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ANALYSIS OF TIME COST TRADE-OFF APPROACH ON CRITICAL PATH METHOD TO ACCELERATE CONSTRUCTION PROJECT COMPLETION

SANTI SARI DEWI[1], TARY PERMATA SARI[2], EFNI AGUSTIARINI[3], ENDANG LILY[4]

[1,2,3,4] Department of Mathematics, Universitas Riau, Pekanbaru 28293, Indonesia
**Corresponding author:* santisaridewi23@gmail.com

Abstract

The article discusses the analysis of project scheduling using the critical path method (CPM) to identify the project's critical path, allowing for the determination of the overall project completion time. This is further analyzed using the time cost trade off (TCTO) approach to evaluate the duration and costs after adding two hours of overtime on the critical path, with the assistance of Microsoft Excel software. The objective of this problem is to optimize project completion time and minimize delays based on the duration and costs of project activities. The calculation results indicate the optimal time and cost for project completion, and suggest that project acceleration can be achieved by selecting activities that can be expedited through the addition of overtime hours.

Keywords: *Project scheduling, critical path method, time cost trade off, addition of overtime hours*

1. INTRODUCTION

Lester [7] explains that project activities are a series of uniquely coordinated activities, with clear starting and ending points, carried out by individuals or organizations to meet specific objectives within established schedule, cost, and performance parameters. In the process of building a project, it must be carried out with careful planning so that the activities carried out are effective and efficient. One way to make the project implementation process effective and efficient is to apply project management. Kerzner [5] states that project management is the planning, organizing, directing, and controlling of company resources that have been set to achieve certain goals and targets.

The success of a project is assessed based on the efficient use of time and costs. Doraisamy et al. [1] explains that in the implementation of construction projects there is often a mismatch between the time schedule and the realization in the implementation, which can cause delays. Delays in construction are a common problem in the construction industry. These delays are often caused by various factors, such as lack of human resource discipline, lack of equipment, delays in material delivery and delays in construction implementation costs which can lead to project failure, decreased profit margins, and public distrust. In general, contractors can be considered as the subjects responsible for the delays.

To avoid delays, efforts are needed to accelerate the duration of the project in order to achieve optimal results. One step that can be taken is to conduct an optimization analysis to determine the estimated time required to complete the project and find appropriate solutions to overcome the challenges of project development. This optimization analysis is carried out by applying the Time Cost Trade Off (TCTO) approach to the Critical Path Method (CPM).

Several relevant studies have been conducted related to this topic. Based on research conducted by Mahardika et al. [8], a high-rise building project was carried out according to the initial schedule, but there was a delay due to land issues. By using CPM, the work duration can be accelerated from 119 to 104 working days. In addition, research by Hasyyati et al. [2] using the TCTO method on activities on the critical path by adding overtime for 3

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hours per day, can accelerate the project duration and cost efficiency by Rp91,596,790 or 0.0041%, and time efficiency by 78 days or 0.2110%.

This article studies the implementation of a development project managed by PT. Allesha Gala Anugrah (Castavia Property), the Mahakam West Park Cluster, is a housing complex located on Jalan Rambutan III, Marpoyan Damai, Pekanbaru. This project was delayed due to the impact of rain and flooding that hampered the supply of construction materials and the implementation of development. Therefore, based on case study examples and previous research, the authors use the CPM method and applies the TCTO approach to find an optimal scheduling acceleration solution in terms of cost efficiency and the timeliness of project completion.

2. RESEARCH METODOLOGY

In this section, several basic concepts are presented as supporting theories that support the discussion in the next section. Some of the theories discussed include CPM and TCTO.

