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Improving Operational Efficiency in Small-Scale Residential Service Delivery: A Critical Path Method and Time Cost Trade Off Analysis

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Abstract

This study examines how schedule optimization can improve operational efficiency in small-scale residential service delivery. In project-based housing businesses, delayed completion and weak cost control often reduce delivery reliability and weaken business performance. This study applies the Critical Path Method and Time Cost Trade Off to a Type 36 housing project in North Sanggata, East Kalimantan, to identify critical activities, accelerate project completion, and evaluate cost consequences. The study uses a case study approach based on interviews, field observation, budget plans, activity sequences, and project scheduling documents. The analysis focuses on activity mapping, dependency structure, critical path identification, and comparison between normal and accelerated project duration. The findings show that the project duration can be reduced from 148 days to 99 days after applying structured scheduling analysis. Total project cost also declined from Rp179,975,421 to Rp165,461,221, producing savings of Rp14,514,200. These findings indicate that CPM and TCTO function not only as technical scheduling tools but also as operational decision tools that improve lead-time efficiency, service delivery reliability, and cost performance in small residential project businesses. The study contributes to the literature by repositioning project scheduling methods within an operational management perspective, especially for small contractors and housing developers that still rely on informal planning practices.

Keywords: *Operational efficiency, service delivery, residential housing business, critical path method, time cost trade off*

1. Introduction

Small-scale residential construction should be understood not only as a technical activity but also as a project-based service business in which schedule, cost, and reliability jointly shape operational performance. Construction projects remain exposed to schedule deviations arising from coordination problems, resource constraints, material availability, and implementation uncertainty. Recent studies show that weak planning and control can translate into delays, cost inefficiency, and reduced project performance (Dwiretnani et al., 2023; Kammouh et al., 2022). In project-based businesses, therefore, schedule management is not merely an engineering function but an operational capability that supports reliable delivery. Recent evidence also links planning quality and project-control discipline with construction performance and delay mitigation (Dwiretnani et al., 2023)

Type 36 housing is a practical segment of residential development in Indonesia, including projects managed at relatively small scale. Although the physical scope is smaller than large construction projects, the interdependence among activities can still create substantial schedule exposure. Evidence from residential and small-project studies indicates that formal activity sequencing and critical-path identification can reveal delays and opportunities for time improvement that may not be visible when projects rely primarily on field experience (Fijra et al., 2025; Perdana & Sari, 2022). Recent Indonesian cases also demonstrate that CPM-based scheduling can improve visibility of critical activities and provide a more systematic basis for project control (Rakasyiwi et al., 2022). Evidence from Indonesian residential cases similarly shows that CPM can expose critical sequences and improve schedule visibility (Perdana & Sari, 2022). The study by Asrul et al., (2025) likewise demonstrates the practical use of CPM to structure activity sequences and identify critical work in a construction setting.

From an operational-management perspective, delivery reliability is closely associated with the ability to complete interdependent activities according to an agreed schedule while controlling resource use. Construction scheduling research increasingly treats schedule performance as a management and decision-making issue rather than only a technical calculation. Kammouh et al., (2022) emphasize the need for active mitigation to maintain timely completion, while Abdzadeh et al., (2022) demonstrate that material and supply decisions can directly affect construction scheduling. For small residential businesses, these considerations make disciplined scheduling relevant to delivery reliability, resource productivity, and cost performance. This operational interpretation is also consistent with research emphasizing active schedule control and the integration of supply-related decisions into construction planning.

Two established methods are particularly relevant to this problem. The Critical Path Method (CPM) identifies the sequence of activities that determines project completion and distinguishes activities with zero or limited float. Recent applications in residential and building projects confirm its usefulness for identifying critical activities and improving schedule control (Dwiretnani et al., 2023). The Time Cost Trade Off (TCTO) method complements CPM by evaluating alternatives for shortening project duration while considering the associated cost consequences. Recent studies show that TCTO can support acceleration decisions through overtime, additional labor, or other feasible interventions (Mardiana et al., 2022; Nabila, 2023). Recent international work further demonstrates the continuing relevance of structured scheduling for activity relationships and control, including BIM-supported scheduling and automated schedule generation (Isaac & Shimanovich, 2021; Soman & Molina-Solana, 2022; Yao et al., 2024).

