ASTONJADRO

pISSN 2302-4240
eISSN 2655-2086

Volume 12, Issue 1, February 2023, pp.223-234
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Optimization with crashing method and linear programming application on type 36 housing projects

[1]Tsulis Iq'bal Khairul Amar, [2]Adi Nurcahyo, [1]Gilang Jenar Bagaskara, [2]Arif Safta Wijaya

[1]Civil Engineering Department, Universitas Muhammadiyah Surakarta, Sukoharjo, INDONESIA
[2]Mathematical Education Department, Universitas Muhammadiyah Surakarta, Sukoharjo, INDONESIA

E-mail: tik154@ums.ac.id

Received October 18, 2022 | Accepted January 05, 2023 | Published January 06, 2023

ABSTRACT

The growth of housing in Indonesia has been very significant in recent years. The most found type of house is type 36. One of the areas with high purchasing power for housing is the Kendal Regency, which became the object of this study. Often housing projects experience delays caused by internal and external factors that can interfere with the duration of the initial planning. The effort that can be made to maintain the level of progress of the project is by acceleration. The optimal cost of the project due to the reduction in duration can be completed by acceleration techniques (Crashing) as linear programming models. In this study, Crashing and Linear Programming methods were chosen to optimize the value of adding costs to accelerate three samples of housing. Housing A, Housing B, and Housing C. The data collected is in the form of RAB, scheduling, and other supporting documents. Linear programming in this study using LINDO software. The plan to accelerate the construction of type 36 housing is carried out using alternative overtime working hours, adding 1, 2 and 4 working hours on critical activities of each project. The optimum time is selected based on the smallest cost slope value from the program crashing calculation. The result is shown that in housing A the most optimal addition was 2 hours of overtime with a total extra cost of Rp. 54,643,600 and a total acceleration of 15 days. In housing B, the optimum value of time and cost is by adding 4 hours of overtime with a total additional cost of Rp. 21,644,140 with a 27-day acceleration. In housing C, the development optimizes by adding 4 hours of overtime at an additional cost of Rp. 74,587,900 with a 29-day acceleration.

Key word: optimization; project acceleration; crashing method; linear programming method; housing.

INTRODUCTION

Home is a basic human need (*basic needs)* in the form of a place to live. Indonesia's housing sector has great potential to grow if the land is still available. Cost is a major factor for consumers in considering a home purchase. Statistics for 2018-2021 show that home purchases tend to be influenced by the COVID-19 pandemic, licensing/bureaucracy, rising prices of building materials, taxation, and the proportion of down payments in mortgage applications in banks (Khalishah, 2021). Houses with type 36 are the most common type found in the community because they are considered to have a price that tends to be affordable and suitable for families of few people.

A survey by the Central Statistics Agency shows that several provinces have the affordability to own decent houses, one of which is Central Java. Central Java Province, with a population of 36,742,501, has more than 65% purchasing power of livable houses (Statistik, 2021), The focus of the research is the area in this Province. Kendal Regency is included in the Kedungsapur Metropolitan area, the fourth largest Metropolitan area after Jabodetabek, Gerbangkertosusila, and Bandung Raya. This area has significant population growth in Central Java became the basic consideration of choosing the location as the research object.

Often housing projects experience delays caused by internal and external factors that can interfere with the duration of the initial planning (Messah et al., 2013). Acceleration is one way to ensure that the project keeps moving forward at its current rate. If ignored, this step will, nevertheless, result in significant issues. The project's optimal cost, using acceleration techniques (Crashing) and linear programming models, can be overcome due to the reduction in duration. (Giri Aspia Ningrum &

Hartono, 2017). These two techniques can be combined to find mathematical models to get several combinations of alternative solutions. Mathematical modeling takes encouragement a linear function, providing recommendations to solve real problems in life (Rahmawati et al., 2018).

For a long time, the literature has focused on analyzing time and cost as the two most important criteria used to determine project performance. The results in many models can be classified according to optimization goals (El-Rayes & Kandil, 2005) : (1) Reducing project time and increasing resources; (2) Minimizing time and costs for non-recurring construction using time cost trade-off analysis; (3): Minimizing the time and cost for repeated construction. The results of this modeling can estimate the minimum cost with various appropriate alternatives (Aboelmagd, 2018). LINDO was chosen for this study because of its ease of use and reliable results (Haryati et al., 2021). The calculated optimization equation can be a reference in a similar project with adjustments. Therefore, the calculation of cost and duration optimization is important to plan so that construction can be carried out to the maximum without compromising quality (Elsina et al., 2013). Delay is the most common problem in housing problems (Durdyev et al., 2017), So it is necessary to accelerate using the proper solution. Finally, it is expected to be a solution for the housing sector, especially to accelerate the fulfillment of the need for housing and become a reference for similar developments.

