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Sub-activity Time-Cost Trade-off Model of Building Structural Beam on the Projects in the North Aceh Region

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Abstract – Problems for both delayed and accelerated activities in scheduling are common in most projects. This problem can implicate on the additional construction cost with different trends as a specific model. A model can provide valuable information to project acceleration judgement. This research aims to develop the TCTO sub-activity model of formwork, rebar work, and concrete work of the building structural beam on the projects in the North Aceh region. We have collected 33 data sourced from the project cost plan report and respondents judgment in the reviewed area. Descriptive statistics and the regression analysis are used to generate the TCTO model. The results show that the activity duration of the structural beam as broken down into sub-activities of formwork, rebar work and concrete work can be compressed until reaching 40%, 50%, and 40% of its normal duration, respectively. The additional cost of the compressed duration for each sub-activity shows the direct incremental cost per days of 3.67%, 3.63%, and 4.27% of its normal cost. Meanwhile, the possible crash cost of each the sub-activities are 122%, 118.15%, 125.61%, respectively. The models practically represent a linear model in the same daily pattern acceleration.

Keywords: Compressed Duration, Additional Cost, Linear TCTO Activity Model, Reinforced Concrete, Building Beam Structure.

Introduction

A construction project is a series of interrelated activities between one and another (Burgan *et al.*, 2014). Each activity has different characteristics between one to another type, one to another project, and one to another region. This condition causes various variations on the time and cost of each project activity that it can have implications for the different trends as they can be shown in the time-cost trade-off model (TCTO). However, a correlation of the time and cost in project activities, as a time-cost trade-off, can be visualized as a pattern of time-cost relationship of each project sub-activity (Hazir *et al.,* 2010). In the case of construction projects, problems with delays and accelerations of sub-activity often occur due to specific various factors, thus giving implications for the addition and reduction of specific construction costs. The project is an interrelated activity of several sub-activities so that delays and acceleration of the implementation of activities can be analyzed based on project activities and even further can be analyzed up to sub-activities. This study focused on structural beam activity in North Aceh area project.

Based on this background, the study aims to develop the TCTO sub-activity model for formwork, rebar work, and concrete work of the building structural beam on the project in the North Aceh region. The Structural Beam activity is broken down into three sub-activities, namely sub-activity of formwork, sub-activity of rebar, and sub-activity of Concrete work. It is done to improve the characteristics of the developed model. Several data related to the implementation of the Structural Beam Activity were collected from 33 respondents, both from secondary data and primary data through questionnaires distributed to several contractors domiciled in North Aceh Regency, namely Director, Project Manager, and Project Estimator. Descriptive method and statistical regression used to generate the TCTO model. Eliminate bias from cost data as secondary data and the response from several respondents; it is good that the cost data is sought to be obtained directly from the relevant respondents. The TCTO of activity model is a model that

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can be used to analyze the acceleration of the duration of activities against the additional costs needed to implement the acceleration of these activities. The TCTO model of project activity was developed on several parameters, namely normal duration, crash duration, normal cost and crash cost. In order to produce the TCTO model of project activity that can be applied more generally to variations in the activity quantity, the normal duration affected by the quantity of work will be controlled by making normal duration as a standard unit.

This research has produced a linear time-cost trade-off (TCTO) model on the structure beam activity, which is broken down into sub-activities of formwork as $Cc_i = -921{,}948(Dc_i) + 34{,}365{,}648$; rebar work of $Cc_i = -1{,}555{,}253(Dc_i) + 58{,}391{,}806$; concrete work of $Cc_i = -2{,}064{,}400(Dc_i) + 69{,}013{,}458$, which is restricted from D_n to D_c. The results showed that the TCTO model of a building structural beam activity is a linear model with maximum duration after accelerated is $40\%\mathrm{D_n}$, $50\%\mathrm{D_n}$, $40\%D_n$, while, the linear cost slope for reduced duration per day about 3.67%, 3.63%, and 4.27% of its normal cost, respectively. The findings of the TCTO model of each sub-activity are linearly indicated of constant increment of the additional cost. It is a logical and natural thing, where this model practically represents the same daily pattern acceleration, as in line with (Deckro and Hebert, 1990; Zeinalzadeh, 2011; Fachrurrazi *et al.,* 2018b). It is the inductive research conducted in North Aceh District as puzzled research for applied to a wider area such as Aceh. However, a smaller scope will be more accurate for implementing the model in the regional characteristics of the model. Hence, the objective of the present study was to to develop the TCTO sub-activity model of formwork, rebar work, and concrete work of the building structural beam on the projects in the North Aceh region

Materials and Methods

Time and site

This study develops the TCTO model on the structural beam activity in the North Aceh area project. This research was carried out in North Aceh district, where datasets were collected using questionnaires distributed on building contractors with small and medium qualifications, in this case, the person for the positions of director, project manager, and project estimator that their characteristics are formal education, age, and working experience, respectively, as shown in Figure 1a, Figure 1b, and Figure 1c.

