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# Critical Path Analysis for Construction Schedule Optimization: RSGM UMSIDA Study Case

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## ABSTRACT

*The development of educational infrastructure represents a fundamental pillar supporting human resource advancement in Indonesia. Universitas Muhammadiyah Sidoarjo, as a growing higher education institution, addresses the need for academic facilities through the construction of a dental hospital (RSGM), demonstrating its commitment to public health services. This project functions as a teaching hospital in collaboration with the Faculty of Medicine at UMSIDA, enabling medical students to conduct clinical practice. This study aims to determine the optimal project duration after acceleration and identify the required costs resulting from this acceleration. The research applied the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) to optimize construction scheduling. Results indicate that CPM effectively reduces project completion time from 147 weeks to 104 weeks, while PERT reduces it to 105 weeks, with additional costs of Rp 580,930,000.00 (3.85% of initial budget) and Rp 567,420,000.00 (3.76%) respectively. The PERT implementation, with critical path A-B-C-D-E-F-J, demonstrates a 99.99% probability of completing the project within 105 weeks. Overall, the acceleration efforts yield time savings of 43 weeks using CPM and 42 weeks using PERT, with PERT offering a more cost-efficient alternative. These findings validate the effectiveness of systematic network analysis approaches in educational healthcare facility construction, providing a replicable framework for similar infrastructure development projects in developing regions.*

**Keywords:** *Construction Cost, Critical Path Method, Project Management, Schedule Optimization*

## INTRODUCTION

Time and cost management represent fundamental components in the successful execution of construction projects (ElSahly et al., 2023; Oshinowo et al., 2025). The increasingly competitive construction industry demands structured, effective, and efficient project planning and control to ensure work completion within target specifications (Maw et al., 2025). However, various projects continue to face constraints such as schedule delays, cost overruns, and resource allocation imbalances. These issues generally arise from suboptimal scheduling and activity control processes during project implementation.

One network analysis method widely employed to address these challenges is the Critical Path Method (CPM). This method serves to identify the critical path, which constitutes the sequence of activities that cannot experience delays without affecting the overall project duration. By determining which activities are critical and non-critical, project managers can allocate resources more appropriately, make time acceleration decisions (crashing), and control additional costs arising from schedule modifications (Antariwati, 2018). The application of CPM also provides a clear representation of logical relationships among activities, enabling more systematic project control.

Beyond scheduling, another significant challenge in construction projects is resource limitations, particularly human resources and equipment. These constraints can reduce productivity, cause duration discrepancies, and increase operational costs. Therefore, integration between scheduling methods such as CPM and resource management strategies with cost optimization becomes essential to ensure efficient project execution. The combination of these approaches enables more accurate planning, measurable supervision, and data-driven decision-making.

Recent studies have demonstrated the effectiveness of CPM and PERT in optimizing construction project schedules across various contexts. Ba'Its et al. (2020) investigated the combination of PERT and CPM for project schedule development, revealing that the integration of both methods provides a more comprehensive approach to managing project timelines under uncertainty. Similarly, Ukamaka (2020) conducted a comparative study implementing PERT and CPM, finding that while CPM is more suitable for projects with deterministic activity durations, PERT offers greater flexibility when dealing with uncertain time estimates. Nahendra et al. (2022) applied PERT and CPM optimization methods to an airport construction project, demonstrating significant time reductions while maintaining cost efficiency. Furthermore, Bagshaw (2021) presented practical examples of PERT and CPM application in contemporary project management, emphasizing their continued relevance in addressing modern construction challenges.

Studies focusing on time-cost optimization through project crashing have also contributed valuable insights to construction management practices. Research by

Aliyu (2013) examined the pragmatic use of CPM in project management, highlighting its effectiveness in identifying activities suitable for acceleration with minimal cost impact. Turkoglu et al. (2023) developed a multiobjective optimization model that balances project time, cost, quality, and schedule flexibility, achieving up to 20 percent improvement in balanced performance over single-objective approaches. Additionally, Alhassan et al. (2024) utilized CPM and PERT in conjunction with linear programming for project planning and scheduling, successfully identifying optimal time-cost trade-offs through systematic crashing analysis. These recent investigations underscore the importance of integrating advanced optimization techniques with traditional scheduling methods to achieve efficient project outcomes while maintaining budget constraints.

