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

Muhammad Rizki Asrul*, Heldina Pristanti[2], Sarifah[3], Syacrul[4], Afifah Syotiroh[5], Erliana Mutiara Dewi[6]

[12345] Politeknik Negeri Samarinda, Indonesia
***Corresponding Author:** muhammadrizkiasrul@polnes.ac.id

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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 is not only a technical activity but also a form of project-based service business. In this context, business performance is closely related to the ability to deliver housing projects on time, control costs, and maintain reliability in service execution. For small contractors and informal housing developers, weak planning often creates schedule delays, inefficient resource allocation, and higher operational costs. These problems can reduce business credibility and limit the ability of firms to compete in a market that increasingly values speed, certainty, and efficiency.

Type 36 housing projects are common in Indonesia because they serve the lower-middle-income housing segment. However, despite their relatively small scale, these projects often face operational challenges. Limited supervision, incomplete planning documents, and unstructured activity sequencing frequently lead to inefficient implementation. In many cases, project execution depends heavily on field experience rather than formal scheduling analysis. As a result, project duration becomes longer than expected, operational costs become difficult to control, and delivery reliability declines.

From a business and management perspective, delivery reliability is an important dimension of service quality in project-based operations. A contractor or developer that can complete a project more quickly and efficiently has a stronger basis for customer trust, cost control, and competitive positioning. Therefore, project scheduling should not be understood only as a technical control mechanism. It should also be viewed as an operational strategy that supports better service performance and business sustainability.

Two methods are relevant in this context. The Critical Path Method, or CPM, is useful for identifying the sequence of activities that directly determines project duration. It helps managers detect which activities cannot be delayed without affecting the overall completion time. The Time Cost Trade Off, or TCTO, complements this approach by analyzing how time acceleration can be achieved without causing disproportionate increases in cost. When these methods are used together, they provide a structured basis for improving operational efficiency.

Previous studies have shown that CPM and TCTO are effective in construction project scheduling and cost control. However, most studies still frame these methods primarily as engineering tools. There is still limited emphasis on how such methods can support operational efficiency and service delivery performance in small project-based businesses. This gap is important because small residential projects often operate under informal management conditions, where practical operational tools are especially valuable.

This study addresses that gap by analyzing a Type 36 housing project in North Sanggata, East Kalimantan. The project was originally implemented without strong formal planning documentation. By applying CPM and TCTO, this study evaluates how schedule optimization can reduce project lead time and cost while improving operational efficiency. Therefore, the purpose of this study is to analyze the role of CPM and TCTO in improving delivery reliability, lead-time efficiency, and cost performance in a small-scale residential project business.

2. Literature Review

2.1 Operational Efficiency in Project-Based Businesses

Operational efficiency refers to the ability of an organization to deliver outputs with effective use of time, labor, and cost. In project-based businesses, operational efficiency is reflected in the ability to complete activities according to plan, avoid unnecessary delays, and manage resources productively. Unlike repetitive manufacturing systems, project-based operations depend on coordination across interdependent activities. This makes scheduling discipline an essential part of business performance.

In small residential projects, operational efficiency is often weakened by informal planning practices. Limited documentation, incomplete coordination, and dependence on field improvisation can result in inefficient sequencing and longer completion time. As a consequence, project lead time increases and cost control becomes more difficult. In such conditions, structured scheduling becomes important not only to control execution but also to strengthen delivery reliability as part of service value.

2.2 Critical Path Method

The Critical Path Method is a scheduling technique used to identify project activities that directly determine total project duration. According to Dwiretnani and Kurnia, CPM is particularly effective when activity durations are relatively clear and stable. The method helps planners map dependencies among activities, calculate earliest and latest event times, and identify activities with zero slack.

From an operational perspective, CPM allows managers to distinguish between critical and non-critical activities. This distinction is important because delays in critical activities directly affect the final completion date. In practical terms, CPM supports better prioritization of supervision, resource allocation, and decision making. For small contractors and project managers, this method offers a systematic basis for improving execution discipline.

