ANALYSIS OF THE PRODUCTIVITY OF SHOVEL AND HAUL TRUCK IN OVERBURDEN STRIPPING OPERATIONS AT PIT 3 BANKO, PT BUKIT ASAM, TANJUNG ENIM, SOUTH SUMATERA

FINAL THESIS

Submitted to the International Undergraduate Program in Industrial Engineering in Partial Fulfillment of the Requirement for the Degree of Sarjana Teknik at the Faculty of Industrial Engineering
Universitas Islam Indonesia

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2026

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Yogyakarta, March 13th, 2026

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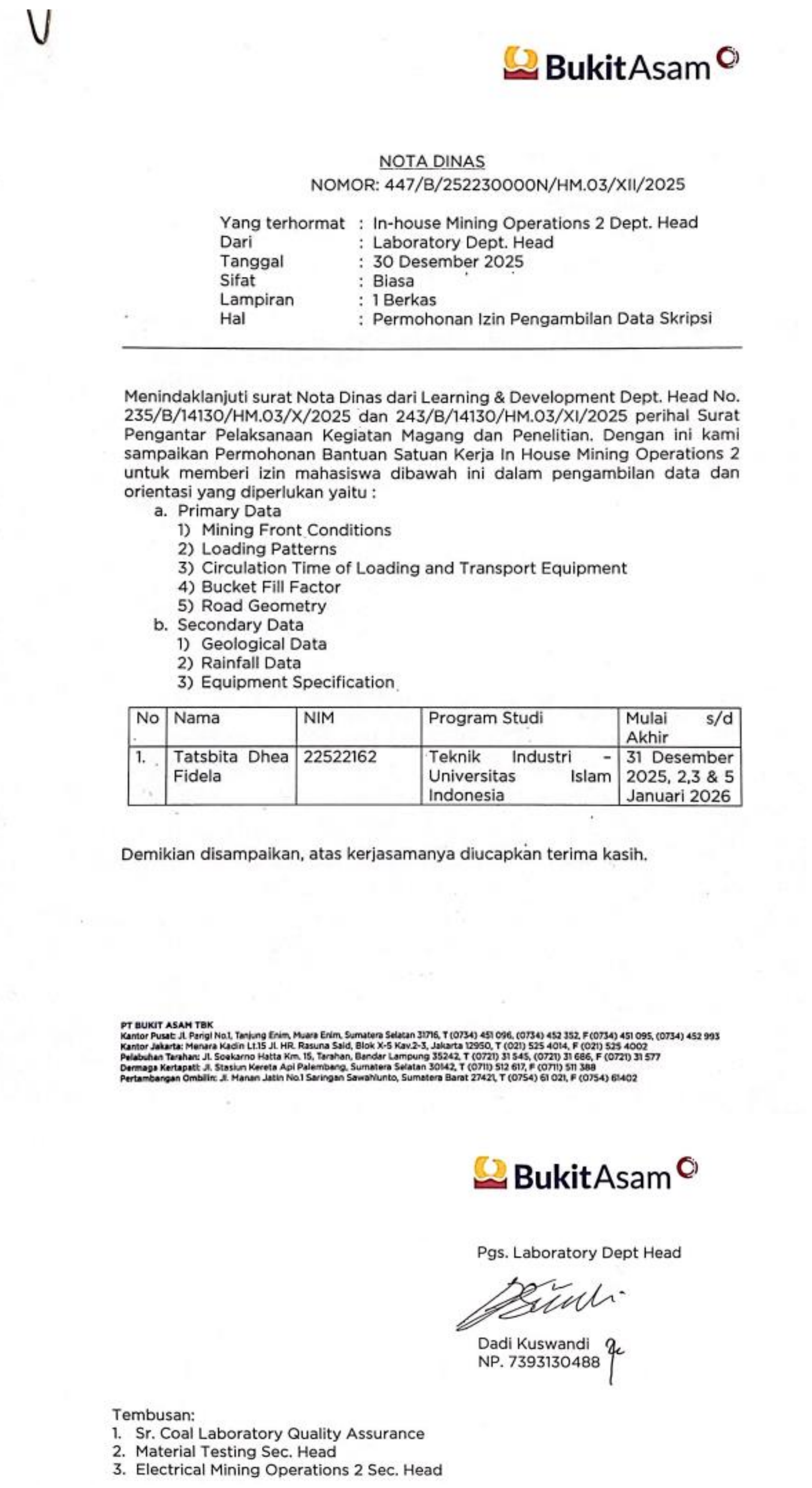
RESEARCH COMPLETION LETTER



