EVALUATION OF COST-TIME RELATIONSHIPS FOR CONTRACTORS PARTICIPATING IN COST-PLUS-TIME BIDDING

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ABSTRACT: State Highway Agencies (SHAs) have started utilizing cost-plus-time bidding (A+B bidding) since Federal Highway Agency (FHWA) declared it operational on May 4, 1995. Although this technique has successfully accelerated many projects by incorporating construction time in the bidding competition, a framework to illustrate the interactions of incentive/disincentive (I/D) rates on the competitiveness of contractors participating in the bid competition is yet to be developed. In a previous research, authors indicated that for each bid competition there is an efficient cap for I/D rates which are dictated by the capabilities of contractors in project acceleration. However, the results of previous study were based on the assumption that there is a statistically significant relationship between cost and time. In this study, the entire cost-plus-time projects implemented by the Oklahoma Department of Transportation (ODOT) were investigated. Then the significance of relationship between cost and time were analyzed for each contractor utilizing Analysis of Variance (ANOVA) technique, and the price-time function of each contractor was determined by regression analysis. The results of the analysis indicate that there is a significant relationship between cost and time for the majority of contractors. However, a quadratic relationship is not always significant and for some contractors a linear price-time relationship is significant. The results of this project can be used not only by ODOT to optimize the incentive/disincentive rates but also by contractors to determine the most competitive strategies of other bid participants.

Keywords: Cost-Time Relationship; ANOVA; Regression; A+B Bid; Incentive/Disincentive Rate; Bid Competition

1. INTRODUCTION

In previous studies it was indicated that the Unit Time Value (UTV) determined by SHAs in price time bi-parameter bidding can affect the competitiveness of contractors [1]. It was suggested in this study that characteristics of contractors and their project acceleration capabilities be taken into account when unit time value or incentive/disincentive rate are determined. In addition, very large or very small UTVs might significantly lower the competitiveness of certain contractors and result in a less competitive bid environment. It was also indicated that for every price-time bi-parameter bidding, there is a maximum threshold for UTV. For UTVs greater than that threshold there would be no contractor capable of accelerating construction with that rate.

In previous research studies performed by the authors it is indicated that if SHAs identify the price time relationship for the contractors participating in price time bi-parameter bidding, UTVs or incentive/disincentive rates can be determined more efficiently. However, the results are dependent on the validity of the assumption that for each contractor there is a particular cost-time relationship. Also to a particular contractor, there is an optimum cost-time point for every construction contract [2].

In this study, the actual A+B bidding data of Oklahoma Department of Transportation (ODOT) are analyzed and cost-time relationship models are created for contractors with sufficient number of A+B data. The models developed in this study use the historical bid data available to the public in the website of ODOT. The public access to this data enables all the current and prospective contractors of ODOT to study the bidding pattern of their competitors and adjust their strategies accordingly. It also provides ODOT with a methodology to determine the cost-time relationships of contractors.

The objective of this paper is to investigate the actual bid data of contractors participating in A+B bidding in Oklahoma Department of Transportation (ODOT) in order to determine the significance of cost-time relationships.

2. BACKGROUND

In price-time bi-parameter bidding (A+B bidding), the contract duration is determined by competition during the bid process. This procurement method incorporates value of construction time with the bid price in evaluating contractors' total combined bid (TCB). The successful bidder is the contractor who submits the lowest TCB using the following formula:

$$TCB = A + (UTV \times t) \quad \text{(Eq. 1)}$$

Where, A is contractor's bid price, UTV is the unit time value, and t is construction time. Unit time value (UTV) represents the cost of delays to the owner and needs to be calculated by the owner for every project.

Arditi et al. [3] suggest that the use of "A+B Bidding" in association with Incentive/Disincentive (I/D) contracts and its likely impact on contract efficiency need to be further explored. They expect that contract durations will be more realistic when the durations are set by the winning bidder compared to when it is set by the owner in I/D contracts. They also expect that "A+B Bidding" competition results in the elimination of inefficient contractors. Herbsman et al. [4] have also felt the need to study the interactions of A+B bidding and I/D provisions. In order to study the impact of I/D provisions on the A+B bidding, the cost-time relationships need to be determined.

