



# Time–Cost Trade-Off Analysis Using the Precedence Diagram Method in Residential Construction Projects: A Case Study in Bali, Indonesia



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## Abstract

Construction project delays remain a major challenge in the construction industry because they significantly affect project cost, productivity, and overall project performance. Residential construction projects in tourism-oriented regions such as Bali are particularly vulnerable to schedule deviations due to design changes, labor shortages, and coordination problems, which may reduce investment performance and operational readiness. Therefore, effective project acceleration strategies are required to minimize delays while maintaining cost efficiency. This study aims to analyze the time–cost trade-off resulting from project acceleration using the Precedence Diagram Method (PDM) and crashing techniques in the Brand New Modern Villa Berawa Canggu Project, Bali, Indonesia. The research employed a quantitative descriptive approach using primary and secondary project data, including work schedules, labor productivity, overtime wages, and project cost data. PDM analysis was conducted using Microsoft Project to identify critical activities, followed by crashing analysis through overtime work and additional labor allocation. The results indicate that project acceleration successfully reduced the project duration from 413 calendar days to 392 calendar days, resulting in a total time efficiency of 21 days. However, the acceleration strategy increased the total project cost from Rp 7,616,541,949.73 to Rp 7,710,193,793.32, with an additional cost of Rp 93,651,843.59 or approximately 1.23% of the normal project cost. The findings also reveal that overtime implementation improved productivity but simultaneously reduced labor efficiency due to worker fatigue. Overall, the integration of PDM and crashing techniques proved effective in optimizing project duration and cost performance, providing practical implications for project managers in selecting efficient acceleration strategies for residential construction projects.

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## 1 Introduction

The construction industry plays a strategic role in supporting economic growth, urban development, and infrastructure expansion worldwide. However, construction projects continue to experience significant challenges related to schedule delays and cost overruns, particularly in residential and infrastructure developments. Globally, project delays have become a persistent issue that negatively affects productivity, financial performance, stakeholder trust, and project sustainability (Kurniawan & Mulyono, 2024). Cost overruns and schedule deviations frequently occur due to design modifications, inadequate planning, labor shortages, poor coordination, material delivery issues, and ineffective project control systems (Ramadhan & Waty, 2025).

In developing countries, including Indonesia, the complexity of construction projects has increased substantially due to rapid urbanization, tourism development, and infrastructure expansion. These conditions intensify the need for effective project scheduling and resource optimization methods. Several studies reported that weak schedule control, design changes, delayed procurement, and labor productivity issues are dominant contributors to project delays in Indonesia (Bastini et al., 2026). In residential construction projects, particularly villa and resort developments in tourism areas such as Bali, project acceleration becomes increasingly important because delays may directly affect investment returns, operational readiness, and market competitiveness (Gunawan et al., 2025).

One of the major industry challenges in construction project management is achieving an optimal balance between project duration and project cost. Accelerating project completion often requires additional labor, overtime work, equipment mobilization, or alternative construction methods, which consequently increase project costs. Conversely, maintaining minimum cost may prolong project duration and increase the risk of delay penalties and indirect losses. Therefore, project managers must determine the most efficient acceleration strategy capable of minimizing project duration without generating excessive cost escalation (Restrepo et al., 2025).

To address these issues, various scheduling and optimization techniques have been developed, including Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Fast Track, and Precedence Diagram Method (PDM). Among these methods, PDM offers greater flexibility because it allows overlapping relationships between activities such as Finish-to-Start (FS), Start-to-Start (SS), Finish-to-Finish (FF), and Start-to-Finish (SF). This capability makes PDM highly suitable for complex construction projects involving multiple interdependent activities (Naufal, 2025). Furthermore, the crashing method is widely applied to reduce project duration through additional working hours or increased labor allocation on critical activities (Nurhidayat, 2021).

