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Analysis of Time Control Strategies Using The Critical Path Method (CPM) In The Development of The Java Residence Cluster For Mass-Product Housing

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KEYWORDS

critical path method, project management, construction, time efficiency, quality control

ABSTRACT

The increasing complexity and scale of industrial and construction projects demand efficient management techniques to ensure timely delivery, cost-effectiveness, and adherence to quality standards. This study focuses on the implementation of the Critical Path Method (CPM) in managing the construction of the Cluster Java Residence in Sidoarjo to enhance time efficiency. The research investigates the effectiveness of CPM in identifying and mitigating delays by analyzing project activities, their interdependencies, and schedule flexibility using forward and backward pass calculations. Secondary data from project schedules and primary data from field observations were analyzed to identify critical paths and optimize project timelines. Results indicate that the implementation of product quality control in the construction of housing units in the Java Residence Cluster is still under control, although the average number of defects or complaints per housing unit is relatively high. The issues of defects or complaints in the construction of housing units in the Java Residence Cluster are caused by factors related to humans, machines or tools, materials, and work methods.

INTRODUCTION

Progress in industrial activities across various aspects demands management with high performance, precision, cost-efficiency, integration, speed, accuracy, meticulousness, and safety to achieve desired outcomes. Managing activities involving large-scale investments and high complexity requires tested methods, quality resources, and the application of appropriate and up-to-date knowledge (Abrar Husen, 2009).

Project management is one of the approaches developed to meet these demands—a method that has been scientifically and intensively refined since the mid-20th century to manage specialized activities in the form of projects (Soeharto, 2001). Construction project management is both a discipline and a concept designed to execute and complete construction projects in a way that ensures timely delivery, budget compliance, and quality standards. This enables the development of effective strategies for managing and mitigating the impacts (Patriadi et al., 2024).The application of project management in construction involves critical elements such as cost estimation, human resources, time management, quality control, effective and efficient execution methods, and productivity in project implementation (Ervianto, 2023).

Time management entails planning, organizing, activating, and controlling time productivity by creating project schedules, measuring and reporting project progress, and comparing planned schedules with actual field progress. Project scheduling, as one of the outputs of planning, provides essential information regarding planned schedules and project progress, focusing on the performance of resources such as costs, labor, equipment, materials, and the planned project duration and progress.

Effective time management implementation helps mitigate delay risks, sustain productivity, and ensure project success. This is particularly important in highly complex projects, such as apartment construction, where uncertainties in the construction process can significantly affect the project's final outcomes (Bishnoi, 2018).

Problem Formulation

Based on the background of the problem, the researcher identifies the research question: Can the use of the Critical Path Method (CPM) improve work time efficiency in the construction project of Cluster Java Residence – Sidoarjo?

Research Objectives

The objective of this research is to improve work time efficiency using the Critical Path Method (CPM) in the construction project of Cluster Java Residence – Sidoarjo.

Literature Review

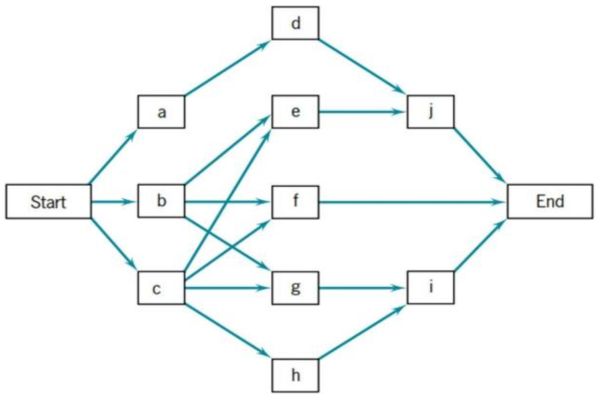
Time Management

Project Scheduling provides a detailed plan that outlines how and when the project will deliver the products, services, and results defined within the project scope. It serves as a tool for communication, managing stakeholder expectations, and a basis for performance reporting. Schedule Management Planning is the process of establishing policies, procedures, and documentation for planning, developing, managing, executing, and controlling the project schedule (Melinda & Suryono, 2018). The primary benefit of this process is that it provides guidance and direction on how the project schedule will be managed throughout the project lifecycle. This process is performed once or at predefined points in the project (PMBOK GUIDE, Sixth Edition) (Olivieri et al., 2019).

