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針對高速工路建構工程成本與時間的函數關係

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Functional Model of Cost and Time for Highway Construction Projects

Abstract

It is commonly accepted that construction cost, time and quality performance has been regarded as the major success factors for a construction project. With the increasing use of innovative contracts in highway construction, the relationship between construction cost and time has become more crucial than ever. Improved control of time value has become necessary, for quantifying the functional relationship between construction cost and time. This study explores the functional relationship between highway construction cost and time. Data from projects of the Florida Department of Transportation (FDOT) in the US is utilized to develop and illustrate the quantifying model. The proposed model provides State Highway Agencies (SHAs) and contractors with increased control and understanding regarding the time value of highway construction projects.

Keywords: Contracting, highway construction, planning and scheduling

1. STATISTICAL ANALYSIS AND MODEL DEVELOPMENT

1.1. Model development

Based on Callahan,[6] this study assumes that Award Bid and Present Contract Time represent the best cost-time balancing point (or normal point) while avoiding the need to consider project I/D for every construction contract listed in Tables 1~3. At this point, the contractor would have the lowest construction cost, as in Figure 1. Days Used is a variation in time from the normal point that yields a corresponding construction cost- the Present Construction Cost. The Award Bid is the price bid by the contractor. Meanwhile, the final construction cost, excluding incentives and disincentives, is termed the Present Construction Cost. The Present Contract Time is the final contract time determined by FDOT, and is adjusted for the weather or additional work. The number of days actually used by the contractor is Days Used.

Four columns of data in Tables 1 to 3 are further analyzed to establish the internal relationship between cost and time: These four columns include Award Bid, Present Construction Cost, Present Contract Time, and Days Used. Due to the difference in the scope of each project, two formulae, (Days Used - Present Contract Time)/(Present Contract Time) and (Present Construction Cost - Award Bid)/(Award Bid), are used to transform the raw data to permit further analysis, as listed in Table 4. Second, analysis of variance for investigating the relationship between costs and time is performed to determine whether or not the independent variable (Days Used - Present Contract Time)/(Present Contract Time) significantly influences the dependent variable (Present Construction Cost - Award Bid)/(Award Bid). Third, in association with step 2 (if significant), regression analysis is performed to fit an appropriate model, which establishes the internal relationship between cost and time.

Table 5 lists the results of the variance and regression analysis. The p-value gives the appraisal of the statistical significance of the independent factor. A p-value is assessed as significant and mildly significant when it is below the threshold values of 0.05 and 0.20, correspondingly. Table 6 lists that the p-value of the analysis of variance is 0.002. Thus, this study concludes that the influence of the independent factor (Days Used - Present Contract Time)/(Present Contract Time) on the dependent factor (Present Construction Cost - Award Bid)/(Award Bid) is highly significant, implying these two factors are very strongly linked. This indicates that a functional relationship between these two factors can be established, and consequently it is reasonable to further apply regression analysis to fit an appropriate model. Regression analysis shows that the corresponding p-values of the Intercept, Day, and Day*Day are 0.0003, 0.1681, and 0.0072, respectively. Therefore, the parameters Intercept, Day, and Day*Day are concluded to have significant, mildly significant, and significant effects on the regression, respectively. As a result, the following fitted appropriate regression model is formulated,

$$\left(\frac{C - C_0}{C_0}\right) = 0.03214 + 0.10481\left(\frac{D - D_0}{D_0}\right) + 0.46572\left(\frac{D - D_0}{D_0}\right)^2 \quad\text{..(1)}$$

where

C - Present Construction Cost;

D - Days Used;

C_0 - Award Bid; and

D_0 - Present Contract Time

The model is extremely robust because it can be applied to all duration sizes. Most of the project costs fall in the 95% confidence interval of the predicted cost. The model was not validated due to limitations of new data resources. However, the model can be validated if more data become available in the future.

1.2. Shifting the curve

Equation (1) displays the interrelationship between construction cost and construction time. The curve is determined following the identification of the Award Bid and Present Contract Time. Since Eqn. (1) is generated from regression analysis, the Award Bid and Present Contract Time are not necessarily located at the normal point. That is, the "normal point" of Eqn. (1) does not occur at the Award Bid and Present Contract Time. This study assumes that the Award Bid and Present Contract Time is a "normal point" for every construction contract. To match the research assumption, Eqn. (1) must be modified to enable some shifting.