RESEARCH METHODS

Materials

This research is a quantitative descriptive study. In the early stages of the study, secondary data collection was carried out related to type 36 housing development projects in the Kendal Regency area in the form of:

1. Cost budget plan
2. Duration of project implementation
3. Other supporting project data.

In addition, to provide data collection, interviews were also conducted to supplement the research data. The case study is housing around Kendal Regency, namely Bancar Regency, Home Forest, and Griya Jati Indah, from now on referred to as housing A, B, and C. House types are similar types 36. The difference is in housing A where the land is more exclusive interiors, luxury, strategic location, premium materials, and wide land area, so the price of construction tends to be more expensive than housing B and C. Housing B has slightly higher specifications than C when viewed from the choice of materials and housing locations. Housing C is the simplest type compared to types A and B.

Methods

The first step in this study is to prepare network planning and determine critical paths using the Microsoft Project application. The identified critical paths were then analyzed by increasing working hours for 1,2,4 hours of overtime work for each housing. Chosen, thus referring to UUK 13/2003, more precisely in Article 78, then adjusted in the Ciptaker Law, states that the time of working overtime is no longer than 4 hours a day and 18 hours a week. (Constitutional Court, 2020). One hour is selected as the smallest value, 2 hours as the median value, and 4 hours as the maximum value. Furthermore, the total acceleration time, the total acceleration cost, and the total acceleration cost per unit of time (cost slope) can be determined. Analysis using the Crashing method requires *crash duration* and *crash cost* to get the optimum value of construction execution (Fachrurrazi & Husin, 2021). The calculation formula of this method is as follows:

Total Acceleration Cost = NT – CT (1)

Total Acceleration Time = CC – NC (2)

Cost Slope $= \frac{CC-NC}{NT-CT}$ (3)

Daily Productivity $= \frac{Volume}{Normal\ Duration}$ (4)

Productivity/hours $= \frac{Daily\ Productivity}{Normal\ Working\ Hours}$ (5)

Productivity after a crash = Daily productivity + (Overtime x Productivity/hour x %) (6)

ASTONJADRO pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.223-234
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

The equation will be used to identify the duration of project completion after it has been accelerated (crash duration) (Citra et al., 2018) with the following equation:

$$\text{Crash Duration} = \frac{Volume}{Productivity\ After\ Crash} \tag{7}$$

$$\text{Crash Cost} = \text{Normal Cost} + \text{Over Working Time Cost} \tag{8}$$

Description:

NT : Normal Time

CT : Crash Time

NC : Normal Cost

CC : Crash Cost

Optimum crash activity is the activity that has the lowest cost slope value. The value will be tested for validity by optimizing the linear integer method, which is considered more reliable (Citra et al., 2018). Mathematical model analysis of LINDO linear program is carried out by analysis steps such as in Fig.1.

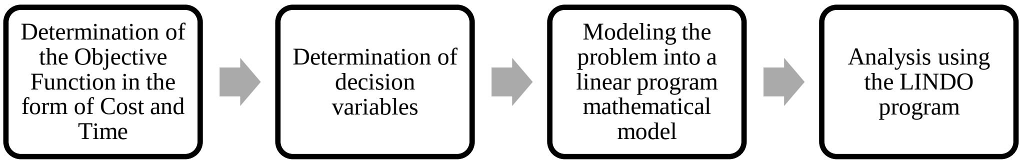


Figure 1. Flow analysis using LINDO software

Linear programming models are generally described in the following equation:

Maximum or minimum value (Z) $= c_1x_1 + c_2x_2 + \ldots + c_ix_j$ (9)

Constraints of some variables

$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1j}x_j \geq \leq b_1 \ldots$ (10)

$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2j}x_j \geq \leq b_2 \ldots$ (11)

$x_1, x_2, x_3, \ldots, \ldots, \ldots, \ldots x_i \geq 0 \ldots$ (12)