Sequencing of Activity

According to Hamilton (2007), three key aspects to consider when sequencing activities are:

- Predecessor: Activities that precede or come before a given activity. For example, land clearing is a predecessor to the surveyor activity.
- Successor/Followers: Activities that follow or occur after a given activity. For instance, the surveyor activity is a successor to land clearing.
- Concurrent: Activities that can occur simultaneously with a given activity.



Here the illustration of predecessor, successor, and concurrent.

Taking Activity E as an example:

- Activities B and C are the predecessors of Activity E.
- Activity J is the successor of Activity E.
- Activities D, F, G, and H are concurrent with Activity E.

The relationships between project activities can be expressed as finish-to-start, start-to-start, finish-to-finish, and start-to-finish, along with lag as shown in the figure below.

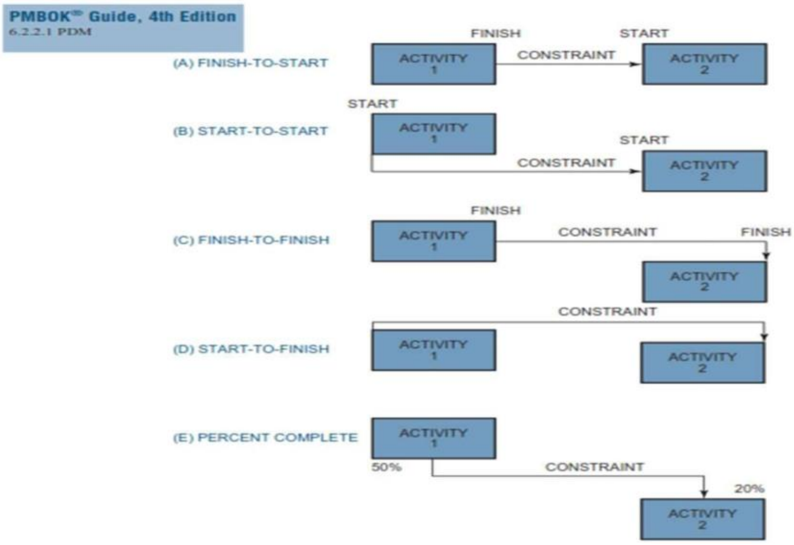


Figure 2 illustrates an example of the relationship between two activities, namely Activity A and Activity B, as follows:

- Finish-to-Start (FS): Activity B can only start after Activity A has finished.
- Start-to-Start (SS): Activity B can start as soon as Activity A begins.
- Finish-to-Finish (FF): Activities A and B must finish at the same time.
- Start-to-Finish (SF): Activity B must finish when Activity A starts.

Additionally, lag refers to the time gap between the start or completion of the predecessor activity and the start or completion of the successor activity. This lag can have either a positive or negative value (Scala et al., 2023).

The Critical Path

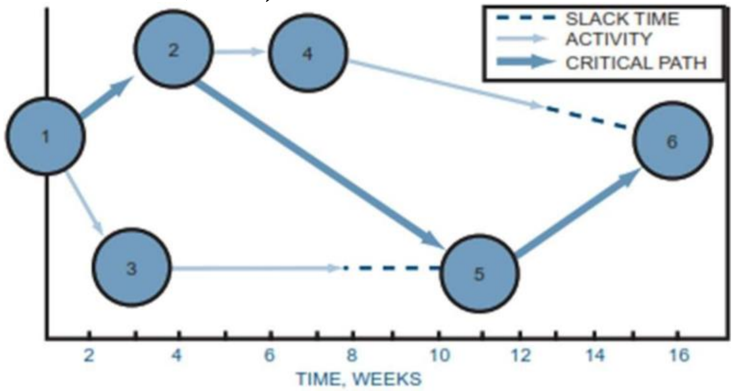
The Critical Path is a scheduling technique used to estimate the minimum project duration by identifying the longest sequence of activities in the schedule. This method involves forward and backward analysis, helping to determine schedule flexibility or "float." The critical path typically has zero total float, meaning any delay in activities on this path directly affects the project completion date (Farida & Anenda, 2022). Total float can be positive or negative, depending on existing constraints, and adjustments to activity durations, logical relationships, or other constraints may be required to optimize the schedule. Additionally, free float indicates how long an activity can be delayed without affecting the start date of its successor (Edition, 2018). Activity durations are calculated using three variables: ta (optimistic time), tb (pessimistic time), and tm (realistic time).