Figure 2 reveals that curve 1 is shifted so that its lowest point (D_1,C_1) matches the normal point (D_0,C_0) of curve 2. The normal point on curve 2 represents the construction plan in which the construction cost is the lowest associated with a specific construction time without considering project I/D. The scale of the curve does not change because of the shifting, but the lowest point of curve 1 (D_1,C_1) approaches the normal point of curve 2 (D_0,C_0). The shifting procedure is summarized as follows:

1. Determine (D_0,C_0);
2. Use Eqn. (1) and (D_0,C_0) to devise the functional relationship between the construction cost and time (represented by curve 2 in Fig. 2);
3. Locate the minimum point (D_1,C_1) based on the functional relationship between the construction cost and time represented by curve 1 in Fig. 2;
4. Calculate the distance between (D_0,C_0) and (D_1,C_1); and
5. Shift the functional relationship between construction cost and time using the distance from step 4 such that the minimum point occurs at (D_0,C_0) in Fig. 2 (shifting curve 1 to curve 2).

Following the adjustment (referring to Appendix), the equation for curve 2 in Fig. 2 is as follows:

where

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

C - Construction Cost;

D - Construction Time;

C_0 - Award Bid; and

D_0 - Present Contract Time

Equation (2) assumes every project has an internal relationship between construction cost and time. After determining the normal point (Present Contract Time, Award Bid), the functional relationship between construction cost and time is also fixed. When using Eqn. (2), C and D are defined as Construction Cost and Construction Time respectively, and both are variables. Each Construction Time has a corresponding Construction Cost. C_0 and D_0 may be the estimates of the engineer or contractor**.**

2. CONCLUSIONS

This study compiles projects completed by the FDOT to establish a model to demonstrate the functional relationship between construction cost and time for the collected highway construction projects. This proposed model not only can give SHAs and contractors increased control and understanding of the time value of highway construction projects, but also can enable contractors to adjust construction time and cost more flexibly, making it easier for them to win a bid. However, more research on construction cost indexes, explaining the cost differences due to location, period, and economic factors, is required to enable the proposed model to be widely used. The research methodology developed for this paper also can be extended to different types of projects. In addition, the model introduced in this study can provide a foundation for:

(1) Determining the maximum days of incentive in an I/D project, and a reasonable range of time duration in an A+B contract for SHAs; and

(2) Developing an improved strategy for determining the bid price for the I/D and A+B+I/D projects for contractors interested in such projects.

For case studies, this work selects projects that adopted A+B, I/D, and No Excuse Bonus. These types of projects were selected primarily because the FDOT has inventory of detailed data, including the contract time/cost and project completion time/cost for each project. In order to perform more accurate statistical analysis of the functional relationship between the construction cost and time requires research on project selection criteria, such as project type, period, location, and amount.

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APPENDIX- Deviation of Equation (1)

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

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

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

$$D\min = D_1 = \left(\frac{-0.10481+0.93144}{0.93144}\right)D_0 = 0.887475D_0$$

$$D_1 = 0.887475D_0$$

$$C_1 = 1.026246C_0$$

The minimum C is at $\left(0.887475D_0, 1.026246C_0\right)$

Distance from $\left(D_0, C_0\right)$ to $\left(0.887475D_0, 1.026246C_0\right) = \left(-0.11252D_0, 0.026246C_0\right)$

Shift Equation (1) minimum from $\left(0.887475D_0, 1.026246C_0\right)$ to $\left(D_0, C_0\right)$:

$$C + 0.026246C_0 = 1.03214C_0 + 0.10481C_0\left(\frac{D-0.11252D_0-D_0}{D_0}\right)$$
$$+ 0.46572C_0\left(\frac{D-0.11252D_0-D_0}{D_0}\right)^2$$

$$C = 1.0059\,C_0 + 0.1048\,C_0\left(\frac{D-1.1125\,D_0}{D_0}\right) + 0.4657\,C_0\left(\frac{D-1.1125\,D_0}{D_0}\right)^2 \quad \text{……..………(2)}$$

