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Forecast Models for Actual Construction Time and Cost

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FORECAST MODELS FOR ACTUAL CONSTRUCTION TIME AND COST

Abstract:

The actual construction time and cost of construction projects may be affected by the client, project and contractual characteristics and in many cases can be very different from the contract time and cost. In this paper, details of 93 Australian construction projects are used to develop several models for actual construction time and cost prediction. A forward crossvalidation regression analysis is used for the development of the model for actual construction time forecast when client sector, contractor selection method, contractual arrangement, project type, contract period and contract sum are known. The standard deviation of the deleted residual indicates the best model for actual construction time prediction to comprise the independent variables log contract time, lump sum procurement and non-standard contractor selection. Regression models are also developed for forecasting the actual construction time and cost when client sector, contractor selection method, contractual arrangement and project type are known while contract period and contract sum are estimated. Different forms of regression analyses, including the standard regression and the crossvalidation regression, are used and the crossvalidation regression model with the smallest deleted residual sum of squares is selected.

Since these models for time and cost are dependent on the contract period and contract sum being known, it is necessary to investigate the effects in situations where these have to be estimated. The results of the sensitivity analyses show that the errors in predicted actual construction time become smaller as the contract period increases. In contrast, the errors in predicted actual construction cost are virtually the same for large and small projects.

The effects of different project type, contractor selection method and contractual arrangement are also examined. The results indicate that the actual construction time for industrial project is the longest when compared with residential, educational and recreational projects and that significant savings in actual construction time can be achieved when negotiated tender and design and build contract are used instead of the traditional open tendering and lump sum contract approaches.

Finally, some practical applications of the models are illustrated for predicting the actual construction time and cost based on the risks and uncertainties of different client sector, contractor selection method, contractual arrangement and project type.

Keywords: Construction, time, cost, forecasting, regression, crossvalidation.

INTRODUCTION

An accurate forecast of construction time and cost is crucial to contract administration as the predicted duration and cost forms a basis for budgeting, planning, monitoring and even litigation purposes. In practice, there are two common methods for estimating construction time and cost: (1) according to the client's available budget and time constraints, i.e. occupancy need, or (2) through a detailed analysis of work to be done and resources available, using estimates of the time and cost requirements for each specific activity (Telford, 1994). The detailed estimation of construction activities usually relies on the estimators' experience and judgement to correctly interpret project and site information and make the best possible decisions (Alfred, 1988).

To reduce the subjectivity of time-cost estimation, Bromilow (1969) developed a regression model for predicting contract duration based on the estimated final cost of construction project. The model, commonly known as Bromilow's Time-Cost (BTC) model[1], is used by clients and contractors for estimating and benchmarking the contract period of construction projects. Various research studies in Australia (Bromilow and Henderson, 1976; Bromilow *et al*, 1980, 1988; Ireland, 1983; Mak, 1991; Ng *et al*, 2000; RAIA, 1989; Sidwell, 1984; Walker, 1994, 1995), United Kingdom (Kaka and Price, 1991), Hong Kong (Chan, 1999; Kumaraswamy and Chan, 1995) and Malaysia (Yeong, 1994) revealed that the time taken to construct a project is highly correlated with the construction size as measured by cost. Ireland (1983:137) concluded that the BTC model is "the best predictor of construction time".

[1] Detailed discussion of the BTC model can be found in Ng *et al* (2001)

Despite the development and use of the BTC model for construction time-cost estimation (developed at the pre-contract stage), the actual construction time and cost (at the post-contract stage) might be influenced by risks and uncertainties emanated from different client sector, project type, contractor selection method and contract arrangement approach. According to Walker (1994), one shortcoming of the BTC model is that it fails to consider factors other than cost when establishing the contract duration.

Several research studies (Ireland, 1983; Laptali *et al*, 1996) have been carried out to improve the accuracy of the BTC model. Ireland (1983) developed a multiple regression model based on the construction time, cost, area and number of storeys. Progress was halted by the occurrence of unreasonably high standard errors. Walker (1994) also measured construction time performance in terms of the gross floor area of a building. However, problems occurred as the construction cost included a significant external works component, which present difficulties in measuring construction scope per unit of construction time.

This paper examines the relationships among the actual construction time/cost and other contract details, such as the estimated construction time and cost, client sector, project type, contractor selection method and contractual arrangement, through 93 recently completed construction projects in Australia. The results indicate that relationships exist between the actual construction time/cost and other contract details as mentioned. This leads to the development of several regression models for actual construction time and cost prediction. Analyses were conducted to examine the sensitivity of the regression models considering the likely inaccuracy in the estimated contract time and cost. The results indicate that the regression models could assist clients and contractors to predict the actual construction time and cost pertinent to a particular client sector, project type, contractor selection method and contractual arrangement when estimated contract time and cost become available.

DATA

Useful data of recently completed construction projects were collected by postal questionnaire survey. Bromilow *et al* (1988) argued that attempts to obtain too much information would be counter-productive, and consequently only the essential variables in which researchers (e.g. Bromilow, 1969; Bromilow and Henderson, 1976; Bromilow *et al*, 1980; Ireland, 1983; Laptali *et al*, 1991; Yeong, 1994; Mak, 1996; Walker, 1995; Chan, 1999; Ng *et al*, 2001) believed to have an influence on a project's time-cost performance were sought. The data requested included the company name, project name, project location, client sector, project type, contractor selection method, contractual arrangement, original contract period, actual contract period, original contract sum, and final contract sum.

The population was confined to projects having a contract value more than AUS$0.5 million completed in the past eight years. Projects below AUS$0.5 million were considered to have limited scope and complexity. For logistical reasons, the survey was limited to projects completed between 1991 and 1998.

Construction companies from two biggest cities of New South Wales, Australia, i.e. Sydney and Newcastle, were considered in this study. Names and addresses of 100 construction companies were obtained by random selection from the telephone directories under the classification of "Building Contractors". Telephone interviews were conducted with the companies and 44 indicated that they were interested in the study and could provide the required data.

A survey package containing a covering letter, survey instructions, six separate sets of survey questionnaires and stamped self-addressed envelopes was distributed to each company. The companies were asked to provide the details of up to six projects for analysis. Due to the sensitivity of the data required, 12 companies dropped out from the study at this stage. The 32 remaining companies provided 93 completed project surveys. This represents a reasonable response rate of 35% (based on 264 project surveys distributed).