Data collection

TCTO model of activity is the relationship of two variables, namely the accelerated duration in per day as an independent variable and the additional cost in IDR per day as a dependent variable, where the parameter model of normal duration used is the standard unit duration of 10 days. This study uses secondary and primary data. Secondary data consist of the activity quantity (Q), and total cost (TC) of the Structural Beam sourced from the contractor budget plan document. The primary data consist of production rate per day (PRPD), Crash Duration by normal duration of 10 days, the percentage of cost increment due to duration compressed per day, which is obtained from the responded questionnaires.

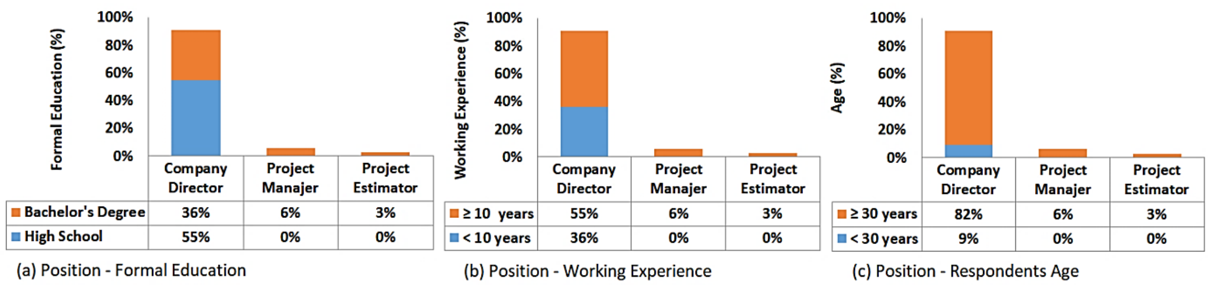

Figure 1. Characteristics of respondents

Data analysis

The steps of model development for TCTO of project activity respectively are normal duration (D_n), normal cost (C_n), crash duration (D_c), crash cost (C_c), and developing the TCTO model of activity, as an illustration in Figure 2. Estimating the normal duration (D_n) based on a paper (Fachrurrazi *et al.,* 2018a) which uses the quantity of activity and production rate per day (PRPD) as a basic estimate analyzed using Eq. (1). The normal cost (Cn) refers to the actual total cost each activity of the project carried out by the respondent. The normal cost standard is analyzed using Eq. (2) as in (Fachrurrazi *et al.,* 2018b). Crash Duration (D_c) is the maximum of the possible compressed duration for each activity based on respondent judgment. The deviation of normal duration (D_n) and crash duration (D_c) is defined as the reduced duration of activity (ΔD), as calculated by Eq. (3) of (Fachrurrazi *et al.,* 2018b).

$$D_n = \frac{Q}{PRPD} \quad (1)$$

$$standard\ of\ C_n for\ 10\ days = \frac{TC_n}{D_n}\ x\ 10\ days \quad (2)$$

$$D_c = (D_n - \Delta D)\ \text{ or }\ \Delta D = (D_n - D_c) \quad (3)$$

Crash cost is a cost incurred when the crash duration is reached. Estimating the crash cost (C_c) as Eq. (4) is calculated base on the accumulative of normal cost (C_n) and additional cost (ΔC). Additional cost (ΔC) as Eq. (5) is derived from additional cost percentage as Eq. (6) and its normal cost (C_n). Based on the based on a formula that has been derived, we analyze the crash cost (C_c) using Eq. (7) as in (Fachrurrazi *et al.,* 2018b):

$$C_c = (C_n + \Delta C) \quad (4)$$

Where,

$$\Delta C = \%\Delta C_{\Delta D}\ x\ C_n \quad (5)$$

$$\%\Delta C_{\Delta D} = \Delta D\ x\ C_s \quad (6)$$

$$C_c = (1 + \%\Delta C_{\Delta D})\ x\ C_n \quad (7)$$

Developing the TCTO model of activity, as an illustration in Figure 2, is obtained by the regression of time-cost data from the previous data analysis and cost slope analysis (Cs). Cost slope (Cs) is the incremental cost per day due to the compressed duration per day of each activity. Elbeltagi (2009) states that the compressed duration of the project can cause a slope change from the time-cost curve when conducting the acceleration of project activities, which is analyzed using eq.(8).

$$C_s = \frac{C_c - C_n}{D_n - D_c} \quad (8)$$

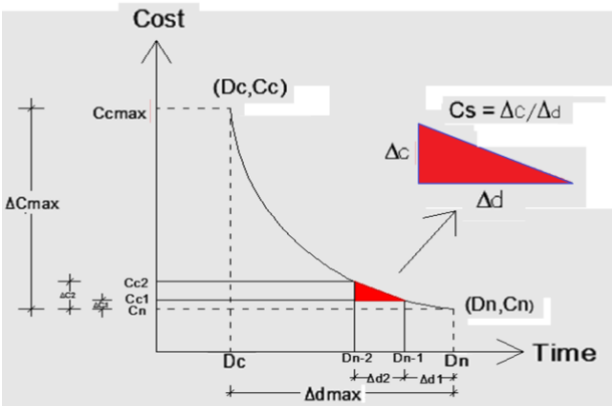

Figure 2. Illustration model of Time-Cost Trade-off for activity (Fachrurrazi *et al.,* 2018b)

