Proceedings of the 4th International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/2026.38491

Excavator-Dump Truck Fleet Planning and Performance Assessment in Road Earthwork: A Case Study

Zhaohui Qin

School of International Education, Suzhou University of Science and Technology, Suzhou, China
jinsunghwii@gmail.com

Abstract. From blasting and excavation to material sourcing, backfilling, haulage planning, and equipment allocation, earthwork strongly influences construction efficiency and project costs. Based on typical engineering parameters, this study establishes a representative road earthwork scenario to define a preliminary construction plan and evaluate the feasibility of the proposed excavator-dump truck combination. Specifically, rock excavation, soil excavation, and backfill shortages are quantified in bank cubic meters (BCM). The required additional soil for haulage is determined by balancing the quantities of material between the excavation and fill areas. The two transport routes are evaluated for safety, with the safer REFO route selected for subsequent analysis. Accordingly, truck payload, transport cycle time, and the required number of trips are determined. The results indicate that approximately 8,337.8 BCM of soil must be transported from Point P. With one Caterpillar 385C FS excavator and 15 CAT 725 trucks, the hauling time is about 23.23 h at 75% efficiency. Thus, it can be found that the selection of routes and operational efficiency have a significant impact on the schedule arrangement and construction planning of the earthwork project.

Keywords: earthwork, blasting, dump truck, excavation, construction planning

1. Introduction

Through coordinated excavation, blasting, filling, and material transportation, road earthwork relies on effective planning for proper equipment and resource allocation [1]. Prior studies have largely explored earthwork quantities, equipment configuration, and production rates in relation to equipment capacity and cycle duration [2]. Nevertheless, in practical initial planning, material balance, haul route choice, and excavator-dump truck coordination are often considered separately, making it hard to evaluate the overall feasibility of a construction scheme [3]. Therefore, an integrated assessment method is needed to connect material requirements, transportation conditions, and equipment operation during early-stage planning. Under typical Class-III mountain highway conditions, this paper establishes a representative road earthwork scenario using standard sections and equipment specifications. In this scenario, rock excavation, soil excavation, backfilling, and external borrow transportation are considered, providing a basis for validating the full earthwork planning process from quantity calculation to fleet scheduling. This study assesses the excavator-dump truck fleet through three aspects: soil-fill balance, haul route conditions, and equipment

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.38491

effects on construction time. The analysis quantifies rock and soil volumes, determines the material balance and truck payload, evaluates haul routes and cycle times, and accounts for equipment efficiency. And these results relate material requirements and haul conditions to fleet performance, providing a direct assessment of the proposed earthwork plan.

2. Literature review

In earthwork construction planning, material volume estimation, equipment selection, and excavation-hauling coordination directly affect construction efficiency [2]. Fleet planning focuses on achieving an appropriate match between excavator loading capacity and dump truck hauling capacity under specific project conditions, including excavation characteristics, haul distance, and required production rate. At the planning stage, excavator and dump truck performance is evaluated by capacity, work conditions, and productivity, with manufacturer data used to determine payload, availability, and operating time [4]. Yet, poor fleet matching can cause truck delays, low use, and longer handling times, highlighting the need to assess excavator-dump truck coordination in early earthwork planning [5, 6].

Although fleet matching sets the maximum output, actual equipment output mainly relies on cycle time, as cycle length determines how much material can be moved in a given time. A dump truck cycle consists of loading, loaded travel, unloading, and empty return, and the time required for each stage contributes to the overall production rate. The resulting cycle time is influenced by equipment speed, haul road conditions, bucket capacity, and truck payload [5, 7]. Yet theoretical cycle time calculations usually assume continuous operation under stable conditions, while actual construction involves delays caused by truck queuing, equipment adjustment, traffic interference, and operator-related factors. Thus, efficiency factors adjust theoretical productivity to estimate actual operating time.

However, existing studies often treat material estimation, excavation, haul route selection, and equipment cycle time as separate tasks, although these factors interact in practice. Blasting conditions affect fragmentation and loading operations [8, 9], while haul route conditions influence truck speed, utilization, and operating stability [10]. Thus, route selection based on distance alone may overlook operational risks and equipment delays. Existing research also relies largely on idealized models or large-scale mining data, with limited attention to small- and medium-sized road projects. To address this gap, this study develops a representative road earthwork scenario using typical parameters to assess material balance, haul conditions, and equipment use within one planning process.