Description,

ci : Cost per unit of activity

xi : The abundance of activities of the i-th

aij : The number of resources i necessary to generate each unit of activity

Data Analysis

The result of the analysis of the crashing program is to add the duration to each work that is a critical activity. Every activity on the critical path needs to be carried out on time, so these activities need to be monitored more specifically and even accelerated for optimal projects (Laksana et al., 2014). Critical path are activities that are critical task in project which should not be late because it can affect the overall performance of the project (Sahid et al., 2020) obtain by network planning analysis. Network Planning obtained using the Microsoft Project application reveals a critical path in each housing development that will be added over time. Table 1 will show critical tasks in every housing development

Table 1. Critical task in housing A, B, and C

Housing A	Housing B	Housing C
Preparatory activity	Preparatory activity	Prepatory activity
Foundation And Concrete	Excavation and Landfill	Foundation
Masonry And Plastering	Foundation	Concrete
Floor And Wall	Masonry	Masonry
Housetop	Sanitation	Housetop

Wall Painting	Electrical	Carpentry
Finishing	Miscellaneous Jobs	Wall Painting

After knowing the critical task of each development, the next step is to determine the completion time if adding overtime is 1, 2, and 4 hours.

Crashing Program

Microsoft Project, as a project management application, in addition to defining critical paths, can also provide an estimate of the completion time when working hours are added (overtime). An example of manual calculation of housing "preparatory activity" Housing A with additional 2 hours overtime:

Daily Productivity $= \frac{76\ \text{M2}}{14}$ = 5,4 M2/day

Productivity/hours $= \frac{5{,}4}{8}$ = 0,7

Productivity after crashing = 5,4 + (2 x 0,7 x 0,8 %) = 6,5

Crash Duration $= \frac{76\ \text{M2}}{6{,}5}$ = 11,7 ~ 12 days

Calculations are performed for each job on the critical path, resulting in a crash duration in Table 2 to Table 10.

Table 2. Recapitulation of housing A completion time plus 1 hour of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	14 days	13 days
Foundation and Concrete	7 days	7 days
Masonry	21 days	20 days
House floors and walls	21 days	19 days
Housetop	7 days	7 days
Ceiling	7 days	7 days
Carpentry	7 days	7 days
Windows and Doors	7 days	7 days
Sanitary	7 days	7 days
Water installation	14 days	13 days
Electricity installation	14 days	14 days
Wall Painting	14 days	13 days
Finishing	2 days	2 days

The original time to develop housing A was 142 days. After a crashing the completion time was 136 days.

Table 3. Recapitulation of housing B completion time plus 1 hour of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	13 days	13 days
Excavation and Landfill	7 days	7 days
Foundation	21 days	20 days
Masonry	19 days	17 days
Concrete	21 days	21 days
Carpentry	7 days	7 days
Roof and Ceiling	7 days	7 days
House Floors and Walls	7 days	7 days
Doors and Windows	2 days	2 days
Sanitation	7 days	6 days
Walls Painting	14 days	14 days

Electrical	12 days	11 days
Water Installation	14 days	14 days
Miscellaneous Jobs	7 days	6 days

The original time to develop housing B was 158 days. After crashing the time of 1 hour overtime the completion was 152 days.

Table 4. Recapitulation of housing C completion time plus 1 hour of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	7 days	6 days
Foundation	14 days	13 days
Concrete	21 days	19 days
Mansory	21 days	19 days
House floors	10 days	10 days
Housetop and Ceiling	11 days	10 days
Carpentry	7 days	7 days
Walls Painting	12 days	11 days
Miscellaneous Jobs	3 days	3 days

The original completion time of housing C was 122 days. After a crashing the overtime time of 1 hour of completion became 116 days.

Table 5. Recapitulation of housing A completion time plus 2 hours of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	14 days	12 days
Foundation and Concrete	7 days	6 days
Masonry	21 days	17 days
House floors and walls	21 days	17 days
Housetop	7 days	6 days
Ceiling	7 days	7 days
Carpentry	7 days	7 days
Windows and Doors	7 days	7 days
Sanitary	7 days	7 days
Water installation	14 days	13 days
Electricity installation	14 days	14 days
Wall Painting	14 days	12 days
Finishing	2 days	2 days

The original time to develop housing A was 142 days. After crashing overtime 2 hours the completion time was 127 days.