Results

Normal Duration of activity is the duration of the activity needed to complete the activity under normal conditions, with normal resources and without adding extra costs. A normal duration for each contractor could vary from one to another, depending on its PRPD (Fachrurrazi *et al.,* 2018a). We use PRPD to analysis normal duration, as shown in Table 1, using eq.(1), which is further generalized to a normal duration standard of 10 days. The normal duration standard is equivalent with the quantity standard of each sub-activity of Formwork for 83.6 m^2, Rebar work for 3433.3 kg, and Concrete work for 62.4 m^3. The normal duration of each sub-activity (formwork, rebar work, and concrete work) for each respondent is shown in Table 1.

Table 1. Normal duration (D_n) for each sub activity

Respondent	Sub-activity Quantity (Q)			Production Rate Per day (PRPD)			Normal Duration base PRPD (D_n)		
	Form work (m2)	Rebar work (kg)	Concrete work (m3)	Form work (m2)	Rebar work (kg)	Concrete work (m3)	Form work (days)	Rebar work (days)	Concrete work (days)
R1	5.20	146.88	0.82	10.00	299.00	11.00	0.52	0.49	0.07
R2	138.50	3,311.28	15.12	5.00	240.00	5.00	27.70	13.80	3.02
R3	27.90	1,171.80	5.58	6.00	280.00	6.00	4.65	4.19	0.93
R4	282.13	11,139.85	7.77	10.00	400.00	8.00	28.21	27.85	0.97
R5	8.51	316.71	2.24	7.00	200.00	5.00	1.22	1.58	0.45
R6	73.60	2,704.74	14.78	7.00	320.00	7.00	10.51	8.45	2.11
R7	20.82	509.96	4.18	8.00	250.00	7.00	2.60	2.04	0.60
R8	83.16	1,499.95	9.90	13.00	250.00	9.00	6.40	6.00	1.10
R9	33.75	1,417.50	6.75	10.00	330.00	9.00	3.38	4.30	0.75
R10	128.16	1,639.97	16.02	19.00	245.00	10.00	6.75	6.69	1.60
R11	21.78	7,913.40	36.30	8.00	200.00	4.00	2.72	39.57	9.08
R12	241.67	11,860.12	33.32	7.00	170.00	6.00	34.52	69.76	5.55
R13	128.00	1,637.92	16.00	6.00	280.00	5.00	21.33	5.85	3.20
R14	54.32	853.60	7.76	5.00	340.00	7.00	10.86	2.51	1.11
R15	282.49	11,154.19	7.78	7.00	380.00	3.00	40.36	29.35	2.59
R16	5.13	178.19	1.03	9.00	560.00	4.00	0.57	0.32	0.26
R17	7.05	2,565.00	10.26	8.00	300.00	5.00	0.88	8.55	2.05
R18	41.60	801.65	4.80	6.00	400.00	4.00	6.93	2.00	1.20
R19	75.68	3,884.33	21.12	7.00	440.00	6.00	10.81	8.83	3.52
R20	4.63	160.89	0.93	8.00	240.00	8.00	0.58	0.67	0.12
R21	15.89	389.18	3.19	9.00	390.00	5.00	1.77	1.00	0.64
R22	3.30	1,082.40	3.30	9.00	460.00	6.00	0.37	2.35	0.55
R23	70.70	1,555.40	7.07	10.00	245.00	7.00	7.07	6.35	1.01
R24	81.7	3,268.00	16.34	11.00	520.00	4.00	0.74	6.28	4.09
R25	46.20	596.97	6.60	12.00	328.00	4.00	3.85	1.82	1.65
R26	33.58	563.38	3.65	10.00	444.00	5.00	3.36	1.27	0.73
R27	14.70	438.94	3.47	9.00	530.00	9.00	1.63	0.83	0.39
R28	52.56	1,080.40	7.30	8.00	349.00	9.00	6.57	3.10	0.81
R29	21.98	2,688.00	2.40	6.00	450.00	6.00	3.66	0.60	0.40
R30	4.03	63.40	0.26	5.00	520.00	8.00	0.81	0.12	0.03
R31	12.40	174.79	1.24	7.00	380.00	3.00	1.77	0.46	0.41
R32	83.26	239.46	18.42	9.00	310.00	5.00	9.25	7.72	3.68
R33	41.33	3,463.61	20.22	5.00	280.00	6.00	8.27	12.37	3.37
Mean				8.36	343.33	6.24			
St.dev				2.79	104.16	2.06			

Normal cost (Cn), crash duration (Dc) and crash cost (Cc)

The normal cost is the total cost of activities paired with normal duration in TCTO model. Meanwhile, the normal cost standard of activity is paired with normal duration standard. The normal cost standard is analysed using eq.(2). Normal cost standard can be lower/larger than the normal cost. It depends on normal duration versus normal duration standard. We use normal cost standard as a parameter of the TCTO model, as shown in Table 2. Crash Duration (Dc) of activity is the duration after a possible maximum compressed of normal duration standard. Where in this research case, normal duration standard is ten days, as shown in

Table 3. It is to easy the respondents make a judgement for the possible crash duration from its normal duration.