Despite the extensive application of CPM and PERT methodologies in various construction projects, significant research gaps remain in the context of specialized healthcare educational facilities, particularly dental hospitals (RSGM) serving dual functions as both clinical service centers and teaching institutions. While numerous studies have examined these methods in commercial buildings, residential projects, and general hospital facilities, limited empirical evidence exists regarding their application in RSGM projects that must accommodate unique requirements such as specialized dental equipment installation, infection control protocols, and educational facility standards. Furthermore, the majority of existing research has focused on either CPM or PERT individually, with insufficient comparative analysis demonstrating the practical differences in cost efficiency and completion probability between these methods when applied to the same complex project. The construction of RSGM UMSIDA presents a unique case study that addresses this gap, as it represents an essential infrastructure development supporting the establishment of a new Faculty of Medicine while simultaneously providing public dental healthcare services in Sidoarjo Regency. This dual-purpose nature, combined with the project's substantial duration (147 weeks) and budgetary considerations, necessitates rigorous optimization analysis to ensure timely completion without compromising financial sustainability or educational functionality.

Therefore, this research was conducted with the following specific objectives: first, to determine the optimal total project duration after implementing acceleration methods in the RSGM UMSIDA construction project; second, to identify the optimal total costs required as a result of project acceleration using both CPM and PERT approaches; third, to conduct a comparative evaluation between CPM and PERT methods in terms of cost efficiency and time reduction effectiveness; and fourth, to calculate the probability of successful project completion within the optimized schedule using the PERT method. Through systematic application and comparative analysis of both CPM and PERT methodologies, this research is expected to contribute valuable insights to the body of knowledge regarding construction project planning and control, particularly in the specialized context of educational healthcare facility development, thereby enabling more informed decision-making for similar future projects.

## RESEARCH METHODOLOGY

### Critical Path Method (CPM)

CPM represents a network analysis approach that seeks to optimize total project costs through the reduction or acceleration of overall project completion time (Yaqin et al., 2023). The CPM method ensures that the time required to complete various stages of a project is determined at the outset before work commences, including the time needed to complete the project and the relationships among the resources utilized (Abuhasel, 2023). The CPM method yields analytical results on a project's activity network in the form of total project cost optimization by shortening the total project completion time.

In the critical path identification process, the first step involves performing backward pass calculations and forward pass calculations. Forward pass calculations in the PERT and CPM methods are conducted to determine the earliest finish time (EF) of a task, the earliest start time (ES) of an activity, and the earliest event time (E), beginning from the start (initial event) to the finish (terminal event). Conversely, backward pass calculations are performed to obtain the latest allowable finish time (LF) of a task, the latest start time (LS) of an activity, and the latest event time (L), proceeding from finish to start (Loka et al., 2025; Santoso et al., 2024). After completing forward and backward pass calculations, the subsequent step involves calculating the time float or slack of activities, which consists of total float and free float.

If an activity possesses no float, in other words S = SF = 0, then that activity is classified as a critical activity. These critical activities form the critical path, which typically extends from the start (initial event) to the finish (terminal event). Consequently, this critical path requires careful control. The CPM method is employed to determine when an activity begins and ends within a project in network analysis, thereby obtaining the optimal time required to complete a project.

### Crashing Process (Acceleration)

CPM constitutes a method for developing project planning and control with the assistance of critical network formation principles (Wicaksono et al., 2024). The objectives of CPM application include determining the duration required for project completion (Farhan et al., 2024) and identifying various critical activities within the project that possess significant potential in determining project duration (Asri et al., 2019). Four types of time terminology are employed in CPM implementation (Yuwono et al., 2021): (1) Earliest start time (EST) represents the earliest possible time an activity can commence. (2) Latest start time (LST) denotes the latest allowable time an activity can begin. (3) Earliest finish time (EFT) indicates the earliest possible time an activity can be completed. (4) Latest finish time (LFT) signifies the latest allowable time an activity can be completed. The subsequent steps involve performing CPM calculations. The following procedures are employed in conducting calculations using this method:

1. Calculate the forward pass or determine ES (Earliest Activity Start Time). Since S represents the start event, the earliest start time $ES_1 = 0$.
2. Calculate the backward pass or determine LF (Latest Activity Finish Time). Since F represents the final activity, the latest finish time equals the earliest start time; therefore: Assumption for activity F time = 0
3. Calculate slack or time float using the formula: S = LS - ES
4. Determine whether the activity lies on the critical path.
5. Determine the fastest completion time, which corresponds to the final EF value.