Recent international research further shows that time-cost trade-off analysis has developed from simple schedule compression toward decision support under resource, quality, and uncertainty constraints (Albayrak, 2023; Yılmaz & Dede, 2023). At the same time, Indonesian studies continue to demonstrate the practical value of CPM and TCTO in building, housing, road, and public-facility projects (Sanjaya & Johari, 2022; Umam, 2022). However, much of this literature remains focused on technical schedule and cost optimization. Less attention is given to how these methods can be interpreted as operational decision tools for small-scale residential service businesses, particularly where project planning is relatively informal. The broader literature also shows that time-cost decisions increasingly incorporate resource, quality, and risk considerations (Alhady et al., 2025; Son & Khoi, 2023), although the present study remains intentionally focused on the CPM-TCTO evidence available from the case project.

This study addresses that gap through an applied case analysis of a Type 36 housing project in North Sanggata, East Kutai, East Kalimantan. The project was originally managed with limited formal planning documentation. By applying CPM and TCTO to the documented activity sequence, duration, and project-cost information, the study evaluates how structured scheduling can reduce lead time and improve cost efficiency. The objective is therefore to analyze the role of CPM and TCTO in improving operational efficiency in a small-scale residential project business, with particular attention to project duration, acceleration priorities, and total cost. The contribution is deliberately practical: rather than proposing a new optimization algorithm, the study demonstrates how established scheduling methods can support managerial decisions in a small residential construction setting.

2. Literature Review

2.1 Operational Efficiency in Project-Based Businesses

Operational efficiency in project-based businesses refers to the ability to transform available labor, materials, time, and financial resources into the required project output with minimal avoidable waste. In construction, this objective is complicated by the interdependence of activities and the temporary nature of project organizations. Recent research on construction performance emphasizes that schedule, resource, and coordination conditions jointly shape project outcomes (Kammouh et al., 2022). Schedule discipline is therefore an important component of operational control because deviations in one activity may propagate to subsequent activities.

Small residential projects may be particularly sensitive to weak planning because project teams and documentation systems are often limited. Research on residential construction has shown that inadequate management and scheduling can contribute to delays, while CPM can expose the activities that determine completion time (Perdana & Sari, 2022) . Similar findings are reported in Indonesian building projects, where identifying critical activities provides a basis for more focused supervision and resource allocation (Dwiretnani et al., 2023). Thus, structured scheduling can function as a relatively simple managerial mechanism for improving operational visibility.

2.2 Critical Path Method

The Critical Path Method (CPM) is a network-based scheduling technique used to identify the chain of activities that determines project completion. The method establishes activity relationships and calculates early and late schedule times, allowing activities with zero float to be recognized as critical. Recent empirical applications in Indonesia confirm that CPM can identify critical sequences and support more disciplined project scheduling in building and residential projects (Dwiretnani et al., 2023). International research also continues to use network-based scheduling as a foundation for more advanced decision-support approaches (Aminbakhsh & Ahmed, 2023; Soman & Molina-Solana, 2022).

The managerial value of CPM lies in its ability to distinguish activities that require continuous control from activities that have some scheduling flexibility. This distinction helps project managers prioritize supervision, material readiness, crew coordination, and corrective action. Kammouh et al., (2022) demonstrate the importance of active schedule control when construction activities are exposed to uncertainty, while Yao et al., (2024) show that schedule optimization increasingly focuses on responsiveness and rescheduling. In small residential projects, the transparency provided by a critical-path network can therefore improve decision focus without requiring an advanced optimization system.