BukitAsam

NOTA DINAS

NOMOR: 447/B/252230000N/HM.03/XII/2025

Yang terhormat : In-house Mining Operations 2 Dept. Head
Dari : Laboratory Dept. Head
Tanggal : 30 Desember 2025
Sifat : Biasa
Lampiran : 1 Berkas
Hal : Permohonan Izin Pengambilan Data Skripsi

Menindaklanjuti surat Nota Dinas dari Learning & Development Dept. Head No. 235/B/14130/HM.03/X/2025 dan 243/B/14130/HM.03/XI/2025 perihal Surat Pengantar Pelaksanaan Kegiatan Magang dan Penelitian. Dengan ini kami sampaikan Permohonan Bantuan Satuan Kerja In House Mining Operations 2 untuk memberi izin mahasiswa dibawah ini dalam pengambilan data dan orientasi yang diperlukan yaitu :

a. Primary Data
    1) Mining Front Conditions
    2) Loading Patterns
    3) Circulation Time of Loading and Transport Equipment
    4) Bucket Fill Factor
    5) Road Geometry
b. Secondary Data
    1) Geological Data
    2) Rainfall Data
    3) Equipment Specification

No	Nama	NIM	Program Studi	Mulai s/d Akhir
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Demikian disampaikan, atas kerjasamanya diucapkan terima kasih.

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EXAMINERS APPROVAL PAGE

ANALYSIS OF THE PRODUCTIVITY OF SHOVEL AND HAUL TRUCK IN OVERBURDEN STRIPPING OPERATIONS AT PIT 3 BANKO, PT BUKIT ASAM, TANJUNG ENIM, SOUTH SUMATERA

FINAL THESIS

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DEDICATION PAGES

Alhamdulillahirabbil'alamin.
All praise and gratitude be to Allah SWT, the Most Gracious and the Most Merciful. By His mercy, guidance, and blessings, I was able to complete this undergraduate thesis entitled: "Analysis of the Productivity of Shovel and Haul Truck in Overburden Stripping at PIT 3 Banko, PT Bukit Asam, Tanjung Enim, South Sumatra."

I dedicate this work to my beloved parents, whose endless love, sacrifices, and prayers have always been my greatest source of strength. Every step I take today is built upon the patience and belief you have placed in me. As the first child, I learned that responsibility often comes early and carries a little more weight. There were moments of doubt and pressure, but those very responsibilities became the reason I kept moving forward, striving to become someone who can carry the hopes of the family with strength and gratitude.
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To my friends and colleagues, thank you for the support, memories, and shared journey that made these years meaningful. Lastly, thank you to myself for not giving up. For continuing to move forward through uncertainty, exhaustion, and doubt. This work stands as a quiet proof that perseverance, patience, and faith can bring a journey to its finish.
Alhamdulillah, we made it.
May this thesis bring benefit to those who read it and become a source of continuous goodness *(amal jariyah)* in the future.

MOTTO

“They planned, but Allah also planned. And Allah is the best of planners”
(QS Al-Anfal: 30)

“Bagaimana mungkin aku menyerah pada hidup, jika untuk melihatku bernapas saja Bunda pernah mempertaruhkan nyawanya dan Ayah rela mengorbankan keringatnya, jadi tidak mungkin aku tidak ada artinya”

- Tatsbita Dhea

“One day you’re going to look back on all the progress you’ve made and be so glad that you didn’t give up”

PREFACE

Bismillahirrahmanirrahim
All praise is due to Allah SWT for His mercy and blessings, which have enabled the completion of this Final Project. Peace and blessings be upon Prophet Muhammad SAW.