Although numerous studies have investigated project acceleration using CPM, PERT, or crashing methods, several important research gaps remain. First, previous studies generally focused only on duration reduction without comprehensively evaluating the interaction between labor productivity degradation, overtime efficiency, and additional project costs (Ariany, 2017). Second, many studies emphasized infrastructure or large-scale industrial projects, while limited research specifically investigated residential villa construction projects in tourism-oriented regions such as Bali (Gunawan et al., 2025). Third, previous studies commonly applied a single acceleration strategy, whereas integrated approaches combining overtime work and additional labor allocation on critical activities remain insufficiently explored (Flyvbjerg et al., 2022).

This study aims to analyze the time–cost trade-off in residential construction projects using the Precedence Diagram Method (PDM) combined with crashing techniques through overtime work and additional labor allocation. The case study focuses on the Brand New Modern Villa Berawa Canggu Project in Bali, Indonesia. The novelty of this research lies in the integration of PDM-based critical path analysis with simultaneous acceleration strategies while considering labor productivity reduction caused by overtime work. Unlike previous studies that mainly evaluated project duration reduction, this research quantitatively examines the relationship between schedule acceleration, crash cost, cost slope, and productivity degradation within a residential tourism-property construction context.

The urgency of this research is strongly associated with the rapid growth of tourism property development in Bali and the increasing demand for efficient project delivery. Delays in residential and villa construction projects may result in significant financial losses, reduced investment performance, contractual disputes, and operational disruptions (Gong et al., 2022). Therefore, identifying the most efficient acceleration strategy is essential for

improving project management performance and supporting sustainable construction practices. The findings of this study are expected to provide practical contributions for contractors, project managers, and construction stakeholders in selecting optimal acceleration alternatives that balance project duration efficiency and cost effectiveness.

## 2 Materials and Methods

### *Research Design*

This study employed a quantitative descriptive approach to analyze the time–cost trade-off resulting from project acceleration strategies in residential construction projects. The quantitative method was selected because the study focused on numerical analysis of project duration, labor productivity, crash duration, crash cost, and total project cost. The research framework integrated the Precedence Diagram Method (PDM) and crashing analysis to evaluate the impact of overtime work and additional labor allocation on project performance.

The research stages consisted of identifying critical activities, calculating normal and accelerated productivity, determining crash duration and crash cost, analyzing cost slope values, and comparing project duration and costs before and after acceleration. The methodological framework adopted in this study aligns with previous project scheduling and construction optimization studies (Ariany, 2017; Naufal, 2025).

### *Research Location and Case Study*

The study was conducted at the Brand New Modern Villa Berawa Canggu Project located in Badung Regency, Bali, Indonesia. The project consisted of residential tourism-property development comprising villa and apartment units constructed on an area of approximately 2,033 m<sup>2</sup>. The project was selected as the case study because it experienced schedule deviations caused by design revisions, labor shortages, and contractor transition issues during the construction phase.

The total contract value of the project was Rp 21,436,488,000 with an initial planned duration of 480 calendar days. However, this research specifically focused on the Villa 1 Bedroom construction segment with a normal project duration of 413 calendar days.

### *Data Collection*

The study utilized both primary and secondary data sources to support the analysis process.

#### *1. Primary Data*

Primary data were collected through:

- a) Direct field observations,
- b) Interviews with project managers and site engineers,
- c) Documentation of labor productivity and overtime implementation.

The primary data included:

- a) Daily labor wages,
- b) Overtime wage rates,
- c) Number of workers involved,
- d) Actual working hours,
- e) Productivity performance during normal and overtime conditions.

#### *2. Secondary Data*

Secondary data were obtained from project documentation provided by the contractor, including:

- a) Bill of Quantity (BoQ),
- b) Work Breakdown Structure (WBS),
- c) Project schedule,
- d) Daily and weekly progress reports,
- e) Construction drawings,
- f) Labor resource allocation data.

These data were used to establish the project network, determine activity dependencies, identify critical paths, and calculate acceleration scenarios.