2.3 Time Cost Trade Off

Time Cost Trade Off is a method used to reduce project duration by accelerating selected activities, usually through additional labor, overtime, or alternative work arrangements. The main principle of TCTO is that time can be shortened, but the economic consequences of acceleration must be carefully evaluated. Therefore, TCTO is useful for finding a balance between faster completion and acceptable cost consequences.

Several studies have shown that TCTO can reduce project time and improve cost efficiency. Priyo and Paridi found that time acceleration can significantly shorten project duration when applied to critical activities. Izzah also reported that TCTO is useful in housing development projects for controlling time and cost more effectively. Mardiana et al. demonstrated that TCTO can produce faster completion while maintaining cost effectiveness. These findings show that TCTO is relevant for operational decision making, especially in projects where completion time has strong managerial implications.

2.4 Small-Scale Residential Projects and Informal Management

Although CPM and TCTO are widely recognized, their application in small residential projects still faces several limitations. Perdana and Sari noted that a major challenge lies in the lack of technical data and trained personnel needed to prepare accurate network diagrams. Hadicara and Rochim also emphasized that structured scheduling requires reliable data and coordination, which are often weak in small-scale project environments.

This condition is highly relevant to small residential service businesses. Many projects are managed through practical experience rather than formal project systems. While such an approach may be workable in routine conditions, it becomes inefficient when multiple activities are interdependent and resources are limited. As a result, the absence of formal scheduling may create hidden inefficiencies that reduce profitability and weaken service performance.

2.5 Research Gap and Conceptual Direction

Existing studies have mainly emphasized the engineering benefits of CPM and TCTO, such as schedule optimization and cost reduction. However, these methods can also be interpreted through an operational management lens. In small residential project businesses, schedule acceleration and cost efficiency are closely linked to delivery reliability, resource productivity, and business competitiveness.

This study contributes by repositioning CPM and TCTO from purely technical project tools to operational decision tools in a project-based business context. The conceptual argument of this study is that better schedule structure leads to better control of execution, which in turn improves lead-time efficiency and cost performance.

3. Method

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 short-duration 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.

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.

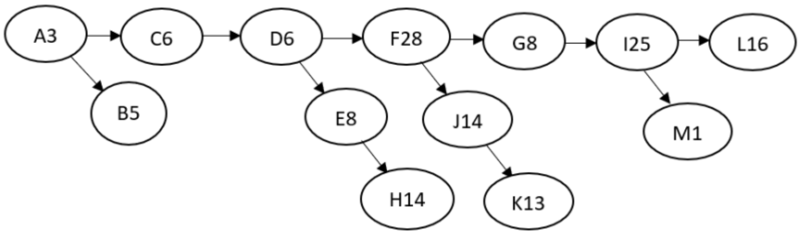

Figure 3 Normal Network Time Plan

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.

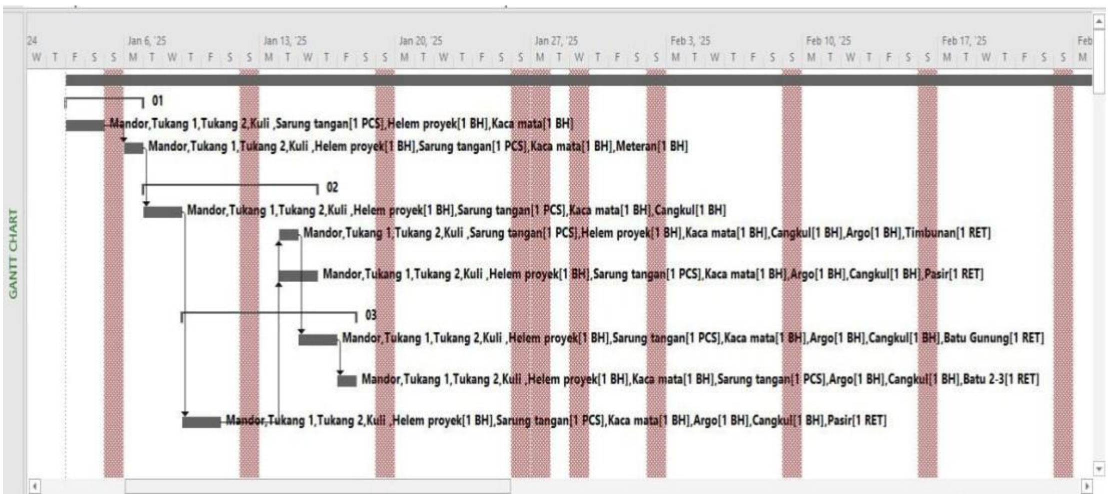

Figure 4 Gantt Chart

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.