Table 6. Recapitulation of housing B completion time plus 2 hours of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	13 days	11 days
Excavation and Landfill	7 days	6 days
Foundation	21 days	17 days
Masonry	19 days	16 days
Concrete	21 days	21 days
Carpentry	7 days	7 days
Roof and Ceiling	7 days	7 days
House Floors and Walls	7 days	7 days
Doors and Windows	2 days	2 days
Sanitation	7 days	6 days
Walls Painting	14 days	14 days

Electrical	12 days	10 days
Water Installation	14 days	14 days
Miscellaneous Jobs	7 days	6 days

The original completion time to develop housing B was 158 days. After a crashing the overtime time of 2 hours of completion became 144 days.

Table 7. Recapitulation of housing C completion time plus 2 hours of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	7 days	6 days
Foundation	14 days	12 days
Concrete	21 days	17 days
Mansory	21 days	17 days
House floors	10 days	10 days
Housetop and Ceiling	11 days	9 days
Carpentry	7 days	6 days
Walls Painting	12 days	10 days
Miscellaneous Jobs	3 days	3 days

The original time to develop housing C was 122 days. After a crashing the overtime time of 2 hours of completion became 106 days.

Table 8. Recapitulation of housing A completion time plus 4 hours of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	14 days	10 days
Foundation and Concrete	7 days	5 days
Masonry	21 days	15 days
House floors and walls	21 days	15 days
Housetop	7 days	5 days
Ceiling	7 days	7 days
Carpentry	7 days	7 days
Windows and Doors	7 days	7 days
Sanitary	7 days	7 days
Water installation	14 days	13 days
Electricity installation	14 days	14 days
Wall Painting	14 days	11 days
Finishing	2 days	2 days

The original time to develop housing A was 142 days. After crashing overtime 2 hours the completion time was 118 days.

Table 9. Recapitulation of housing B completion time plus 4 hours of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	13 days	9 days
Excavation and Landfill	7 days	5 days
Foundation	21 days	14 days
Masonry	19 days	13 days
Concrete	21 days	21 days
Carpentry	7 days	7 days
Roof and Ceiling	7 days	7 days
House Floors and Walls	7 days	7 days
Doors and Windows	2 days	2 days
Sanitation	7 days	5 days

ASTONJADRO pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.223-234
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Walls Painting	14 days	14 days
Electrical	12 days	8 days
Water Installation	14 days	14 days
Miscellaneous Jobs	7 days	5 days

The original completion time to develop housing B was 158 days. After a crashing the 4-hour overtime time of completion became 131 days.

Table 10. Recapitulation of housing C completion time plus 4 hours of overtime

Task	Normal Duration	Crashing Duration
Prepatory activity	7 days	5 days
Foundation	14 days	10 days
Concrete	21 days	14 days
Mansory	21 days	14 days
House floors	10 days	10 days
Housetop and Ceiling	11 days	8 days
Carpentry	7 days	5 days
Walls Painting	12 days	8 days
Miscellaneous Jobs	3 days	3 days

The original completion time to develop housing C was 122 days. After a crashing of 4 hours of completion overtime time became 93 days.

Linear Program

The optimization's purpose is to obtain the optimum combination of the right shortest duration and the minimum cost of an addition. In formulating the problem, data from Tables 11,12 and 13 are made into the LP equation after going through data modeling from crashing program calculations. The empty data on some slopes are empty because the duration does not decrease even though overtime has been added, so the value is not changed from the initial cost. The calculation of crashing method will be recalculated using the Linear Program.

Table 11. Cost Slope of Housing A (Rupiah)

Decision Variables	Task	Cost Slope 1 hour	Cost Slope 2 hours	Cost Slope 4 hours
X1	Preparatory activity	2.404.100	2.090.521	1.463.365
X2	Foundation And Concrete	-	15.071.105	10.549.774
X3	Masonry And Plastering	13.184.198	2.846.588	4.194.972
X4	Floor And Wall	543.848	413.324	609.109
X5	Housetop	-	10.052.400	7.036.680
X6	Wall Painting	1.496.351	4.033.643	9.108.225
X7	Finishing	4.752.813	4.132.881	5.786.033

Table 12. Cost Slope of Housing B (Rupiah)

Decision Variables	Task	Cost Slope 1 hour	Cost Slope 2 hours	Cost Slope 4 hours
X1	Preparatory activity	-	329.264	235.188
X2	Excavation and Landfill	-	614.401	460.800
X3	Foundation	2.061.288	579.737	515.322
X4	Masonry	1.918.315	2.841.948	1.989.364