**Worker Additional Cost (Crash Cost)**

The addition of working hours increases costs for labor beyond normal labor costs. Based on the Decree of the Minister of Manpower and Transmigration of the Republic of Indonesia Number KEP. 102/MEN/VI/2004, the calculation for additional worker costs can be formulated as follows:

1. Normal worker cost per day = Daily productivity × Unit price of worker wages
2. Normal worker cost per hour = Hourly productivity × Unit price of worker wages
3. Worker overtime cost = 1.5 × normal hourly wage for the first additional working hour (overtime) + 2 × n × normal hourly wage for subsequent additional working hours (overtime), where: n = number of additional working hours (overtime)
4. Worker crash cost per day = (Working hours per day × Normal worker cost) + (n × Overtime cost per hour)

## RESULT AND DISCUSSION

The geographical location of a construction project plays a crucial role in determining logistics, resource accessibility, and project implementation strategies. In this study, the RSGM building project was located at JL. Sekardangan No. 1, Sidoarjo District, Sidoarjo Regency. This strategic location within the university campus area facilitates coordination between construction activities and academic operations while ensuring accessibility for future clinical and educational functions.


**Figure 1** Location of RSGM Building Construction Project
**Source:** Google Maps (2025)

## RSGM Building Project Schedule Plan

Project scheduling represents a fundamental tool for monitoring and controlling construction progress, providing a visual representation of the relationship between time and planned activities. The RSGM building project implementation included a planned S-curve. The planned S-curve represents a graphical relationship between time and project planning with cumulative progress values from project initiation to completion. The planned S-curve serves to predict project completion and enables project managers to identify potential deviations from the baseline schedule, thereby facilitating timely corrective actions. The planned S-curve for the RSGM Building is presented in Figure 4.2.

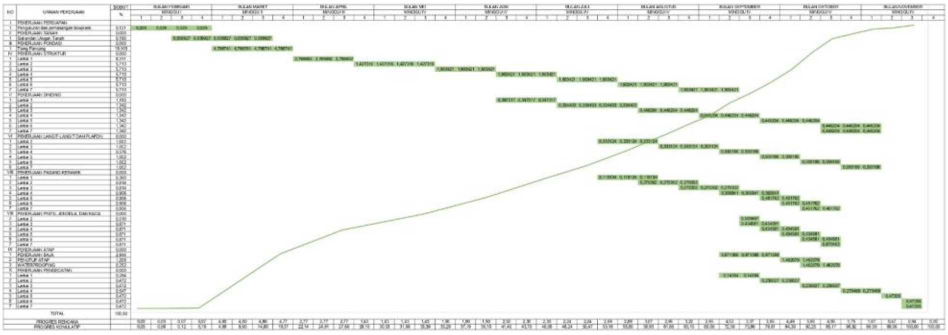

**Figure 2** Planning and Scheduling Data for RSGM Building
**Source:** S-Curve at Project Location (2025)

## Project Work Using CPM Method

The application of the Critical Path Method provides a systematic approach to analyzing project networks and identifying activities that directly influence overall project duration. The RSGM building project plan comprised 7 floors with a total budget of Rp 15,095,415,000.00 and a total weight of 100 percent, with a planned duration of 147 weeks. This comprehensive project encompasses ten major work categories, each with specific budget allocations and time requirements that must be carefully coordinated to achieve optimal project outcomes. This information is presented in Tables 4.1 and 4.2.

**Table 1** RSGM Budget Plan Data 2025

| No. | Work Type | Cost |
|---|---|---|
| 1 | Preparatory Work | Rp 20.520.000,00 |
| 2 | Earthwork | Rp 30.890.160,00 |
| 3 | Foundation Work | Rp 2.885.936.000,00 |
| 4 | Structural Work | Rp 6.445.147.262,00 |
| 5 | Wall Work | Rp 1.588.476.120,00 |
| 6 | Ceiling and Plafond | Rp 1.011.128.400,00 |
| 7 | Floor Work | Rp 862.749.975,00 |
| 8 | Doors and Windows | Rp 723.922.560,00 |
| 9 | Roof Work | Rp 671.129.125,00 |
| 10 | Painting Work | Rp 936.382.320,00 |
| **Total** | | Rp 15.095.415.000,00 |

**Source:** BP2M Universitas Muhammadiyah Sidoarjo (2025)

**Table 2** Time Schedule Data for RSGM Work 2025

| No. | Work Type | Activity Code | Duration (weeks) |
|---|---|---|---|
| 1 | Preparatory Work | A | 5 |
| 2 | Earthwork | B | 6 |
| 3 | Foundation Work | C | 5 |
| 4 | Structural Work | D | 28 |
| 5 | Wall Work | E | 28 |
| 6 | Ceiling and Plafond Work | F | 18 |
| 7 | Ceramic Floor Work | G | 22 |
| 8 | Doors and Windows | H | 12 |
| 9 | Roof Work | I | 9 |
| 10 | Painting Work | J | 14 |