2.1 Critical Path Method

Critical Path Method (CPM) or commonly known as the critical path is an integrated network consisting of a series of interconnected activities aimed at obtaining maximum work efficiency. CPM concentrates on the most important tasks that can ensure the project is completed on time and according to the schedule that has been set, the path where delays should not occur in any project activity is called the critical path. Heizer and Render [3] explain that there are two stages how to calculate critical paths, namely forward evaluation and backward evaluation, with the following explanation:

Forward pass, is a calculation that is done from the initial event to the terminal event.

$$\begin{aligned} EF_j &= ES + t_{i,j}, \\ ES_j &= \max\{EF_i \text{ all direct predecessors}\}, \\ ES_j &= \max\{ES_i + t_{i,j} : i < j\}, \end{aligned} \quad (1)$$

where ES_j is the earliest time activity j can start, EF_i the earliest time activity i can finish, and $t_{i,j}$ time duration from activity i to activity j.

Backward pass, is a calculation that moves from the terminal event to the initial event.

$$\begin{aligned} LS_j &= LF_j - t_{i,j}, \\ LF_i &= \min\{LS_j \text{ all activities that immediately follow}\}, \\ LF_i &= \min\{LF_j - t_{i,j} : i < j\} \end{aligned} \quad (2)$$

where LS_j is the latest time activity j can start and LF_j is the latest time it can finish.

After both stages of calculation are completed, the slack time can be calculated. Lawrence and Pasternack [6] state that the critical path can be known when the slack value is 0. Slack can be formulated as follows:

$$\text{Slack of activity } j = LS_j - ES_j = LF_j - EF_j \quad (3)$$

2.2 Time Cost Trade Off

Time Cost Trade Off (TCTO) or also known as the exchange of time and cost aims to accelerate the duration of a project by compressing the activity time to achieve the fastest completion duration with optimal costs. This time compression is carried out especially on critical activities and has the lowest cost slope.

In an effort to speed up the project duration, it is important to understand the level of effectiveness of the main resource, namely labor. Speeding up the duration by adding overtime hours certainly results in a decrease in productivity caused by worker fatigue, limited vision at night, and cold due to additional working hours. Hasyatti et al. [2] conclude that there was a decrease in productivity of 0.1 in every additional one hour of overtime.

Once the productivity coefficient is known when working hours are added, daily productivity after the crash can be calculated using the following equation:

$$\begin{aligned}\text{Daily productivity after crash} \\ &= (\text{working hours per day} \times \text{productivity per hour}) \\ &+ (a \times b \times \text{productivity per hour})\end{aligned} \tag{4}$$

where a is the number of additional working hours (overtime), and b is the coefficient of productivity reduction due to overtime.

Based on the daily productivity value after the crash, t_{crash} can be found as follows:

$$t_{crash} = \frac{\text{volume}}{\text{daily productivity after crash}} \tag{5}$$

where t_{crash} is the duration after acceleration (crash duration). Calculations for additional labor costs are presented by Hasyyati et al. [2] as follows:

Worker overtime costs

$$C_{overtime} = (1.5 \times C_{normal/hour}) + (2 \times (n-1) \times C_{normal/hour}) \tag{6}$$

where $C_{overtime}$ is the overtime wage cost, $C_{normal/hour}$ is the normal wage cost per hour, and n is the number of overtime.

Total overtime cost

$$C_{overtime\ total} = C_{overtime/day} \times t_{crash} \tag{7}$$

Crash cost

$$C_{crash} = C_{normal} + C_{overtime\ total} \tag{8}$$

Cost slope

$$Cost\ Slope = \frac{C_{crash} - C_{normal}}{t_{normal} - t_{crash}} \tag{9}$$

with C_{crash} being the wage cost for the crash duration, C_{normal} being the wage cost for the normal duration.

3. RESULTS AND DISCUSSIONS

The implementation of this housing development project consists of a series of activities that must be carried out at each stage. Table 1 describes the list of activities and costs associated with the construction of the Mahakam West Park cluster house.

TABLE 1. The list of activities and project activity costs.