2.3 Time Cost Trade Off

Time Cost Trade Off (TCTO) is used to examine how project duration can be reduced by accelerating selected activities and how such acceleration affects cost. In conventional construction practice, acceleration may involve additional labor, overtime, alternative sequencing, or other resource arrangements. Recent Indonesian studies demonstrate the practical application of TCTO for balancing time and cost in construction projects (Nakti et al., 2024). International studies likewise emphasize that the relationship between duration and cost is not linear and requires systematic evaluation of alternative schedules (Bettemir & Birgonul, 2025).

The recent literature also indicates that TCTO is increasingly treated as a decision-support problem rather than only a calculation of crash duration. Albayrak, (2023) demonstrate multi-objective approaches for identifying alternative time-cost solutions. At the applied-project level, Indonesian studies report that acceleration can produce meaningful time savings, although the economic effect depends on the selected intervention (Pangemanan et al., 2025). These findings support the use of TCTO in the present case, while also reinforcing the need to interpret acceleration decisions in relation to available project data. Comparable Indonesian studies report different acceleration outcomes depending on the intervention, including overtime, additional labor, and shift arrangements (Paputungan et al., 2025).

3. Research Methodology

This study used an applied case study approach to examine operational efficiency in a small-scale residential construction service project. The case focused on a Type 36 private housing project located in North Sanggata, East Kutai Regency, East Kalimantan. A case study design was selected because it allows an in-depth analysis of project activities, work dependencies, time allocation, and cost consequences within a real project setting. The project was considered suitable for this study because it represents a small-scale housing service project that was managed under relatively informal planning conditions.

The study used both primary and secondary data. Primary data were collected through direct interviews with the field foreman and through on-site observation during project implementation. These data were used to identify the sequence of work activities, predecessor relationships, estimated durations, labor allocation, and implementation conditions. Secondary data were obtained from internal project documents, including the budget plan, design records, work schedules, material requirements, activity recapitulation, and project cost data. These sources were used to support the reconstruction of the project network and the comparison of project duration and cost before and after optimization.

The data were analyzed in three stages using the Critical Path Method and Time Cost Trade Off. First, all project activities were identified, coded, and ordered according to their immediate predecessor relationships to build the project network and determine the critical path. Second, an acceleration scenario was prepared only for critical activities by combining three feasible field strategies, namely additional labor on labor-intensive work packages, limited overtime on shortduration technical activities, and tighter material readiness and crew sequencing on installation work. Third, the optimized scenario was compared with the normal plan in terms of duration and total cost. This analytical sequence is consistent with recent applications that identify critical paths before evaluating acceleration alternatives (Nakti et al., 2024; Sanjaya & Johari, 2022).

To support acceleration decisions, the study followed the TCTO cost-slope principle, namely Cost Slope = (Crash Cost - Normal Cost) / (Normal Time - Crash Time). Activities with lower expected cost slope were prioritized because they offered the most economical time reduction. Because the field project did not maintain fully disaggregated crash-cost records for each activity, the article reports the cost-slope logic together with a simplified activity-level cost proxy based on activity expenditure per day saved and then discusses the realized cost change at the aggregate project level. Project completion time and total project cost were used as the main indicators of operational performance. A shorter project duration and lower total cost after optimization were interpreted as evidence of improved operational efficiency in the residential project service process.

4. Result And Discussion

4.1 Project Overview and Data Description

This study examines a private Type 36 residential construction project located in North Sanggata, East Kutai Regency, East Kalimantan. Data were collected through direct observation and interviews with the field foreman during project implementation. Since the project owner provided the main materials, logistical constraints were relatively limited. However, the project still required effective coordination across multiple work stages to ensure efficient completion.