The average time for construction was 237 working days, the longest and shortest times being 864 and 60 working days respectively. All costs were rebased to March 1998 prices using the Building Price Index (BPI) in the price book (Rawlinsons, 1998). The average rebased cost of projects in the sample was AUS$21.4 million, the lowest and highest costs being AUS$0.5 million and AUS$619 million respectively.

ANALYSIS

The first analysis aims to develop a model for forecasting actual construction time when client sector, contractor selection method, contractual arrangements, project type, contract period and contract sum are known. This model is more relevant to the post-contract stage as the contract period, contract sum, and other contract details are readily available during this stage. The model will assist the client and contractor predicting the actual construction time required to complete a project.

Forward Crossvalidation Regression

In this analysis, the dependent variable is the actual construction time (ATIME) to practical completion. Various forms of ATIME were considered, including log and power transformations. The choice of dependent variable is very much restricted due to the difficulties in comparing models with different forms of dependent variables. Bromilow (1969) and others (e.g. Chan, 1999; Ng *et al*, 2000) have shown log construction time to be the generally most appropriate variable to analyse. This (LATIME) was then used as the dependent variable. The form of the independent variables is less of a problem and various forms can be examined and compared for their contribution. Dummy variables may be created for the categorical factors of client sector, project type, contractor selection method and contractual arrangements but, with only 93 cases to analyse, this cannot be done in any nonarbitrary way. The method of analysis eventually chosen was to concentrate solely on the various forms of contract time (CTIME) and contract cost (CCOST) as independent variables, with the intention of checking the residuals for any significant sub-group (within client sector, project type, contractor selection method and contractual arrangements) effects.

The regression model was built by a forward crossvalidation procedure. Each independent variable was tested separately for inclusion by the standard deviation of the deleted residual. As a result, the log contract time (LCTIME), with a deleted residual standard deviation of 0.179, was selected for inclusion in the model. The next stage was to repeat the test for inclusion of further form of cost and time variables (Table 1). No improvement to the deleted residual standard deviation was found and therefore the procedure stopped.

< Table 1 >

The deleted residuals of the final model were analysed for differences between the sub-groups of client sector (SECTOR), contractor selection method (SELECTION), contractual arrangements (CONTRACT) and project type (TYPE). Table 2 shows the results of the ANOVA means tests and Levine variance homogeneity tests. The SELECTION and CONTRACT groups produced significantly different means, with selective tendering residuals being higher than 'other' forms of contractor selection (mainly negotiated) and lump sum being higher than design and construct contractual arrangements. This indicated that at least one variable was missing from the regression equation. Dummy variables were therefore created for the SELECTION sub-groups of selective tendering and 'other' and the CONTRACT sub-groups of lump sum and D&C and entered into a forward stepwise crossvalidation regression on LATIME along with LCTIME (Table 1). This showed the best model to comprise the independent variables LCTIME and the 'other' and 'lump sum' dummies. Analysis of the subgroups showed that the significant differences had disappeared (Table 2).

< Table 2 >

Although the procedure is essentially nonparametric, it is of interest to check the Gauss assumptions. The fitted model to all the data is:

$$LATIME = 0.207638 + 0.966737(LCTIME) + 0.097269(LS) - 0.083980(OT) \quad \ldots (1)$$

(R=0.96984455, R^2=0.94059846, Adjusted R^2=0.93859616, $F_{(3,89)}$=469.76, p<0.0000, Std. Error of Estimate=0.16382, see Table 3) where LATIME, LCTIME, LS and OT denote the log-actual time, log-contract time, lump sum dummy variable and 'other' selection dummy variable. D-W's d=1.592, K-S d=0.104 (p>0.2) and the ANOVA on categorised LCOST is $F_{(3,89)}$=1.262 (p=0.292), suggesting the regression assumptions are not unduly violated.

< Table 3 >

'Standard' Crossvalidation Regression

To avoid the arbitrary nature of the forward crossvalidation regression, a 'standard' crossvalidation was conducted. This involves simultaneously entering **all** the independent variables into the equation. The model used was:

$$y = \alpha_{0j}\beta_0 + \alpha_{1j}\beta_1 x_{1j} + \alpha_{2j}\beta_2 x_{2j} + \alpha_{3j}\beta_3 x_{3j} + ... + \alpha_{nj}\beta_n x_{nj} \qquad (\beta \geq 0) \qquad \ldots (2)$$

where α_{0j} , α_{1j}, α_{2j}, α_{3j} , ..., α_{nj} are the crossvalidation regression coefficients and x_{1j}, x_{2j}, x_{3j}, ..., x_{nj} are the values of the independent variables for the $j=1, 2, ... , n$ cases (projects). The β_0, β_1, β_2, β_3, ..., β_n coefficients are computed to minimise the deleted residual sum of squares (ssq) by means of a quasi-Newton algorithm. The α coefficients are then calculated for all the (noncrossvalidation) data and the $\alpha\beta$ products obtained. This method enables the best crossvalidation model to be found, the β coefficients, once computed, being simply multiplied by the α coefficients. Table 4 summarises the results (the columns 'alpha', 'beta1' and 'ab1' give the α , β and $\alpha\beta$ coefficients and the last two rows give the residual ssq and deleted residual ssq)[2]. This shows that the standard regression model ('alpha' column), as expected produced a better residual ssq than the crossvalidation regression ('ab1' column) with 2.11909 compared with 2.15984 but that the crossvalidation regression produced a better deleted residual ssq than the standard regression with 2.43525 compared with 3.12966 (ssq=2.43525 = 0.162 deleted residual standard deviation – representing a marginal improvement on the 0.168 of the forward method). As the 'ab1' coefficients show, the 16 independent variables plus the constant show seven to be redundant for crossvalidation prediction, with zero β coefficients.

< Table 4 >

Actual Construction Time

The column 'beta2' in Table 4 gives the results when β is unconstrained and 'ab2' provide the consequent $\alpha\beta$ coefficients. The ssq results show that the residual ssq values to be worse than the 'ab1' model but the deleted residual ssq value is better at 1.77817. The last two models, 'beta3' and 'beta4', are obtained by setting all α coefficients to unity, with the 'beta3' model for $\beta \geq 0$ and the 'beta4' model for unconstrained β. The 'beta3' model, with 10 zero coefficients is close to the model obtained earlier by forward crossvalidation, whilst the 'beta4' model has a reduced deleted residual ssq of 2.09846 against 2.37386. However, the 'ab2' model is preferred because of its smallest deleted residual ssq of 1.77817.