The review of literature indicates that researchers and practitioners have shown great interest in identifying the cost-time relationship and they have come up with mixed results [5-7]. One important area that cost functions are necessary is project compression. With this cost functions for each task in a critical path method (CPM), project managers would be able to optimize the compression by minimizing both the duration and cost of project. Both linear and non-linear cost functions have been developed in the literature [5]. Moussourakis et al [5] believes that the type of cost function is dependent upon the nature of activity. In a study to find the time-cost relationship in Australian building construction projects, Love et al. [8] conclude that project cost is a poor measure of project time without considering project types. They developed a model to predict the time of building construction based on ground floor area and then the number of floors. Construction cost and time for undertaking a specific construction project are interrelated [9, 10]. Trost and Oberlender [11] have created a model to predict the accuracy of early construction cost estimates. According to their model, Bidding and Labor Climate is one of the significant factor groups influencing the accuracy of construction cost estimating. Since project schedule is one of the factors in this group, it can be inferred that project schedule can affect the accuracy of construction cost estimates. Callahan et al. [2] report that for a specific construction company, there is an optimum cost-time balancing point for every construction contract where construction cost is minimum.

2.1 Total Combined Bid Iso-Map

In A+B bidding, contractors are allowed to adjust their Total Combined Bid (TCB) by trading-off between contract time and bid price. As can be seen in Eq. 1, the contractor would be able to increase the construction duration (t) and keep the TCB constant by discounting the original bid price (A). Since TCB is the only factor that defines the winner of A+B bidding contract, all the bidding strategies that result in the same TCB have the same level of competitiveness. In fact, with a given UTV, Eq. 1 suggests that there are infinite combinations of bid price (A) and contract time (t) that give the same TCB. In a price-time right-angled coordinate diagram, these combinations form a line, which has been called Iso_line by Shen et al. (1999) as shown in Fig. 1. The slope of the Iso-line is determined by the UTV and since all the points on the line have the same TCB, the line is called TCB Iso-line. Therefore, A+B bidding can be reduced to a single parameter bidding by considering the total combined bid.

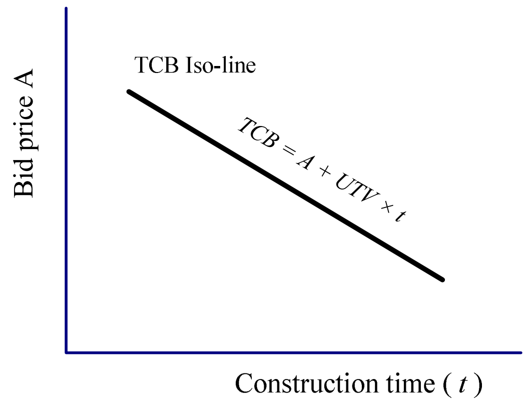

Figure 1. Contractor's overall competitiveness: TCB Iso-Line [10]

2.2 Time-Cost Function

To a particular contractor, there is an optimum cost-time point for every construction contract [2]. At this point, the contractor would have the lowest construction cost. In general, the interrelationship between construction cost and time can be expressed in a curve as shown in Figure 2 [12]. Upon development of the construction cost-time curve, the bid price-time relationship can be developed by adding a certain profit margin to the construction cost. Since the bid price-time curve is first decreasing and, after reaching its minimum, then increasing, several studies have suggested a quadratic or second-order polynomial function to approximate the relationship between bid price (A) and construction time (t) [10, 12-14].

$$A = a + b_1 t + b_2 t^2 \quad \text{(Eq. 2)}$$

Shen et al. (1999) suggests estimating the constants of the quadratic equation of time-price relationship by assuming three feasible bid plans based on the contractor's background and previous experience. One of these points is the shortest time bid plan which is also called the crash point. This is a point where the contractor is not able to compress the project duration further. The next point is the most likely bid plan by which the contractor tends to offer. And the third point is the lowest construction cost bid plan which is also called the normal point. By using these three data points and incorporating them in Eq. 2, three different equations are developed that can be used to solve for the three unknown constant values (a, b1, b2).