Index	Predecessor	Day	Budget
A	-	7	7.230.000,00
B	A	3	1.100.000,00
C	B	7	11.192.000,00
D	C	5	20.058.000,00

Index	Predecessor	Day	Budget
E	C	15	37.888.000,00
F	D,E	17	29.210.000,00
G	D,E	24	14.346.000,00
H	C	7	32.910.000,00
I	H	3	17.427.000,00
J	F,G	35	31.424.000,00
K	J,I	20	36.579.000,00
M	L	10	20.149.000,00
N	M	1	2.379.000,00
O	N	2	6.650.000,00
P	O	7	27.785.000,00
Q	P	10	13.034.000,00
R	O,Q	4	3.932.000,00
S	R	14	36.261.000,00
T	S	3	8.748.000,00
U	T	7	19.031.000,00
V	U	10	41.799.000,00
W	U	5	22.892.000,00
X	U	2	9.450.000,00
Y	V,W,X	5	2.368.000,00
Z	Y	2	550.000,00

In improving the efficiency of completing the Mahakam West Park housing construction project, an additional strategy implemented is to extend the work duration by adding overtime hours. The impact of accelerating the completion of this project will affect the wage cost or normal cost of workers because it reduces the number of working days. Therefore, it is necessary to have data that includes the volume of work and wage costs for each activity in order to evaluate productivity after implementing the acceleration strategy. Information related to the volume of work and wage costs can be seen in Table 2.

TABLE 2. The list of work and wage costs

Index	Volume	Unit	C_{normal}
A	1,00	Ls	1.430.000
B	20,05	m^3	402.000
C	4,29	m^3	2.639.000
D	5,87	m^3	5.875.000
E	7,28	m^3	12.045.000
F	7,35	m^3	9.248.000
G	8,48	m^3	4.200.000
H	220,40	m	15.120.000
I	24,00	unit	1.539.000

J	365,99	m²	9.135.000
K	731,58	m²	21.260.000
L	14,20	m²	142.000
M	124,40	m²	3.110.000
N	31,77	m	675.000
O	19,00	m²	0
Index	Volume	Unit	C_{normal}
P	190,00	unit	10.598.000
Q	148,44	m²	3.650.000
R	31,77	m	952.000
S	167,24	m²	9.968.000
T	49,96	m²	1.965.000
U	731,98	m²	5.859.000
V	15,00	unit	5.900.000
W	34,74	m²	2.250.000
X	4,50	m²	0
Y	28,03	m²	325.000
Z	1,00	Ls	200.000

Keterangan: Ls := lumpsum

In project scheduling analysis using the CPM method, the first important step is to determine the critical path of the project. Winston [10, p. 440] states that the role of the critical path is very important in project implementation because delays or constraints on critical activities can cause delays in the completion of the entire project. Before determining the critical path, forward calculation, backward calculation and slack steps are required using equations (1) and (2). Keane and Catleka [4, p. 31] explain that the forward calculation starts from the first node in the network, because the first node is the starting point that is not affected by other activities. The backward calculation starts from the last node and goes back to the starting node in the network. The process of calculating the *LF* (last finish time) of the activity at node 27. Slack calculations can be done after running the forward and backward calculation processes. Figure 1 shows that the activities that are the critical path are marked with thick arrows. The critical path consists of a sequence of activities represented by arrows connecting the nodes $\mathrm{A-B-C-E-G-J-K-L-M-Q-R-S-T-U-V-Y-Z}$. The total duration of the project is determined by the latest finish time (*LF*) of the last activity on the critical path. Based on the analysis using the CPM method is 185 days. This time is the sum of the durations of the activities on the critical path, without any additional slack time.