The result shows that the average crash duration of each activity based on 10 days normal duration is about 4 days (40%) for Formwork, 5 days (50%) for rebar work, and 4 days (40%) for concrete work, as shown in Table 3. Based on the results, we determine the maximum compressed duration (ΔD), they are 6 days, 5 days, and 6 days, respectively. Based on the value of the maximum compressed duration (ΔD), the respondents judge the percentage of the additional cost (ΔC_i) based on the reduced duration (ΔD), as shown in Table 3. Average of additional percentage cost is used to analyze the activity cost after day by day compression in the range of ΔD.

Table 2. Normal cost standard for each sub-activity

Respondent	ND Based on PRPD (D_n)			Total Cost of Activity (TC_n)			Normal Cost Standard Per 10 days		
	Form work (days)	Rebar work (days)	Concrete work (days)	Form work (IDR)	Rebar work (IDR)	Concrete work (IDR)	Form work (IDR)	Rebar work (IDR)	Concrete work (IDR)
R1	0.52	0.49	0.07	1,295,571	2,111,800	973,498	24,897,015	42,989,861	130,591,207
R2	27.70	13.80	3.02	8,913,462	43,864,526	8,583,624	3,217,875	31,792,800	28,385,000
R3	4.65	4.19	0.93	2,070,041	9,240,346	2,463,012	4,451,700	22,079,680	26,484,000
R4	28.21	27.85	0.97	23,621,225	120,154,411	5,157,415	8,372,500	43,144,000	53,100,800
R5	1.22	1.58	0.45	3,572,308	4,740,886	2,316,637	29,377,530	29,938,000	51,710,650
R6	10.51	8.45	2.11	5,461,078	21,328,498	6,523,892	5,193,650	25,233,920	30,898,000
R7	2.60	2.04	0.60	-	-	-	-	-	-
R8	6.40	6.00	1.10	53,783,895	16,679,883	8,777,590	84,077,757	27,800,750	79,796,276
R9	3.38	4.30	0.75	2,703,375	15,336,996	3,444,930	8,010,000	35,705,175	45,932,400
R10	6.75	6.69	1.60	39,734,983	29,293,098	20,415,888	58,907,980	43,761,900	127,440,000
R11	2.72	39.57	9.08	-	-	-	-	-	-
R12	345.24	697.65	5.55	583,650,110	2,238,596,125	49,685,951	16,905,497	32,087,476	89,470,500
R13	21.33	5.85	3.20	-	-	-	-	-	-
R14	10.86	2.51	1.11	10,193,691	7,807,026	5,352,150	9,383,000	31,096,400	48,279,700
R15	40.36	29.35	2.59	49,583,548	191,144,489	10,880,806	12,286,546	65,118,966	41,956,834
R16	0.57	0.32	0.26	429,459	1,921,957	683,673	7,535,250	60,401,600	26,550,400
R17	0.88	8.55	2.05	532,206	33,978,555	6,076,152	6,040,400	39,741,000	29,610,876
R18	6.93	2.00	1.20	4,301,613	10,617,828	3,814,968	6,204,225	52,980,000	31,791,400
R19	10.81	8.83	3.52	37,193,120	68,586,141	23,112,040	34,401,990	77,691,328	65,659,205
R20	0.58	0.67	0.12	387,764	1,735,360	617,297	6,698,000	25,886,400	53,100,800
R21	1.77	1.00	0.64	1,209,933	3,443,044	1,648,911	6,854,625	34,502,988	25,845,000
R22	0.37	2.35	0.55	2,592,975	10,009,494	1,351,433	70,717,500	42,538,500	24,571,500
R23	7.07	6.35	1.01	6,182,715	18,397,271	3,592,974	8,745,000	28,978,600	35,574,000
R24	0.74	6.28	4.09	10,367,730	22,876,000	12,351,406	139,590,000	36,400,000	30,236,000
R25	3.85	1.82	1.65	3,432,198	8,399,368	4,268,682	8,914,800	46,149,600	25,870,800
R26	3.36	1.27	0.73	15,043,034	9,389,813	3,201,919	44,797,600	74,001,480	43,861,900
R27	1.63	0.83	0.39	7,595,594	5,245,722	2,780,112	46,503,900	63,340,300	72,210,690
R28	6.57	3.10	0.81	3,904,682	15,201,228	4,721,421	5,943,200	49,104,300	58,209,300
R29	3.66	0.60	0.40	10,616,864	32,828,864	1,131,907	28,976,157	54,714,775	28,297,680
R30	0.81	0.12	0.03	390,446	1,053,140	173,994	4,849,500	86,372,000	53,128,000
R31	1.77	0.46	0.41	821,044	1,820,159	555,979	4,634,924	39,570,844	13,451,100
R32	9.25	7.72	3.68	52,287,384	2,539,382	15,070,784	56,521,199	3,289,354	40,908,750
R33	8.27	12.37	3.37	1,239,890	47,347,482	10,985,526	1,500,000	38,276,000	32,598,000
Average	17.62	27.73	1.76	31,437,065	99,856,296	7,357,152	25,150,310	42,822,933	48,184,025
Stdev	59.54	120.60	1.90	105,608,660	405,894,962	9,856,327	31,127,013	17,962,396	28,213,468