X5	Sanitation	191.198	764.790	573.597
X6	Electrical	613.594	525.938	350.625
X7	Miscellaneous Jobs	281.443	1.125.771	844.329

Table 13. Cost Slope of Housing C (Rupiah)

Decision Variables	Task	Cost Slope 1 hour	Cost Slope 2 hours	Cost Slope 4 hours
X1	Prepatory activity	128.571	514.286	385.714
X2	Foundation	1.435.066	1.669.363	995.760
X3	Concrete	1.515.019	1.899.785	1.154.300
X4	Masonry	3.242.412	4.065.882	2.470.409
X5	Housetop	7.761.505	9.587.741	8.522.436
X6	Carpentry	-	12.850.000	6.241.429
X7	Wall Painting	2.604.184	3.138.376	1.602.575

Acceleration on housing A by using a crashing program for 1, 2, and 4 consecutive hours of overtime is 6, 15, and 24 days from the normal duration of 142 days. Acceleration on housing B by using the crashing program for 1, 2, and 4 hours respectively, is 6, 13, and 27 days from the normal duration of 158 days. Acceleration in housing C by using a crashing program for 1, 2, and 4 consecutive overtime hours is 7, 16, and 29 days from the normal duration of 106 days. The data is then modeled as the objective and constraint functions according to the data obtained. The destination function is illustrated in table 14. Constraint functions are defined against the limits of maximum time shortening (duration of acceleration per activity), subtraction of overall time (total duration of acceleration), and non-negativity (variable value greater than 0). The constraint functions of each activity are shown in Table 15.

Table 14. Objective function Linear programming modeling

Development	Objective Function		
	1 hour	**2 hours**	**4 hours**
Housing A	Min Z = 2404100X1+ 13184198X2+543848X3 +1496351X4+4752813X5	Min Z = 2090521X1+ 15071105X2+ 2846588X3+ 413324X4+10052400X5+ 4033643X6+4132881X7	Min Z = 1463365X1+ 10549774X2+4194972X3 609109X4 +7036680X5 9108225X6+5786033X7
Housing B	Min Z = 2061288X1+ 1918315X2+191198X3 +613594X4+281443X5	Min Z = 329264+ 614401X2+579737X3+ 2841948X4+764790X5+ 525938X6+1125771X7	Min Z = 235188X1+ 460800X2+515322X3 1989364X4+573597X5 350625X6+844329X7
Housing C	Min Z = 128571X1+ 1435066X2+1515019X3 +3242412X4+7761505X5 +2604184X6	Min Z = 514286X1 +1669363X2+1899785X3 +4065882X4 +9587741X5 +12850000X6 +3138376X7	Min Z = 385714X1 +995760X2+1154300X3 +2470409X4 + 8522436X5 + 6241429X6+ 1602575X7

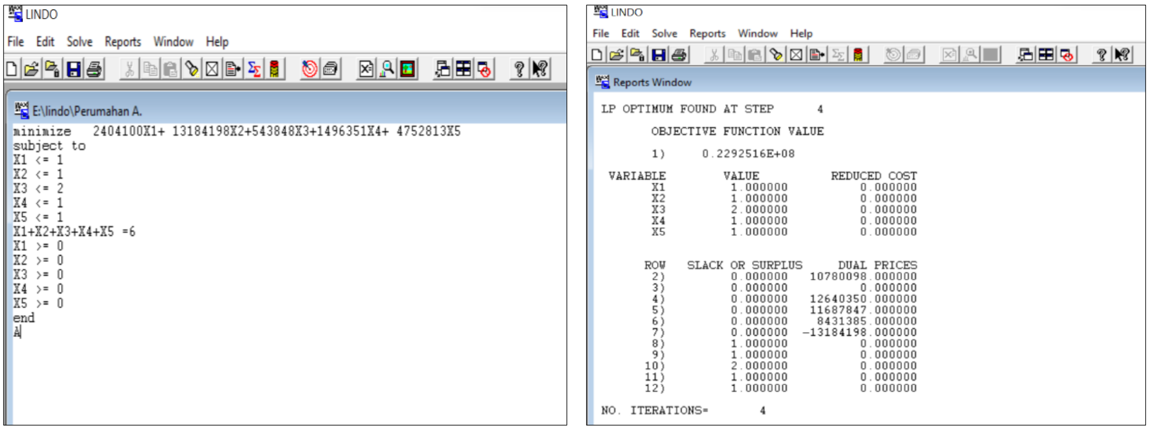
Table 15. Constraint function linear programming modeling