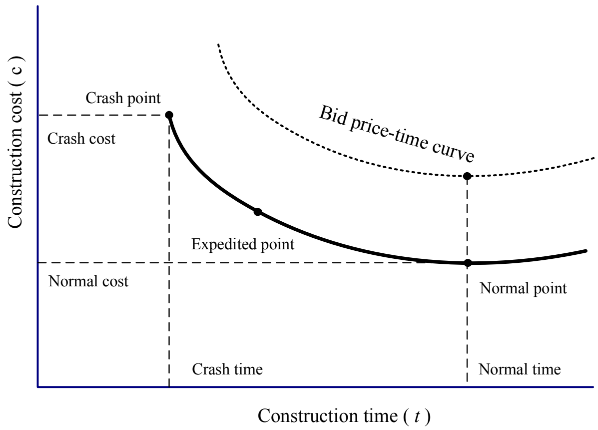

Figure 2. Construction cost and bid price versus time [12]

3. DATA PREPARATION

The data used in this study have been collected from the website of Oklahoma Department of Transportation (ODOT). It includes all the completed price-time bi-parameter bidding projects that ODOT has ever let. For the purpose of regression analysis, only the contractors that have three or more number of A+B projects are selected for further analysis in this study. The historical data base contains 58 data points for 14 contractors. The projects examined for building the formula for construction cost as a function of duration are shown in Table 1. The award bid is the price that the contractor bids. The final construction cost is the final construction cost excluding incentive/disincentive. The bid days are the duration proposed by the contractor during the A+B bidding process. The final contract time is the bid day that is adjusted for the weather, additional work, or change orders. Days used is the number of days that the contractors used to from the start of project to substantial completion. Also Incentive/Disincentive rates, Incentive cap, and Incentive paid to the contractor or the Disincentive that the contractor is charged are available for each project.

Because the scopes of projects are different, two indices are defined to represent the time and cost of each project in a manner that can be compared together. The equations utilized to calculate cost and time indices are as below:

$$\text{Time Index: } \frac{(\text{days used} - \text{final contract time})}{\text{final contract time}} \quad \text{(Eq. 3)}$$

$$\text{Cost Index: } \frac{(\text{final construction cost} - \text{award bid})}{\text{award bid}} \quad \text{(Eq.4)}$$

Table 2 shows the time and cost indices for Plains contractor. The time and cost indices are calculated for all the projects indicated in Table 1 as per the above mentioned equations. Then the analysis of variance is performed to investigate the relationship between cost and time indices, determining whether or not the effect of independent variable, time index, on the dependent variable, cost index is significant.

Table 2. Time and Cost Indices for Plain Contractor

Contractor	Contract ID	Cost Index	Time Index
Plains Bridge Contracting of Oklahoma, LLC	060121	0.0439	0.0482
	060386	0.0182	-0.0333
	070206	0.0183	-0.2179
	070206	0.0266	-0.2416

4. DATA ANALYSIS

For each contractor cost index trends are investigated based on time indices. The entire analysis is explained for Plains contractor. The cost index is fit to linear and quadratic functions of time index. A quadratic term, DaySq, is created in the analysis since polynomial effects such as Time*Time cannot be specified in the statistical model. The model is run for both linear and quadratic relationships between cost and time indices using SAS® software.

4.1 Linear Regression

The analysis of variance and parameter estimates tables for linear regression are displayed in Table 3. The F statistic of the linear model is not significant ($F = 1.03$, $p = 0.4168$), indicating that the model is not a good fit for a significant portion of variation in the data. The R-square indicates that the model only accounts for 34% of the variation in cost index. The fitted equation for this model is:

$$\text{Cost index} = 0.0323 + 0.04993 \times \text{Time index} \quad \text{(Eq.5)}$$

The graphical representations of output statistics are available in Figure 3. These diagnostics indicate an inadequate model because 1) the plots and studentized residual versus predicted value show a clear quadratic pattern, 2) the normal quantile plot of the residuals and the residual histogram are not consistent with the assumption of Gaussian errors because the residuals themselves still contain the quadratic behavior that is not captured by the linear model, and 3) the plot of cost versus the predicted value exhibits a quadratic form around the 45-degree line that represents a perfect fit. Figure 4 shows the Fit Plot consisting of a scatter plot of the data overlaid with the regression line, and 95% confidence and prediction limits. This plot also indicates that the model fails to capture nature of the data. The results of the linear regression analysis provide strong evidence that the TimeSQ needs to be added to the model.