Table 1 Material Requirements Recapitulation

No	Material Description	No	Material Description
1	Cement	31	Elbow 3
2	Sand	32	Elbow 2
3	Stone 2-3	33	Tee 2
4	Sirtu	34	Elbow ½
5	Mountain Stone	35	Elbow thread in ½
6	Heap	36	Tee ½
7	Brick	37	Water valve valve
8	Iron D6	38	Light steel
9	Iron D10	39	Light steel purlins
10	Door frame (main + bedroom)	40	Fascia
11	Iron Binding Wire	41	Spandek Roof 0.25
12	Window frame	42	Nok
13	Vent	43	Light steel scrup
14	Panel door leaf	44	Steel spandek scrup
15	Plywood door leaf	45	Nail 5
16	Window shutters	46	Nail 7
17	Bathroom door	47	Nail 10
18	Lock the door	48	Concrete Nails
19	5/7 wood ceiling frame	49	Ceiling nails
20	3mm plywood	50	Single 2.5 cable
21	Ceiling Molding	51	Single 1.5 cable

22	40x40 Ceramic	52	Switch bowl / socket
23	20x25 bathroom ceramics	53	Fitting
24	Wall paint 20 liters	54	14 Watt Lamp
25	20 liter ceiling paint	55	Electric Pipe
26	Oil paint 1 liter	56	Cable insulation
27	Brush roll	57	Single Switch
28	Hand brush 2	58	Double switch
29	Hand brush 4	59	Electric socket
30	Thinner 1 liter	60	MCB
61	Mcb Box	63	Water pump
62	Electrical Installation 900	64	Boreholes

The material requirements used in the project are presented in Table 1. The table indicates that the project involved a broad range of materials, including structural materials, finishing materials, sanitary components, and electrical equipment. Although the project is small in scale, the diversity of required materials shows that operational planning remains essential to maintain work continuity and avoid implementation disruption.

Table 2 Job Activities

No	Job Name	Completion Time
1	Preparatory work	3 days
2	Earthworks	4 days
3	Foundation Work	5 days
4	Concrete Work	13 days
5	Reinforcement Work	21 days
6	Wall Couple Work	17 days
7	Frame & Door Installation Work	13 days
8	Ceiling Work	11 days
9	Roofing Work	7 days
10	Sanitary Work	10 days
11	Electrical Work	6 days
12	Floor Work	20 days
13	Finishing Work	18 days
	Total	**148day**

Table 3 Work Activities and Expenses

No	Job Name	Expenditure
1	Preparatory work	Rp. 573,400.00
2	Earthworks	Rp. 293,739.69
3	Foundation Work	Rp. 2,198,234.80
4	Concrete Work	Rp. 1,860,994.39
5	Reinforcement Work	Rp. 1,557,809.93
6	Wall Work	Rp. 6,904,590.00
7	Frame & Door Work	Rp. 2,633,554.00
8	Ceiling Work	Rp. 1,132,776.71
9	Roofing Work	Rp. 2,322,982.20
10	Electrical Work	Rp. 567,888.00

11	Sanitary Work	Rp. 1,483,167.06
12	Floor Work	Rp. 2,224,938.10
13	Finishing Work	Rp. 1,494,156.13
	Total	**Rp. 25,248,221.01**

Table 4 Worker Salary

No	Worker Name	Salary Amount
1	Foreman	Rp. 9,300,000
2	Handyman 1	Rp. 8,416,073
3	Handyman 2	Rp. 8,416,073
4	Coolie	Rp. 8,416,073
	Total	**Rp. 34,548,221**

The major work activities are summarized in Table 2, which shows thirteen stages of project execution, beginning with preparatory work and ending with finishing work. These activities form the basic operational sequence of the project. To complement this overview, Table 3 presents work activity expenditures, while Table 4 reports the wage structure of the labor force, consisting of one foreman, two builders, and one laborer. These tables show that project performance depends not only on technical execution but also on the efficiency of labor and cost allocation.

