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Optimization of residential building construction time using the critical path method in bontang

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ABSTRACT

The construction of residential housing is a complex process that requires optimal time management to ensure timely project completion. Delays in construction project implementation are often caused by various internal and external factors, such as limited resources, weather conditions, and challenges in coordinating project activities. This research aims to optimize the construction duration of a type 130 residential house in Bontang City through the application of the Critical Path Method (CPM). This method functions to identify the critical path in the stages of project activities and determine the estimated minimum project completion duration. Project activity data were obtained through field observations and interviews with the project implementers, then analyzed using the CPM approach by calculating Early Start (ES), Early Finish (EF), Late Start (LS), and Late Finish (LF). The analysis results indicate that by identifying and managing the critical path, the project—which was initially estimated to take 166 days—can be completed in 135 days with a total of 13 main activities, resulting in a time acceleration of 31 days. This study demonstrates that the CPM method is effective in controlling project execution time and has the potential to serve as a strategic solution to minimize delays in similar future projects.

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INTRODUCTION

Residential home is one of the basic human needs that has an important role in supporting survival, providing protection and supporting daily activities (Matasik, 2020). The construction of residential housing is a complex process that requires thorough time planning to ensure completion according to target. The execution of a project requires structured and effective planning, scheduling, and management, including resources, material availability, equipment, geographical conditions, climate, and various other external factors that may influence project progress (Farhan et al., 2024). Project is a collection of interrelated activities designed to achieve a specific goal, such as construction, while still paying attention to the specified time, cost, and quality constraints. Activities in this project include a number of stages, starting from planning, implementation, to the maintenance stage (Sutopo & Hendarti, 2022). In project execution, time is one of the crucial elements that determine project success. However, in practice, many projects fail to be completed according to the planned schedule, resulting in delays during implementation (Putra et al., 2023).

According to Puspitasari et al. (2022), the failure to complete construction projects is often caused by ineffective duration control. Therefore, construction project scheduling is a crucial element in planning, aiming to ensure that projects are completed within the specified time frame. Another opinion by (Saputra et al., 2021) states that the success or failure in executing a project is often influenced by the lack of thorough activity planning and weak control during the implementation process. Such conditions may cause inefficiency in project execution, leading to delays, reduced work quality, and increased implementation costs.

Timely completion of infrastructure projects is one of the main priorities in construction management. Time factors and the quality of human resources significantly affect operational costs, especially in terms of labor wages. One of the common issues encountered in the field is project delays caused by suboptimal planning, which may result in project failure that directly affects all involved workers (Astari et al., 2021).

Meanwhile, (Mustafaruddin et al., 2020) conducted a study on the factors causing delays in the construction process of habitable housing for underprivileged communities in Aceh Province. The results showed that the constraints in project execution were influenced by various aspects, including design and planning, implementation stage and working relationships, material availability, labor, equipment, site conditions, and external factors beyond the contractor's control. The results of research from Sanaky, (2021) said there are four main indicators in efforts to control project delays, including control over change factors, labor, equipment and materials. These four indicators are considered to play a significant role in determining the smoothness and timeliness of construction project implementation. Another research conducted by Huda et al., (2021) work accidents are also a significant factor that hinders the progress of construction projects. The results of research by Romadhon & Tenriajeng, (2020) show that delay factors originating from employment aspects have a significant influence on delays in project implementation.

Although several previous studies have revealed the causes of delays in residential building projects, comprehensive studies examining the relationships between these factors are still limited, especially in non-social projects such as private or commercial housing. Furthermore, the development of solution-oriented strategies in the form of delay mitigation and structured time management is still rarely found in construction practices.

Based on these conditions, this study aims to contribute academically through a systematic analysis of the work stages in the residential construction process in Bontang City. Therefore, this research focuses on identifying and mapping the sequence of construction activities that have the potential to become sources of delay, while also evaluating the interrelation between these stages and the internal and external factors that affect project performance. Through this approach, the study is expected to provide a holistic understanding of the construction process, identify critical points in time management, and serve as a foundation in developing more effective, targeted, and applicable delay mitigation strategies for similar future projects.

In addition, this study also provides a significant contribution in efforts to overcome the problem of delays in construction projects through the application of the CPM method. This approach allows the identification of critical activity paths that have a direct impact on the total duration of project completion. By applying the CPM method to the type 130 residential construction project located in Bontang City, the study succeeded in optimizing the project completion time from the original 166 days to only 135 days. This reflects a time efficiency of 31 days that can be achieved through proper and systematic scheduling analysis.