### *Precedence Diagram Method (PDM)*

The Precedence Diagram Method (PDM) was used to develop the project scheduling network and identify critical activities. PDM is an Activity-on-Node (AON) scheduling technique that represents activities as nodes and logical relationships as connecting arrows. Compared with conventional CPM, PDM provides greater flexibility because it supports overlapping relationships among activities, including:

- a) Finish-to-Start (FS),
- b) Start-to-Start (SS),
- c) Finish-to-Finish (FF),
- d) Start-to-Finish (SF).

PDM analysis was performed using Microsoft Project software to determine:

- a) Earliest Start (ES),
- b) Earliest Finish (EF),
- c) Latest Start (LS),
- d) Latest Finish (LF),
- e) Float values,
- f) Critical paths.

Activities with zero float were categorized as critical activities requiring acceleration intervention (Nurhidayat, 2021).

### *Project Crashing Analysis*

Project crashing was implemented to reduce project duration by accelerating activities located on the critical path. Two acceleration strategies were applied simultaneously:

1. Additional overtime working hours,
2. Additional labor allocation.

The maximum overtime duration applied in this study was four hours per day, following project operational regulations. The acceleration analysis focused on evaluating the effect of crashing on project duration and total project cost.

### *Labor Productivity Analysis*

Labor productivity under normal working conditions was calculated using Equation (1):

$$\text{Productivity per Day} = \frac{\text{Work Volume}}{\text{Normal Duration}}$$

The productivity per hour was calculated using Equation (2):

$$\text{Productivity per Hour} = \frac{\text{Productivity per Day}}{\text{Working Hours per Day}}$$

To account for reduced efficiency caused by worker fatigue during overtime work, a productivity reduction

coefficient was applied. Based on field observations and previous studies, overtime productivity efficiency was assumed to decrease by 40%, resulting in an effective productivity coefficient of 0.6 (Ariany, 2017).

The overtime productivity was calculated using Equation (3):

$$\text{Overtime Productivity} = \text{Normal Productivity} + (\text{Overtime Hours} \times \text{Productivity per Hour} \times \text{Productivity Coefficient})$$

### *Crash Duration Analysis*

Crash duration refers to the reduced activity duration obtained after acceleration measures were implemented. The crash duration was determined using Equation (4):

$$\text{Crash Duration} = \frac{\text{Work Volume}}{\text{Accelerated Productivity}}$$

The crash duration analysis was conducted for all critical activities to determine the potential reduction in project completion time.

### *Crash Cost and Cost Slope Analysis*

Crash cost represents the additional cost incurred due to project acceleration through overtime work and additional labor resources. The total crash cost included:

- a) Overtime wages,
- b) Additional labor wages,
- c) Additional operational expenses associated with acceleration activities.

The cost slope value was used to determine the most economically efficient activity for acceleration. Cost slope was calculated using Equation (5):

$$\text{Cost Slope} = \frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal Duration} - \text{Crash Duration}}$$

Activities with lower cost slope values were prioritized for crashing because they provided the most efficient time reduction with minimum additional cost (Poerba et al., 2022).

### *Data Analysis Procedure*

The data analysis process consisted of the following stages:

- 1) Identification of project scheduling problems,
- 2) Collection of primary and secondary project data,
- 3) Preparation of project activity networks using PDM,
- 4) Identification of critical activities,
- 5) Calculation of normal productivity,
- 6) Analysis of overtime and additional labor productivity,
- 7) Determination of crash duration and crash cost,
- 8) Calculation of cost slope values,
- 9) Comparison of project duration and project costs before and after acceleration,
- 10) Evaluation of the effectiveness of acceleration strategies.

The final analysis aimed to determine the optimal acceleration strategy capable of reducing project duration while maintaining acceptable additional project costs.

## **3 Results and Discussions**

### *3.1 Project Overview and Existing Schedule Condition*

The Brand New Modern Villa Berawa Canggu Project is a residential tourism-property development located in Badung Regency, Bali, Indonesia. The project consists of 7 units of one-bedroom villas, 6 units of two-bedroom villas, and a four-story apartment complex constructed on a total land area of approximately 2,033 m<sup>2</sup>. The project was managed by Alex Villa Group as the owner and PT Svaha Property Development as the contractor.