Actual Construction Cost

[2] The raw CCOST, $CCOST^2$ and $CTIME^2$ could not be handled by the procedure, presumably due to scaling problems.

Table 4 also gives the results of the various models when applied to forecasting the actual construction cost (forward crossvalidation regression was not used). This shows a similar pattern of results to the time forecasts, with the ‘alpha’ (ordinary regression) model having a good residual ssq (1.08674) but relatively poor deleted residual ssq (1.77806). The crossvalidation model ab1 again has a worse residual ssq (1.15303) and better deleted residual ssq (1.02433). Again, the ‘ab2’ model produces the best forecasts, with a deleted residual ssq of only 0.56923, against 1.17982 and 1.08395 for the ‘beta3’ and ‘beta4’ models respectively, making the ‘ab2’ the preferred model once again.

SENSITIVITY ANALYSIS

All the models described to this point assume that the contract period and contract sum are known. In practice, this is rarely the case, and contract period and contract sum are simply estimated from whatever information is available at time of estimation. Therefore, since the prediction of actual construction time and cost is based on the estimated contract period and contract sum, it is necessary to examine how sensitive the prediction models are when the contract period and contract sum deviate from their estimates.

Assume a contract sum of $10M and the other project particulars are public sector client, residential building, open tendering and lump sum contract. The actual construction time for a range of projects with an estimated contract period of 100 to 1000 days could be derived by substituting all data into the prediction models ‘ab2’ for time. The actual construction time as predicted by the model ranges from 122.51 days (CTIME=100) to 1056.93 days (CTIME=1000) with zero percent estimate error (Table 5). This indicates that the actual construction time is, on average, longer than the contract period by +22.51% for 100 day contract period reducing to +5.693% for a 1000 day contract period.

< Table 5>

The contract period estimate error was altered at ±5% intervals to examine the effects on the actual construction time prediction. In the prediction model, the contract period is expressed in several different forms, including CTIME, LCTIME, RCTIME, and INVCTIME. The deviations (ie. +5% of the contract period) were applied to all different forms of contract period when the calculating the revised actual construction time. Figure 1 shows the results of the sensitivity analysis for contract period. At ±5% deviation level, the variations to the actual construction time were between ±3.5% (CTIME=1000) to ±5.2% and (CTIME=100) (Table 5). These indicate that the 'ab2' model for time is more sensitive at 100 days than 1000 days contract period.

< Figure 1 >

Similarly, the actual construction costs for projects between $1M to $10M were calculated using the 'ab2' model for cost. The actual costs derived from the model ranged from $0.92M (CCOST=$1M) to $9.47M (CCOST=$10M) with a zero percentage error (Table 6).

< Table 6 >

Assuming a contract period of 100 days and the contract sum ranging from $1M to $10M, the effects on the actual construction costs due to the deviations from the estimated contract sum were examined by altering the contract sum at ±5% intervals. The deviations were reflected in different forms of contract sum, including LCCOST, RCCOST, and INVCCOST. The results of sensitivity analysis for ‘ab2’ model for cost is presented in Figure 2. The variations of the ‘ab2’ model for cost are very constant throughout the $1M to $10M range. At ±5% levels of deviation, the variations were approximately ±5% throughout the analysed contract cost range.

< Figure 2 >

The sensitivity of other factors, including project type, contractor selection method and contractual arrangement approach, was also examined. Figure 3 depicts the sensitivity of the ‘ab2’ model for time to different project types, assuming that open tendering and lump sum contract are used. The results as also shown in Table 5 indicate that the average actual construction time for industrial, educational and recreational projects will take much longer than that of the residential type. The differences in actual construction time between the residential building and each of the industrial, educational and recreational buildings were +11.06%, +4.73% and +5.73% respectively.

< Figure 3 >

Figure 4 shows the sensitivity of the ‘ab2’ model for time to different contractor selection methods and contractual arrangements, assuming a residential building. The results as shown in Table 5 indicate that the actual construction time for negotiated tender and design and construct contract is much less than open tender and lump sum contract. A saving of the actual construction time of 16.67% can be achieved if negotiated tender instead of lump sum tender is used. When a design and construct contract is used, a saving of 12.26% in the actual construction time can be achieved over the lump sum contract (Table 5).

< Figure 4 >

PRACTICAL APPLICATIONS

With the ‘ab2’ models, contract administrators could predict the actual time and cost for a given project type, contractor selection method and contractual arrangement based on the estimated contract time and cost. However, since the risk attitudes of clients may vary, it is necessary to be able to cater for different risk perceptions. The effects on actual time and cost due to the changes in risk attitudes can be represented diagrammatically by the actual time and cost curves.

Figures 5 and 6 illustrates the actual time and cost curves of a typical project with an estimated construction period of 237 days and contract sum of AUS$21.4 million. The differences in risk attitudes are presented as the percentage deviations from the estimated contract time and cost (±20% on *x*-axis), and the effects to the predictions are shown in the actual time and cost curves. The actual time and cost curves facilitate a client to predict the appropriate actual time and cost of a project based on his risk attitude. For instance, a risk-seeking client is optimistic with the actual construction time and cost, and the predictions along the left of the *x*-axis (-5% to -20%) could be referred to. A risk-averse client is pessimistic with the actual construction time and cost. This type of client could refer to the predictions along the right of the *x*-axis (+5% to +20%).

< Figure 5 >

< Figure 6 >

The actual time and cost curves for different types of project, contractor selection and contractual arrangement are presented in Figures 5 and 6. These curves can assist the client in selecting an appropriate contractor selection and contractual arrangement approaches during the pre-contract stage. Once the project type is identified, a client can compare the actual time and cost curves for different contractor selection method and contractual arrangement to determine which is the best option for a particular project. The contractor selection method and contractual arrangement that would result in the shortest actual time and least actual cost are preferred. In addition, the effects of risks on different contractor selection and contractual arrangement options could be compared through the actual time and cost curves.

CONCLUSIONS

A set of 93 Australian construction projects was used to develop several models for actual construction time and cost prediction. A forward crossvalidation regression analysis was adopted for the development of the model for actual construction time forecast when client sector, contractor selection method, contractual arrangement, project type, contract period and contract sum are known. The standard deviation of the deleted residual revealed that the best model for actual construction time prediction comprises the independent variables 'log contract time' (LCTIME), 'lump sum' (LS) in the CONTRACT sub-group, and 'other' (OT) in the SELECTION sub-group.

