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Application of the Least Cost Analysis Method in Optimizing the Time and Cost of Mechanical Earthwork in Construction Projects

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Abstract

Earthwork is one of the critical stages in a construction project because it directly affects the project's timeline and costs. This study aims to analyze the application of the Least Cost Analysis method in determining the most efficient combination of heavy equipment for earthwork operations. The research method used is a descriptive quantitative approach through the analysis of heavy equipment productivity, work duration, and operational costs based on several alternative combinations of excavators and dump trucks. The volume of earthwork analyzed was 1,500,000 m³. The results of the study indicate that a combination of 5 excavators and 15 dump trucks yields a productivity of 7,500 m³/day with a project duration of 200 days and total operational costs of Rp5,700,000,000. Meanwhile, a combination of 4 excavators and 12 dump trucks yields lower productivity, requiring 250 days to complete the work with relatively similar operational costs. These results indicate that selecting the appropriate combination of heavy equipment can improve work efficiency without increasing operational costs. The findings of this study can serve as a consideration in the planning and management of heavy equipment usage for construction projects with similar work characteristics.

Keywords: Cost Optimization, Earthwork, Heavy Equipment, Least Cost Analysis, Productivity.

1. INTRODUCTION

The construction industry is one of the sectors that plays a crucial role in supporting infrastructure development and economic growth. The execution of construction projects is not only required to produce buildings that meet technical specifications but must also be completed on time and within the planned budget. In reality, project execution in the field often faces various obstacles that lead to delays in work or increased implementation costs (Kabakci et al., 2026). These conditions can affect the overall project performance and result in losses for both the contractor and the project owner. Therefore, controlling time and cost aspects is one of the most critical elements in construction project management. One of the tasks that significantly impacts the success of project execution is mechanical earthwork (Luan et al., 2025). This task is an initial phase that serves as the foundation for structural work and other construction activities. If earthwork is delayed, subsequent work phases will also be delayed. Additionally, earthwork costs are generally substantial because they involve the use of heavy equipment with specific capacities and productivity levels (Napolitano et al., 2024). Therefore, thorough planning is required to ensure that earthwork can be carried out effectively and efficiently.

Mechanical earthwork encompasses various activities such as soil stripping, excavation, material handling, backfilling, grading, and soil compaction using heavy equipment (Jin et al., 2022). In practice, these operations are influenced by various factors, including site conditions, soil type, weather, material transport distance, equipment capacity, and the skill of heavy equipment operators (Sekar & Dhanraj, 2025). A mismatch between project requirements and the quantity or type of heavy equipment used can result in low productivity(Mohadi et al., 2026). Additionally, suboptimal use of heavy equipment can lead to idle time between machines, making the work less efficient (De Zoysa et al., 2025). In construction projects, the use of heavy equipment entails relatively high operational costs. These costs include equipment rental fees, fuel consumption, maintenance costs, operator wages, and equipment mobilization costs (Khan et al., 2025). If the management of heavy equipment usage is not handled properly, project implementation costs can increase significantly. In some cases, contractors often increase the number of heavy equipment units with the aim of speeding up the work; however, this decision does not always result in cost efficiency (Tilioua et al., 2025). Adding more equipment can actually increase expenses if the equipment's productivity does not justify the costs incurred.

Issues related to project delays and cost overruns are still frequently encountered in mechanical earthwork projects (Du et al., 2025). These conditions typically arise from inadequate planning of heavy equipment productivity, mismatched work schedules, and weak control over resource utilization on-site. Additionally, changes in field conditions that deviate from the initial plan can also cause the project duration to exceed the planned timeline (Udhayasankar & Kumar, 2025). If these issues are not addressed promptly, the project may experience a decline in efficiency, which can negatively impact the overall quality of project management (Reddy et al., 2025). One approach that can be used to address these issues is the application of the Least Cost Analysis method. This method is used to analyze the relationship between project execution time and required costs, thereby identifying the most economical execution alternative. In this method, calculations are performed on various possible combinations of heavy equipment usage and work durations to determine the minimum total cost (Rahman et al., 2026). Consequently, contractors can identify execution alternatives that are more efficient in terms of both time and cost.

The application of the Least Cost Analysis method is important because, fundamentally, any reduction in project duration will affect project costs. The faster a project is completed, the greater the resource requirements typically become, thereby increasing direct project costs (Nguyen & Nguyen, 2024). Conversely, if the project duration is too long, indirect costs—such as supervision costs, project administration costs, and field operational costs—will increase. Therefore, a balance between project duration and costs is necessary to achieve the most optimal outcome. In mechanical earthwork, time and cost optimization can be achieved by considering the productivity of each piece of heavy equipment used. Equipment productivity is influenced by the equipment's capacity, cycle time, site conditions, and operational efficiency (Raja et al., 2024). By analyzing equipment productivity, the optimal number of machines required to complete a specific volume of work can be determined. This analysis is crucial to avoid both the overuse of heavy equipment and a shortage of equipment, which can lead to project delays.