Table 1 Historical A+B Bidding Information at Oklahoma Department of Transportation

Contractor	Contract ID	Award bid (k) ($)	Final construction cost (k) ($)	Final contract time (d)	Days used	Incentive /disincentive ($/d)	Incentive cap (k) ($)	Incentive paid (k) ($)
Becco	060001	21,126	20,744	375	383	10,000	350	-80
	060001	21,126	20,694	275	293	10,000	350	-30
	040221	16,879	16,724	490	428	15,000	900	900
	060306	1,947	1,964	125	154	5,000	625	-145
	080425	3,971	3,864	210	159	10,000	800	500
DUIT	090326	27,597	28,796	550	522	7,500	750	210
	040211	4,867	5,279	191	171	7,500	150	150
	040211	4,867	5,279	145	125	7,500	150	150
	060301	18,736	19,923	369	333	10,000	3,690	360
	070175	27,499	28,887	90	93	5,000	200	-15
Haskell Lemon	060214	4,072	4,153	210	204.3	2,000	420	11.5
	060341	10,750	10,808	273	273	5,000	300	-65
	070174	4,148	4,573	173	186	4,000	320	-180
	080166	4,444	4,679	200	157	2,000	120	84
	090003	7,400	7,671	135	73	5,000	300	300
APAC-Oklahoma	40194	3,883	3,329	198	181	10,000	150	150
	40348	3,214	3,200	120	87	3,334	10	10
	060333	2,174	2,011	125	104	10,000	200	200
	080319	4,400	4,405	60	66	7,000	420	-42
APAC-Central	080346	2,421	2,452	228	228	2,000	90	-156
	080365	2,806	3,039	200	170	7,000	210	210
	090536	4,320	4,283	231	231	4,000	200	200
	090536	4,320	4,447	60	51	4,000	100	36
Allen	050185	1,141	1,061	100	84	2,000	60	30
	060383	6,347	6,249	300	249	5,500	275	275
	070357	7,778	7,953	238	237	5,000	350	0
	080421	4,341	4,060	220	176	2,500	150	110
C-GAWF	080414	368	377	40	17	2,000	80	46
	080415	685	684	50	18	2,000	80	64
	090415	990	1.2	90	64	3,250	146.3	84.5
M.J. Lee	070021	1,071	982	105	71	5,000	150	150
	070028	1,353	1,352	125	84	5,000	150	150
	070200	3,518	3,467	190	164	3,350	201	83.8
Muskogee	080006	3,786	3,839	446	446	3,500	105	0
	080299	5,132	6,783	90	38	9,000	405	405
	080299	5,132	6,781	60	37	18,000	1,080	407.3
	090035	2,320	2,401	170	213	2,000	340	-86
OBC	080121	6,480	7,858	250	175	6,500	487.5	487.5
	080121	6,480	8,245	35	25	10,000	100	100
	090335	1,370	1,378	100	87	3,750	75	48.8
	100609	1,174	1,257	89	70	3,000	150	57
Plains	060121	4,078	4,257	166	174	2,500	100	-20
	060386	2,359	2,402	90	87	6,000	360	18
	070206	4,319	4,398	179	140	3,250	130	123.5
	070206	4,319	4,434	149	113	2,500	87.5	87.5
Sewell	050639	18,464	18,474	473	493	4,500	1,643	-90
	050639	18,464	18,334	70	40	1,667	117	50
	070102	865	853	30	18	4,000	60	44
	080374	6,290	5,993	217	172	5,000	300	23
	090624	4,603	4,481	263	263	3,550	320	0
Wittwer	070296	1,597	1,412	90	88	2,000	60	10
	080409	1,547	1,498	75	5	2,500	175	175
	080411	660	651	80	28	1,500	120	75

Table 3. Analysis of Variance Procedure for Linear Model

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.000149	0.000149	1.03	0.4168
Error	2	0.000289	0.000145		
Corrected Total	3	0.000439			

R-Square = 0.3402 C.V. = 44.97106 Root mean square error = 0.01203
Adjusted *R*-Square = 0.0103 Cost Mean = 0.02675 C.V. = Root mean square error/Cost Mean

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	0.03230	0.00813	3.97	0.0579
Time	1	0.04993	0.04917	1.02	0.4168