Development	Constraint		
	1 hour	**1 hour**	**4 jam**

ASTONJADRO pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.223-234
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Housing A	X1 ≤ 1; X2 ≤ 1; X3 ≤2; X4≤1 ; X5≤ 1; X1 + X2 + X3 + X4 + X5 = 6; X1,X2,X3,X4,X5 ≥ 0	X1 ≤ 2; X2≤ 1; X3≤ 4; X4≤ 4; X5 ≤1; X6 ≤ 1; X7 ≤2; X1 +X2 +X3 +X4 +X5 +X6+X7 = 15; X1 ,X2 ,X3, X4 ,X5 ,X6 ,X7 ≥ 0	X1 ≤ 4; X2≤ 2; X3≤ 6; X4 ≤6; X5 ≤ 2; X6 ≤ 1; X7 ≤ 3; X1 +X2 +X3 +X4 +X5 +X6+X7 = 24; X1 ,X2 ,X3, X4,X5,X6,X7 ≥ 0
Housing B	X1 ≤ 1; X2 ≤ 2; X3 ≤1; X4≤1 ; X5≤ 1; X1 + X2 + X3 + X4 + X5 = 6; X1,X2,X3,X4,X5 ≥ 0	X1 ≤ 2; X2≤ 1; X3≤ 4; X4≤ 3 ; X5 ≤1; X6 ≤ 2; X7 ≤1; X1 +X2 +X3 +X4 +X5 +X6+X7 = 14 ; X1 ,X2 ,X3, X4 ,X5 ,X6 ,X7 ≥ 0	X1 ≤ 4; X2≤ 2; X3≤ 7; X4 ≤6; X5 ≤ 2; X6 ≤ 4; X7 ≤ 2; X1 +X2 +X3 +X4 +X5 +X6+X7 = 27; X1 ,X2 ,X3, X4,X5,X6,X7 ≥ 0
Housing C	X1 ≤ 1; X2 ≤ 1; X3 ≤2; X4≤2 ; X5≤ 1; X6 ≤ 1; X1 + X2 + X3 + X4 + X5+ X6 = 8; X1,X2,X3,X4,X5 ≥ 0	X1 ≤ 1; X2≤ 2; X3≤ 4; X4≤ 4 ; X5 ≤2; X6 ≤ 1; X7 ≤ 2; X1 +X2 +X3 +X4 +X5 +X6+X7 = 16 ; X1 ,X2 ,X3, X4 ,X5 ,X6 ,X7 ≥ 0	X1 ≤ 2; X2≤ 4; X3≤ 7; X4≤ 7 ; X5 ≤3; X6 ≤ 2; X7 ≤4; X1 +X2 +X3 +X4 +X5 +X6+X7 = 29 ; X1 ,X2,X3, X4 ,X5 ,X6 ,X7 ≥ 0

The mathematical model above enters the LINDO program formulation to perform calculations by iterating. Figure 2 displays examples of LINDO program input and output data.



a. Inputing data in LINDO software b. Output data from LINDO software

Figure 2. Sample input objective function and constraint (a) iteration calculation result (b)

RESULT AND DISCUSSION

The surcharge for applying overtime is calculated based on the number of hours of overtime for each task. The calculation is obtained by adding the normal cost to the overtime cost. Table 16 provides an overview of the number of additional costs due to the program crashing in each housing A, B, and C.

Table 16. Crashing Cost (Rupiah)

Development	Normal Cost	Crash 1 hour	Crash 2 hours	Crash 4 hours
Housing A	415.507.850	438.433.008	470.151.453	511.825.034
Housing B	200.045.328	207.029.480	215.105.487	221.689.462
Housing C	157.995.055	179.439.240	224.012.966	232.582.952

The crashing process is a way of estimating variable costs in determining the most maximum and most economical duration reduction of an activity that is still possible to reduce (Ervianto, 2004). The table values above will be used in the calculation of cost slope as an optimization consideration, where the smallest slope value and the fastest duration are the main choices. Table 17 will illustrate the cost slope in each housing A, B, and C.