The Critical Path Method (CPM) is a network diagram technique used to predict the total project duration. This method is crucial for addressing project schedule delays. The critical path in a project is a series of activities that determines the earliest possible project completion date with the least slack or float. Slack or float refers to the amount of time an activity can be delayed without affecting its successor activities or the project completion date (POLIANI, 2019).

In many projects, multiple tasks are performed in parallel, often resulting in several paths within the network diagram. The longest path, which contains the critical tasks, determines the project completion date (Grant & Ray, 2018). Below is an illustration of a CPM activity diagram.

Once the tasks and activities have been identified, the next step is to define the relationships between tasks and create a Network Diagram encompassing the entire project.

Using the Network Diagram, an analysis can be performed using the CPM method. By considering task durations and their interrelationships, we can determine the earliest expected completion time and the latest allowable time for each activity (Levin and Kirkpatrick, 1972, as cited in (Setyadewi & Retnani, 2017).



The urgency of this research stems from the increasing complexity and scale of construction projects, which demand efficient time management to prevent delays and cost overruns. Projects like the Java Residence Cluster are crucial for addressing housing needs, but poor scheduling and project delays can lead to increased expenses, reduced stakeholder confidence, and missed economic opportunities. Implementing effective management strategies, such as the Critical Path Method (CPM), is essential for ensuring timely project delivery and maintaining quality standards.

Despite the widespread adoption of CPM in construction project management, there is limited research on its practical application in mass-product housing developments in Indonesia. Existing studies often focus on large infrastructure projects, leaving a gap in understanding how CPM can address time management challenges specific to residential housing projects. Additionally, the integration of CPM with quality control measures to mitigate defects and complaints has not been extensively explored, creating a need for further investigation.

The novelty of this study lies in its application of CPM to a mass-product housing project, providing insights into its effectiveness in improving time efficiency and identifying critical paths. By combining CPM with quality control analysis, such as Pareto and control charts, this research introduces a comprehensive approach to optimizing both scheduling and construction quality. This dual focus on time management and defect reduction sets this study apart, offering practical solutions tailored to the Indonesian housing sector.

The objective of this research is to evaluate the effectiveness of CPM in improving time efficiency and managing quality in the Java Residence Cluster construction project. The findings aim to benefit contractors and project managers by providing actionable recommendations for addressing delays and defects. Additionally, this study contributes to academic literature by expanding knowledge on CPM's applicability in residential housing projects. The research outcomes are expected to enhance project execution efficiency, reduce costs, and improve overall housing quality, supporting the development of sustainable construction practices.

RESEARCH METHOD

Research Objective

This research is conducted to identify the factors causing delays in the scheduling of work on the Mass Product Cluster Java Residence construction project, as well as to provide solutions to construction stakeholders (Contractors) when the schedule is not followed properly.

Research Time

The research was conducted from November 17 to December 7, 2024 which began in stages from field observations, secondary data collection, primary data creation, research, and secondary data analysis.

Data

The types of data in this study include primary data and secondary data. Primary data in this study was gathered directly from the staff of PT. Mitra Usaha Konstruksi (contractor) at the Java Residence Construction Project in Sidoarjo. The secondary data includes materials such as lecture notes, books, and articles on project and construction management, risk management, simulation, and other relevant sources.