Based on the project schedule and Bill of Quantity (BoQ), the normal duration for the Villa 1 Bedroom construction segment was 413 calendar days with a total analyzed project cost of Rp 7,616,541,949.73. However, project implementation experienced schedule deviations caused by design revisions, labor shortages, and contractor

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transition issues. Similar findings have been reported in previous studies, where design changes, poor schedule control, and labor productivity problems were identified as dominant causes of construction delays in Indonesia (Bastini et al., 2026; Ramadhan & Waty, 2025).

Construction project delays continue to be a major challenge globally because they directly affect project profitability, operational readiness, and investment performance. Previous studies indicated that cost overruns and time delays are strongly correlated with uncertainty in project execution, inadequate planning, and inefficient resource allocation (Susanti, 2020; Abdelalim et al., 2025).

### 3.2 Critical Path Analysis Using PDM

The Precedence Diagram Method (PDM) was implemented using Microsoft Project software to identify critical activities affecting project completion time. The scheduling network incorporated activity dependencies including Finish-to-Start (FS) and Start-to-Start (SS) relationships. The analysis identified several critical activities within the Villa 1 Bedroom construction segment, including:

- a) Brick wall installation,
- b) Wall plastering,
- c) Wall smooth plaster,
- d) Gypsum ceiling installation,
- e) Lavastone installation,
- f) GRC installation,
- g) Pebble stone finishing.

These activities possessed zero float values, indicating that any delay occurring within these activities would directly impact overall project completion time. Previous studies confirmed that PDM is highly effective for identifying schedule-sensitive activities and improving project control in construction projects (Naufal, 2025; Sholekah, 2026).

The identification of critical activities is essential because crashing efforts should only be applied to activities located on the critical path to achieve optimal project acceleration. Similar observations were reported by Kurniawan & Mulyono (2024), who emphasized that schedule acceleration through crashing techniques becomes effective only when critical activities are accurately identified and systematically controlled.

### 3.3 Labor Productivity Analysis

A labor productivity analysis was conducted to determine the capability of workers under normal and accelerated working conditions. Productivity values were calculated based on work volume and activity duration. For example, the wall plastering activity had a work volume of 440.98 m<sup>2</sup> with a normal duration of 14 days. Therefore, the normal productivity was calculated as follows:

$$Productivity = \frac{440.98}{14} = 31.499 \text{ m}^2/\text{day}$$

The hourly productivity was then determined using the standard 8-hour working day:

$$Hourly \text{ Productivity} = \frac{31.499}{8} = 3.937 \text{ m}^2/\text{hour}$$

To accelerate project duration, overtime work of four hours per day was implemented. However, overtime work caused productivity degradation due to worker fatigue. Based on field observations and previous studies, overtime efficiency decreased by approximately 40%, resulting in an effective productivity coefficient of 0.6 (Ariany, 2017).

The overtime productivity for the wall plastering activity was calculated as follows:

$$Overtime \text{ Productivity} = 31.499 + (4 \times 3.937 \times 0.6) = 40.948 \text{ m}^2/\text{day}$$

The findings indicate that overtime work increased productivity output; however, the productivity increment was not proportional to additional working hours due to fatigue effects. Similar results were reported in previous studies showing that excessive overtime may reduce worker efficiency, increase physical fatigue, and negatively affect construction quality (Ariany, 2017; Restrepo et al., 2025).

### 3.4 Crashing Analysis and Project Acceleration

Project crashing was implemented through two simultaneous acceleration strategies:

- 1) Overtime work,
- 2) Additional labor allocation.

The acceleration process focused on activities located on the critical path with the objective of minimizing total project duration. Additional workers and masons were allocated without increasing supervisory personnel to maintain coordination efficiency.