**Source:** S-Curve RSGM (2025)

**Table 3** Recapitulation of RSGM Project Activity List 2025

| No. | Work Type | Activity Code | Preceding Activity | Duration (weeks) |
|---|---|---|---|---|
| 1 | Preparatory Work | A | - | 5 |
| 2 | Earthwork | B | A | 6 |
| 3 | Foundation Work | C | B | 5 |
| 4 | Structural Work | D | C | 28 |
| 5 | Wall Work | E | D | 28 |
| 6 | Ceiling and Plafond Work | F | E | 18 |
| 7 | Ceramic Floor Work | G | D | 22 |
| 8 | Doors and Windows | H | E | 12 |
| 9 | Roof Work | I | D | 9 |
| 10 | Painting Work | J | E,F,G,H,I | 14 |
| **Total** | | | | **147** |

**Source:** Calculation Results (2025)

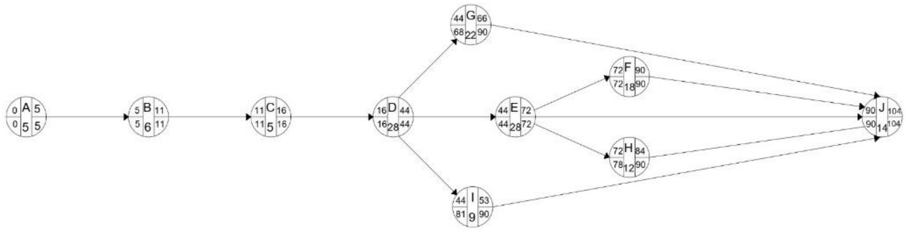


**Figure 3** CPM Network Diagram for RSGM 2025
**Source:** Calculation Results (2025)

**Table 4** CPM Float Time Calculations

| Code | Work Type | Duration (weeks) | ES | EF | LS | LF | Slack | Status |
|---|---|---|---|---|---|---|---|---|
| A | Preparatory Work | 5 | 0 | 5 | 0 | 5 | 0 | Critical |
| B | Earthwork | 6 | 5 | 11 | 5 | 11 | 0 | Critical |
| C | Foundation Work | 5 | 11 | 16 | 11 | 16 | 0 | Critical |
| D | Structural Work | 28 | 16 | 44 | 16 | 44 | 0 | Critical |
| E | Wall Work | 28 | 44 | 72 | 44 | 72 | 0 | Critical |
| F | Ceiling and Plafond Work | 18 | 72 | 90 | 72 | 90 | 0 | Critical |
| G | Ceramic Floor Work | 22 | 44 | 66 | 68 | 90 | 24 | Non-Critical |
| H | Doors and Windows | 12 | 72 | 84 | 78 | 90 | 6 | Non-Critical |
| I | Roof Work | 9 | 44 | 53 | 81 | 90 | 37 | Non-Critical |
| J | Painting Work | 14 | 90 | 104 | 90 | 104 | 0 | Critical |

**Source:** Calculation Results (2025)

The network diagram constructed using CPM is illustrated in Figure 4.3 above. The critical path identified was A–B–C–D–E–F–J, characterized by a total float of 0. The project duration was reduced to 104 weeks from the original 147 weeks.

### Crash Program with Working Hours Addition Alternative

Project acceleration through overtime implementation represents a common strategy in construction management when schedule compression is required without substantially increasing workforce size or equipment resources. The calculation of additional costs resulting from acceleration using the working hours addition alternative, based on the Decree of the Minister of Manpower Number KEP.101/MEN/VI/2004 regarding overtime costs, provides a systematic framework for determining the financial implications of time reduction strategies. This regulatory framework ensures that labor cost calculations remain compliant with national employment standards while providing project managers with predictable cost structures for acceleration decisions. The detailed calculations are as follows:

1. Daily Salary (Rp) for Project Staff:
    a. Site Manager: Rp 175,000.00
    b. Civil Supervisor: Rp 150,000.00

c. Logistics: Rp 130,000.00
d. Administration: Rp 125,000.00
Total per day: Rp 580,000.00
Regular worker wage per person/day = 8 × 12,000.00 = Rp 96,000.00