Regression models were also developed for forecasting the actual construction time and cost when client sector, contractor selection method, contractual arrangement and project type are known while contract period and contract sum are estimated. Different forms of regression analyses, including the standard regression and the crossvalidation regression, were adopted. However, the results of analyses show that the crossvalidation regression models ‘ab2’, with the smallest deleted residual ssq of 1.77817 for time and 0.56923 for cost, are preferred.

Since the ‘ab2’ models for time and cost are dependent on the contract period and contract sum being known, it is necessary to investigate the effects in situations where these have to be estimated. The results of the sensitivity analyses on the ‘ab2’ models show that the errors in predicted actual construction time become smaller as the contract period increases. In contrast, the errors in predicted actual construction cost are virtually the same for large and and small projects. The reliability of the actual construction time and cost prediction based on ‘ab2’ models thus depends on the accuracy of the estimated contract period and contract sum.

The effects of different project type, contractor selection method and contractual arrangement were also examined. The results indicate that the actual construction time for industrial project is the longest when compared with residential, educational and recreational projects. A significant saving in actual construction time can be achieved when negotiated tender and design and build contract are used instead of the traditional open tendering and lump sum contract approaches.

Despite the ‘ab2’ models for time and cost being influenced by inaccurate contract period and contract sum, the models provide practical tools for clients and contractors to predict the actual construction time and cost based on the risks and uncertainties of different client sector, contractor selection method, contractual arrangement and project type.

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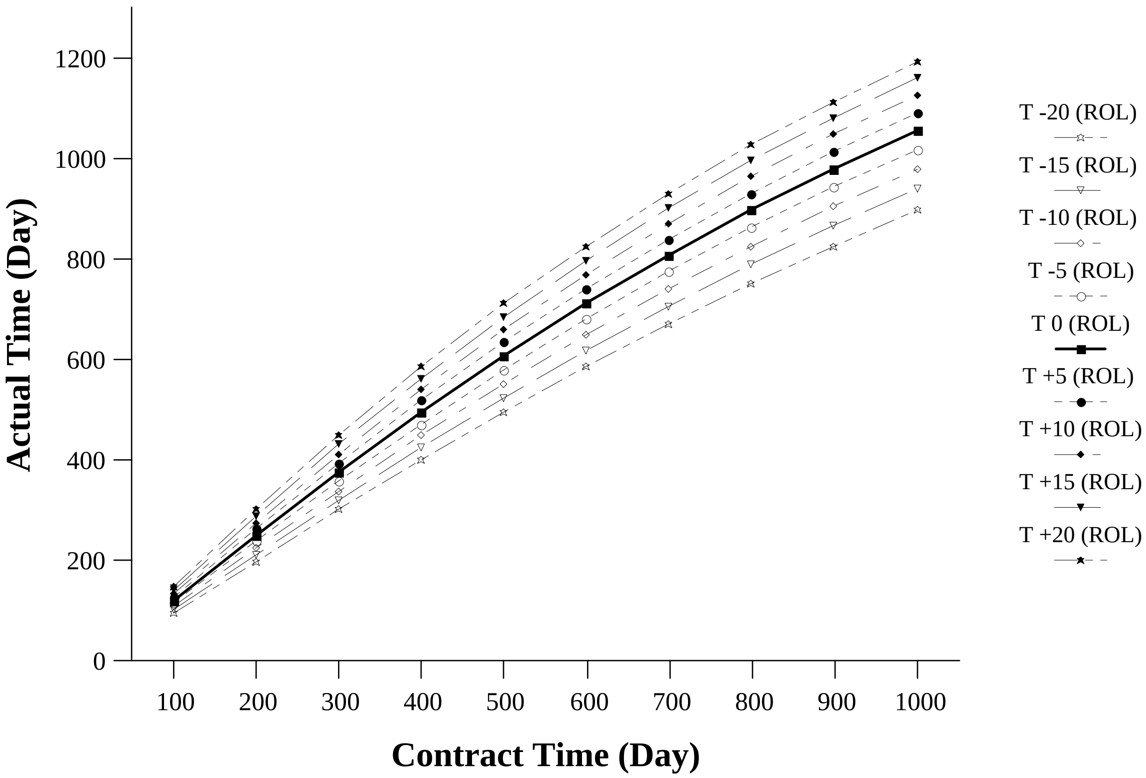
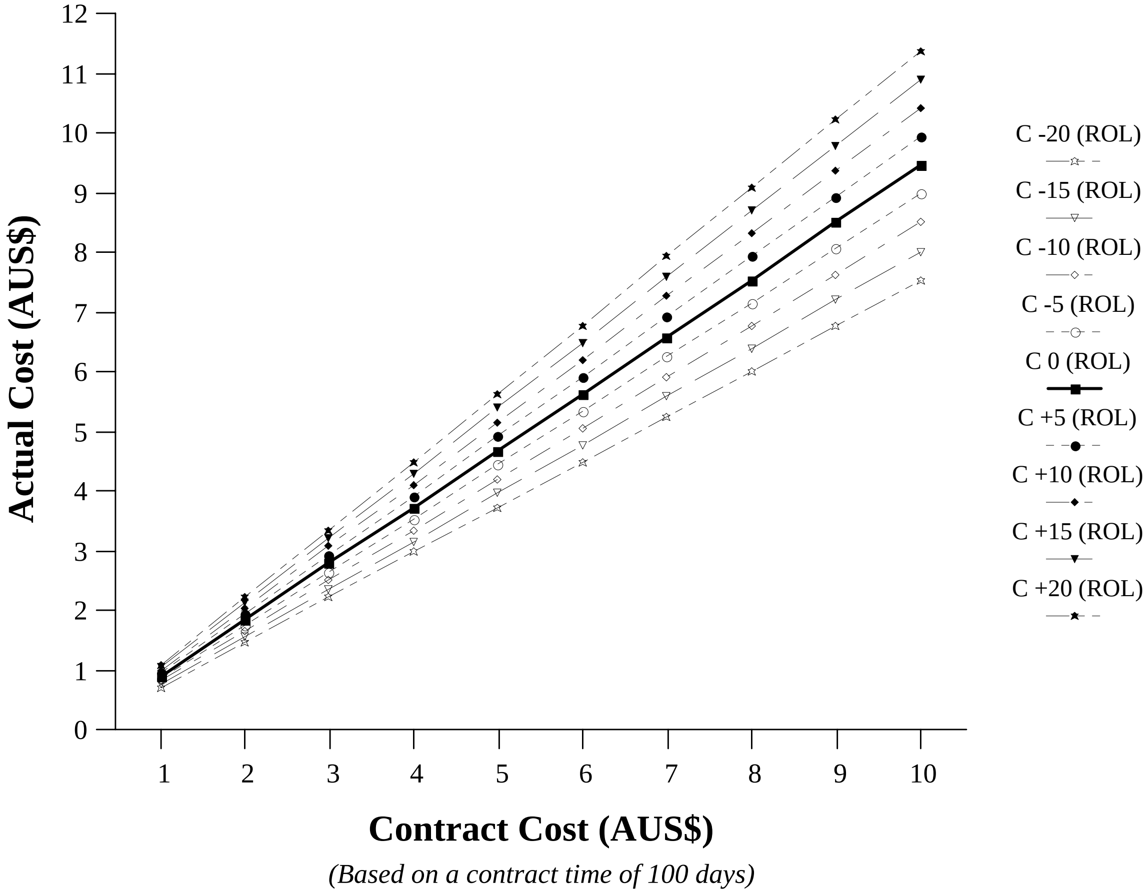
LIST OF CAPTIONS