In addition to these achievements, this study also identified a number of main factors that trigger project delays. Among them are suboptimal initial planning, limitations in the availability of labor and building materials, and the influence of external factors such as weather or regulations. These findings emphasize the importance of integrated planning that covers all technical and non-technical aspects from the early stages of the project.

As a solution, this study offers a more structured and efficient scheduling strategy to reduce the risk of delays, such as allocating resources proportionally and adjusting the schedule based on the priority of the critical path. Therefore, in addition to providing practical benefits for the implementation of construction projects in the field, this study enriches the academic literature in the field of project management, especially in the aspect of time control which is the key to the success of construction projects.

Time management in construction projects plays an essential role in identifying, planning, and controlling the entire sequence of activities to ensure that the project is completed on time according to the plan. According to Mewengkang et al., (2023), project management is a process that encompasses all planning, execution, control, and coordination stages of a project from start to finish, with the objective of achieving timely results, cost efficiency, and compliance with the defined quality standards.

In this context, the complexity of managing and executing a construction project is increasing, thus requiring good management to control the process. The success of a construction project heavily depends on its implementation. Time management in construction is necessary to ensure that all execution stages can be completed within the planned schedule (Maliki, 2020). Project scheduling is a planning process that regulates the order of work activities in order to complete a job with a specific purpose and within a clearly determined completion time (Fazis & Tugiah, 2022).

In the context of residential building construction, particularly for houses classified as "Type 130"—a mid-sized, two-story house with a total built area of approximately 130 square meters, including structural, architectural, and installation work of high complexity—delays in implementation can lead to increased costs and disruptions to other scheduled project activities. According to Rachman et al., (2024), one common issue in project implementation is the mismatch between the volume of work and the allocated budget. Therefore, cost estimation planning must be carefully and precisely prepared to minimize the risk of loss during project execution.

Time optimization becomes a crucial aspect in medium-scale construction projects such as the development of a Type 130 residential house. The application of the CPM is carried out to identify potential delays and calculate the resulting cost implications, which are further analyzed using the crashing method (Damara & Hepiyanto, 2021). Project delays are defined as an extension of the time required to complete work beyond what was planned and specified in the contract documents (Astari et al., 2021).

In a study by Rahmatullah et al., (2022) entitled "*Comparison of Critical Path Method (CPM) with Program Evaluation and Review Technique (PERT) on Project Time Scheduling (Case Study of the UMI Faculty of Law Development Project)*", the CPM method resulted in a duration of 17 weeks, while the PERT method resulted in a duration of 22 weeks. Another results of study by (Santoso & Handayani, (2025) entitled "*A Comparative Analysis of the CPM and PERT Methods in Project Time Management for a High-Rise Building Construction Project in Yogyakarta*" showed that the CPM method predicted a project duration of 419 days, which was 237 days faster than the original schedule, while the PERT method estimated a duration of 580 days, or 76 days faster than the original schedule. Therefore, the researcher chose the CPM method as it was considered more effective in supporting acceleration planning to optimize the project execution time.

RESEARCH METHOD

The verification and validation process of project activity duration data obtained through interviews and direct field observations is carried out through systematic stages designed to ensure the accuracy, alignment, and relevance of data before being used in CPM-based analysis. This approach aims to minimize the potential for data bias and ensure that all information used truly represents real conditions in the field, so that the results of the project analysis can be relied on for managerial decision making.

In formulating the research problem, the CPM is used as the primary analytical tool to optimize the duration of the residential construction project. CPM was developed as a supporting tool for planning construction projects, with the objective of providing a systematic analytical basis for effectively planning and scheduling project implementation (Wijaya et al., 2022).

The use of the CPM method is based on its capability to identify the critical activity path in a construction project, enabling the calculation of the estimated optimal project completion time as well as the analysis of activities with time flexibility (float). According to Nathasia et al., (2024), the CPM method serves to identify activities that belong to the critical path, meaning that any delays in these activities will directly affect the overall project duration.

The application of this method allows for time savings across various project stages. Nathasia et al., (2024) also stated that the critical path consists of activities from the beginning to the end of the project, and determines the earliest possible completion time. This path includes critical activities whose delays would directly extend the overall project duration.

Various studies have demonstrated that the Critical Path Method is used to analyze project activity networks, with the aim of optimizing project costs through accelerated project completion (Aprillia et al., 2023). CPM is a sequence of activities that determines the longest duration required to complete a project. The method aims to minimize potential delays and reduce disruptions to the execution schedule (Saputra et al., 2024). CPM is considered capable of structuring the relationships between activities systematically and determining the most efficient execution sequence, thereby supporting optimal time management in projects.