Data Analysis Technique

a. Critical Path Analysis:

- Identification of Project Activities: List all activities that must be completed, including their durations and the precedence relationships between activities.
- Network Diagram Creation: Use Activity on Node (AON) or Activity on Arrow (AOA) diagrams to visualize the sequence of activities.
- Determining Activity Durations: Input the duration of each activity based on project data.
- Forward Pass: Calculate Early Start (ES) and Early Finish (EF) to determine the earliest possible start and finish times for each activity.
- Backward Pass: Calculate Late Start (LS) and Late Finish (LF) to determine the latest possible start and finish times for each activity.
- Identification of the Critical Path: Identify the longest path with no float (slack) in the project network. The activities on this path are the critical focus of the project.

b. Slack Time Calculation:

- Total Float: The additional time available for an activity without delaying the project work.
- Free Float: The additional time available for an activity without delaying the subsequent activity.

c. Project Completion Time Acceleration Analysis:

- Reducing the duration of activities on the critical path.
- Testing all project activities.
- Focusing on activities on the critical path.

d. Earned Schedule Analysis:

Earned Schedule (ES) is an extension of Earned Value Management (EVM) used to measure project schedule performance based on actual progress compared to the planned schedule. Unlike EVM, which focuses primarily on cost value, ES is more relevant for evaluating the time performance of a project. The Schedule Performance Index (SPI(t)) is calculated using the following formula:

$$SPI(t) = \frac{ES(Earned\ Schedule)}{AT\ (Actual\ Time)}.$$

This index provides insight into how well the project is adhering to its schedule. An SPI(t) value greater than 1 indicates the project is ahead of schedule, while a value less than 1 means the project is behind schedule.

In addition to calculating the SPI(t), the Earned Schedule method can also be used to determine the Forecasted Duration (FD) to estimate the remaining time required to complete the project. The formula for calculating Forecasted Duration typically involves:

$$FD = \frac{PD(Planned\ Duration).}{SPI(t)}$$

This estimation helps project managers forecast the remaining duration of the project based on current performance trends.

e. Analysis using Control Chart:

- Percentage of Complains

$$P(Percentage\ of\ Complains) = \frac{Number\ per\ complaint}{Total\ number\ of\ complaints}$$

- Mean

$$P(Average\ Complaints) = \frac{Total\ complaints}{Number\ of\ households}$$

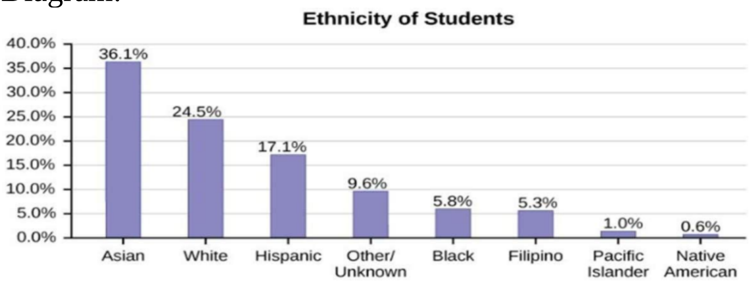
- Upper Control Limit

$$UCL = \vec{p} + 3\frac{\sqrt{P(1-p)}}{n}$$

- Upper Control Limit

$$LCL = \vec{p} - 3\frac{\sqrt{P(1-p)}}{n}$$

f. Analysis Pareto Diagram:



RESULTS AND DISCUSSION

Time Management

The first step in time control analysis using the Critical Path Method is to make a comparison between the planned schedule and the actual schedule to determine if there is any time delay. Then, determine the work paths and identify the critical path using MS Project, based on the determination of Slack Time and time acceleration.

Form and Check Sheet

The Complaint Form is useful for simplifying the data collection process as well as data analysis (College, n.d.). In addition to being used for data collection and analysis, the Complaint Form also helps identify the problem areas based on the type of complaint and can serve as a basis for decision-making regarding whether improvements should be made.