(Based on a contract cost of AUS$10 million)

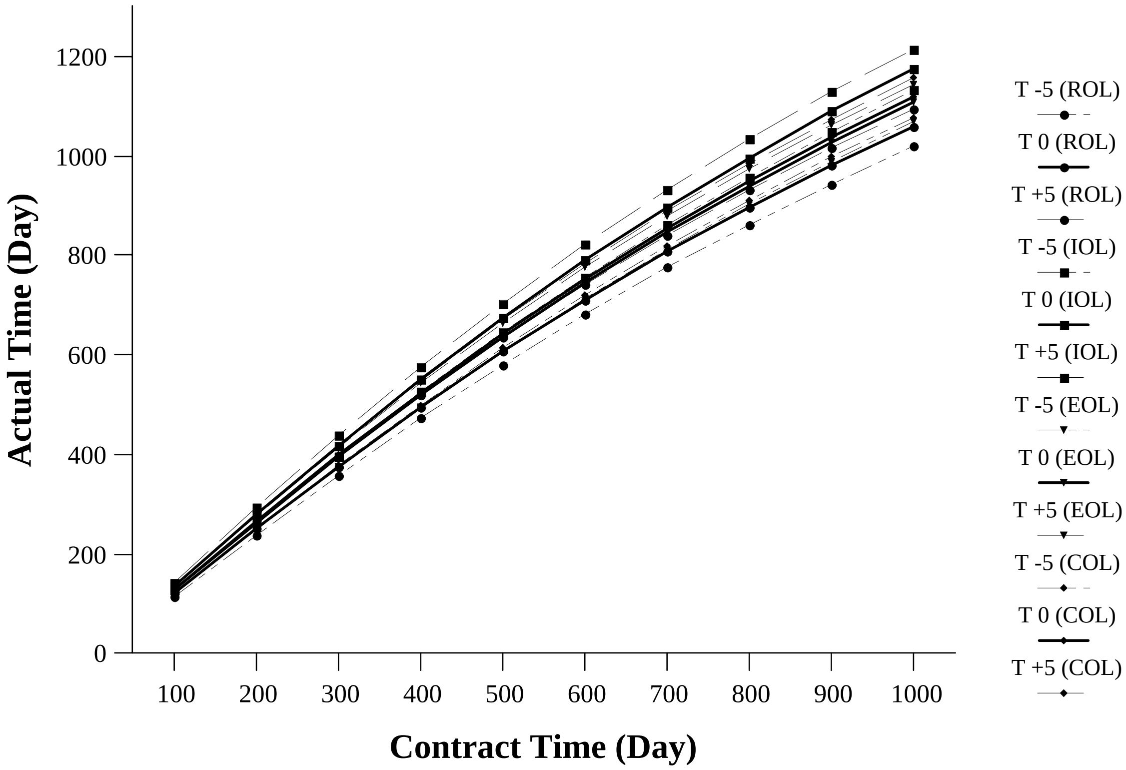
Note: T -20 = -20% of contract time, ROL = residential + open tendering + lump sum

Figure 1: Sensitivity analysis on contract time



Note: C -20 = -20% of contract cost, ROL = residential + open tendering + lump sum

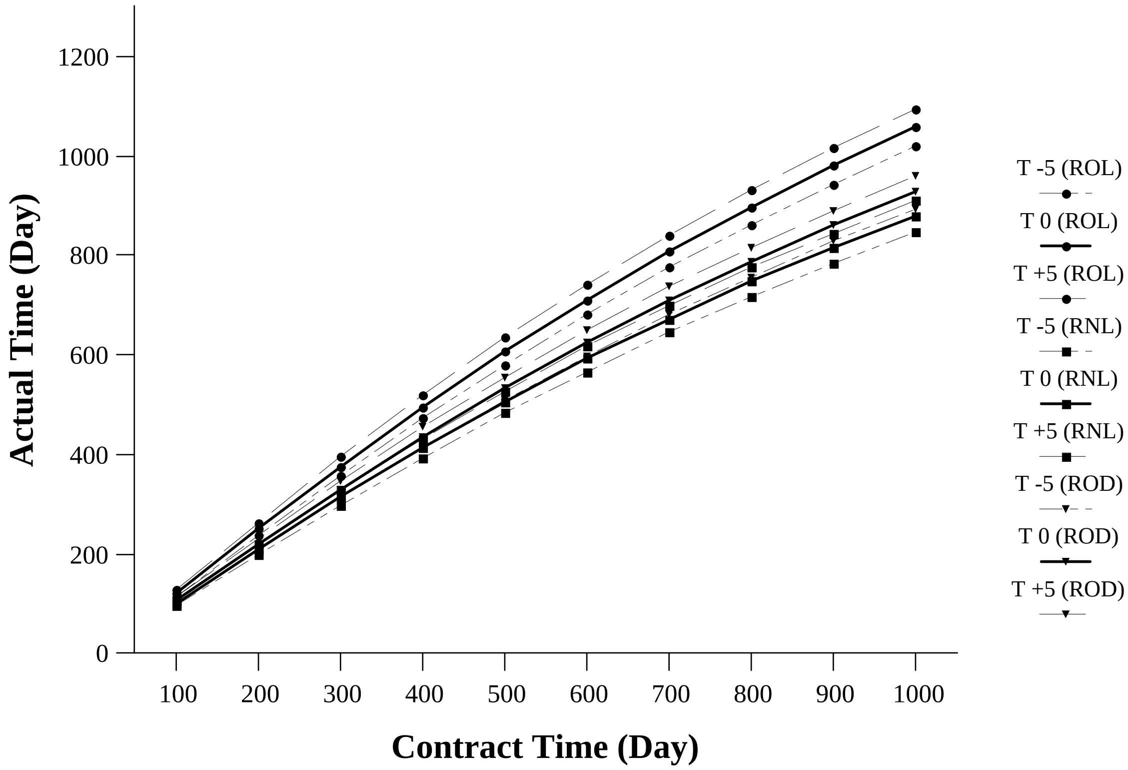
Figure 2: Sensitivity analysis on contract cost