This Final Thesis is submitted as a partial fulfillment of the requirements for the bachelor's degree in industrial engineering, Faculty of Industrial Technology, Universitas Islam Indonesia, entitled "Analysis of the Productivity of Shovel and Haul Truck in Overburden Stripping Operations at Pit 3 Banko, PT Bukit Asam, Tanjung Enim, South Sumatra." The author hopes that this research will contribute to academic development and provide valuable insights on this occasion, the author would like to express his gratitude to all those who have helped in the preparation of this Final Thesis:

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The author acknowledges the limitations of this thesis and welcomes constructive feedback. It is hoped that this research will benefit future scholars and contribute meaningfully to the advancement of distribution optimization strategies.

Yogyakarta, February 28th, 2026

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ABSTRACT

Productivity of mechanical equipment is a critical factor in overburden stripping operations because it directly affects coal exposure and production continuity. At Pit 3 Banko, PT Bukit Asam Tbk, overburden removal is performed using one Komatsu PC3000 shovel and three Belaz 75135 haul trucks. Operational observations indicate that production performance has not reached optimal levels, suggesting an imbalance within the shovel-haul truck system. This research evaluates equipment productivity using cycle time analysis, work efficiency calculation, match factor assessment, and Discrete-Event Simulation (DES) with FlexSim. Field observations show an average shovel cycle time of 3.44 minutes and haul truck cycle time of 20.9 minutes. Work efficiency is 51.39% for the shovel and 47.92% for haul trucks, reflecting considerable non-productive time. The existing configuration produces a match factor of 0.49 (49.4%), indicating significant shovel idle time due to insufficient truck availability. Simulation results reveal that increasing the fleet to six haul trucks improves the match factor to 0.987 (98.7%), creating a near-balanced system and minimizing idle time. Adding seven trucks results in overcapacity (MF = 1.15) and truck queuing. Therefore, six haul trucks represent the optimal configuration under current operating conditions. The integration of analytical and simulation approaches provides a realistic basis for improving overburden stripping productivity without additional major equipment investment.

Keywords: Overburden Stripping, Shovel and Haul Truck System, Productivity Analysis, Match Factor, Discrete Event Simulation, Mining Operations Efficiency.

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CHAPTER I
INTRODUCTION

1.1 Background

Coal remains one of the primary energy sources in Indonesia and plays a strategic role in supporting national electricity generation, industrial activities, and export revenue. Indonesia is consistently ranked among the world's largest coal producers and exporters, supplying both domestic power plants and international markets. According to data from the Ministry of Energy and Mineral Resources (ESDM), national coal production reached approximately 565 million tons in 2020, increased to 614 million tons in 2021, and further rose to 687 million tons in 2022. In 2023, production significantly increased to about 775 million tons, and in 2024, it reached approximately 836 million tons, exceeding the government's annual production target. For 2025, the approved production target under the RKAB scheme is approximately 735 million tons, and based on semester I realization and national projections, total production is expected to remain above 700 million tons by the end of the year.

