D_0}{D_0}\right)+0.4657C_0\left(\frac{D-1.1125D_0}{D_0}\right)^2 \tag{2}$$

Appendix II. The Procedure of Optimizing Eq. (5)

$$C=1.0059C_0+0.1048C_0\left(\frac{D-1.1125D_0}{D_0}\right)+0.4657C_0\left(\frac{D-1.1125D_0}{D_0}\right)^2+(I)\times(D-D_1) \tag{5}$$

$$\frac{\partial C}{\partial D}=0.1048\frac{C_0}{D_0}+0.93144\frac{C_0}{D_0^2}(D-1.1125D_0)+I=0$$

$$\text{Construction time }(D)=D_0-1.0736\times\left(\frac{\mathrm{I}\times D_0^2}{C_0}\right) \tag{6}$$

Notation

The following symbols are used in this paper:

C = final construction cost, construction cost;
CC = functional relationship between construction cost and time duration;
C_0 = award bid, construction cost estimate, normal cost;
C_1 = minimum construction cost;
D = days used, construction time;
D_0 = final contract time, construction time estimate, normal time;
D_1 = contract time; and
T = anticipated maximum incentive.

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