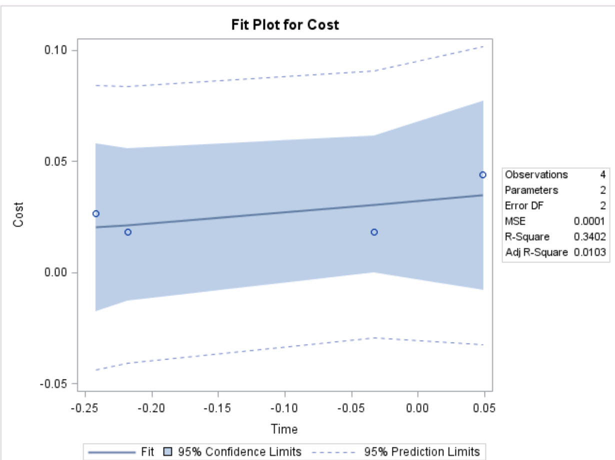

Figure 3. Fit Plot for Cost in the Linear Model

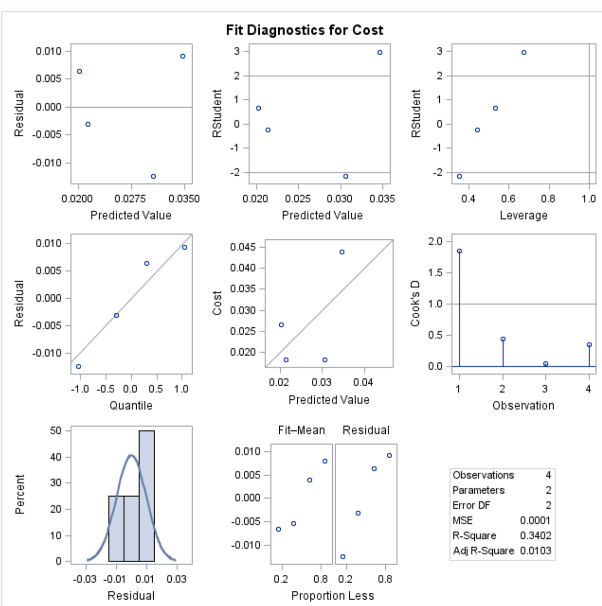

Figure 4. Fit Statistics for Cost in the Linear Model

Table 4. Analysis of Variance Procedure for Quadratic Model

4.2 Polynomial Regression

Consider a response variable Y that can be predicted by a polynomial function of an independent variable X. The polynomial function shown below is determined after estimating β_0, the intercept; β_1, the slope due to X; and β_2, the slope due to X_2.

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 X_i + \varepsilon_i \quad \text{(Eq. 6)}$$

For the observations i = 1,2,…,n.

Table 4 indicates the ANOVA table and parameter estimates for the new model. The overall *F* statistic is significant (F = 102.66, p < 0.1). The R-square has increased from 0.3402 to 0.9952, indicating that the model now accounts for 99.5% of the variation in Cost Index. All effects are significant with p < 0.06 for each effect in the model. The fitted equation is now

Cost index = 0.02655 + 0.30414 × Time + 1.24476 × TimeSQ (Eq.7)

Figure 5 shows the data, predictions, and residuals by Time index. These plots confirm that the quadratic polynomial model successfully model the cost index for contractor Plains.

Figure 6 shows the panel of diagnostics for this quadratic polynomial model. These diagnostics indicate that this model is considerably more successful than the corresponding linear model because 1) the plots of residuals and studentized residuals versus predicted values indicate no obvious patterns, 2) the points on the plot of the dependent variable versus the predicted values are on the 45-degree line, indicating that the model successfully predicts the behavior of the cost index.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.000437	0.000218	102.66	0.0696
Error	1	0.000002	0.000002		
Corrected Total	3	0.000439			

R-Square = 0.9952 C.V. = 5.45088 Root mean square error = 0.00146
Adjusted *R*-Square = 0.9855 Cost Mean = 0.02675 C.V. = Root mean square error/Cost Mean

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	0.02655	0.00110	24.08	0.0264
Time	1	0.30414	0.02267	13.42	0.0474
TimeSQ	1	1.24476	0.10708	11.62	0.0546