3. Methods

3.1. Project conditions and equipment configuration

The project scenario employed in this study is developed based on typical conditions found in Class-III mountain highway earthwork projects, incorporating standard cross-sectional parameters, commonly used equipment models (CAT 725 trucks and Caterpillar 385C FS excavators), and representative haul route characteristics. The project covers rock excavation, soil excavation, backfilling, and material transportation. Existing ground conditions and excavation-fill sections are included in the earthwork quantity calculation. On the engineering plan, the work areas are identified by characteristic points: ABGH represents the rock layer enclosed by A, B, G, and H; BHI denotes the soil excavation area enclosed by B, H, and I; IJC represents the filling area enclosed by

DOI: 10.54254/2755-2721/2026.38491

I, J, and C; and Point P serves as the external borrow source. Material is transported along one of two haul routes, QO or REFO, defined by their terminal and intermediate points. The site conditions, equipment configuration, and operating assumptions for the excavator-dump truck fleet are listed in Table 1.

Table 1. Project conditions, equipment configuration, and operational assumptions

Item	Description
Project type	Road earthwork construction
Road class / section length	Class-III mountain highway (approx. 2.4 km)
Main activities	Rock excavation, soil excavation, backfilling, and material transport
Rock excavation area	ABGH rock layer
Soil excavation / fill area	BHI excavation area and IJC fill area
Borrow point	Point P (external borrow source)
Haul routes	QO (direct) and REFO (via R, E, and F)
Selected route	REFO
Loading equipment	Caterpillar 385C FS excavator
Hauling equipment	CAT 725 dump truck
Fleet size	15 trucks (initial match; not optimized)
Working efficiency	75%

The fleet includes one Caterpillar 385C FS excavator for loading and CAT 725 dump trucks for hauling. Fifteen trucks are assumed to match the excavator's loading capacity; this fleet size is not optimized. The haul routes are compared by travel distance and operating conditions, and the more suitable route is selected for transport analysis. The theoretical operating time is then adjusted using a 75% working efficiency factor to estimate the expected working duration.

3.2. Earthwork quantity estimation and material balance analysis

The earthwork quantities are calculated from the assumed road cross-sections and elevation data of the developed scenario, taking into account the elevation differences between the existing ground surface and the designed road profile, as well as the corresponding cross-sectional dimensions. These volumes are then compared with the fill demand to determine the available excavation material balance.

For the volume calculation, three material volume states are used. Bank cubic meter (BCM) means the in-situ volume before excavation, loose cubic meter (LCM) the expanded volume after blasting or excavation, and compacted cubic meter (CCM) the final volume after filling and compaction. These states are related by two conversion factors: the loosening factor (LCM/BCM) accounts for volume expansion, while the compaction factor (BCM/CCM) converts compacted fill volume to its equivalent in-situ volume. All material quantities are therefore expressed in BCM for the balance calculation. The fill requirement is obtained in CCM from the designed embankment dimensions and converted to BCM using the assumed compaction factor, whereas the available excavation material is measured in BCM. When the available excavation volume falls short of the

DOI: 10.54254/2755-2721/2026.38491

fill requirement, the difference gives the additional material required. This balance is expressed as follows:

$$V_{shortage}=V_{fill}-V_{excavation} \tag{1}$$

where $V_{shortage}$ is the additional material requirement (BCM), V_{fill} represents the required filling volume (BCM), and $V_{excavation}$ denotes the available excavation volume (BCM).

3.3. Excavator-dump truck fleet performance evaluation

Using manufacturer data and standard civil engineering practice, equipment parameters such as truck payload, soil density, bucket capacity, and travel speed are determined. These parameters, together with the truck cycle and hauling capacity, are used to assess the excavator-dump truck fleet. The assessment covers payload, soil density, bucket capacity, loading time, dumping time, loaded travel time, and empty return time; these values determine the truck cycle time, required trips, and hauling duration at the assumed efficiency. For the fleet assessment, 15 trucks are assumed to match the excavator's loading capacity, without fleet-size optimization.

The truck loading volume is calculated from the rated payload and soil density:

$$Q_t=\frac{M_t}{\rho} \tag{2}$$

where Q_t is the truck loading volume (m^3), M_t represents the rated truck payload (*t*), and ρ refers to the soil density (t/ m^3).