(Based on a contract cost of AUS$10 million)

Note: ROL = residential + open tendering + lump sum, IOL = industrial + open tendering + lump sum, EOL = educational + open tendering + lump sum, COL = recreational + open tendering + lump sum

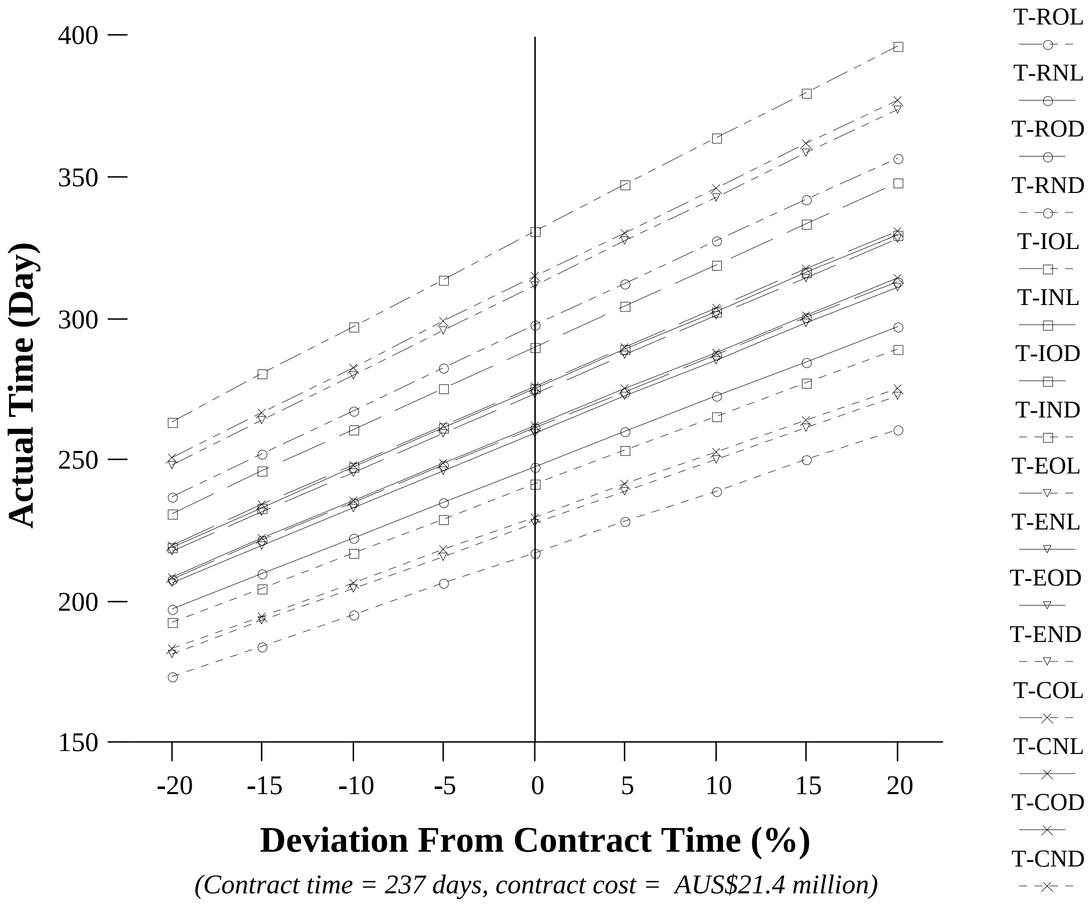
Figure 3: Sensitivity analysis on project type



(Based on a contract cost of AUS$10 million)

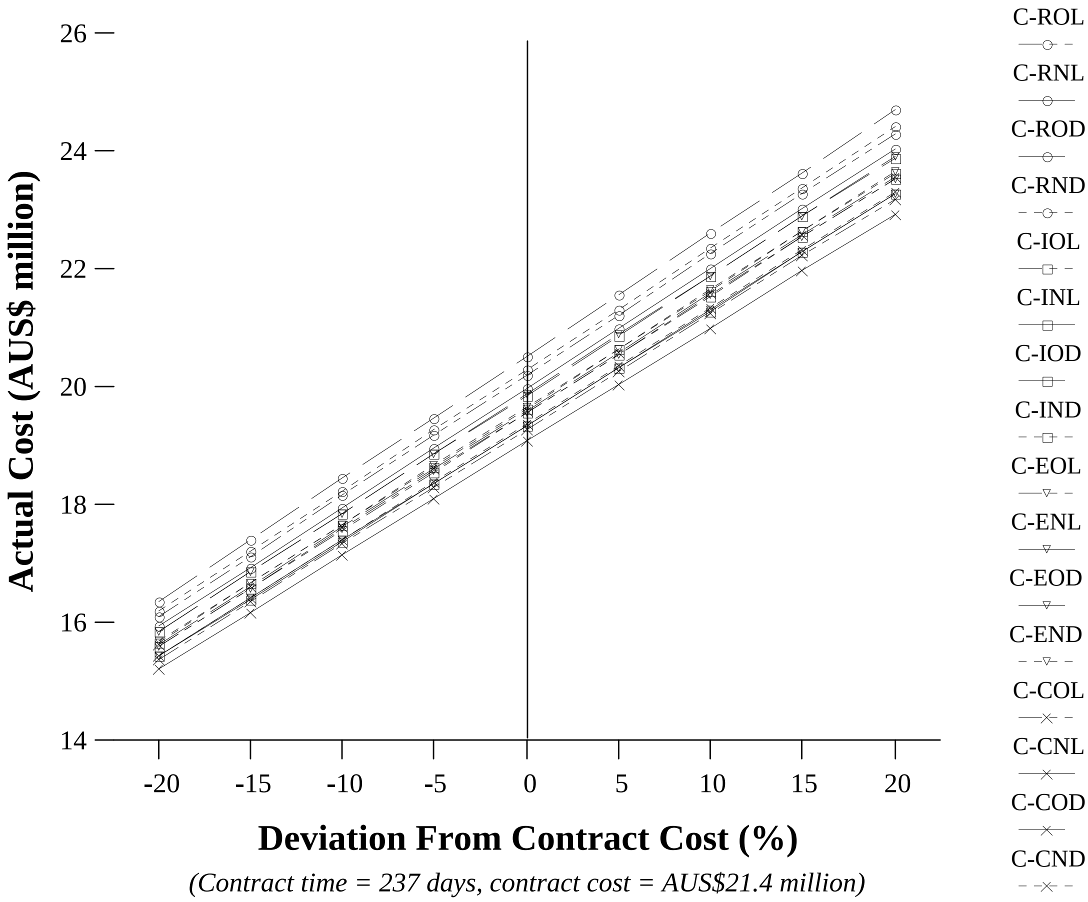
Note: ROL = residential + open tendering + lump sum, RNL = residential + negotiated tender + lump sum, ROD = residential + open tendering + design & contract