TCTO model of structural beam activity

The TCTO is a model visualizing the additional costs and its compressed duration day per day of normal duration until it reaches the crash duration. TCTO model for the activities of formwork, rebar work, concrete work, is shown in Figure 3, Figure 4, Figure 5, respectively. The change in the compressed duration and its cost is explained as the cost slope of TCTO. The cost slope of TCTO of each activity is analyzed using Eq. (8). Cost slope for each activity of Formwork, Rebar work, Concrete work is IDR 921,948; IDR 1,555,253; and IDR 2,064,400, respectively, as shown in Table 4. The cost slope is an incremental cost

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required for compressing duration per day of the activity, which in percentage terms are 3.67%, 3.63%, 4.27%, respectively, as shown in Table 4. The result of the crash cost percentage (C_c) based on the compressed duration of the sub-activities are 20.1% for formwork, 17.8% for rebar work, and 24.6% for concrete work, as shown in Table 3. Percentage of crash cost is used to calculate the crash cost based on the compressed duration per day, as shown in Table 4.

Table 3. Crash duration and normal cost for sub-activity of formwork

Respondent	*Dn*	Percentage of additional cost based on the reduced duration																						
		Formwork								Rebar work							Concrete work							
		Dc	$\frac{\Delta d_0}{\Delta C_0}$	$\frac{\Delta d_1}{\Delta C_1}$	$\frac{\Delta d_2}{\Delta C_2}$	$\frac{\Delta d_3}{\Delta C_3}$	$\frac{\Delta d_4}{\Delta C_4}$	$\frac{\Delta d_5}{\Delta C_5}$	$\frac{\Delta d_6}{\Delta C_6}$	*Dc*	$\frac{\Delta d_0}{\Delta C_0}$	$\frac{\Delta d_1}{\Delta C_1}$	$\frac{\Delta d_2}{\Delta C_2}$	$\frac{\Delta d_3}{\Delta C_3}$	$\frac{\Delta d_4}{\Delta C_4}$	$\frac{\Delta d_5}{\Delta C_5}$	*Dc*	$\frac{\Delta d_0}{\Delta C_0}$	$\frac{\Delta d_1}{\Delta C_1}$	$\frac{\Delta d_2}{\Delta C_2}$	$\frac{\Delta d_3}{\Delta C_3}$	$\frac{\Delta d_4}{\Delta C_4}$	$\frac{\Delta d_5}{\Delta C_5}$	$\frac{\Delta d_6}{\Delta C_6}$
	(days)	(days)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(days)	(%)	(%)	(%)	(%)	(%)	(%)	(days)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
R1	10	7	0	4	5	6	8	10	13	7	0	3	6	9	11	14	7	0	3	4	6	7	10	14
R2	10	5	0	1	2	3	4	5	6	3	0	1	2	3	4	5	3	0	1	2	3	4	5	6
R3	10	8	0	4	5	7	9	12	15	9	0	6	8	12	15	21	8	0	6	7	11	16	25	28
R4	10	2	0	3	5	9	11	13	16	6	0	5	9	13	17	20	4	0	6	12	18	24	30	35
R5	10	1	0	2	6	12	16	20	24	3	0	6	14	17	19	20	2	0	3	9	12	17	19	23
R6	10	5	0	2	4	5	6	9	11	4	0	2	5	7	8	9	1	0	1	2	3	4	5	6
R7	10	4	0	5	8	11	13	16	17	2	0	7	10	17	20	27	5	0	4	5	13	22	32	36
R8	10	3	0	6	7	16	17	24	26	3	0	10	12	17	19	20	4	0	11	15	20	25	30	34
R9	10	2	0	7	8	10	13	16	22	3	0	6	8	9	10	20	3	0	6	7	9	11	13	15
R10	10	8	0	8	16	22	28	35	41	9	0	9	18	25	33	40	7	0	7	14	19	26	32	37
R11	10	2	0	3	6	9	12	15	16	4	0	4	5	6	7	8	3	0	3	8	11	16	22	25
R12	10	3	0	4	8	10	14	17	20	5	0	3	5	7	9	12	4	0	5	8	10	13	16	19
R13	10	4	0	5	15	17	20	25	28	4	0	5	10	14	18	20	5	0	5	9	13	15	17	19
R14	10	5	0	2	4	6	13	16	20	5	0	6	12	18	21	25	6	0	4	2	12	16	18	24
R15	10	6	0	3	5	12	15	20	21	3	0	5	7	9	16	22	1	0	3	15	19	28	32	37
R16	10	5	0	2	3	5	6	10	16	2	0	2	4	16	32	34	2	0	3	8	15	16	20	24
R17	10	4	0	1	3	6	8	13	17	6	0	4	5	7	10	13	3	0	2	6	11	14	19	23
R18	10	4	0	2	5	12	13	14	15	3	0	3	6	9	15	19	4	0	7	14	21	26	29	30
R19	10	3	0	3	4	8	9	12	16	2	0	5	7	9	10	12	2	0	8	11	14	17	19	20
R20	10	7	0	5	7	10	12	15	17	7	0	5	8	10	13	17	7	0	3	6	9	11	13	16
R21	10	5	0	5	10	15	26	29	32	4	0	1	4	8	12	16	2	0	3	5	7	9	11	13
R22	10	2	0	6	12	18	20	23	25	5	0	2	5	8	23	25	2	0	1	5	9	12	15	18
R23	10	3	0	5	9	16	23	27	28	3	0	5	8	13	14	16	3	0	3	12	21	27	30	34
R24	10	1	0	2	5	7	9	10	11	2	0	3	6	9	12	15	2	0	6	7	11	16	17	20
R25	10	4	0	4	7	9	12	15	17	2	0	3	7	10	13	16	3	0	2	6	12	18	20	21
R26	10	2	0	3	6	13	16	19	24	3	0	5	10	15	20	25	4	0	3	8	17	26	33	38
R27	10	2	0	1	2	8	19	23	26	5	0	4	8	9	15	17	1	0	10	11	21	31	41	51
R28	10	5	0	2	5	9	15	17	20	6	0	2	7	8	11	13	5	0	9	18	27	32	41	50
R29	10	3	0	1	4	8	13	16	18	3	0	2	5	10	13	15	2	0	1	3	5	8	10	13
R30	10	1	0	5	7	8	10	14	19	2	0	4	6	8	10	12	1	0	2	7	11	13	16	19
R31	10	4	0	8	16	23	25	27	28	4	0	2	5	6	12	16	2	0	5	9	17	20	27	35
R32	10	2	0	2	5	7	13	16	25	5	0	4	6	8	10	12	5	0	4	8	9	12	16	18
R33	10	8	0	2	4	6	8	10	12	9	0	2	4	6	8	10	8	0	2	4	6	8	10	12
		3.9	-	3.5	6.6	10.4	13.8	17.1	20.1	5.0	-	4.1	7.3	10.7	14.6	17.8	3.7	-	4.3	8.1	12.8	16.9	21	24.6
		4.0								5.0							4.0							