The truck cycle time is determined by the sum of loading, travelling, dumping, and returning time:

$$T_c=T_l+T_h+T_d+T_r \tag{3}$$

where T_c refers to the total truck cycle time (min), T_l indicates loading time (min), T_h represents loaded travel time (min), T_d is dumping time (min), and T_r represents empty return travel time (min).

The required number of truck trips is calculated according to the transportation volume and truck loading capacity:

$$N=\frac{V}{Q_t} \tag{4}$$

where N is the required number of truck trips, and *V* represents the total transportation volume (m^3).

The theoretical transportation time is calculated based on fleet productivity and adjusted using the working efficiency factor:

$$T_a=\frac{T_t}{\eta} \tag{5}$$

where T_a is the estimated actual transportation time, T_t refers to the theoretical transportation time, and η represents the working efficiency factor.

DOI: 10.54254/2755-2721/2026.38491

4. Results

4.1. Earthwork quantity and material balance results

The earthwork quantities are calculated from the assumed cross-sections and elevation data of the developed scenario to determine the material balance between excavation and filling requirements. As illustrated in Table 2, the results include the original rock volume, loose rock volume after blasting, available soil excavation volume, required filling volume, and additional borrow soil requirement.

Table 2. Earthwork quantity and material balance results

Material or work	Calculation result
Rock original volume	240000 BCM
Loose rock volume	268800 LCM
BHI soil excavation volume	43040 BCM
IJC filling requirement	46240 CCM
Required soil before compaction	51377.8 BCM
Additional borrow soil requirement	8337.8 BCM

Note: The IJC filling requirement of 46240 CCM is converted to 51377.8 BCM using an assumed compaction factor of approximately 1.11, representing the equivalent in-situ volume required before compaction.

The excavation-fill balance shows that the available BHI soil volume (43,040 BCM) is lower than the IJC fill requirement (51,377.8 BCM). And the resulting shortfall is 8,337.8 BCM, which must be supplied from Point P. This volume defines the hauling quantity for the fleet.

4.2. Transportation route and fleet performance results

Two haul routes, QO and REFO, are considered for material transport under the terrain conditions of the project. QO is shorter, at approximately 4,700 m, but includes steeper gradients of up to 8% and unpaved sections, which may increase truck slipping and tire wear. By contrast, REFO is longer, at approximately 5,800 m, but has gentler gradients (≤5%) and more stable gravel surfaces, resulting in lower operating risk under wet conditions. Thus, REFO is selected for the fleet performance calculation.

Based on the selected route and equipment parameters, the cycle time and transportation capacity of the CAT 725 dump truck fleet are calculated. The truck loading volume is determined from the rated payload (25 t) and assumed soil density (1.84 t/ m^3), yielding around 13.58 m^3 per load; the loading time of 1.2 min corresponds to roughly six excavator bucket cycles (bucket capacity approximately 2.3 m^3). The cycle time components are summarized in Table 3.

Table 3. Truck cycle time calculation results

Time Item	Calculation	Result
Empty return time	5,800 m ÷ (35 km/h × 1000/60)	9.94 min

DOI: 10.54254/2755-2721/2026.38491

Table 3. (continued)

Loaded travel time	5,800 m ÷ (25 km/h × 1000/60)	13.92 min
Total travel time	9.94 + 13.92	23.86 min
Loading and dumping time	1.2 + 0.5	1.70 min
Theoretical cycle time	23.86 + 1.70	25.56 min/truck

Note: Empty and loaded travel speeds are converted to meters per minute (583.33 m/min and 416.67 m/min, respectively) for consistency with the distance unit.

Using the calculated cycle time of 25.56 min, one truck can complete approximately 2.35 cycles per hour (60÷25.56). With 15 trucks operating at the same time, the fleet productivity reaches about 35.25 cycles per hour. For the required transportation volume of 8,337.8 BCM and a truck loading capacity of 13.58 m^3 per trip, 614 truck trips are required (8,337.8÷13.58). The theoretical hauling time is 17.42 h (614÷35.25) and rises to 23.23 h after applying the 75% working-efficiency factor. The adjusted time represents the expected hauling duration under the assumed operating conditions.

5. Discussion

The results indicate that earthwork planning depends on the interaction between material supply and transport conditions. The material balance identifies a soil deficit that requires external borrowing, showing that accurate volume conversion and material balance directly affect the transport demand. The route comparison also indicates that a longer haul route can be preferable when its gradient and surface conditions provide safer truck operation. Thus, route selection should consider both distance and operating conditions rather than distance alone.