From the data gathered through the Complaint Form, it can be determined what causes defects or damage in the construction of house units, how much impact it has on the construction process, and the extent of the damage caused during the construction period. The results of the data collection through the Complaint Form can be seen in the following table:

Table 1. Complaints Form

Housing Unit	Complaint Items														Tota of Complaints
	TMN	RSTR	PJ	PV	CP	HTK	CAT	SNTY	MEP	SH	PFD	KNP	MJD	ATP	
1	1	-	1	1	-	1	1	-	1	-	-	-	-	1	7
2	-	1	1	-	1	1	1	-	1	-	-	1	-	-	7
3	1	1	1	-	1	1	1	-	1	-	1	1	-	-	9
4	1	-	1	-	1	-	1	-	1	-	-	1	-	-	6
5	1	-	1	-	1	1	-	1	-	-	-	1	-	-	6
6	1	-	1	-	-	-	1	-	1	-	-	-	-	-	4
7	1	-	1	-	-	-	1	1	-	-	-	-	-	-	4
8	-	1	1	-	-	-	1	1	-	-	1	1	-	-	6
9	1	-	1	-	-	1	1	1	1	-	-	1	-	1	8
10	1	-	1	-	-	-	1	-	-	-	-	1	-	1	5
11	1	-	1	-	-	1	1	1	1	-	1	-	-	1	8
12	-	-	1	-	-	1	1	-	1	-	-	1	1	1	7
13	1	-	1	-	-	1	-	1	1	-	1	-	1	1	8
14	1	-	1	-	1	-	1	1	-	-	1	1	-	1	8
15	-	-	1	-	1	-	1	1	-	-	1	1	-	-	6
16	-	-	1	-	1	-	-	-	1	-	-	1	-	1	5
17	-	1	1	-	1	-	1	-	1	-	1	-	-	-	6
18	-	-	1	-	1	1	-	1	1	-	1	1	-	-	7
19	-	-	1	-	-	1	1	-	-	-	1	-	-	1	5
20	-	1	1	-	1	1	1	-	1	-	-	1	-	1	8
21	1	-	1	1	-	1	-	1	1	-	1	-	1	1	9
22	-	-	1	-	1	1	1	-	1	-	1	-	-	-	6
23	-	-	1	-	1	1	1	1	1	-	-	1	1	1	9
24	-	-	1	-	-	1	-	1	-	-	-	-	-	-	3
25	-	-	1	-	-	1	1	-	1	-	1	1	-	1	7
26	-	-	1	-	-	1	1	-	1	-	1	1	-	1	7
27	-	-	1	-	1	-	-	1	1	-	-	-	-	-	4
28	-	-	1	-	1	1	1	1	1	-	1	1	-	-	8
29	1	-	1	-	1	-	-	1	1	-	-	1	-	-	6
30	1	-	1	-	-	-	1	-	-	1	-	1	-	-	5
31	-	-	1	-	-	-	1	-	-	-	-	1	-	-	3
32	-	-	1	-	1	-	1	-	-	-	1	1	-	-	5
33	-	-	1	-	-	-	1	-	-	-	-	-	-	-	2
34	-	1	1	-	1	1	1	-	-	-	-	1	-	-	6
35	-	-	1	-	-	-	-	-	-	-	-	1	-	-	2
36	-	-	1	-	-	1	1	1	1	-	1	1	1	-	8
37	1	-	1	-	-	1	-	-	-	-	-	1	-	-	4
38	-	-	1	-	-	1	1	-	-	-	-	-	-	-	3
39	1	-	1	-	-	1	-	1	-	-	1	1	1	1	8
40	-	-	-	-	-	-	-	1	1	1	-	-	-	-	3

Explanation of Complaint Types:
TMN : Garden
RSTR : Roster
PJ : Doors and Windows
PV : Paving
CP : Carport
SNTY : Sanitary
MEP : MEP (Mechanical, Electrical, Plumbing)
SH : Smart Home
PFD : Plafond
KNP : Canopy
MJD : Kitchen Table

ATP : Roof

Control Chart

A control chart is a tool that is graphically used to monitor and evaluate whether an activity or process is under statistical quality control or can be used as a tool to improve quality (College, n.d.). The following is the result of the control chart.