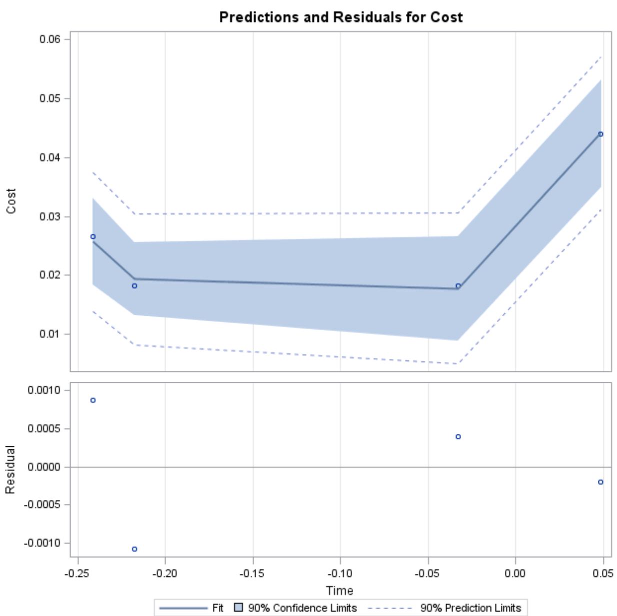

Figure 5. Fit Plot for Cost in the Quadratic Model

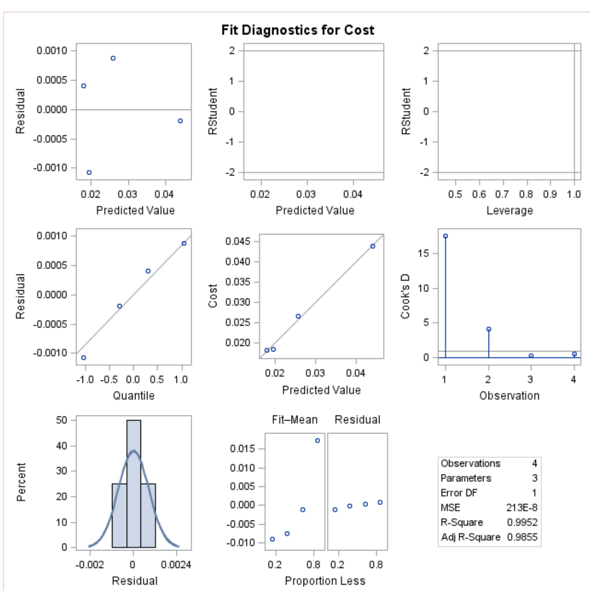

Figure 6. Fit Statistics for Cost in the Quadratic Model

5. RESULTS

The ANOVA and regression analysis is performed for all the contractors individually. The results of the analysis are shown in Table 5. For each contractor the ANOVA reveals that whether or not the relationships between the dependent and independent variables (Cost Index and Time index respectively) are significant. The regression analysis also results in the linear and quadratic equations that relates cost index to time index combined with the R-squares which is a goodness of fit factor.

As can be seen in the results of the analysis, for Wittwer, The Cummins, and C-GAWF there are only three data points to fit the price-time curve. For these contractors, the quadratic equation is the curve that passes through all the data points which results in R-square of equal to 1. For Wittwer and C-GAWF the linear regression can explain the relationship between cost index and time index as well. The R-squared of the linear curves in this case are 0.7880 and 0.9617 accordingly with *P* values of 0.3046 and 0.1255 indicating that the linear equation can also relate dependent variable to independent variable. However, for the Cummins the R-squared value for linear equation is very low (0.0531) with *P* value of 0.8519 indicating that the relationship between dependent and independent variables cannot be explained by a linear equation. For Sewell and Plains the *P* values for polynomial regression are 0.0636 and 0.0696 respectively indicating a significant relationship between time index and cost index with confidence level of 90%. Also the R-squared values for these contractors are 0.9364 and 0.9952 meaning that the fitted curves would predict 93.64% and 99.52% of variations in cost index. The ANOVA and regression results for the Haskell Lemon indicate the lowest R-squared values for both linear and polynomial regression analyses. For other contractors, the R-squared value ranges from 0.6371 to 0.9250. Although for some contractors the *P* value is larger than 0.1, the large R-squared value indicates that the fitted curve accounts for variation in the Cost index.