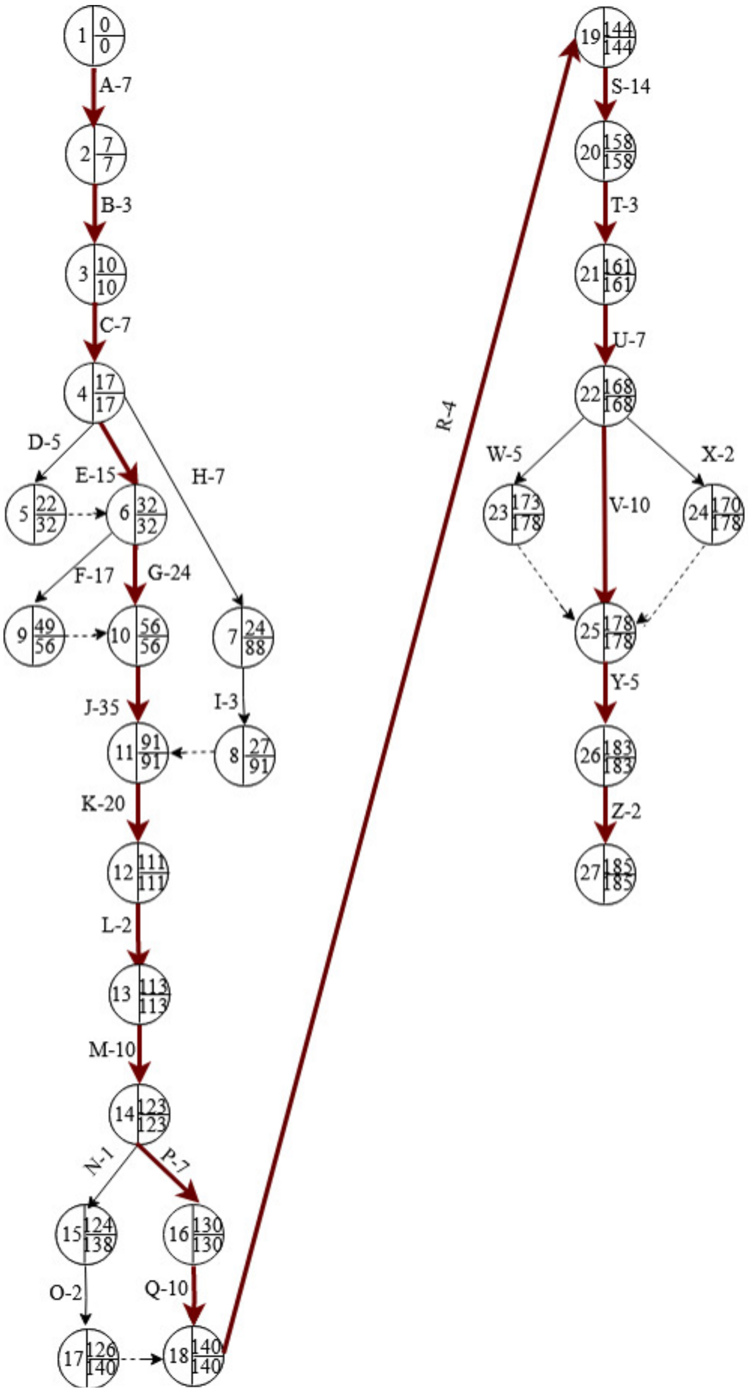

Figure 1. Critical path using CPM

Time efficiency is needed to prevent project delays. Crash duration is calculated through daily and hourly productivity using equations (4) and (5). The results are listed in Table 3.

TABLE 3. Acceleration of project time with the addition of two hours of overtime

ID	Vol.	Duration (days)	Daily Prod. (vol/day)	Prod. Each Hour (vol/hour)	Prod. After Crashing (vol/day)	Duration After Crashing (days)
A	1,00	7	0,1429	0,0179	0,1714	5,83
B	20,05	3	6,6833	0,8354	8,0200	2,50
C	4,29	7	0,6129	0,0766	0,7354	5,83
D	5,87	5	1,1740	0,1468	1,4088	4,17
E	7,28	15	0,4853	0,0607	0,5824	12,50
F	7,35	17	0,4324	0,0540	0,5188	14,17
G	8,48	24	0,3533	0,0442	0,4240	20,00
H	220,40	7	31,4857	3,9357	37,7829	5,83
I	24,00	3	8,0000	1,0000	9,6000	2,50
J	365,99	35	10,4569	1,3071	12,5482	29,17
K	731,58	20	36,5790	4,5724	43,8948	16,67
L	14,20	2	7,1000	0,8875	8,5200	1,67
M	124,40	10	12,4400	1,5550	14,9280	8,33
N	31,77	1	31,7700	3,9713	38,1240	0,83
O	19,00	2	9,5000	1,1875	11,4000	1,67
P	190,00	7	27,1429	3,3929	32,5714	5,83
Q	148,44	10	14,8440	1,8555	17,8128	8,33
R	31,77	4	7,9425	0,9928	9,5310	3,33
S	167,24	14	11,9457	1,4932	14,3349	11,67
T	49,96	3	16,6533	2,0817	19,9840	2,50
U	731,98	7	104,5686	13,0711	125,4823	5,83
V	15,00	10	1,5000	0,1875	1,8000	8,33
W	34,74	5	6,9480	0,8685	8,3376	4,17
X	4,50	2	2,2500	0,2813	2,7000	1,67
Y	28,03	5	5,6060	0,7008	6,7272	4,17
Z	1,00	2	0,5000	0,0625	0,6000	1,67