The analysis demonstrated that several critical activities could be accelerated by 1–3 days, depending on labor productivity and work complexity. Overall project duration was successfully reduced from 413 calendar days to 392 calendar days.

The results show that the crashing strategy achieved a total time efficiency of 21 days. This finding confirms that overtime work and additional labor allocation can effectively reduce project duration when applied selectively to critical activities. Similar findings were reported in previous construction acceleration studies using PDM and crashing approaches (Sholekah, 2026; Poerba et al., 2022).

Furthermore, recent studies highlighted that acceleration strategies significantly improve schedule performance when supported by accurate project planning and systematic resource management (Kurniawan & Mulyono, 2024).

### 3.5 Crash Cost and Cost Slope Analysis

The implementation of crashing strategies increased direct project costs due to overtime wages and additional labor allocation. The total project cost after acceleration increased from Rp 7,616,541,949.73 to Rp 7,710,193,793.32, resulting in an additional cost of Rp 93,651,843.59.

The percentage increase in total project cost was calculated as follows:

$$\text{Cost Increase} = \frac{93,651,843.59}{7,616,541,949.73} \times 100\% = 1.23\%$$

Although project costs increased, the additional cost remained relatively acceptable considering the significant reduction in project duration. Previous studies similarly found that schedule acceleration generally increases direct costs but may reduce indirect costs and delay-related losses (Poerba et al., 2022; Abdelalim et al., 2025). Cost slope analysis was conducted to determine the most economically efficient activity for acceleration. The analysis showed that:

- a) Pebble Dark Colour had the lowest cost slope value at Rp 663,000/day,
- b) Gypsum Ceiling had the highest cost slope value at Rp 7,817,972/day.

Activities with lower cost slope values were prioritized because they provided more efficient time reduction with lower additional cost. Similar approaches have been widely adopted in construction project optimization studies to improve acceleration efficiency (Naufal, 2025; Sholekah, 2026).

### 3.6 Discussion

The findings of this study demonstrate that the integration of the Precedence Diagram Method (PDM) and crashing techniques provides an effective approach for optimizing project duration and cost performance in residential construction projects. The acceleration strategy implemented through overtime work and additional labor allocation successfully reduced the project duration by 21 days, from 413 calendar days to 392 calendar days, with an additional project cost increase of only 1.23%. These results indicate that selective acceleration on critical activities can significantly improve project scheduling efficiency while maintaining manageable cost escalation.

The effectiveness of project acceleration in this study is consistent with recent studies on time–cost trade-off (TCTO) analysis in construction management. Afrida et al. (2025) reported that acceleration strategies through overtime work and additional labor could substantially reduce project duration while maintaining acceptable cost efficiency levels. Their study further emphasized that overtime acceleration may provide higher nominal cost

efficiency, whereas additional labor allocation tends to produce more stable implementation performance in projects with adequate workspaces (Afrida et al., 2025; Santosa & Yusuf, 2025).

The results also indicate that PDM is highly effective in identifying critical activities requiring acceleration intervention. The flexibility of PDM in representing overlapping activity relationships enables more realistic construction scheduling compared with conventional CPM approaches. This finding supports previous research emphasizing that PDM-based scheduling improves project monitoring, activity sequencing, and acceleration planning in complex construction environments (Naufal, 2025; Dewanto, 2024).

One of the most important findings of this study is related to labor productivity degradation caused by overtime work. Although overtime implementation increased total daily productivity, hourly productivity gradually decreased as working hours increased. This phenomenon indicates the existence of diminishing productivity returns caused by physical fatigue and reduced worker endurance. Similar findings were reported by Paradiba & Mirnayani (2025), who found that overtime extension beyond one hour significantly reduced hourly productivity in rebar installation, concrete casting, and formwork activities. Their study concluded that prolonged overtime increases labor costs disproportionately while reducing productivity efficiency due to worker fatigue effects (Eshtehardian et al., 2009).