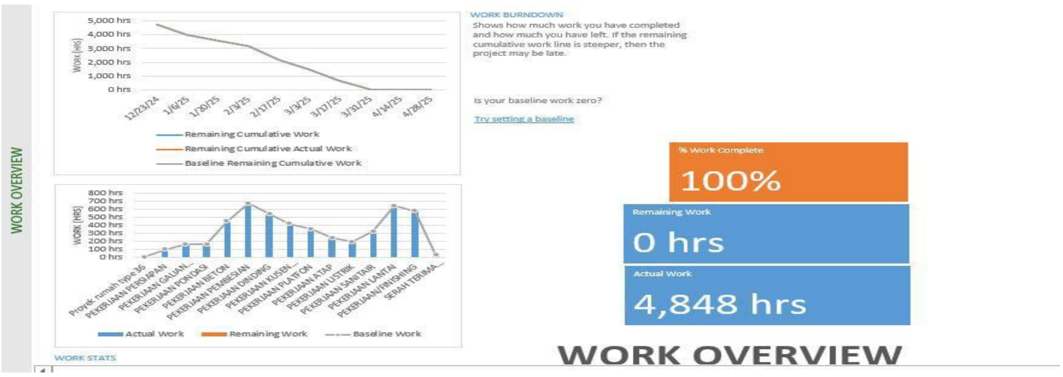

Figure 1 Work Overview

Figure 2 Project Overview

The actual field condition of the project is illustrated in Figure 1 and Figure 2. These figures provide visual confirmation that the study reflects a real small-scale residential service project rather than a simulated case.

4.2 Activity Sequence and Critical Path Analysis

Table 5 Project Activity Recapitulation

No	Type of activity	Activity Symbol	Duration (Normal Day)	Duration (Quick Time)	Predecessor
1	Preparatory work	A	3	3	-
2	Earthworks	B	4	3	A
3	Foundation Work	C	5	4	B
4	Concrete Work	D	13	11	C
5	Reinforcement Work	E	21	14	D
6	Wall Couple Work	F	17	12	E
7	Frame & Door Installation Work	G	13	10	F
8	Ceiling Work	H	11	8	G
9	Roofing Work	I	7	5	H
10	Sanitary Work	J	10	7	I
11	Electrical Work	K	6	4	J
12	Floor Work	L	20	10	K
13	Finishing Work	M	18	8	L

Source: Residential Housing Production Project (2025)

The main basis for the scheduling analysis is provided in Table 5, which presents the project activity recapitulation, including activity codes, corrected normal duration, corrected quick duration, and immediate predecessor relationships. This table clarifies the dependency structure of the project and provides the basis for the CPM analysis.

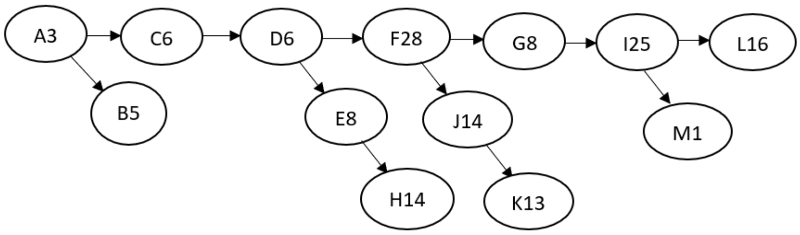

Figure 3 Normal Network Time Plan

Based on Table 5, the project was initially planned to start on January 3, 2025, and to be completed on May 13, 2025, with a total duration of 148 working days. Using these data, a normal network time plan was constructed, as shown in Figure 3. The network diagram illustrates the sequence of activities and clarifies the logical relationship among work stages.