Table 2. Control Chart

Housing Number Unit	Number of Complaint Items	Percentage of Complaints	Average Number of Complaint Items	UCL (3σ)	LCL (3σ)
1	7	50%	5,95	11,91	-0,01
2	7	50%	5,95	11,91	-0,01
3	9	64%	5,95	11,91	-0,01
4	6	43%	5,95	11,91	-0,01
5	6	43%	5,95	11,91	-0,01
6	4	29%	5,95	11,91	-0,01
7	4	29%	5,95	11,91	-0,01
8	6	43%	5,95	11,91	-0,01
9	8	57%	5,95	11,91	-0,01
10	5	36%	5,95	11,91	-0,01
11	8	57%	5,95	11,91	-0,01
12	7	50%	5,95	11,91	-0,01
13	8	57%	5,95	11,91	-0,01
14	8	57%	5,95	11,91	-0,01
15	6	43%	5,95	11,91	-0,01
16	5	36%	5,95	11,91	-0,01
17	6	43%	5,95	11,91	-0,01
18	7	50%	5,95	11,91	-0,01
19	5	36%	5,95	11,91	-0,01
20	8	57%	5,95	11,91	-0,01
21	9	64%	5,95	11,91	-0,01
22	6	43%	5,95	11,91	-0,01
23	9	64%	5,95	11,91	-0,01
24	3	21%	5,95	11,91	-0,01
25	7	50%	5,95	11,91	-0,01
26	7	50%	5,95	11,91	-0,01
27	4	29%	5,95	11,91	-0,01
28	8	57%	5,95	11,91	-0,01
29	6	43%	5,95	11,91	-0,01
30	5	36%	5,95	11,91	-0,01
31	3	21%	5,95	11,91	-0,01
32	5	36%	5,95	11,91	-0,01
33	2	14%	5,95	11,91	-0,01
34	6	43%	5,95	11,91	-0,01
35	2	14%	5,95	11,91	-0,01
36	8	57%	5,95	11,91	-0,01
37	4	29%	5,95	11,91	-0,01
38	3	21%	5,95	11,91	-0,01

39	8	57%	5,95	11,91	-0,01
40	3	21%	5,95	11,91	-0,01

Based on the calculations and the control chart above, it can be observed that quality control in Cluster 1 Stage 3 is already under control. However, the average number of complaints per housing unit remains high. This is indicated by the absence of points exceeding the upper control limit and lower control limit, but it does not meet the company's complaint tolerance threshold of 0.05. It can be concluded that quality control for the Java Residence Project is within control limits; however, the complaint tolerance level is still high. Therefore, further improvements are needed in quality control for housing unit construction to address the high number of complaints and prevent an increase in complaints regarding the quality of future housing units.

Identifying the Type of Complaints

The identification of types of complaints/damages is conducted using a Pareto diagram. A Pareto diagram is a chart used to identify and rank the types of complaints/damages (College, n.d.). Using this diagram, the most dominant types of complaints/damages can be determined, as shown in Table 3 and Figure 5 below.

Complaints by User	**Number of Complaint Items**	**%**	**Accumulative %**
Doors and Windows	39	16,39%	16,39%
Wall paint	28	11,76%	28,15%
Canopy	26	10,92%	39,08%
HT & Ceramic	23	9,66%	48,74%
MEP	23	9,66%	58,40%
Sanitair	18	7,56%	65,97%
Carport	17	7,14%	73,11%
Plafond	17	7,14%	80,25%
Garden	16	6,72%	86,97%
Roof	15	6,30%	93,28%
Roster	6	2,52%	95,80%
Kitchen Table	6	2,52%	98,32%
Paving	2	0,84%	99,16%
Smarthome	2	0,84%	100,00%
Total	**238**	**100,00%**	