The findings of this study therefore reinforce the argument that overtime acceleration should be carefully controlled to avoid excessive productivity degradation and potential quality reduction. Excessive overtime may increase worker fatigue, construction errors, rework risks, and occupational safety issues (Yusuf et al., 2022; Lilik et al., 2022). In construction management literature, sustainable workforce utilization has become increasingly important because labor-intensive projects are highly dependent on worker physical performance and coordination efficiency (Hartmann & Briskorn, 2022; Santiana et al., 2026).

Furthermore, the study demonstrates that cost slope analysis is essential for determining the most economical acceleration alternatives. Activities with lower cost slope values provided more efficient time reductions with smaller additional costs, making them priority targets for crashing implementation. The Pebble Dark Colour activity exhibited the lowest cost slope value, while the Gypsum Ceiling work had the highest cost slope value due to higher labor intensity and finishing precision requirements. Similar findings were reported in recent crash program studies where labor-intensive finishing activities generally generated higher crash costs because of skilled labor requirements and limited productivity flexibility (Thoengsal, 2024).

Another important discussion point concerns the comparative effectiveness of overtime work and additional labor allocation. The results of this study indicate that combining both strategies simultaneously produced more effective acceleration outcomes compared with relying solely on overtime work. This finding aligns with recent studies suggesting that integrated acceleration approaches improve schedule flexibility and reduce excessive dependence on prolonged overtime (Lutfi et al., 2025). The combination strategy allows project managers to balance productivity improvement and workforce sustainability while minimizing excessive labor fatigue.

This study contributes to construction project management literature by specifically examining residential tourism-property construction projects in Bali, Indonesia. Previous studies predominantly focused on infrastructure and industrial projects, whereas limited studies addressed residential villa developments within tourism-oriented environments. The tourism-property sector possesses unique project characteristics because schedule delays may directly affect operational readiness, investment profitability, and tourism market competitiveness. Consequently, efficient project acceleration becomes strategically important in maintaining investor confidence and reducing financial losses (Tofighian & Naderi, 2015).

The findings also suggest that acceleration decisions should not solely focus on achieving the shortest possible project duration. Instead, project managers should consider multidimensional factors, including productivity degradation, crash cost efficiency, labor availability, workspace conditions, work quality, and occupational safety. Recent studies have increasingly emphasized the importance of integrating legal labor regulations, worker welfare, and sustainable resource management into construction acceleration models (Thoengsal, 2024; Gunawan et al., 2025). From a managerial perspective, the results indicate that effective acceleration requires:

- a) accurate identification of critical activities,
- b) proper workforce planning,
- c) controlled overtime implementation,
- d) efficient cost slope prioritization,
- e) and continuous productivity monitoring.

Without proper project control mechanisms, acceleration efforts may increase direct costs excessively while generating limited schedule improvement benefits. Therefore, project managers must adopt data-driven acceleration strategies supported by integrated scheduling analysis tools such as PDM and Microsoft Project.

Overall, this study confirms that the integration of PDM and crashing techniques provides a practical and effective framework for optimizing project duration and cost performance in residential construction projects. However, sustainable acceleration practices should carefully balance project efficiency, labor productivity, cost control, construction quality, and worker welfare to achieve long-term project success.

## 4 Conclusion

This study analyzed the implementation of the Precedence Diagram Method (PDM) combined with crashing techniques to optimize project duration and cost performance in the Brand New Modern Villa Berawa Canggus residential construction project in Bali, Indonesia. Based on the results of the analysis and discussion, the application of project acceleration strategies through overtime work and additional labor allocation proved effective in reducing project completion time while maintaining acceptable additional project costs.

The results demonstrated that the implementation of crashing techniques on critical activities successfully reduced the project duration from 413 calendar days to 392 calendar days, resulting in a total time efficiency of 21 days. The acceleration process focused on critical path activities identified through PDM network analysis, including wall plastering, gypsum ceiling installation, lavastone installation, and architectural finishing works. These findings confirm that PDM is an effective scheduling method for identifying schedule-sensitive activities and supporting acceleration decision-making in construction projects.