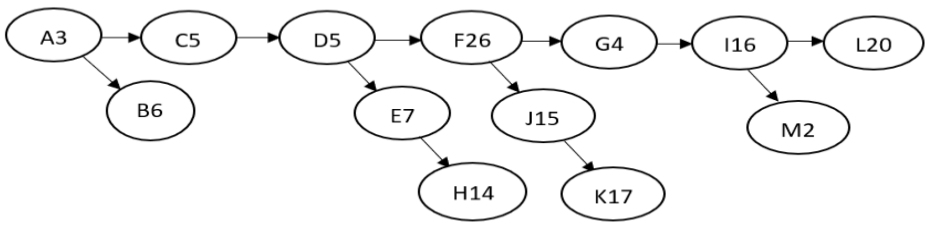

Figure 5 Fast Network Time Plan

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.

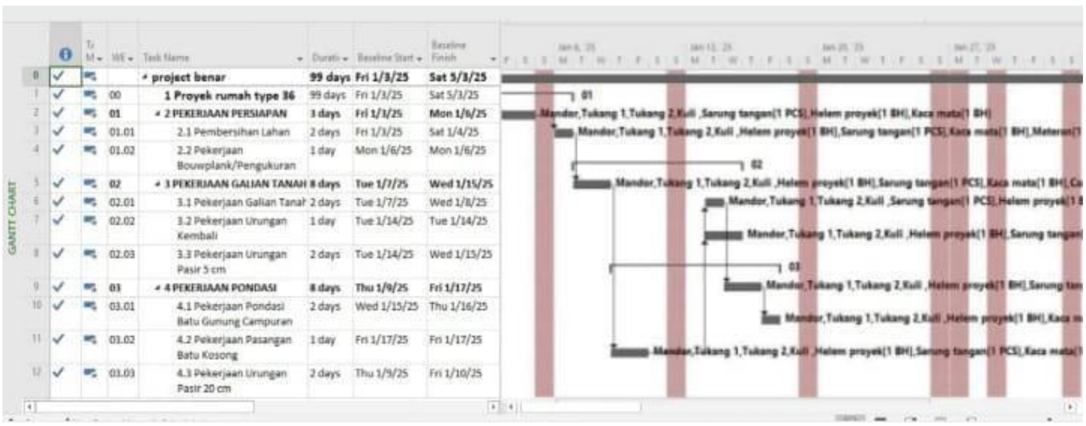

Figure 6 Gantt Chart

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 presented in Table 5 to Table 8 and Figure 3 to Figure 6 show that structured scheduling improves both implementation speed and cost performance. The project's main weakness was not simply the availability of resources, but the lack of formal planning and scheduling discipline. The revised acceleration scenario also demonstrates that not all critical activities should be accelerated in the same way. Instead, project managers need to prioritize activities that provide higher time savings with relatively lower cost commitment.

This study supports previous research showing that CPM and TCTO are effective for reducing project duration and controlling costs. However, the present study extends this understanding by interpreting the results from an operational management perspective. In this case, scheduling efficiency contributes not only to technical project control but also to delivery reliability and cost effectiveness in a small-scale residential business context. The finding that activity-related implementation cost fell while labor cost remained fixed indicates that the main efficiency gain came from reduced execution waste and better sequencing rather than from wage suppression.

An important implication of the critical-path result is the high operational risk created by zero slack across all major activities. Under this condition, any delay in material delivery, labor attendance, weather exposure, or rework can immediately affect final completion time. For small residential projects, the appropriate mitigation measures include daily monitoring of critical activities, buffer stock for key materials, tighter coordination between foreman and workers, short-interval rescheduling, and early corrective action when slippage appears. These practices are necessary because a project with a fully critical activity chain has very limited tolerance for disruption.

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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