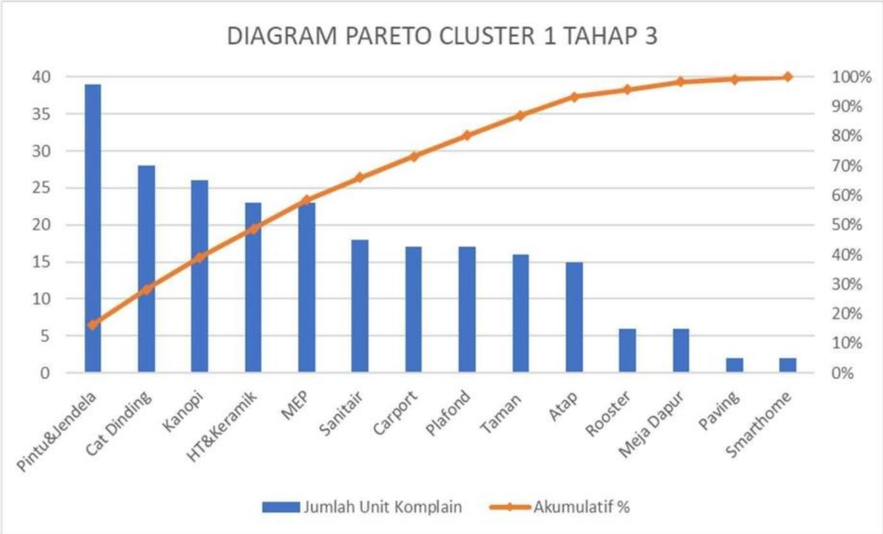
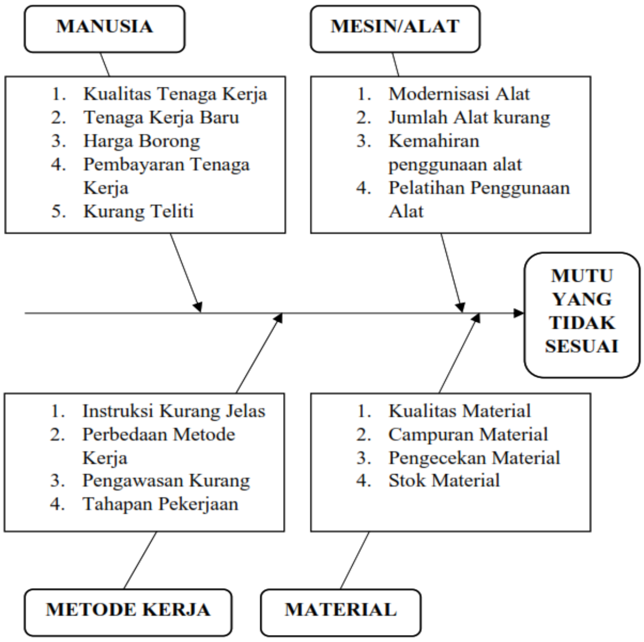


Table 3. Type of Complaints

Based on the Pareto diagram results above, it can be seen that nearly 60% of complaints/damages in the construction of housing units in Cluster 1 Stage 3 are dominated by five (5) types of complaints/damages: issues with doors & windows, wall paint, canopies, HT & ceramic tiles, and MEP works. Therefore, improvements for these complaints or damages in the construction of subsequent housing units will be focused on these five (5) types of complaints or damages to prevent future complaints in housing unit construction.

Identifying the Cause and Effect

The identification of the causes of damage occurring during the construction process of housing units in the Java Residence project was conducted using a fishbone diagram. A fishbone diagram is a type of chart that helps organize ideas in writing. It is used as a diagram-based approach to brainstorm all possible arguments for a problem and analyze the situation based on those arguments. The cause-and-effect diagram was created based on the results of interviews and discussions with the Project Control and Site Manager of Java Residence. The findings are presented below.