Figure 4: Sensitivity analysis on contractor selection method & contractual arrangement



Note: T = time,
1st letter after hyphen represents project type: R = residential, I = industrial, E = educational, C = recreational
2nd letter after hyphen represents contractor selection method: O = open tendering, N = negotiated tender
3rd letter after hyphen represents contractual arrangement: L = lump sum, D = design & construct

Figure 5: Actual construction time curves



Note: C = cost,
1st letter after hyphen represents project type: R = residential, I = industrial, E = educational, C = recreational
2nd letter after hyphen represents contractor selection method: O = open tendering, N = negotiated tender
3rd letter after hyphen represents contractual arrangement: L = lump sum, D = design & construct

Figure 6: Actual construction cost curves

	Variable	Standard deviation			
		Step 1	***Step 2***	***Step 3***	***Step 4***
Model 1	CTIME	0.332	0.184		
	CTIME2	0.735	0.454		
	√CTIME	0.231	0.180		
	lnCTIME	**0.179**	-		
	1/CTIME	0.270	0.179		
	CCOST	0.701	0.186		
	CCOST2	0.759	1.264		
	√CCOST	0.619	0.193		
	lnCCOST	0.448	0.179		
	1/CCOST	0.518	0.181		
Model 2	**ln**CTIME	**0.179**		-	-
	Select	-	0.173	0.169	na
	Other	-	0.172	**0.168**	-
	Lump sum	-	**0.170**	-	-
	D&C	-	0.175	0.171	0.169

Table 1: Results of forward crossvalidation procedure

	Group	Sub-group	n	Mean	Deleted residuals ANOVA (p)	Variance	Levine's test (p)
Model 1	Sector	public	31	0.022	0.404	0.031	0.830
		private	62	-0.011		0.031	
	Project type	recreational	9	-0.048	0.722	0.032	0.651
		industrial	26	0.010		0.030	
		educational	15	0.001		0.018	
		residential	11	0.058		0.039	
		other	32	-0.015		0.039	
	Contractor selection	selective	59	0.035	0.012	0.035	0.064
		open	15	-0.010		0.021	
		other	19	-0.102		0.018	
	Contractual arrangements	lump sum	61	0.043	0.005	0.032	0.201
		D&C	16	-0.083		0.011	
		other	16	-0.081		0.036	
	Total		*93*	*0.000*		*0.032*	
Model 2	Sector	public	31	-0.004	0.872	0.030	0.591
		private	62	0.002		0.028	
	Project type	recreational	9	-0.007	0.900	0.039	0.669
		industrial	26	0.022		0.027	
		educational	15	-0.024		0.017	
		residential	11	0.020		0.032	
		other	32	-0.012		0.033	
	Contractor selection	selective	59	0.005	0.852	0.033	0.174
		open	15	-0.023		0.025	
		other	19	0.000		0.018	
	Contractual arrangements	lump sum	61	-0.001	0.991	0.031	0.352
		D&C	16	-0.004		0.013	
		other	16	0.004		0.035	
	Total		*93*	*0.000*		*0.028*	

Table 2: Deleted residuals by sub-groups

	BETA	**_Std. Err. of BETA_**	**_B_**	**_Std. Err. of B_**	**_t(89)_**	**_p-level_**
Intercept	.207638		.144462		1.43732	.154133
LCTIME	.970507	.026231	.966737	.026129	36.99849	0.000000
Lc	.070275	.028096	.097269	.038889	2.50122	.014206
OT	-.051494	.027914	-.083980	.045524	-1.84476	068399

Note: $R=0.96984455$ $R^2=0.94059846$ Adjusted $R^2=0.93859616$ $F_{(3,89)}=469.76$ $p<0.0000$
Std. error of estimate=0.16382