Table 4. Parameter of sub-activities TCTO model of compressed duration

	Description	Sub-Activities		
		Formwork	Rebar work	Concrete work
D_n	Normal Duration Standard (in days)	10	10	10
D_c	Crash Duration (in days)	4	5	4
ΔD	Max. Compressed Duration (in days)	6	5	6
C_n	Normal Cost of 10 days (Δd_0) (in IDR)	25,150,310.67	42,822,933.23	48,184,025.60
C_9	Cost after one day compressed (Δd_1) (in IDR)	26,069,112.93	44,505,483.60	50,581,246.93
C_8	Cost after two days compressed (Δd_2) (in IDR)	26,862,985.49	45,894,340.31	52,458,550.16
C_7	Cost after three days compressed (Δd_3) (in IDR)	28,014,140.16	47,329,010.23	54,672,002.18
C_6	Cost after four days compressed (Δd_4) (in IDR)	28,906,889.36	49,216,609.72	56,729,211.48
C_5	Cost after five days compressed (Δd_5) (in IDR)	29,782,144.07	50,596,091.60	58,693,534.61
C_4	Cost after six days compressed (Δd_6) (in IDR)	30,598,503.06		60,620,016.96
C_c	Crash Cost on the Crash Duration (in IDR)	30,598,503.06	50,596,091.60	60,620,016.96
C_n	Normal Cost at 10 days ($\Delta \mathrm{d}_0$) (in IDR)	25,146,168	42,839,276	48,369,458
C_c	Crash Cost on the Crash Duration (in IDR)	30,677,856	50,615,541	60,755,858
$\%C_c$	Crash Cost Percentage of its Normal Cost (in %)	122	118.15	125.61

$\%C_s$	Percentage of incerement cost (in %)	3.67	3.63	4.27
C_s	Cost Slope of the developed model (in IDR)	921,948	1,555,253	2,064,400