Table 16. Total Cost Slope (Rupiah)

Development	Cost Slope 1 hour	Cost Slope 2 hours	Cost Slope 4 hours
Housing A	3.820.860	3.642.907	4.013.216
Housing B	1.164.025	1.075.725	801.635
Housing C	2.680.523	4.126.120	2.571.996

The final stage in crashing the program is determining which acceleration is most worth value. Table 12 shows that Housing A will be optimal by choosing 2 hours of overtime with an acceleration duration of 15 days and a total cost of Rp. 470.151.453. Housing B will be optimal if you do overtime for 4 hours with an acceleration duration of 27 days and a total cost of Rp. 221.689.462. Lastly, housing C will be optimal after overtime for 2 hours with an acceleration duration is 16 days and requires a fee of Rp. 231.443.325. The acceleration by program crashing resulted in optimizations made from the project's critical path, with duration and cost slope data formulated by linear program modeling. Mathematical models validated using the iteration method with LINDO software generate optimum costs for each acceleration. Table 17 displays the results of iterations of the LINDO software.

Table 17. Optimization Result using LINDO software (Rupiah)

Development	Extra Cost 1 hour	Cost Slope 1 hour	Extra Cost 2 hours	Cost Slope 2 hours	Extra Cost 4 hours	Cost Slope 4 hours
Housing A	22.925.160	3.820.860	54.643.600	3.642.907	4.013.216	4.013.2156
Housing B	6.984.153	1.164.026	15.060.160	1.075.726	21.644.140	801.635
Housing C	21.444.190	2.680.524	66.017.910	4.126.119	74.587.900	2.571.997

The iteration results of the LINDO application in table 17 show additional costs and cost slopes. The optimization cost selection is based on the lowest cost slope. Housing A will be optimal by adding 2 hours of overtime with a total additional cost of Rp. 54.643.600 with a total acceleration of 15 days. In housing B, the development will be optimal by adding over time for 4 hours with a total additional cost of Rp. 21.644.140 with a 27-day acceleration. In housing C, the development will be optimal if it adds 4 hours of over time at an additional cost of Rp. 74.587.900 with a 29-day acceleration.

CONCLUSION

To find the optimum time with the best cost, this article offers techniques for resolving the issue of time and cost optimization in the construction of project housing using a mathematical model that is an integer linear program. The locations of housing A, B, and C were chosen based on the population density and level of housing affordability. According to the findings, using mathematical models to determine the ideal duration and time was valid. The model which displays several acceleration choices with variable durations, cost slopes, and final costs, is based on the crashing program depicted in tables (1) through (10). The choice of acceleration to be carried out is an important step in the crashing program. Table 12 shows choosing 2 hours of overtime with an acceleration period of 15 days and a total cost of Rp. 470.151.453 will make Housing A the most practical choice. Housing B will be better if the overpayment for 4 hours for 27 days with a total of Rp. 221.689.462. After working an additional 2 hours for 16 days, residential C will function properly at the cost of Rp 231.443.325. Linear Program Modeling is the result of a program crashing to provide optimization on critical project paths using accelerated data on duration and cost slope. The surcharge and cost slope are shown in table 17. The LINDO application tests mathematical models using an iteration method to determine the best price for each acceleration. Input data on a linear program resulting in a value proportional to the program's crash value. As can be observed, adding 2 hours of overtime to housing A at an additional cost of Rp 54.643.600 would be ideal. The construction of housing B will be most optimal by add four additional hours of work, with a total cost of Rp. 21.644.140. If the construction in housing C adds 4 hours of over time at an additional cost of Rp. 74.587.900, it will be considered optimal. The results show that the application of mathematical models that are linear integers in this study can be applied effectively. The residential construction developer can use the optimization, or the project owner will be able to choose the best solution based on the aspect of construction costs. So that in the future, work that becomes critical task can be optimized. This study recommends that mathematical model applications can be applied to other, more complicated problems using linear program applications such as ILOG CPLEX.

ACKNOWLEDGEMENT

This research was supported funding by annual Competitive Research grant provided by Universitas Muhammadiyah Surakarta. The author is also grateful to those who have helped carry out this study.

REFERENCES

Aboelmagd, Y. M. R. (2018). Linear programming applications in construction sites. *Alexandria Engineering Journal*, *57*(4), 4177–4187. https://doi.org/10.1016/j.aej.2018.11.006

Citra, Z., Susetyo, B., & Wibowo, P. D. (2018). *Optimasi Kinerja Proyek Dengan Penerapan Metode Crashing Dan Linear Programming*. *7*(2), 106–113.