Table 3: Regression Summary for Dependent Variable – LATIME

	i	Label	alpha	beta1	ab1	beta2	ab2	beta3	beta4
LATIME results	1	Constant	-1.25943	0.85662	-1.07885	1.26350	-1.59130	0.06807	-11.44751
	2	CTIME	0.00106	0.30771	0.00033	-0.00067	0.00000	0.00000	0.00752
	3	LCTIME	1.48502	0.93565	1.38947	0.95108	1.41237	0.98254	4.50414
	4	RCTIME	-0.09797	0.67958	-0.06658	0.45174	-0.04426	0.00000	-0.64119
	5	INVCTIME	-0.18694	0.00000	0.00000	-83.29847	15.57190	0.00000	92.78079
	6	LCCOST	-0.00275	0.89772	-0.00247	1.05852	-0.00291	0.00000	0.00652
	7	RCCOST	-0.00001	0.00000	0.00000	0.16468	0.00000	0.00000	-0.00001
	8	INVCCOST	-0.00004	1.00001	-0.00004	1.00003	-0.00004	0.00000	-209.57518
	9	SECTOR	-0.03344	0.00000	0.00000	-2.12731	0.07113	0.00000	-0.02638
	10	REC	0.00325	0.00000	0.00000	-7.27903	-0.02364	0.00000	0.00855
	11	IND	0.07385	0.59430	0.04389	0.34626	0.02557	0.03747	0.07104
	12	EDUC	-0.05669	0.53680	-0.03043	0.58582	-0.03321	0.00000	-0.04831
	13	RESID	0.01259	0.00000	0.00000	-6.30386	-0.07936	0.01927	0.00871
	14	OPEN	-0.00986	0.00000	0.00000	-6.67807	0.06582	0.00823	-0.00826
	15	NEG	-0.10604	1.04052	-0.11033	1.11113	-0.11782	0.00000	-0.10949
	16	LUMP	0.11396	0.89200	0.10165	1.15205	0.13128	0.14686	0.10860
	17	D&C	0.00956	0.00000	0.00000	0.04803	0.00046	0.01991	0.00523
		resid ssq	*2.11909*		*2.15984*		*2.37572*		
		dresid ssq	*3.12966*		*2.43525*		*1.77817*	*2.37386*	*2.09846*
LACOST results	0	Constant	0.13130	0.00000	0.00000	1.00432	0.13187	0.14177	3.84230
	1	CTIME	-0.00031	0.00000	0.00000	-1.63171	0.00051	0.00000	-0.00267
	2	LCTIME	0.04819	0.58187	0.02804	-0.19688	-0.00949	0.08086	-1.05199
	3	RCTIME	0.01609	0.45427	0.00731	-1.19396	-0.01921	0.00000	0.21409
	4	INVCTIME	0.01284	244.04398	3.13318	-394.38433	-5.06333	0.00000	-33.86345
	5	LCCOST	0.97442	1.01515	0.98919	1.03972	1.01312	0.96680	0.97112
	6	RCCOST	-0.00001	1.20251	-0.00001	1.23071	-0.00001	0.00000	-0.00001
	7	INVCCOST	0.00000	1.00000	0.00000	1.00000	0.00000	0.00000	236.25736
	8	SECTOR	-0.03424	0.00000	0.00000	-0.19823	0.00679	0.00000	-0.03680
	9	REC	-0.05940	0.87335	-0.05188	0.34267	-0.02036	0.00000	-0.06142
	10	IND	0.00655	0.00000	0.00000	-0.99174	-0.00649	0.01986	0.00755
	11	EDUC	-0.07906	0.35664	-0.02820	0.07325	-0.00579	0.00000	-0.08208
	12	RESID	-0.00394	0.00000	0.00000	-6.62376	0.02609	0.00930	-0.00258
	13	OPEN	0.01746	0.00000	0.00000	-2.09804	-0.03663	0.02385	0.01688
	14	NEG	-0.02534	0.24503	-0.00621	1.88626	-0.04781	0.00000	-0.02405
	15	LUMP	-0.02753	0.00000	0.00000	-0.81953	0.02256	0.00000	-0.02555
	16	D&C	-0.00221	0.00000	0.00000	-17.40347	0.03842	0.00809	-0.00055
		resid ssq	*1.08674*		*1.15303*		*1.29445*		
		dresid ssq	*1.77806*		*1.02433*		*0.56923*	*1.17982*	*1.08395*

Table 4: LATIME and LACOST forecasting model results (X years)

		Contract time (days)									
		100	***200***	***300***	***400***	***500***	***600***	***700***	***800***	***900***	***1000***
Accuracy	-20%	97.39	199.61	302.10	401.33	496.09	585.98	670.94	751.06	826.51	897.50
	-15%	103.61	212.52	321.01	425.46	524.71	618.42	706.58	789.35	866.98	939.70
	-10%	109.88	225.41	339.79	449.31	552.85	650.16	741.30	826.51	906.07	980.31
	-5%	116.18	238.29	358.42	472.85	580.51	681.22	775.13	862.55	943.84	1019.36
	0%	122.51	251.13	376.91	496.09	607.68	711.59	808.07	897.50	980.31	1056.93
	+5%	128.86	263.94	395.25	519.03	634.37	741.30	840.15	931.39	1015.53	1093.05
	+10%	135.24	276.71	413.43	541.65	660.59	770.35	871.39	964.25	1049.53	1127.78
	+15%	141.63	289.43	431.45	563.97	686.32	798.75	901.79	996.11	1082.36	1161.16
	+20%	148.04	302.10	449.31	585.98	711.59	826.51	931.39	1026.99	1114.05	1193.26
Project type	Residential	122.51	251.13	376.91	496.09	607.68	711.59	808.07	897.50	980.31	1056.93
	Industrial	136.06	278.92	418.61	550.98	674.91	790.32	897.47	996.79	1088.76	1173.86
	Educational	128.30	262.99	394.72	519.52	636.38	745.20	846.24	939.89	1026.61	1106.85
	Recreational	129.53	265.52	398.51	524.52	642.50	752.37	854.38	948.93	1036.48	1117.49
Contractor selection	Open	122.51	251.13	376.91	496.09	607.68	711.59	808.07	897.50	980.31	1056.93
	Negotiate	101.96	209.00	313.68	412.86	505.73	592.21	672.51	746.93	815.85	879.61
Contractual arrangement	Lump sum	122.51	251.13	376.91	496.09	607.68	711.59	808.07	897.50	980.31	1056.93
	Design & build	107.49	220.34	330.70	435.26	533.17	624.33	708.98	787.45	860.10	927.32

Note: Base Contract cost = $10M, project type = residential, contractor selection method = open, contractual arrangement = lump sum

Table 5: Sensitivity of contract time, project type, contractor selection and contractual arrangements

%	Contract cost ($ million)									
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
-20	0.73	1.48	2.23	2.99	3.74	4.50	5.26	6.02	6.79	7.55
-15	0.78	1.57	2.37	3.17	3.98	4.79	5.60	6.41	7.22	8.03
-10	0.83	1.67	2.51	3.36	4.22	5.07	5.93	6.79	7.65	8.51
-5	0.87	1.76	2.65	3.55	4.45	5.36	6.26	7.17	8.08	8.99
0	0.92	1.85	2.80	3.74	4.69	5.64	6.60	7.55	8.51	9.47
+5	0.97	1.95	2.94	3.93	4.93	5.93	6.93	7.94	8.94	9.95
+10	1.01	2.04	3.08	4.12	5.17	6.22	7.27	8.32	9.37	10.43
+15	1.06	2.14	3.22	4.31	5.41	6.50	7.60	8.70	9.80	10.91
+20	1.11	2.23	3.36	4.50	5.64	6.79	7.94	9.09	10.24	11.39

Note: Contract time = 100 days, project type = residential, contractor selection method = open, contractual arrangement = lump sum

Table 6: Sensitivity of contract cost