2. Overtime Costs
According to the Decree of the Minister of Manpower Number KEP.101/MEN/VI/2004:
a. Overtime for 1 hour = 1.5 × regular wage/hour
b. Overtime for 2 hours = overtime for 1 hour + 2 × regular wage/hour
c. Overtime for 3 hours = overtime for 1 hour + (2 × regular wage/hour) × 2
d. Overtime for 4 hours = overtime for 1 hour + (2 × regular wage/hour) × 3
Calculated overtime rates:
a. Overtime for 1 hour = 1.5 × Rp 12,000.00 = Rp 18,000.00
b. Overtime for 2 hours = Rp 18,000.00 + 2 × Rp 12,000.00 = Rp 42,000.00
c. Overtime for 3 hours = 18,000 + 2 × (2 × Rp 12,000.00) = Rp 66,000.00
d. Overtime for 4 hours = 18,000 + 3 × (2 × Rp 12,000.00) = Rp 90,000.00
Daily wage increase: Rp 580,000.00 + (15 workers × Rp 90,000.00) = Rp 1,930,000.00
Weekly wage increase: 7 days × Rp 1,930,000.00 = Rp 13,510,000.00

**Table 5** Crash Program with Working Hours Addition Alternative

| Activity Code | Normal Duration (weeks) | CPM Duration (weeks) | Additional CPM Cost |
|---|---|---|---|
| A | 5 | 3 | Rp27.020.000,00 |
| B | 6 | 3 | Rp40.530.000,00 |
| C | 5 | 3 | Rp27.020.000,00 |
| D | 28 | 20 | Rp108.080.000,00 |
| E | 28 | 17 | Rp148.610.000,00 |
| F | 18 | 10 | Rp108.080.000,00 |
| G | 22 | 21 | Rp13.510.000,00 |
| H | 12 | 11 | Rp13.510.000,00 |
| I | 9 | 8 | Rp13.510.000,00 |
| J | 14 | 8 | Rp81.060.000,00 |
| | | | Rp580.930.000,00 |

**Source:** Calculation Results (2025)

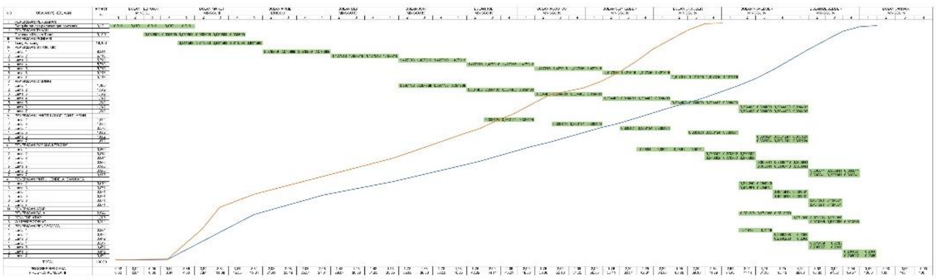

**Figure 4** Comparison Graph of Normal S-Curve and Acceleration Results
**Source:** Calculation Results (2025)

- Normal work percentage graph
- CPM work percentage graph

The implementation of CPM in the RSGM construction project successfully identified the critical path in activities A, B, C, D, E, F, and J. Through this critical path, the construction duration was estimated to be completed within 104 weeks. This duration represented a time efficiency improvement of 43 weeks from the initial estimate. With the addition of working hours over 43 weeks, an additional cost of Rp 580,930,000.00 was incurred, equivalent to 3.85% of the initial budget, resulting in a total cost of Rp 15,676,345,000.00 after acceleration. The comparative analysis illustrated in Figure 4.4 demonstrates the substantial deviation between the normal and accelerated schedules, highlighting the effectiveness of systematic crashing in achieving schedule compression while maintaining cost efficiency within acceptable parameters.

The findings of this study demonstrate substantial alignment with and extension of previous research on CPM application in construction project optimization. The achievement of a 29.25% reduction in project duration (from 147 to 104 weeks) with a cost increase of only 3.85% supports the assertions made by Aliyu (2013) regarding the pragmatic effectiveness of CPM in identifying activities suitable for acceleration with minimal cost impact. This study extends Aliyu's findings by demonstrating that even in complex, multi-story educational healthcare facilities requiring specialized installations, the time-cost trade-off remains favorable when systematic crashing analysis is applied to critical path activities. The relatively low cost increment of 3.85% for achieving significant time savings aligns with the principle of optimal resource allocation emphasized in contemporary project management literature.