Table 5. Results of ANOVA and Regression Analyses for ODOT Contractors

Contractor	Data	Linear Regression			Polynomial Regression		
		P Value	Equation	R-squared	P Value	Equation	R-squared
Wittwer	3	0.3046	y = -0.1036 x - 0.109	0.7880	-	y = -0.2498 x2 - 0.3305 x - 0.1228	1.0000
The Cummins	3	0.8519	y = 0.0085 x - 0.0111	0.0531	-	y = -0.2235 x2 - 0.0578 x - 0.0004	1.0000
Sewell	5	0.9752	y = -0.0017 x - 0.0192	0.0004	0.0636	y = 0.7991 x2 + 0.3095 x - 0.0194	0.9364
Plains	4	0.4168	y = 0.0499 x + 0.0323	0.3402	0.0696	y = 1.2448 x2 + 0.3041 x + 0.0266	0.9952
OBC	4	0.0636	y = -1.4800 x - 0.2034	0.8768	0.3189	y = 5.3035 x2 + 0.8055 x + 0.0171	0.8983
Muskogee	4	0.0773	y = -0.4238 x + 0.0980	0.8513	0.3674	y = 0.2565 x2 - 0.3402 x + 0.0778	0.8650
M.J. Lee	3	0.7786	y = 0.1378 x + 0.0034	0.1162	-	y = 104.7365 x2 + 48.6140 x + 4.6767	-
C-GAWF	3	0.0171	y = 0.4702 x + 0.2974	0.9993	-	y = 0.2338 x2 + 0.6828 x +0.3398	1.0000
Allen	4	0.1672	y = 0.4159 x - 0.0235	0.6936	0.5527	y = 0.4420 x2 + 0.4992 x + 0.0243	0.6945
APAC-Central	4	0.2018	y = -0.3607 x + 0.0021	0.6371	0.2018	y = 98.9734 x2 + 0.0292 x + 0.0289	0.6371
APAC-Oklahoma	4	0.9231	y = 0.0329 x - 0.0517	0.0059	0.2739	y = 3.5154 x2 + 0.6018 x - 0.0972	0.9250
Haskell Lemon	5	0.7572	y = 0.0334 x + 0.0476	0.0368	0.8120	y = 0.4815 x2 + 0.2244 x + 0.0462	0.1880
DUIT	5	0.1292	y = -0.2204 x + 0.0495	0.5901	0.2044	y = 2.6500 x2 + 0.0360 x + 0.0450	0.7956
Becco	5	0.1625	y = 0.0552 x - 0.0126	0.5311	0.3518	y = 0.1712 x2 + 0.0580 x - 0.0172	0.6482

For OBC, Muskogee, and Allen linear regression is performing better than polynomial regression in terms of *P*-values. For Duit and Becco the linear regressions are performing better in terms of *P*-values however, the R-squared values of polynomial regression are larger indicating that the quadratic curves are a better fit for the data. There are only three points to fit a curve for M.J. Lee and linear regression is not indicating significant relationship between independent and dependent variables. In addition, the quadratic curve passing through the only three available points in the data set is over-fitting the data. The performance of linear and polynomial regression models for the APAC-Central are similar. Therefore for this contractor the linear model is selected to relate cost index to time index. For APAC-Oklahoma polynomial regression model outperforms the linear model with R-squared value of 0.9950 and *P*-value of 0.2739.

The fitted model for Sewell is:

$$\left[\frac{C - C_0}{C_0}\right] = -0.0194 + 0.3095\left[\frac{D - D_0}{D_0}\right] + 0.7991\left[\frac{D - D_0}{D_0}\right]^2 \quad \text{(Eq.8)}$$

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

By rearranging the equation we will have the following equation:

$$C = 0.9806\, C_0 + 0.3095\, C_0\left[\frac{D - D_0}{D_0}\right] + 0.7991\, C_0\left[\frac{D - D_0}{D_0}\right]^2 \quad \text{(Eq.9)}$$

This equation illustrates the internal relationship between the construction cost and time for Sewell. The functional relationship between construction cost and time is determined by deciding (D_0, C_0). The (D_0, C_0) can be SHA's or contractors' estimate about the expected duration and construction cost of the project at the normal point. The normal point is the location on the price-time curve where the construction cost is the minimum. Table 6 shows the price-time functions for different contractors participating in price-time bi-parameter bidding in Oklahoma Department of Transportation.