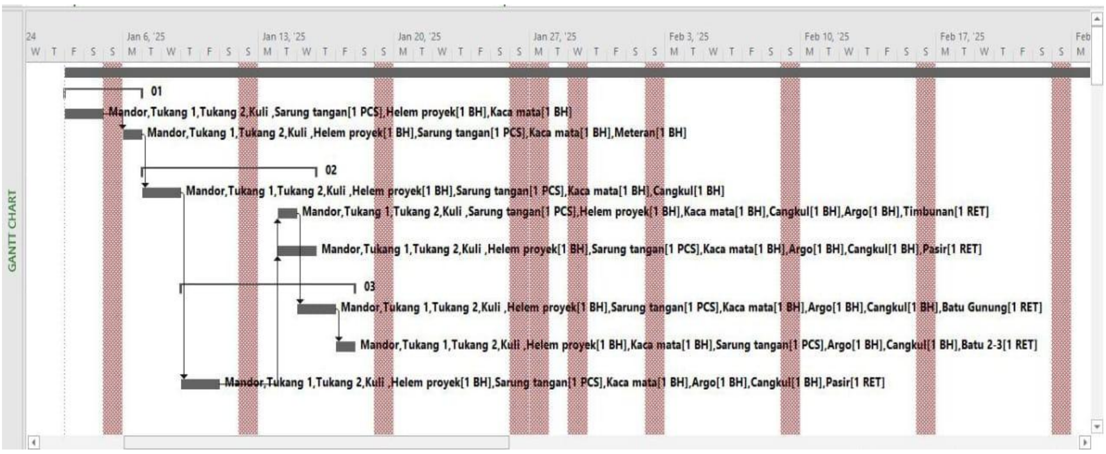

Figure 4 Gantt Chart

The same normal schedule is further visualized in Figure 4 using a Gantt chart. Based on the CPM analysis, the critical path is identified as A-B-C-D-E-F-G-H-I-J-K-L-M. This indicates that all major project activities lie on the critical path, meaning that any delay in one activity directly affects the overall project completion time.

From an operational perspective, this finding shows that the project had very limited scheduling flexibility. In a small residential project, such a condition implies that delivery performance depends heavily on strict coordination and close supervision throughout the entire activity chain.

4.3 Accelerated Schedule and Time Efficiency

Table 6 Acceleration Priority Based on Simplified Cost-Slope Proxy

No	Type of activity	Activity Symbol	Activity Cost (Rp)	Time Saved (Day)	Cost Proxy (Rp/Day Saved)
1	Preparatory work	A	573,400.00	0	-
2	Earthworks	B	293,739.69	1	293,739.69
3	Foundation Work	C	2,198,234.80	1	2,198,234.80
4	Concrete Work	D	1,860,994.39	2	930,497.20
5	Reinforcement Work	E	1,557,809.93	7	222,544.28
6	Wall Couple Work	F	6,904,590.00	5	1,380,918.00
7	Frame & Door Installation Work	G	2,633,554.00	3	877,851.33
8	Ceiling Work	H	1,132,776.71	3	377,592.24
9	Roofing Work	I	2,322,982.20	2	1,161,491.10
10	Sanitary Work	J	1,483,167.06	3	494,389.02
11	Electrical Work	K	567,888.00	2	283,944.00
12	Floor Work	L	2,224,938.10	10	222,493.81
13	Finishing Work	M	1,494,156.13	10	149,415.61

After identifying the critical path, the next step was to examine the accelerated work scenario. Table 6 summarizes the activity-level acceleration priority using a simplified cost-slope proxy, calculated as activity expenditure divided by the number of days saved in the acceleration scenario. Although this proxy does not replace the classical crash-cost formula, it helps show which critical activities offer more economical time reduction under limited field data.