From the cost perspective, project acceleration increased the total project cost from Rp 7,616,541,949.73 to Rp 7,710,193,793.32, resulting in an additional cost of Rp 93,651,843.59 or approximately 1.23% of the normal project cost. Although the acceleration strategy increased direct labor costs due to overtime implementation and additional workforce allocation, the additional cost remained relatively proportional compared with the achieved reduction in project duration. The study also demonstrated that overtime implementation did not proportionally increase labor productivity because worker fatigue significantly affected performance. The productivity degradation coefficient applied in this study showed that overtime work improved production output; however, productivity efficiency decreased due to physical fatigue and reduced worker endurance. In addition, cost slope analysis proved important for identifying the most economical activities for acceleration, where activities with lower cost slope values provided more efficient time reduction with lower additional costs.

The findings indicate that the integration of PDM and crashing techniques can provide an effective decision-support framework for contractors and project managers in managing project delays and improving schedule efficiency in residential construction projects, particularly within tourism-property developments in Bali. The study also highlights the importance of balancing project duration reduction, labor productivity, and cost efficiency to achieve sustainable construction management practices. For future research, it is recommended to incorporate additional acceleration alternatives such as shift work systems, equipment optimization, prefabrication methods, and advanced digital technologies, including Building Information Modeling (BIM) and Artificial Intelligence-based scheduling systems. Further studies are also encouraged to integrate construction quality, occupational safety, and long-term labor productivity impacts into project acceleration analysis to provide more comprehensive and sustainable project management strategies.

### *Conflict of interest statement*

The authors declared that they have no competing interests.

### *Statement of authorship*

The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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## References