Murthy [9, p. 658] states that before reducing the activity duration, it is necessary to understand the costs associated with the activity. The acceleration cost is calculated by adding 2 hours of time using equations (6), (7), and (8). The results are presented in Table 4.

TABLE 4. Perhitungan crash cost untuk penambahan 2 jam lembur

Index	$C_{totalovertime}$ (Rp)	C_{crash} (Rp)
A	521.354	1.951.354
B	146.563	548.563
C	962.135	3.601.135
D	2.141.927	8.016.927
E	4.391.406	16.436.406
F	3.371.667	12.619.667
G	1.531.250	5.731.250
H	5.512.500	20.632.500

Index	$C_{totalovertime}$ (Rp)	C_{crash} (Rp)
I	561.094	2.100.094
J	3.330.469	12.465.469
K	7.751.042	29.011.042
L	51.771	193.771
M	1.133.854	4.243.854
N	246.094	921.094
O	0	0
P	3.863.854	14.461.854
Q	1.330.729	4.980.729
R	347.083	1.299.083
S	3.634.167	13.602.167
T	716.406	2.681.406
U	2.136.094	7.995.094
V	2.151.042	8.051.042
W	820.313	3.070.313
X	0	0
Y	118.490	443.490
Z	72.917	272.917

Based on Table 4 and Table 3, the cost slope of each activity can be determined using equation (9). The results of the cost slope calculation for each activity included in the critical path are presented in Table 5.

TABLE 5. List of cost slope for activities that can be accelerated

Index	ΔC (Rp)	Δt (day)	Cost Slope (Rp)
A	521.354	1,17	446.875
B	146.563	0,50	293.125
C	962.135	1,17	824.688
E	4.391.406	2,50	1.756.563
G	1.531.250	4,00	382.813
J	3.330.469	5,83	570.938
K	7.751.042	3,33	2.325.313
L	51.771	0,33	155.313
M	1.133.854	1,67	680.313
P	3.863.854	1,17	3.311.875
Q	1.330.729	1,67	798.438
R	347.083	0,67	520.625
S	3.634.167	2,33	1.557.500
T	716.406	0,50	1.432.813
U	2.136.094	1,17	1.830.938
V	2.151.042	1,67	1.290.625

Y	118.490	0,83	142.188
Z	72.917	0,33	218.750

The calculation is performed for all activities on the critical path starting from the lowest cost slope value. The results of the calculation of the total cost due to compression on all activities on the critical path are presented in Table 6.