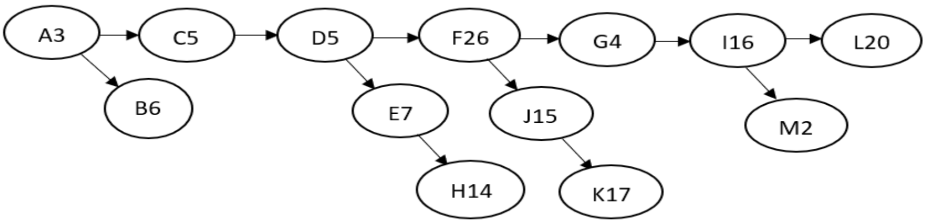

Figure 5 Fast Network Time Plan

In practical terms, the accelerated scenario was implemented through additional labor on reinforcement, wall, floor, and finishing activities; limited overtime on concrete, ceiling, sanitary, and electrical work; and tighter sequencing and material readiness on frame and roofing work. These actions explain how the project duration was reduced without interrupting the overall workflow.

Using the proxy in Table 6, the most attractive acceleration points were finishing work, floor work, reinforcement work, electrical work, and earthworks because they offered lower expenditure per day saved than other critical activities. By contrast, foundation, wall, and roofing work required relatively higher expenditure commitment and therefore were not prioritized as the first acceleration targets.

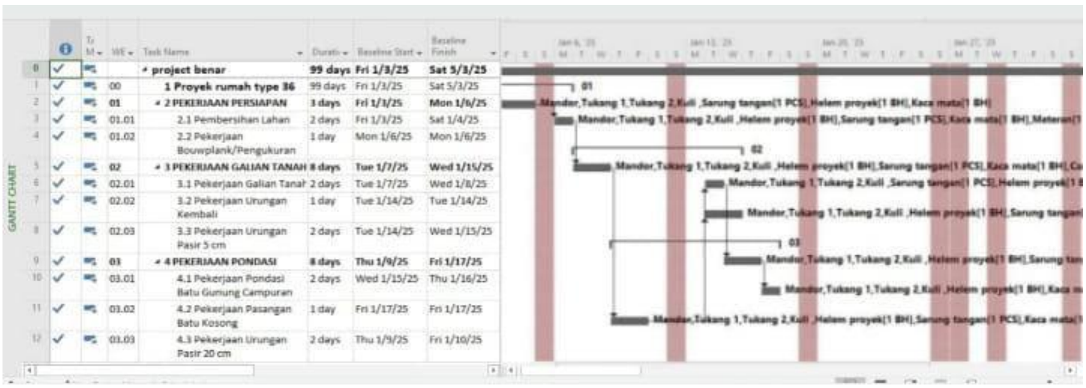

Figure 6 Gantt Chart

Using the accelerated scenario, a fast network time plan was developed and is presented in Figure 5. In addition, the accelerated implementation schedule is visualized in Figure 6 through a Gantt chart. These figures show the revised sequence and shorter duration of project activities after schedule optimization.

The corrected acceleration scenario indicates that the total project duration could be reduced from 148 days to 99 days, meaning that the project experienced a time reduction of 49 days. This result confirms that the application of CPM and TCTO can significantly improve project lead-time efficiency.

For small-scale residential businesses, shorter project duration is not merely a technical achievement. Faster completion also improves delivery reliability, reduces exposure to on-site uncertainty, and enhances the firm’s ability to manage future projects more effectively. Therefore, schedule acceleration in this study can be interpreted as an improvement in operational performance.

4.4 Cost Comparison

Table 7 Total Cost According to Project Owner

No	Project Name	Total Cost
1	Project Activity Costs	Rp. 154,727,200
2	Worker Salary Cost	Rp. 34,548,221.
	Total	**Rp. 179,975,421**

Table 8 Total Cost After Using CPM

No	Project Name	Total Cost
1	Project Activity Costs	Rp. 130,913,000
2	Worker Salary Cost	Rp. 34,548,221
	Total	**Rp. 165,461,221**

The financial effect of the scheduling improvement is presented in Table 7 and Table 8. Table 7 shows the initial total project cost according to the project owner, while Table 8 presents the total project cost after applying the Critical Path Method.