Fleet performance is closely related to the match between loading capacity, truck cycle time, and transport demand. The assumed fleet provides sufficient hauling capacity for the identified material demand, but the 15-truck configuration is an initial match rather than an optimized solution. Changes in fleet size, cycle time, or working efficiency would affect hauling output and project duration. This highlights the need to consider equipment coordination when planning earthwork operations.

The assessment is limited by the use of assumed engineering parameters rather than field data. In addition, the loading model also assumes fixed bucket counts and uniform material density, while actual performance may vary with material condition, operator skill, and truck positioning. Cost factors such as fuel, maintenance, and equipment rental are not included. Future studies could use field data and cost analysis together with fleet optimization to develop more practical equipment plans.

6. Conclusion

This study develops a representative road earthwork scenario and assesses excavator-dump truck fleet performance via material balance, haul route selection, and cycle time analysis. Within the assumed scenario, the available BHI excavation soil is insufficient to satisfy the IJC filling requirement, thus resulting in an additional soil transportation demand of 8337.8 BCM from Point P. Based on the selected REFO route and the CAT 725 dump truck-Caterpillar 385C FS excavator combination, the required hauling arrangement is estimated through truck capacity and cycle time

DOI: 10.54254/2755-2721/2026.38491

analysis. The 75% efficiency factor increases hauling time from 17.42 to 23.23 h, thus highlighting the role of operational efficiency in scheduling. Route selection should also account for surface conditions, gradients, and equipment reliability, rather than distance alone. Overall, the proposed calculation approach provides a practical method for preliminary earthwork planning by connecting material requirements with fleet operation performance. Further improvement can be achieved by incorporating detailed cost analysis, formal fleet optimization, and field measurements of loading and transportation operations.

References

[1] Choi, G., & Han, S. (2023). Reinforcement learning-based dynamic planning of cut and fill operations for earthwork optimization. *Automation in Construction, 156*, 105111.
[2] Fernandes, P. G., Júnior, E. F. N., & Prata, B. D. A. (2022). Optimization of earthworks planning: A systematic mapping study. *Canadian Journal of Civil Engineering, 49*(12), 1781-1795.
[3] Park, S., Kim, J., Cho, K., & Seo, J. (2024). Integrating task component design in excavator-truck operation planning: Enhancing automation systems through a web-based system. *Applied Sciences, 14*(14), 6052.
[4] Šopić, M., Vukomanović, M., & Car-Pušić, D. (2024). Machine cost-effectiveness in earthworks: Early warning system and status of the previous work period. *Sustainability, 16*(17), 7294.
[5] Prasetyo, Y. T., Paradise, M., & Mukarrom, F. (2024). Productivity assessment of digging and loading equipment (Cat 330D2L) and hauling equipment (Fuso 220PS) in coal mining at PT. Bhumi Sriwijaya Perdana Coal, Musi Banyuasin Regency, South Sumatra. *Indonesian Journal of Earth Sciences, 4*(2).
[6] Taufiq, M. R., Putri, F. A. R., & Fanani, Y. (2024). Productivity analysis of digging, loading, and hauling equipment in overburden removal activities at PT. Anugrah Borneo Sinergy in Keramat Mina field, South Kalimantan, Indonesia. *Journal of Earth and Marine Technology (JEMT), 5*(1), 66-79.
[7] Mnzool, M., Almujibah, H., Bakri, M., Gaafar, A., Elhassan, A. A., & Gomaa, E. (2024). Optimization of cycle time for loading and hauling trucks in open-pit mining. *Mining of Mineral Deposits, 18*(1), 18-26.
[8] Liao, Z., Ding, X., Liang, M., et al. (2025). Research on the optimization of optimal blasting parameters and fragmentation control based on coal seam geological conditions. *Scientific Reports, 15*(1), 12238.
[9] Saadoun, A., Fredj, M., Boukarm, R., & Menacer, K. (2025). Effect of blasting parameters on rock size induced by fragmentation in quarries: A case study. *ARPHA Proceedings, 9*, 170-179.
[10] Lotsu, J. S., Frimpong, S., & Raza, M. A. (2026). Geometric and operational design principles for autonomous haulage systems in open-pit mining: A systematic review. *Mining, 6*(3), 45.