In addition, the application of the Least Cost Analysis method can also help project implementers determine a more appropriate work execution strategy. Through this method, contractors can compare several alternatives for the use of heavy equipment and select the alternative that offers the lowest total cost while ensuring that the execution time remains within the project's target (Ovi & Sajjad, 2026). With more optimal planning, it is hoped that the use of project resources can become more effective and the risk of losses due to cost overruns can be minimized. Previous studies have shown that optimizing time and costs using a minimum cost analysis approach can improve the efficiency of construction project execution. The use of an appropriate combination of heavy equipment can accelerate project completion while reducing operational costs. However, since every project has different conditions and characteristics, optimization results from one project may not be directly applicable to another. Factors such as soil conditions, work volume, material transport distances, and the types of heavy equipment used must be specifically analyzed according to the conditions of the project under review.

Based on the above discussion, it is evident that mechanical earthwork plays a crucial role in determining the success of a construction project, particularly in terms of project duration and costs. Therefore, a study is needed on the application of the Least Cost Analysis method to optimize the time and costs of mechanical earthwork in construction projects. This study is expected to provide an overview of the most efficient work execution alternatives, thereby assisting contractors in making decisions regarding the use of heavy equipment and project execution control. Additionally, the results of this study are also expected to serve as a reference in efforts to improve the effectiveness and efficiency of construction work execution in similar projects in the future.

2. METHOD

This study was conducted on a residential development project involving a substantial scope of work, particularly during the mechanical earthwork phase. In this project, activities such as excavation, backfilling, material transport, and site grading were the primary tasks requiring the support of various types of heavy equipment to ensure the implementation process proceeded smoothly and in accordance with planned targets. The large volume of earthwork made heavy equipment management a critical factor in determining both the project's time efficiency and cost-effectiveness.

The initial site conditions were dominated by open areas with uneven ground surfaces. Some sections were relatively flat, while others exhibited significant elevation differences. These conditions necessitate cut-and-fill operations to achieve the site elevation required for the planned development of the area. This process of adjusting the land contours naturally requires proper planning for the use of heavy equipment to ensure the work is completed optimally without incurring unnecessary operational costs. The selection of this project as the research subject is based on the consideration that the execution of earthwork at the site involves a combination of heavy equipment with a fairly high level of activity. However, the use of such equipment has not yet been analyzed in depth from an efficiency perspective

This project was selected as the subject of this study based on the consideration that earthwork operations at the site involve the use of heavy equipment at a fairly high level of activity. However, the use of this equipment has not yet been thoroughly analyzed in terms of time efficiency or implementation costs. Furthermore, the complex site conditions and the large volume of work make this project a suitable case study for the optimization of mechanical earthwork.

Through this study, an analysis of heavy equipment productivity and the relationship between work duration and implementation costs was conducted to identify more efficient implementation alternatives. Consequently, the research findings are expected to provide insights into the most optimal combination of heavy equipment usage based on the Least Cost Analysis method, thereby serving as a basis for decision-making in the execution of similar construction projects. A map of the study site used in this research is shown in Figure 1.

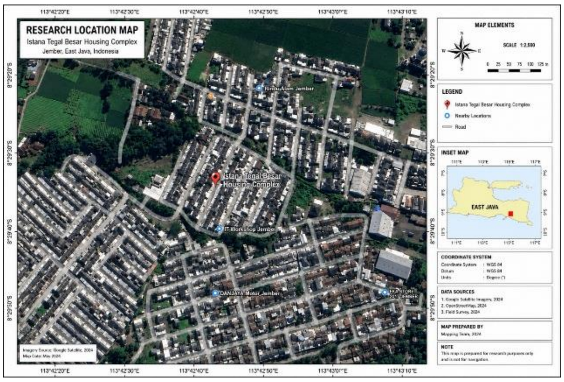

Fig. 1 Research Location Map

This study employs a descriptive quantitative approach, which aims to describe the efficiency of heavy equipment configurations based on an analysis of productivity and operating costs. This approach was chosen to enable an objective and measurable comparison of different heavy equipment combinations.

3. DISCUSSION

3.1 Earthwork Volume Data

Based on the results of the analysis of cross-section data in the project design drawings, the total volume of mechanical earthwork was determined to be 1,500,000 m³. This volume includes earth-cutting work in areas with higher elevations and backfilling work in areas with lower elevations. In its implementation, the earthwork is planned by applying the concept of balance between excavation and backfill volumes so that excavated material can be optimally reused for backfilling needs in other areas. This method is applied to reduce the need for soil material from outside the project site while also reducing the cost of earthwork.