Table 6. Results of ANOVA and Regression Analyses for ODOT Contractors

Contractor	Equation
Wittwer	$C = 0.8772\ C_0 - 0.3305\ C_0 \left[\frac{D - D_0}{D_0}\right] - 0.2498\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
The Cummins	$C = 0.9996\ C_0 - 0.0578\ C_0 \left[\frac{D - D_0}{D_0}\right] - 0.2235\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
Sewell	$C = 0.9806\ C_0 + 0.3095\ C_0 \left[\frac{D - D_0}{D_0}\right] + 0.7991\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
Plains	$C = 1.0266\ C_0 + 0.3041\ C_0 \left[\frac{D - D_0}{D_0}\right] + 1.2448\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
OBC	$C = 0.7966\ C_0 - 1.4800\ C_0 \left[\frac{D - D_0}{D_0}\right]$
Muskogee	$C = 1.0980\ C_0 - 0.4238\ C_0 \left[\frac{D - D_0}{D_0}\right]$
C-GAWF	$C = 1.3398\ C_0 + 0.6828\ C_0 \left[\frac{D - D_0}{D_0}\right] + 0.2338\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
Allen	$C = 0.9765\ C_0 + 0.4159\ C_0 \left[\frac{D - D_0}{D_0}\right]$
APAC-Central	$C = 1.0021\ C_0 \quad 0.3607\ C_0 \left[\begin{matrix} D - D_0 \\ D_0 \end{matrix}\right]$
APAC-Oklahoma	$C = 0.9028\ C_0 + 0.6018\ C_0 \left[\frac{D - D_0}{D_0}\right] + 3.5154\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
DUIT	$C = 1.0450\ C_0 + 0.0360\ C_0 \left[\frac{D - D_0}{D_0}\right] + 2.6500\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$
Becco	$C = 0.9828\ C_0 + 0.0580\ C_0 \left[\frac{D - D_0}{D_0}\right] + 0.1712\ C_0 \left[\frac{D - D_0}{D_0}\right]^2$

8. CONCLUSIONS

In this paper the historical A+B bid data of Oklahoma Department of Transportation were analyzed to identify the time-cost relationships. Only contractors that had performed three or more A+B resurfacing projects were selected for the purpose of this study. This was due to the fact that three is the least number of data points to fit a quadratic curve. The review of literature indicated that both linear and quadratic relationship has been considered to model the relationship between time and cost. Therefore, both linear and polynomial analyses were performed using SAS® software. Since the scope of projects was not identical, normalized cost and time indices were calculated and used in the ANOVA and regression analysis. The results of ANOVA and regression analysis indicated that for the majority of contractors there is a significant relationship between time and cost. The price-time curves developed for nine out of fourteen contractors that have performed three or more A+B contracting job for Oklahoma Department of Transportation have R-square of 80% or more. In other words, for the majority of the contractors the developed models account for 80% or more of the variation in Cost Index. For some contractors a quadratic relationship is significant and for others a linear relationship.

The results of this study shed light on the cost-time function of contractors working for Oklahoma Department of Transportation (ODOT). This study shows an application of data mining in extracting knowledge from the historical bid information. The review of literature indicates that the main obstacle in developing price-time curves have been lack of access to contractors' internal financial information. In other words, contractors are reluctant in providing access to their financial information in order to remain competitive in the market by not revealing their strategies. The ability to determine the cost-time function of contractors would enable not only Oklahoma Department of Transportation (ODOT) to evaluate the capabilities of contractors in terms of construction acceleration but also contractors to analyze the bidding strategies of their competitors in order to obtain the competitive edge for winning the bid competition.

As the continuation of this study the authors would perform case studies to analyze the impact of different Unit Time Values (UTVs) on the competitiveness of contractors in A+B bidding. The results of these studies would enable State Highway Agencies (SHAs) to determine the optimum Incentive/Disincentive rates that maximize the competition among contractors and result in selection of the most efficient contractor in construction acceleration.

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