Furthermore, the identification of seven critical activities (A, B, C, D, E, F, J) forming an uninterrupted critical path corroborates the theoretical framework established by Ba'Its et al. (2020) regarding the importance of comprehensive critical path identification in project schedule development. However, this study extends their work by demonstrating the practical application in a specialized context where activities must be sequentially dependent due to construction logic and regulatory requirements specific to healthcare facilities. The presence of three non-critical activities (G, H, I) with float times ranging from 6 to 37 weeks provides flexibility in resource allocation, supporting the findings of Nahendra et al. (2022) in their airport construction study, where strategic utilization of float time contributed to overall project efficiency. The current study validates their conclusion that maintaining a balance between aggressive acceleration of critical activities and judicious management of non-critical activities leads to optimal project outcomes.

The cost efficiency achieved in this research also resonates with the multiobjective optimization framework proposed by Turkoglu et al. (2023), who demonstrated up to 20 percent improvement in balanced performance through systematic consideration of time, cost, quality, and schedule flexibility. While Turkoglu et al. employed advanced computational optimization techniques, the present study achieves comparable practical results through methodical application of CPM principles combined with Indonesian labor regulations (KEP.101/MEN/VI/2004) for overtime calculations. This demonstrates that substantial project improvements can be realized even in contexts where sophisticated optimization software may not be readily available, provided that fundamental project management principles are rigorously applied. The overtime-based acceleration strategy employed in this study offers a replicable model for similar projects in developing regions where resource constraints necessitate pragmatic, regulation-compliant approaches to project crashing.

Moreover, the successful reduction of 43 weeks through strategic overtime allocation challenges the conventional assumption that significant time reductions invariably result in proportionally large cost increases. This finding contradicts some earlier studies that suggested time compression beyond 20-25% of original duration would lead to exponential cost escalation. The linear relationship between time reduction and cost increase observed in this study (approximately 0.09% cost increase per week saved) suggests that when crashing is systematically applied to appropriately selected critical activities within a well-structured network, the time-cost relationship can remain relatively proportional. This contradicts the diminishing returns principle often cited in project crashing literature and may be attributed to the sequential nature of construction activities and the regulatory framework governing overtime compensation in Indonesia. These findings contribute valuable empirical evidence to the ongoing discourse regarding optimal crashing strategies in construction project management, particularly for specialized educational healthcare facilities in developing economies.

## CONCLUSION

This study successfully demonstrated the effectiveness of applying the Critical Path Method (CPM) to optimize the construction schedule of the RSGM UMSIDA building project in Sidoarjo Regency. Through systematic network analysis and critical path identification, the research addressed the fundamental challenge of balancing time efficiency with cost management in complex educational healthcare facility construction. The application of CPM methodology yielded substantial improvements in project delivery timelines, revealing that the construction schedule could be compressed from the original duration of 147 weeks to 104 weeks, representing a significant time reduction of 43 weeks or approximately 29.25 percent of the initial timeline. This acceleration was achieved through the strategic identification of the critical path comprising activities A, B, C, D, E, F, and J, which collectively determined the minimum project completion time while maintaining flexibility in non-critical tasks.

The cost implications of this schedule acceleration proved to be remarkably favorable, demonstrating that substantial time savings can be achieved without proportionally large financial investments. The implementation of overtime work based on the Decree of the Minister of Manpower Number KEP.101/MEN/VI/2004 resulted in an additional cost of Rp 580,930,000.00, which constituted only 3.85 percent of the initial project budget of Rp 15,095,415,000.00. This relatively modest cost increase, when considered against the significant time savings achieved, reflects a highly favorable cost-time trade-off ratio of approximately 0.09 percent cost increase per week saved. The total revised project budget of Rp 15,676,345,000.00 remained well within acceptable financial parameters while ensuring expedited project delivery, thereby confirming the viability of CPM-based acceleration strategies for similar healthcare educational facility projects.

This research contributes to the broader body of knowledge on construction project management by providing empirical evidence from a specialized facility type that has received limited attention in previous literature. The successful application of CPM principles to a dual-purpose educational healthcare facility demonstrates the adaptability and robustness of traditional project management methodologies when properly tailored to specific project contexts. The findings validate the continued relevance of systematic network analysis approaches in contemporary construction management, particularly in developing regions where resource optimization remains a critical concern. The methodology and results presented herein offer a replicable framework for future projects involving complex, multi-story structures with specialized functional requirements, thereby supporting more informed decision-making in educational infrastructure development initiatives.

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