The details of the earthwork volume obtained from the calculations can be seen in Table 1 below.

Table 1. Analysis of the Heavy Equipment Used

Job Type	Volume (m^3)	Description
Cut	750.000	Excavated material is used for backfill
Fill	730.000	Using excavated material
Borrow	20.000	Additional red soil backfill
Total Volume	1.500.000	

Check the sufficiency of the backfill material (shrinkage) :

a. Material from Cut:

$$V_{compacted\ cut} = 750.000 \times (1 + 0{,}15)$$
$$= 637.500\ m^3$$

b. Material Borrow:

$$V_{compacted\ borrow} = 20.000 \times (1 + 0{,}15) = 17.000\ m^3$$

c. Total available reserves:

$$637.500 + 17.000 = 654.500\ m^3$$

Compare with the fill requirement:

$$654.500 < 730.000$$

Field correction factor (assumed to be 85%):

$$V_{efektif} = 654.500 \times 0{,}85 = 556.325\ m^3$$

According to Table 1, the total volume of mechanical earthwork is 1,500,000 m³, consisting of 750,000 m³ of excavation (cut), 730,000 m³ of backfill (fill), and 20,000 m³ of borrow material. The excavated material is planned to be reused as fill material to reduce the need for soil from outside the project. However, not all of the excavated soil can be used due to a 15% shrinkage factor resulting from the compaction process. Calculations show an effective volume of excavated soil of 637,500 m³, while the borrow material yields an effective volume of 17,000 m³. Thus, the total material available for fill work is 654,500 m³.

This amount is still less than the required 730,000 m³ of fill material, meaning that the available material is insufficient to meet on-site needs. Additionally, this study applied a site correction factor of 85% to account for actual site conditions, such as material loss and equipment efficiency. After correction, the effective volume of soil that can be utilized is 556,325 m³. These results indicate that site conditions significantly affect the availability of fill material in the execution of mechanical earthwork.

3.2 Application of the Least-Cost Method

The Least Cost Analysis method is used as an approach to determine the most time-efficient construction alternatives while still considering project cost efficiency. This method is applied by analyzing work activities that significantly impact project duration, followed by an evaluation of various potential ways to accelerate the work to identify the most effective combination of time and cost. During the analysis process, each acceleration alternative is compared based on the additional costs incurred relative to the reduction in project duration, thereby identifying the most efficient implementation option.

In this study, the analysis focuses on the combination of excavation equipment (excavators) and transport equipment (dump trucks), as these two types of equipment are the primary factors influencing the productivity of mechanical earthwork. The suitability of the capacity and number of machines is crucial for the smoothness of the excavation and material transport processes on-site. Meanwhile, supporting equipment such as bulldozers and compactors are still used in the execution of the work; however, they are considered to have relatively constant usage conditions across each analysis alternative and are therefore not included as comparison variables in this study.

1. Combination A (5 Excavators + 15 Dump Trucks) – Project Data

Excavator productivity data:

Excavator capacity per unit : 150 m³/hour

Rental rate : Rp. 180,000,000/hour

Working hours : 10 hours/day

Number of units : 5 units

-Total excavator productivity : 150 x 10 x 5

: 7,500 m³/day

Dump truck productivity data:

Capacity : 10 m³/trip

Rental Rate : Rp. 130,000,000/hour

Average frequency: 49 trips/day per unit (from 1,500,000 trips - Original project data)

Number of units : 15 units

Total transport : 10 x 49 x 15

: 7,350 m³/day

Balance results:

Excavator : 7,500 m³/day

Dump Truck : 7,350 m³/day

Project Duration:

Workload : 1.500.000 m³

Duration : $\frac{1.500.000}{7.500}$

: 200 days (6.67 months)/2,000 hours

Operating costs::

Total cost of the excavator : 5x180.000x2000

: Rp. 1.800.000.000

Total cost of a dump truck : 15x130.000x2000

: Rp. 390.000.000

Total cost : Rp. 1.800.000.000 + Rp. 3.900.000.000

: Rp. 5.700.000.000

Conclusion: Option A results in 200 days of progress at a total cost of Rp 5,700,000,000.