The determination of crash duration in the application of the CPM method is based on several technical and managerial assumptions. From a technical perspective, it is assumed that the acceleration of activities on the critical path can be achieved through the addition of resources, such as labor, equipment, or the use of more effective technology, without compromising work quality. From a managerial standpoint, it is assumed that such acceleration efforts can be organized and controlled properly so as not to disrupt the sequence of project activities. The economic justification for the accelerated duration is based on an analysis comparing the additional costs of acceleration with the economic benefits obtained, such as reductions in overhead costs, earlier receipt of project benefits, or the avoidance of penalties for delays. Therefore, the crash duration is determined to achieve an optimal project execution time with more efficient total project costs. The study conducted by Ali et al., (2024) shows that the implementation of one hour of overtime contributes to accelerating project completion by 12 working days, with an additional cost of IDR 24,488,758. The cost slope analysis reveals that this acceleration requires an additional overtime cost of IDR 12,244,379.

Within the scope of this study, data on project activities including types of work, normal implementation duration, and duration after acceleration (crashing) were collected directly through interaction with the project implementer and through comprehensive observation of the implementation of the construction of type 130 residential houses located in Bontang City. Verification was carried out by comparing the results of interviews with the factual situation at the project location, including the order of work, allocation of resources used, and recording the actual time of each stage of work. Validation was then carried out by reviewing the suitability of the data to the generally applicable project implementation time standards, to historical data from previous similar projects to assess the rationality and feasibility of the information collected.

Additionally, the method involves analyzing the critical path by first constructing a project network, followed by calculating Early Start (ES), Early Finish (EF), Late Start (LS), and Late Finish (LF), with the goal of identifying critical activities so that the project schedule can be arranged with optimal duration (Permatasari et al., 2023). Network planning through critical path identification is one of the project management approaches used to design and control the project implementation process. This approach allows for mapping activity interrelations and determining key timing points during project execution. The determination of the critical path aims to increase time efficiency, so that project completion duration can be achieved optimally (Irawan et al., 2020).

The data that has gone through the verification and validation process is then used as the main basis in compiling the project schedule and in calculating important parameters in CPM, such as Early Start (ES), Early Finish (EF), Late Start (LS), and Late Finish (LF). The use of data that has been thoroughly studied allows researchers to identify the critical path of the project accurately and determine the most efficient project completion time estimate. Therefore, the reliability of the verification and validation process is an essential component in ensuring that the critical path analysis carried out truly reflects the dynamics of the field accurately and can be accounted for academically and practically.

A study by Perdana & Sari, (2022) on the application of CPM in residential housing projects showed that the project experienced a time reduction of 13 days, with the completion time shortened from 99 days to 86 days and a probability rate of 93.65%. Similarly, Afiya & Alhaq, (2023) applied the CPM method to the Griya Mahari Housing project and reported an acceleration of 28 days, with the project completed in 92 days instead of the planned 120 days. These findings prove that even for small to medium-scale projects, the application of CPM provides significant benefits in time management.

RESULTS AND DISCUSSIONS

Project Activities

The design data for the construction project activities were obtained based on interviews with the implementers of the Type 130 residential housing construction project in Bontang City. This construction project is coordinated by a project leader supported by ten team members. The role of labor and project management is crucial in supporting the implementation of CPM results in the field. Therefore, with a large number of workers, it is expected to contribute to achieving a more efficient project duration. The project activity data includes the time schedule. A time schedule refers to the allocation of available time for each activity in the project execution, with the goal of completing all tasks optimally. The schedule is prepared by considering various limitations to achieve time efficiency and a final result that meets the target (Safitri et al., 2023). According to (Saputra et al., 2024), the schedule data is used to determine the duration of each work activity.

Table 1. Project Activity Data

No	Type of Activity	Symbol	Duration (Days) Normal	Duration (Days) Quick Time	*Predecessor*
1	Preparation Work	A	25	21	-
2	Concrete Work	B	17	14	21
3	Masonry Work	C	14	10	31
4	Installation of Frames, Doors & Windows	D	7	5	36
5	Floor & Wall Ceramic Work	E	14	13	49
6	Sanitary Work	F	3	1	31
7	Roof Frame Work	G	16	14	63
8	Ceiling Frame Work	H	18	15	78
9	Painting Work	I	17	15	93

No	Type of Activity	Symbol	Duration (Days) Normal	Duration (Days) Quick Time	*Predecessor*
10	Electrical Installation	J	7	5	78
11	Concrete Fence Work	K	14	11	111
12	Fence Masonry Work	L	7	6	117
13	Cleaning	M	7	5	122

Based on Table 1, it shows the types of activities from the beginning to the end of the construction. These activities are represented by symbols and are accompanied by both the normal and quick-time durations. The total normal duration is 166 days, from which a construction process path with normal duration can be arranged as follows.