Constitutional Court. (2020). Putusan Mahkamah Konstutisi Nomor 91/PUU-XVIII/2020. *Mahkamah Konstitusi Republik Indonesia*, 1–327. https://www.mkri.id/public/content/persidangan/putusan/putusan_mkri_8240_1637826598.pdf

Durdyev, S., Omarov, M., & Ismail, S. (2017). Causes of delay in residential construction projects in Cambodia. *Cogent Engineering*, *4*(1). https://doi.org/10.1080/23311916.2017.1291117

El-Rayes, K., & Kandil, A. (2005). Time-Cost-Quality Trade-Off Analysis for Highway Construction. *Journal of Construction Engineering and Management-Asce - J CONSTR ENG MANAGE-ASCE*, *131*. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:4(477)

Elsina, K., Mandagi, L. R. J. M., Tarore, H., & Malingkas, G. Y. (2013). Optimasi Biaya Dan Durasi Proyek Menggunakan Program Lindo (Studi Kasus: Pembangunan Dermaga Penyeberangan Salakan Tahap Ii). *Jurnal Sipil Statik*, *1*(4), 226–232.

Ervianto, Wulfram I. (2005). Manajemen Proyek Konstruksi (Edisi 3). Yogyakarta: Andi Offset.

Fachrurrazi, & Husin, S. (2021). Practical crash duration estimation for project schedule activities. *Journal of King Saud University - Engineering Sciences*, *33*(1), 1–14. https://doi.org/https://doi.org/10.1016/j.jksues.2019.09.005

Giri Aspia Ningrum, F., & Hartono, W. (2017). *Penerapan Metode Crashing Dalam Percepatan Durasi Proyek Dengan Alternatif Penambahan Jam Lembur Dan Shift Kerja (Studi Kasus: Proyek Pembangunan Hotel Grand Keisha, Yogyakarta)*.

Haryati, F., Panggabean, E. M., & Wahyuni, S. (2021). Pengembangan Bahan Ajar Mata Kuliah Program Linier Berbantuan Software Lindo. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *10*(4), 2791. https://doi.org/10.24127/ajpm.v10i4.3470

Khalishah, P. V. (2021). Analisis Hubungan Tingkat Suku Bunga Dan Penjualan Properti Pada Sektor Residensial. *Jurnal Manajemen Aset Dan Penilaian*, *1*(1), 23–30.

Laksana, A. W., Prasetyo, H. S., Wibowo, M. A., & Hidayat, A. (2014). Optimalisasi Waktu dan Biaya Proyek dengan Analisa Crash Program (Optimizing Project Time and Cost Using Crash Program Analysis). *Jurnal Karya Teknik Sipil*, *3*(3), 747–759.

Messah, Y. A., Penyebab, K., Pelaksanaan, K., Konstruksi, P., Di, G., Kupang, K., & Messah, Y. A. (2013). Kajian Penyebab Keterlambatan Pelaksanaan Proyek Konstuksi Gedung Di Kota Kupang. In *Jurnal Teknik Sipil: Vol. II* (Issue 2).

Rahmawati, D., Darmawijoyo, D., & Hapizah, H. (2018). Desain Pembelajaran Materi Fungsi Linier Menggunakan Pemodelan Matematika. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *7*(1), 65. https://doi.org/10.24127/ajpm.v7i1.1311

Sahid, M. N., Mulyono, G. S., Nuryanto, A. S. J., & Abdurrosyid, J. (2020). Evaluasi Pengendalian Waktu dan Produktivitas Tenaga Kerja Pelaksanaan Proyek Pembangunan Gedung Parkir Menggunakan Metode Jaringan Kerja Critical Path Methode (CPM) (Studi Kasus : Gedung Parkir Balai Kota Semarang). *Dinamika Teknik Sipil: Majalah Ilmiah Teknik Sipil*, *13*(2), 71–79. https://doi.org/10.23917/dts.v13i2.13057

Statistik, B. P. (2021). *Proporsi rumah tangga dengan status kepemilikan rumah milik dan sewa/kontrak menurut provinsi 2019-2021*. https://www.bps.go.id/indicator/29/2018/1/proporsi-rumah-tangga-dengan-status-kepemilikan-rumah-milik-dan-sewa-kontrak-menurut-provinsi.html