- Abdelalim, A. M., Salem, M., Salem, M., Al-Adwani, M., & Tantawy, M. (2025). Analyzing Cost Overrun Risks in Construction Projects: A Multi-Stakeholder Perspective Using Fuzzy Group Decision-Making and K-Means Clustering. *Buildings*, *15*(3), 447.
- Afrida, W. D., Renjani, M. S., Rahmawati, D., & Radinal. (2025). Comparative analysis of time and cost efficiency in project acceleration strategies: A case study of the construction of a police service building. *Global Education Journal*, *3*(1), 211–217.
- Ariany, F. (2017). Analysis of project acceleration by increasing optimum working hours in construction projects. *Jurnal Ilmiah Teknik Sipil*, *14*(2), 120–129.
- Bastini, F. J., & Ulandari, A. H. T. (2026). Dominant Factors Causing Construction Project Delays in Indonesia and Their Mitigation Strategies: A Literature Review. *Jurnal Teknik Sipil*, *1*(1), 16-23.
- Dewanto, W. P. (2024). Analysis of project time and cost using the crash program method with overtime and additional labor alternatives. *CIVED Journal*, *11*(3), 1057–1068.
- Eshtehardian, E., Afshar, A., & Abbasnia, R. (2009). Fuzzy-based MOGA approach to stochastic time–cost trade-off problem. *Automation in construction*, *18*(5), 692-701. <https://doi.org/10.1016/j.autcon.2009.02.001>
- Flyvbjerg, B., Budzier, A., Lee, J. S., Keil, M., Lunn, D., & Bester, D. W. (2022). The empirical reality of IT project cost overruns: Discovering a power-law distribution. *Project Management Journal*, *53*(4), 1–15.
- Gong, Y., Yang, K., Seo, J., & Lee, J. G. (2022). Wearable acceleration-based action recognition for long-term and continuous activity analysis in construction site. *Journal of Building Engineering*, *52*, 104448. <https://doi.org/10.1016/j.job.2022.104448>
- Gunawan, M. I., Suryana, H., Patra, O., & Nugraha, E. (2025). Analysis of Delay Factors in EPC Power Plant Projects (Case Study: PLTMG Project in Sumbawa). *Journal Research of Social Science, Economics & Management*, *5*(2).
- Hartmann, S., & Briskorn, D. (2022). An updated survey of variants and extensions of the resource-constrained project scheduling problem. *European Journal of Operational Research*, *297*(1), 1–14.
- Kurniawan, B. N., & Mulyono, N. B. (2024). Minimizing delay in construction project at PT Freeport Indonesia using crashing CPM-PERT approach and Monte Carlo simulation. *European Journal of Business Management and Research*, *9*(5), 61–69.
- Lutfi, M. A., Witjaksana, B., & Purnama, J. (2025). Cost and Time Analysis of Project Acceleration using the Crashing Method with Additional Working Hours and Labor. *Asian Journal of Social and Humanities*, *3*(7), 1430-1438.
- Naufal, Z. S. (2025). Optimization of time and cost using Precedence Diagram Method (PDM) in construction projects. *Journal of Civil Engineering and Planning*, *4*(2), 130–138.
- Nurhidayat, A. A. (2021). Optimization of apartment construction projects using Precedence Diagram Method (PDM). *Jurnal Teknik Industri*, *10*(1), 22–32.
- Paradiba, H., & Mirnayani. (2025). The impact of overtime duration variations on labor productivity and labour utilization rate in apartment construction projects. *Calamity*, *2*(2), 118–126.
- Poerba, Y., et al. (2022). Analysis of project acceleration using crashing method in building construction projects. *Jurnal Teknik ITS*, *11*(3), 45–53.
- Ramadhan, J. S., & Waty, M. (2025). Impact of change orders on cost overruns and delays in large-scale construction projects. *Engineering, Technology & Applied Science Research*, *15*(1), 20291–20299.
- Restrepo, A. F., & Machado, C. A. R. (2025). Predicting delays and cost overruns in construction projects using machine learning models. *International Journal of Project Management Studies*, *7*(1), 1–14.
- Santiana, I. M. A., Wibawa, I. G. S., Wiraga, I. W., Sujahtra, I. W., Budiadi, I. M., & Yusuf, M. (2026). Determinants of variation orders and their impact on cost overrun in coastal construction projects: A case study in Bali, Indonesia. *International Research Journal of Engineering, IT and Scientific Research*, *12*(2), 14–24.
- Santosa, I. G., & Yusuf, M. (2025). Integration of ergonomic principles in the design and construction of car wheel polishing tools to improve operator performance. *International Research Journal of Engineering, IT and Scientific Research*, *11*(4), 105–113.
- Sholekah, A. N. (2026). Project acceleration analysis using Precedence Diagram Method and crashing approach in irrigation construction projects. *Jurnal Teknik Sipil dan Lingkungan*.
- Sudijeng, L., Tarwaka, T., Sutapa, I. K., Sudana, M., & Yusuf, M. (2023). Ergonomic tetrapod reduces the MSDs risk and productivity of steel-bar assembly for reinforcement concrete beams. *International research journal of engineering, IT & scientific research*, *9*(1), 1-13.

- Susanti, R. (2020). Cost overrun and time delay of construction project in Indonesia. *Journal of Physics: Conference Series*, 1444(1), 012050.
- Thoengsal, J. (2024). Project acceleration analysis using the crashing method with alternatives for adding manpower and additional working hours in drainage works. *Journal of Research in Engineering Science and Technology*.
- Tofighian, A. A., & Naderi, B. (2015). Modeling and solving the project selection and scheduling. *Computers & Industrial Engineering*, 83, 30-38. <https://doi.org/10.1016/j.cie.2015.01.012>
- Yusuf, M., Sudiajeng, L., Suryawan, K. A., & Sudana, I. M. (2022). Redesign of Ergonomic Worktables in Reinforced Concrete Sheet Works Reduce Ergonomic Risk Level. In *Proceedings of the 5th International Conference on Applied Science and Technology on Engineering Science iCAST-ES*, ScitePress Digital Library (pp. 370-374).