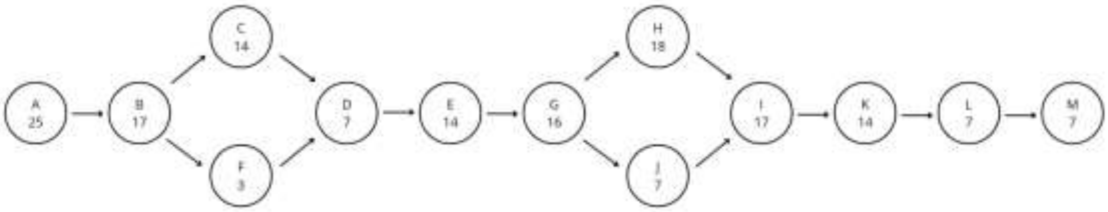

Figure 1. Normal Duration Workflow

Based on Figure 1, the workflow stages are shown. This process begins from activity A (preparation work) to activity M (cleaning), where each activity has a normal estimated duration that must be completed sequentially. By applying the CPM to the project execution, the critical path becomes key in determining the overall duration. Based on the estimated duration of each process, the total standard time required for the project activities is estimated to be 166 days.

Quick Time Workflow

The quick-time workflow follows the same activity sequence as the normal duration.

Table 2. Project Activity Data – Quick Time

No	Type of Activity	Symbol	Quick Time Duration (Days)	*Predecessor*
1	Preparation Work	A	21	-
2	Concrete Work	B	14	21
3	Masonry Work	C	10	31
4	Installation of Frames, Doors & Windows	D	5	36
5	Floor & Wall Ceramic Work	E	13	49
6	Sanitary Work	F	1	31
7	Roof Frame Work	G	14	63
8	Ceiling Frame Work	H	15	78
9	Painting Work	I	15	93
10	Electrical Installation	J	5	78
11	Concrete Fence Work	K	11	111
12	Fence Masonry Work	L	6	117
13	Cleaning	M	5	122

Based on Table 2, the quick-time process shows a reduction of 31 days. From this, the critical path can be determined as follows.

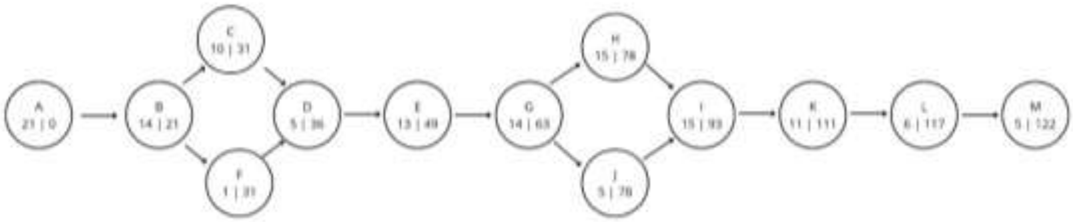

Figure 2. Quick Time Workflow

From Figure 2, the efficient project duration using a Gantt Chart can be seen as follows.