From the diagram above, the following factors contribute to damages or complaints during the construction process:

1. Human Factor

   Humans play a critical role in the construction process, acting as the driving force behind whether a project produces high-quality outcomes. Employees become a factor that realizes optimal performance (Sajiyo, Fathurrahman, L., Prasnowo, M.A., Rodli, A.F., Makki, 2019). The factors related to humans that may lead to damages or complaints include:

   - Worker Quality: In construction, the skills and quality of workers play a significant role. Poor worker quality can lead to defects or complaints about the housing units being constructed.
   - Labor Costs and Payments: The contract rate for labor and delayed payments to workers can significantly impact their output. If the contract rates are too low or payment is delayed, workers may not perform at the desired quality level.

2. Machines and Tools

   Machines and tools are key determinants of whether the production process runs smoothly. They are often a significant source of issues in construction. The five main types of complaints or damages can be traced back to improper use of machines or tools. This happens because:

   - Modernization and Training on New Tools: Workers may not be trained to use modern tools, resulting in continued reliance on conventional tools during construction.
   - Quantity and Maintenance of Tools: Besides the lack of implementation of modern tools, the limited number of tools available and the time required for tool maintenance mean tools cannot be used effectively and uniformly.

3. Materials

   Materials, in this case, refer to the raw materials used in the production or construction of housing units. Based on data on types of complaints or damages, it can be concluded that one of the causes of complaints or damages also originates from the use of materials.

4. Work Methods

   The methods used during the construction of housing units can affect production results or quality. Methods that do not comply with established standards can cause damages in the production or construction process. The role of the Site Project team is crucial in checking the work methods used and ensuring that the work phases proceed as they should. Periodic training and guidance on correct work methods should also be provided to workers to prevent the use of conventional methods with a high rate of defects or complaints.

Discussion

Based on the analysis conducted using the Critical Path Method (CPM) for the Cluster Java Residence development project in Sidoarjo, it can be concluded that the application of the CPM method has significantly contributed to improving the efficiency of project scheduling. In this study, the comparison between the planned schedule and the actual schedule revealed delays in project implementation. However, by using the critical path analysis, the activities that directly affect the project completion duration were successfully identified. Thus, time management can be focused on the activities within the critical path to expedite the completion process.

The delays in this project were largely caused by external factors, such as delayed material supplies and a lack of skilled labor. This indicates the need for better risk management, including more thorough material procurement planning and enhanced worker training. Nevertheless, with the application of CPM, improvements can be made by further analyzing activities affecting the critical path and proactively addressing these issues to prevent further delays. Furthermore, despite delays occurring at several stages, the project's cost estimation remained under control, as reflected in the Estimate at Completion (EAC) value, which was still in line with the planned budget. Thus, although the project experienced delays in certain phases, cost control was maintained, which is an important factor in ensuring the financial smoothness of the project.

In terms of quality control, the analysis results indicate that while the product quality in the house construction was controlled, complaints about damage and defects in some units were still relatively high. The most frequent issues reported included problems with doors and windows, wall paint, canopies, and damage to electrical and mechanical installations. Therefore, it is recommended that the project manager conducts regular inspections of the work quality and provides additional training for workers to minimize errors in construction. With these research findings, it is hoped that the application of CPM in future housing development projects or similar projects can be more optimal, focusing on more efficient time management and stricter quality control. Furthermore, it is crucial to improve communication and coordination among the involved parties, such as contractors, material suppliers, and workers, to avoid delays and minimize unnecessary additional costs.

CONCLUSION

Based on the analysis and discussion, it can be concluded that the implementation of product quality control in the construction of housing units at the Java Residence Cluster remains under control. This is demonstrated by the fact that 40 housing units in Cluster 1 Stage 3 fall within the upper control limit (UCL) and lower control limit (LCL), although the average number of defects or complaints per unit remains relatively high at 5.95 items. The cause-and-effect diagram analysis highlights that these defects or complaints stem from various factors, including human error, machinery or tools, material quality, and work methods, indicating the need for improvements across multiple aspects of the construction process.

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