Table 1 Results of A+B projects awarded by FDOT

Project No. (1)	Work Description (2)	FDOT Contract Est. ($1,000) (3)	Bid Days (d) (4)	Award Bid ($1,000) (5)	Present Construction Cost ($1,000) (6)	Days Used (d) (7)	Present Contract Time[b] (d) (8)	FDOT Max. Allowable Days (d) (9)	I/D ($/d) (10)	I/D Paid ($1,000) (11)
238320[a]	Add Lanes	7,354	385	6,900	7,557	372	437	485	3,500	227.5
210623	Replace	9,213	300	9,424	9,718	311	381	650	6,000	234.9
210897	Widen	3,359	101	3,101	3,151	145	162	N/A	2,694	43.1
217902	Replace	15,378	429	14,325	14,612	460	468	739	2,200	30.8
250164	Resurface	1,775	199	1,551	1,601	142	199	N/A	2,000	100
257017	Resurface	3,119	120	2,945	2,991	135	142	135	5,000	0
257060	Resurface	1,432	150	1,700	1,800	97	160	N/A	3,000	0

[a]: Wasn't used to develop the model. [b]: The Present Contract Time is the contract time at the end of the project. That is different from the initial contract time due to change orders or other factors.

Table 2 Results of I/D projects awarded by FDOT

Project No. (1)	Work Description (2)	FDOT Contract Estimate ($1,000) (3)	FDOT Contract Time Estimate. (d) (4)	Award Bid ($1,000) (5)	Present Construction Cost ($1,000) (6)	Days Used (d) (7)	Present Contract Time[b] (d) (8)	I/D Paid ($1,000) (9)
194507[a]	Add Lane	6,247	505	6,199	6,742	572	572	0
195578 [a]	Resurface	2,598	200	2,991	2,972	301	233	0
231437[a]	Miscellaneous	376	140	332	376	144	144	0
229622	Resurfacing	7,321	510	7,112	7,598	533	526	200
237453	Add Lane	3,356	245	3,437	3,534	297	327	162
242633	Resurface	13,764	440	14,136	14,617	515	575	475
258638	Resurface	328	120	273	290	81	120	10

[a]: Wasn't used to develop the model. [b]: The Present Contract Time is the contract time at the end of the project. That is different from the initial contract time due to change orders or other factors.

Table 3 Results of No Excuse Bonus projects awarded by FDOT

Project No. (1)	Work Description (2)	FDOT Contract Estimate ($1,000) (3)	FDOT Contract Time Estimate (d) (4)	Award Bid ($1,000) (5)	Present Construction Cost ($1,000) (6)	Days Used (d) (7)	Present Contract Time[b] (d) (8)	I/D Paid ($1,000) (9)
213076[a]	Add Lane	12,473	295	10,866	11,817	373	373	375
257024[a]	Resurface	782	110	931	1,003	130	130	0
200704	Bridge	1,285	185	1,172	1,605	84	185	100
240843	Add Lane	4,169	340	4,333	4,415	401	401	300
251240	Add Lane	6,676	400	4,220	4,300	397	400	300
251280	Add Lane	4,243	400	3,177	3,323	266	400	400
257074	Resurface	1,210	175	1,280	1,330	172	192	0

[a]: Wasn't used to create the model. [b]: The Present Contract Time is the contract time at the end of the project. That is different from the initial contract time because of change orders or other factors.

Table 4 Data correction for regression analysis

Project No. (1)	Project Type (2)	(Days Used - Present Contract Time) / Present Contract Time (Independent Variable: DAY) (3)	(Present Construction Cost - Award Bid) / Award Bid (Dependent Variable: COST) (4)
210623	A+B	-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	I/D	0.0133	0.0683
237453		-0.0917	0.0282
242633		-0.1043	0.0340
258638		-0.3250	0.0623
200704	No Excuse Bonus	-0.5459	0.1135
240843		0.0000	0.0189
251240		-0.0075	0.0190
251280		-0.3350	0.0460
257074		-0.1042	0.0391

Table 5 Analysis of variance procedure

Source (1)	DF (2)	Sum of Squares (3)	Mean Square (4)	F Value (5)	Pr > F (6)
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 MSE = 0.01431; COST Mean = 0.04022 C.V. = Root MSE/COST Mean					
Parameter (1)	**Estimate (2)**	**T (3)**	**Pr > |T| (4)**	**S. E. (5)**	
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	
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.					