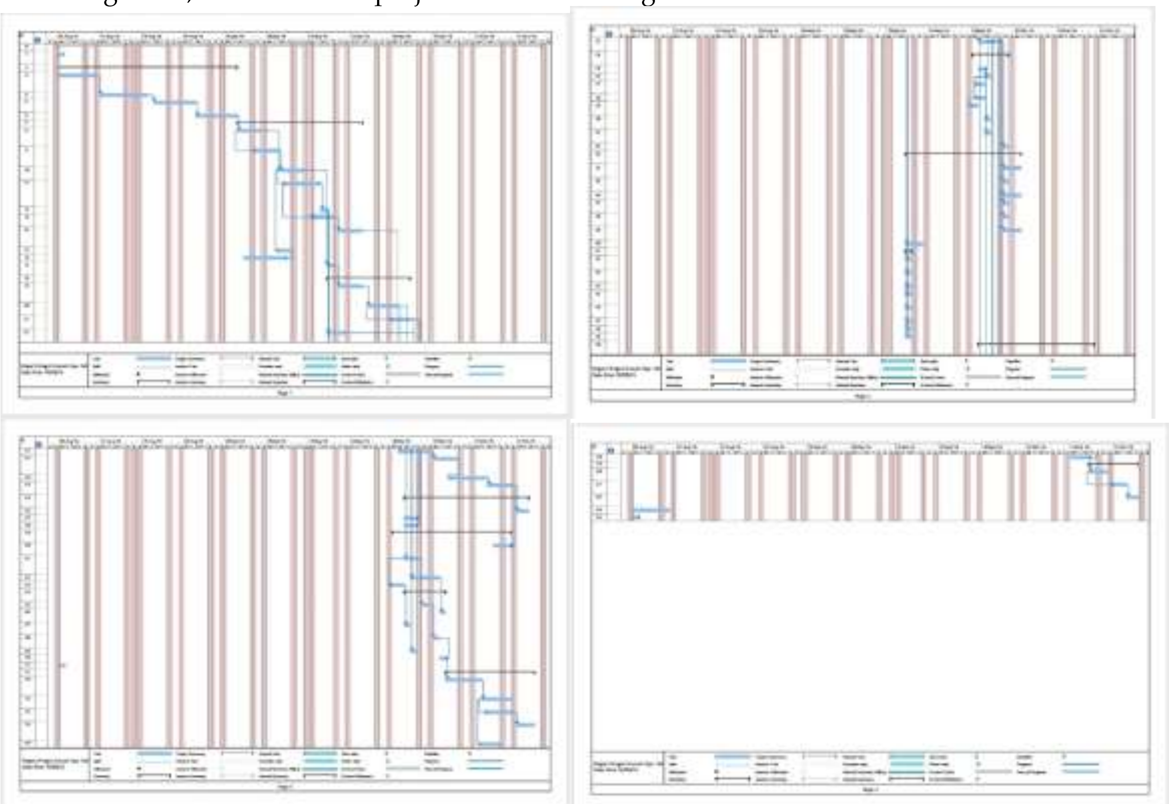

Figure 3. Quick Time Gantt Chart

Based on Figure 2, the quick-time workflow is established with a known critical path and duration. The process begins from activity A (preparation work) to activity M (cleaning). The total time required to complete the project using the critical path approach in CPM is 135 days, which is 31 days faster than the normal estimated duration.

Based on the results of the analysis conducted in this study, the determination of activities included in the critical path is carried out through the application of the CPM method. This method identifies a series of activities starting from activity A (preparation work) to activity M (cleaning). The critical path describes the sequence of activities with the longest cumulative duration and without any slack time (float), so that any delay in one of the activities in this path will have a direct impact on the overall project completion time. In the case study of the construction of a Type 130 residential house located in Bontang City, identification of the critical path shows that the optimal project implementation time can be achieved in 135 days. This figure represents an acceleration of implementation by 31 days compared to the previous normal duration, which was 166 days. Furthermore, the sensitivity of the project to potential delays is also influenced by non-critical activities that have a certain slack time. Non-critical activities will not directly affect the overall project duration as long as the delay is still within the available float range. However, if the delay exceeds this limit, the activity is at risk of moving to the critical path, which can change the structure and dynamics of the overall project schedule. This shift can not only disrupt the efficiency of implementation, but also have an impact on the management of work quality. Therefore, strict supervision of all activities, both critical and non-critical, is very crucial to ensure the achievement of the project implementation time target effectively without sacrificing the quality of construction results.

CONCLUSION

This study concludes that the optimization of the construction time for a Type 130 residential house in Bontang City using the CPM involved 13 activities that covered all stages from the beginning to the end of the project. Based on the critical path analysis, it was found that the project—initially estimated to be completed in 166 days—could be optimized to 135 days, resulting in a time acceleration of 31 days. These findings demonstrate that the application of the CPM method is effective in managing activities to shorten project duration without compromising the process flow of the work. This study provides practical implications for developers or contractors, indicating that the CPM method can be used as a reference in designing future project schedules, thereby enabling planning and time control to be carried out in a more structured and effective manner. To ensure that the acceleration of the implementation time achieved through the CPM does not reduce the quality of construction work, it is necessary to implement a comprehensive integrated managerial strategy. This approach includes arranging the number of workers proportional to the workload, strengthening the technical supervision system in the field to minimize technical errors, and ensuring the availability of materials and work equipment that have met the established quality standards. On the other hand, a review of the activity schedule must be carried out systematically and carefully, in order to avoid conflicts between activities that can hinder project productivity. Effective coordination between team members and consistent and open communication are also key elements in maintaining the quality of construction results even though the project runs in a shorter time. By implementing these strategies, the acceleration of the project duration can be achieved without causing a significant decrease in the quality of work.

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