2. Combination B (4 Excavators + 12 Dump Trucks)-Least-Cost Calculation

Productivity data:

Excavator capacity per unit : 150 m³/hour

Rental rate : Rp. 180,000,000/hour

Working hours : 10 hours/day

Number of units : 4 units

Total excavator productivity: 150 x 10 x 4

: 6,000 m³/day

Dump truck data:

Capacity: 10 m³/trip

Rental rate : Rp. 130,000,000/hour

Average frequency : 49 trips/day per unit

Number of units : 12 units

Total transport : 10 x 49 x 12

: 5,880 m³/day

Balance results:

Excavator : 6.000 m³/day

Dump Truck : 5.880 m³/day

Project Duration:

Workload : 1.500.000 m³

Duration : $\frac{1.500.000}{6.000}$

: 250 days (8,3 months)/2,500 hours

Operating costs::

Total cost of the excavator : 4x180.000x5000

: Rp. 1.800.000.000

Total cost of a dump truck : 12x130.000x2500

: Rp. 390.000.000

Total cost : Rp. 1.800.000.000 + Rp. 3.900.000.000

: Rp. 5.700.000.000

Conclusion: Option B is not cost-effective, as it has a longer duration (250 days vs. 200 days) but the cost remains the same (Rp. 5.700.000.000)

3. Comparison of Combinations A and B

Table 2. Results of the Least-Cost Interpretation for Combinations A and B

Criteria	Combination A (5exc + 15DT)	Combination B (4exc + 12DT)
Daily productivity	7,500 m³/day	6,000 m³/day
Total duration	200 days (6.67 months)	250 days (8.3 months)
Total cost	Rp. 5.700.000.000	Rp. 5.700.000.000

Based on the results of the analysis of heavy equipment combinations for mechanical earthwork, a comparison was conducted between Combination A and Combination B to determine the most efficient implementation alternative in terms of both time and cost. This analysis focused on the productivity of excavators and dump trucks, as these two types of equipment play a key role in the earthwork process. Combination A utilizes 5 excavators and 15 dump trucks. Each excavator has a production capacity of 150 m³/hour with a daily operating time of 10 hours, resulting in a total excavator productivity of 7,500 m³/day.

Meanwhile, the dump truck's transport capacity is 10 m³ per trip, with an average of 49 trips per day per unit, resulting in a total transport productivity of 7,350 m³ per day. These results indicate that the capacities of the excavators and dump trucks are sufficiently balanced, allowing the work process to proceed more effectively with minimal downtime between machines. With a total project volume of 1,500,000 m³, Combination A was able to complete the work in approximately 200 days, or the equivalent of 6.67 months. In terms of operating costs, the total cost of using excavators and dump trucks amounted to Rp. 5,700,000,000. These results indicate that Combination A has a fairly high level of productivity with a relatively shorter project duration.

Meanwhile, Combination B utilized 4 excavators and 12 dump truck. The reduction in the number of machines has led to a corresponding decline in overall productivity. The productivity of the excavators in this combination is only 6,000 m³/day, while that of the haulers is 5,880 m³/day. This decrease in production capacity has a direct impact on the project timeline, resulting in a longer completion time. Based on the calculations, Combination B takes approximately 250 days, or 8.3 months, to complete the same volume of work. Although fewer pieces of equipment are used, the total operating cost remains at Rp. 5,700,000,000.

This indicates that reducing the number of equipment units does not result in cost savings because the project duration is longer, thereby increasing the equipment's operational time. From the comparison of the two combinations, it can be seen that Combination A is more effective than Combination B. This is evident from the shorter project duration at the same total cost. Furthermore, the balanced productivity between the excavator and the dump truck in Combination A also makes the work process more optimal and reduces the potential for equipment downtime on-site. Therefore, based on the Least Cost Analysis method, Combination A is evaluated as a more efficient implementation alternative for mechanical earthwork in construction projects

4. CONCLUSION

Based on the results of the study, the Least Cost Analysis method can be used as an approach to determine the most efficient combination of heavy equipment for earthwork operations. Of the alternatives analyzed, the combination of 5 excavators and 15 dump trucks yielded the best results, with higher productivity compared to the other alternatives. This combination is capable of completing a work volume of 1,500,000 m³ within 200 days at a total operational cost of Rp5,700,000,000. The research results indicate that the appropriate number and capacity of excavation and transport equipment significantly influence work productivity. An imbalance between these two types of equipment can lead to reduced work efficiency, which in turn extends the project duration. Therefore, the planning of heavy equipment usage must be carried out carefully to ensure that project time and cost targets are optimally achieved. The findings of this study can serve as a basis for contractors and project managers in determining strategies for heavy equipment usage in earthwork projects with similar characteristics. This study still has several limitations, including the use of only two alternative heavy equipment combinations and the failure to consider field factors that can affect productivity, such as weather conditions, operator skills, transportation access, and changes in soil conditions during the execution of the work. Therefore, future research is expected to examine a wider variety of heavy equipment combinations and integrate more comprehensive optimization methods so that the analysis results obtained can more realistically reflect field conditions.

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