Notes: Dependent Variable: COST = (Present Construction Cost - Award Bid)/Award Bid
Independent Variable: DAY = (Days Used - Present Contract Time)/Present Contract Time

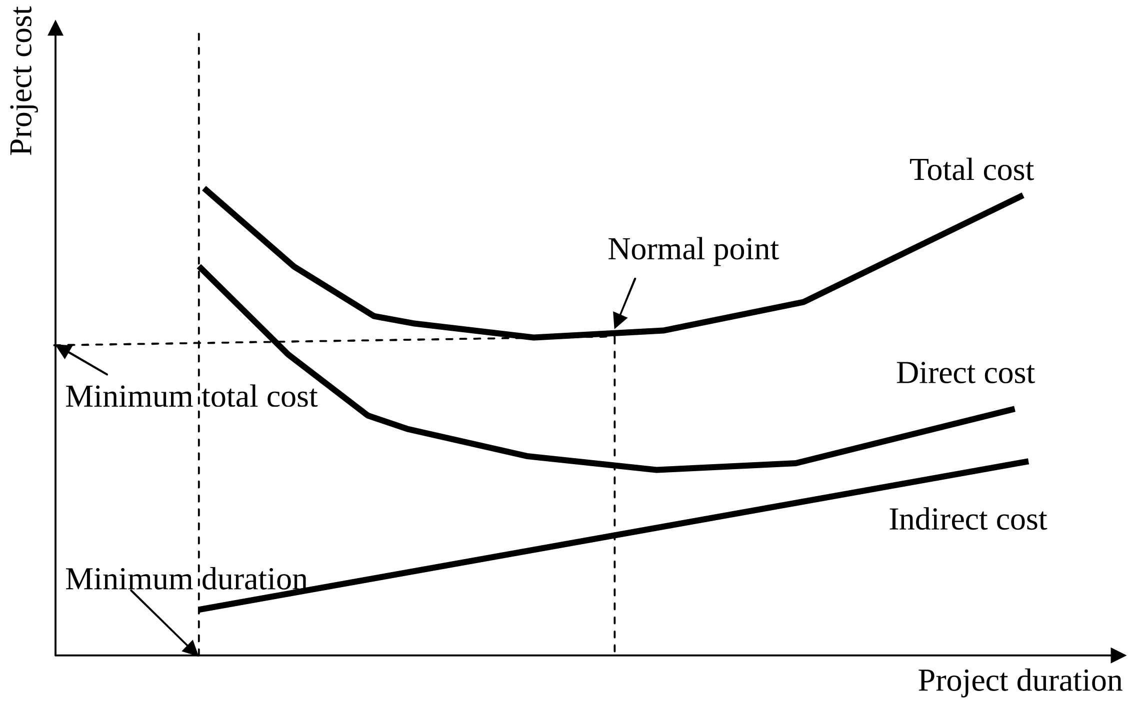

Fig. 1 Project cost and time relationship

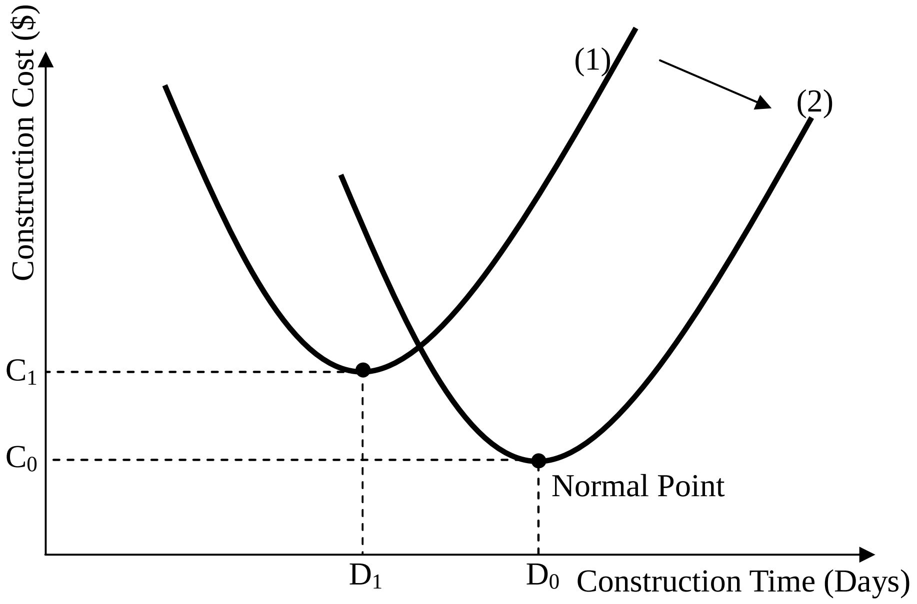

Fig. 2 Shift of the curve with the functional relationship between the construction cost and time