Before optimization, the total project cost was Rp179,975,421, consisting of Rp154,727,200 for project activity costs and Rp34,548,221 for worker salary costs. After CPM-based optimization, the total cost decreased to Rp165,461,221, with project activity costs reduced to Rp130,913,000, while labor cost remained Rp34,548,221. This means that the main saving came from activity-related implementation cost, which declined by Rp23,814,200, rather than from reducing labor compensation.

This comparison shows that the application of structured scheduling produced a total saving of Rp14,514,200. At the aggregate level, the optimization scenario was equivalent to a net saving of about Rp296,208 for each day of project duration shortened. This finding is important because project acceleration is often assumed to increase total cost. In this case, however, the scheduling analysis not only reduced project duration but also lowered total expenditure.

From a business perspective, these savings are meaningful for small contractors and residential developers. Lower operational cost can improve project margins, support more competitive pricing, and strengthen the financial sustainability of project-based service businesses. The result also suggests that the original implementation still contained operational inefficiencies that could be minimized through better planning and control.

4.2 Discussion

Overall, the findings show that structured scheduling improved both implementation speed and cost performance in the case project. The normal schedule of 148 days was reduced to 99 days, while the project cost declined from Rp179,975,421 to Rp165,461,221. This pattern is consistent with recent Indonesian studies showing that CPM and TCTO can provide a systematic basis for identifying critical work and evaluating acceleration alternatives (Mardiana et al., 2022; Nabila, 2023). It is also consistent with international evidence that time-cost decisions require explicit consideration of activity dependencies, resource conditions, and alternative acceleration strategies (Yilmaz et al., 2022). The result is also comparable with Indonesian housing and building cases in which structured CPM/TCTO analysis generated measurable schedule improvements (Fijra et al., 2025; Nakti et al., 2024).

The critical-path result is particularly important because all major activities in the corrected network were identified as critical. This means that the project had little scheduling flexibility and that slippage in one activity could propagate to final completion. Similar CPM applications in Indonesian building and residential projects have demonstrated how critical-path identification improves schedule visibility and supports managerial prioritization (Dwiretnani et al., 2023; Fijra et al., 2025). From an operational perspective, the present finding suggests that supervision should be concentrated on activity continuity, material readiness, and timely hand-offs rather than distributed equally across all work packages. The finding is consistent with international research emphasizing that schedule control and activity sequencing are central to timely construction delivery (Aminbakhsh & Ahmed, 2023; Kammouh et al., 2022; Tomczak & Jaśkowski, 2022).

The cost result provides an additional managerial insight. The optimized scenario reduced activity-related expenditure while keeping worker salary costs unchanged. Thus, the observed saving was associated primarily with improved execution and scheduling rather than wage suppression. This differs from acceleration cases in which overtime or additional labor increases direct cost, as reported in several TCTO studies (Umam, 2022). The present case therefore illustrates why acceleration decisions should be evaluated from project-specific data rather than assuming that shorter duration will always increase total expenditure. Recent TCTO research likewise emphasizes that the time-cost relationship depends on the selected activities, resource configuration, and acceleration mechanism (Albayrak, 2023; Bettemir & Birgonul, 2025). The risk implication is also consistent with research showing that material, resource, and operational constraints can influence construction schedule performance (Abdzadeh et al., 2022).

5. Conclusion

This study concludes that CPM and TCTO can improve operational efficiency in small-scale residential service delivery when acceleration is focused on critical activities and guided by cost-efficiency considerations. The revised analysis shows that project duration can be reduced from 148 days to 99 days, while total project cost decreases from Rp179,975,421 to Rp165,461,221, resulting in savings of Rp14,514,200.

The managerial implication is that small contractors and housing developers can use simple scheduling discipline, targeted acceleration, and proactive risk control to improve delivery reliability and cost performance even in informal project settings. This study is limited by the availability of field cost records at the activity level. Future studies may strengthen the TCTO analysis by collecting detailed crash-cost data for each critical activity so that full activity-level cost slope calculations can be reported.

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