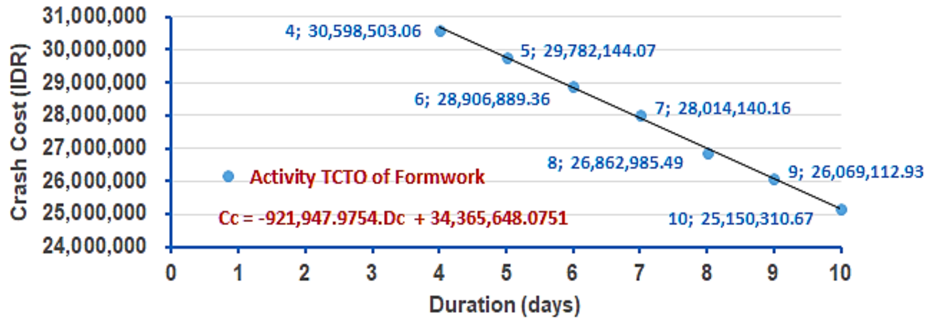

Figure 3. TCTO Model for Formwork of the Building Structural Beam

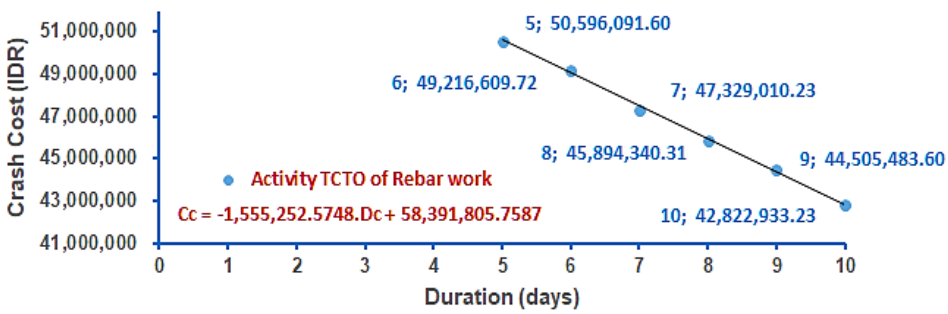

Figure 4. TCTO Model for Rebar work of the Building Structural Beam

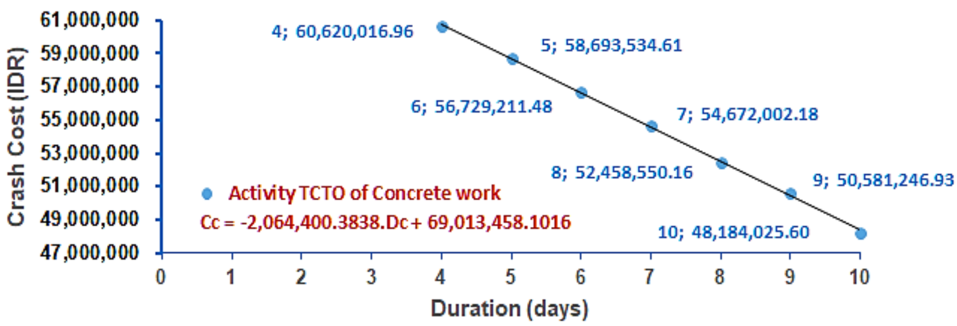

Figure 5. TCTO Model for Concrete work of the Building Structural Beam

Discussions

Model TCTO of structural beam activity, as broken into sub-activities of formwork as $\mathrm{Cc_i} = -921{,}948(\mathrm{Dc_i}) + 34{,}365{,}648$, rebar work of $Cc_i = -1{,}555{,}253(Dc_i) + 58{,}391{,}806$, concrete work of $Cc_i = -2{,}064{,}400(Dc_i) + 69{,}013{,}458$, which is restricted from D_n to D_c. Where Dc_i is the activity duration after being accelerated (in i days), meanwhile, Cc_i value is the total cost after the activity duration accelerated (in i days). This research has developed a TCTO model of activity that can be used to develop and optimise TCTO for projects (Fachrurrazi *et al.*, 2018c), although for this purpose, it requires the involvement of the TCTO of several other activities. Therefore further research is still needed for several other activity models.

The findings of TCTO model for each activity are linearly indicated of constant increment of the additional cost. It is a logical and natural thing, where this model gives a difference with a nonlinear model that is not practical to be applied in the practice of daily acceleration. This due to the increasing cost slope is inconstant. Most studies show that the activity model can vary: discrete, linear and non-linear, as linear as in the study (Deckro and Hebert, 1990; Zeinalzadeh, 2011; Fachrurrazi *et al.,* 2018b); the nonlinear is in (Deckro *et al.,* 1995), (Siemens and Gooding, 1995); protect the discrete are in Kang *et al.* (2015), and Son *et al.* (2013). These models generated from several project data and respondents judgments can be applied as a standard model to similar activities of the different projects. This analysis is the difference between other studies that only modelled base on a specific project. Several other studies also provided TCTO model activities, but unfortunately, they did not show how the activity model was obtained, such as (Su *et al.,* 2015; Son *et al.,* 2013).