TABLE 6. Project crashing results

Compression Stage	ID	Duration (days)	Direct Cost (Rp)	Indirect Cost (Rp)	Total Cost (Rp)
Normal		185	409.655.700	45.517.300	455.173.000
Stage 1	Y	184,17	409.774.190	45.312.267	455.086.457
Stage 2	L	183,83	409.825.960	45.230.254	455.056.214
Stage 3	Z	183,50	409.898.877	45.148.241	455.047.118
Stage 4	B	183,00	410.045.440	45.025.221	455.070.661
Stage 5	G	179,00	411.576.690	44.041.063	455.617.753
Stage 6	A	177,83	412.098.044	43.754.017	455.852.061
Stage 7	R	177,17	412.445.127	43.589.991	456.035.118
Stage 8	J	171,33	415.775.596	42.154.761	457.930.357
Stage 9	M	169,67	416.909.450	41.744.695	458.654.145
Stage 10	Q	168,00	418.240.179	41.334.629	459.574.808
Stage 11	C	166,83	419.202.315	41.047.583	460.249.898
Stage 12	V	165,17	421.353.356	40.637.517	461.990.874
Stage 13	T	164,67	422.069.763	40.514.498	462.584.260
Stage 14	S	162,33	425.703.929	39.940.406	465.644.335
Stage 15	E	159,83	430.095.335	39.325.307	469.420.642
Stage 16	U	158,67	432.231.429	39.038.261	471.269.690
Stage 17	K	155,33	439.982.471	38.218.129	478.200.600
Stage 18	P	154,17	443.846.325	37.931.083	481.777.408

Based on the compression results in Table 6, the optimum time and cost are obtained by adding 2 hours of overtime on the critical path for 183 days with a total cost of Rp455,070,661. The results of the project completion duration using the CPM method, the project can be completed in 185 days and after being accelerated by applying TCTO on the CPM critical path, the maximum duration is 183 days with a cost of Rp455,070,661. The CPM method can accelerate the construction duration of the Mahakam West Park project by 42 days faster than the duration determined by PT. Allesha Gala Anugrah and can be accelerated up to 44 days than the duration determined by the company with a cost efficiency of Rp102,339.

5. CONCLUSIONS

The analysis conducted shows that the application of the accelerated CPM method with the TCTO approach can accelerate the completion of the Mahakam West Park Cluster housing development project by adding overtime hours, more effectively than the method used by PT. Allesha Gala Anugrah. The main advantage of implementing overtime hours is its ability to shorten the duration of the project, as well as providing flexibility in schedule planning, allowing more work to be completed in the same time without the need to add labor or change other activity schedules.

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REFERENCES

1. Doraisamy, S. V., Akasah, Z. A., and Yunus, R., 2015, An overview on the issue of delay in the construction industry, *Springer Science+Business*, **Volume** : 1 pp 313–319.
2. Hasyyati, S. N., Puspita, I. A., and Tripiawan, W., 2020, Project acceleration of outside plant-fiber optic (OSP-FO) project in PT. XYZ using time cost trade off (TCTO) method by adding overtime hours, *IOP Conference Series: Material Science and Engineering*, **Volume** : 852 pp 1–6.
3. Heizer, J., and Render, B., 2011, *Operations Management, Tenth Edition*, Prentice Hall, Upper Saddle River.
4. Keane, P. J., and Caletka, A. F., 2008, *Delay Analysis in Construction Contracts*, Blackwell Publishing, Chichester.
5. Kerzner, H., 2009, *Project Management: A Systems Approach to Planning, Scheduling, and Controlling, Tenth Edition*, John Wiley and Sons Incorporated, Hoboken.
6. Lawrence, J. A., and Pasternack, B. A., 2002, *Applied Management Science: Modeling, Spreadsheet Analysis, and Communication for Decision Making, Second Edition*, John Wiley and Sons Incorporated, New York.
7. Lester, A., 2006, *Project Management Planning and Control: Managing Engineering, Construction and Manufacturing Projects to PMI, APM and BSI Standards, Fifth Edition*, Elsevier Science and Technology Books, Oxford.
8. Mahardika, A. G., Fadriani, H., Muntiyono, Afiyah, S., and Ramady, G. D., 2019, Analysis of time acceleration costs in level building using critical path method, *Journal of Physics: Conference Series*, **Volume** : 1424 pp 1–6.
9. Murthy, P. R., 2007, *Operations Research, Second Edition*, New Age International (P), New Delhi.
10. Winston, W. L., 2004, *Operations Research: Applications and Algorithms, Fourth Edition*, Thomson Learning, Belmont.