Crash duration data shows that there is a variation between one and other activities. This is possible due to the characteristics of the sub-activities and factors that influence the work carried out by the contractor. This is in line with the opinion of AbouRizk and Sawhney (1993) which states that the scheduling of construction projects has uncertain content studies, which requires subjective knowledge about various factors that might influence the duration of project activities. Crash duration obtained in this study is also in line with research by Icmeli and Erenguc (1996), who found that the minimum acceleration to maximum activity is 40% to 60%.

Conclusions

This research has produced the linear time-cost trade-off (TCTO) model for the Structural Beam activity, which is broken down into the formwork, the rebar work, and the Concrete work, respectively

- $Cc_i = -921{,}948(Dc_i) + 34{,}365{,}648, Dc_i \in \{10, 9, \ldots, 4\}$
- $Cc_i = -1{,}555{,}253(Dc_i) + 58{,}391{,}806, Dc_i \in \{10, 9, \ldots, 5\}$
- $Cc_i = -2{,}064{,}400(Dc_i) + 69{,}013{,}458, Dc_i \in \{10, 9, \ldots, 4\}$

Where Dc_i is the duration crashing applied toward i value, meanwhile i is the 0 to ΔD (the maximum compressed duration). Based on the results and the discussion, we state that the linear model is the simplest and patterned model, compared to the nonlinear model as a complex and the discrete model as a less patterned. The crash duration of formwork, the rebar work, and the concrete work can be achieved by 40%D_n, 50%D_n, and 40%D_n, respectively. Linear TCTO of the building structural beam provides an increment cost of 3.67%, 3.63%, 4.27% of its normal cost. This condition indicates that the sub-activity of concrete work provide the highest cost slope than two others, although the total costs after the compressed duration are affected by the normal cost also, as a multiplier in the total additional costs, as for IDR 27,451,000; IDR 353,340,000; IDR 54,596,000.

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References

Abou-Rizk, S. M., Sawhney, A. 1993. Subjective and interactive duration estimation. Canadian journal of civil engineering, 20(3): 457-470.

Burgan, S. C., Burgan, D.S. 2014. One size does not fit all: Choosing the right project approach. Paper presented at PMI® Global Congress 2014—North America, Phoenix, AZ. Newtown Square, PA: Project Management Institute.

Csordas, H. 2017. An Overview of the time-cost trade-off problems of project planning. Procedia Engineering, 196: 323–326.

Deckro, R.F., Hebert, J.E., Verdini, W.A., Grimsrud, P.H., Venkateshwar, S. 1995. Nonlinear time/cost tradeoff models in project management. Computers and Industrial Engineering, 28(2): 219-229.
Deckro, R.F., Hebert, J.E. 1990. A multiple objective programming frameworks for tradeoffs in project scheduling. Engineering Costs and Production Economics, 18(3): 255-264.
Ebeltagi, E. 2009. Lecture notes on construction project management. Mansoura University, Egypt.
Fachrurrazi, F., Abdullah, A., Away, Y., Aulia, T. B. 2018a. Estimating the normal duration using normal Production Rate Per Day (PRPD) of project activity. MATEC Web Conf. 197, 10004.
Fachrurrazi, F., Mahmuddin, M., Anas, C.Y. 2018b. Time-cost trade-off model for tie beam activity. Jurnal Teknik Sipil, 7(1): 9-15.
Fachrurrazi, F., Abdullah, A., Away, Y., Aulia, T.B. 2018c. Negative total float to improve a multi-objective integer non-linear programming for project scheduling compression. International Journal of Electrical and Computer Engineering, 8(6): 5292-5302.
Hazır, Ö., Haouari, M., Erel, E. 2010. Robust scheduling and robustness measures for the discrete time/cost trade-off problem. European Journal of Operational Research, 207(2): 633-643.
Icmeli, O., Erenguc, S.S. 1996. The resource constrained time/cost trade-off project scheduling problem with discounted cash flows. Journal of Operations Management, 14(3): 255-275.
Kang, N., Son, J., Lee, S. 2015. New time-cost trade-off model considering the sequence of alternatives between activities. Journal of Asian Architecture and Building Engineering, 14(2): 379-386.
Priyo, M., Muhamad, R, A. 2015. Application of the time-cost trade-off method for construction projects: a case study of the indonesian building construction project. Journal Ilmiah Semesta Teknika, 18(1): 30-43.
Siemens, N., Gooding, C. 1975. Reducing project duration at minimum cost: A time-cost tradeoff algorithm. Omega, 3: 569–581.
Son, J., Hong, T., Lee, S. 2013. A mixed (continuous+ discrete) time-cost trade-off model considering four different relationships with lag time. KSCE Journal of Civil Engineering, 17(2): 281-291.
Su, Z.X., Qi, J.X., Wei, H.Y. 2015. A float-path theory and its application to the time-cost tradeoff problem. Journal of Applied Mathematics, 2015: 539374
Zeinalzadeh, A. 2011. An application of mathematical model to time-cost tradeoff problem (case study). Australian Journal of Basic And Applied Sciences, 5(7): 208-214.