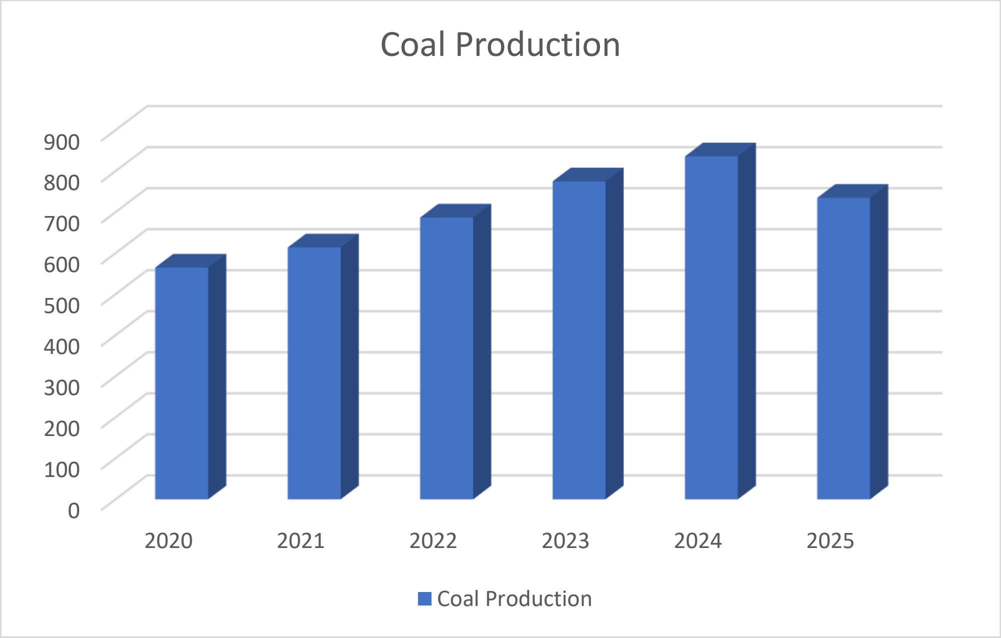


Figure 1.1 Coal Production Chart

The increasing production trend indicates that maintaining operational stability at the mine level is essential to achieving national targets. In open-pit coal mining, production activities follow an integrated and sequential process. The mining cycle generally begins with land clearing and topsoil removal, followed by overburden stripping to expose the coal seam according to the mine plan. Once the coal seam is exposed, coal-getting activities are conducted, followed by loading and hauling to stockpile areas. The coal is then transported through train loading station (TLS) facilities or other transportation systems to port terminals before final distribution to domestic power plants and export markets. Because each stage is interconnected, disruptions at upstream activities, particularly overburden removal, may directly affect coal exposure and overall production continuity. Among these stages, overburden stripping plays a fundamental role in determining whether coal seams can be accessed on schedule. If overburden removal does not run efficiently, coal exposure will be delayed, and downstream production targets may be affected (Indonesianto, 1968). Therefore, the productivity of loading and hauling equipment used in overburden operations becomes a critical factor in maintaining operational balance.

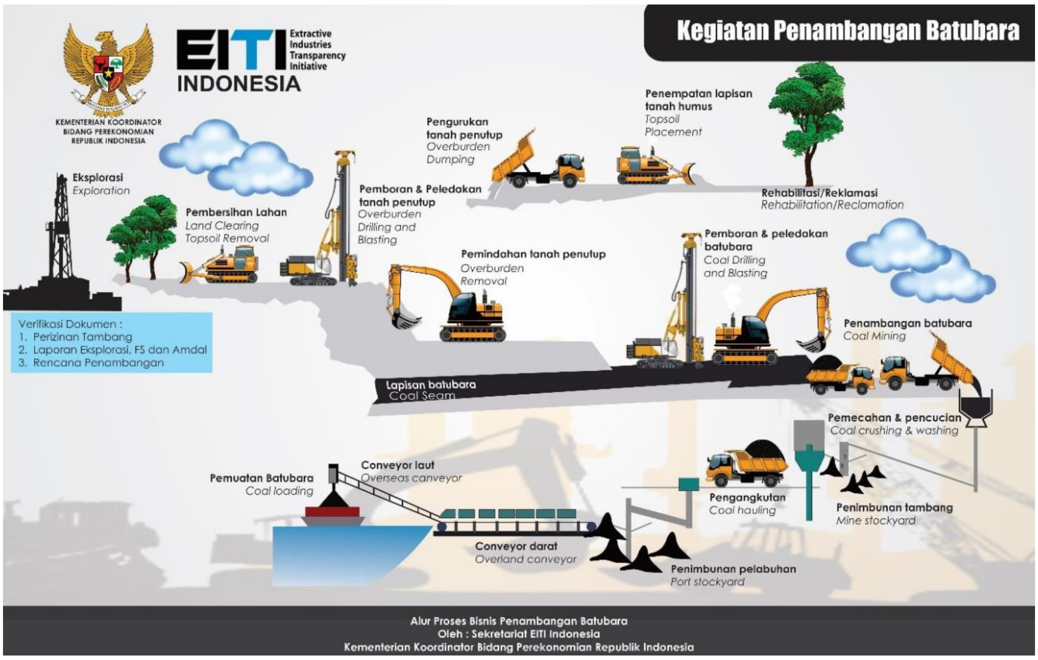


Figure 1.2 Mining Process

In open-pit coal mining, the material that covers the coal seam is called overburden. Overburden consists of soil and rock layers located above the coal deposit and generally has no economic value. This material must be removed before coal extraction can begin, and the process is known as overburden stripping. Because coal cannot be mined without first removing this layer, overburden stripping becomes a critical stage in surface mining operations (Hartman, 1987).

Figure 1.3 Open Pit

At the operational level, overburden stripping activities at Pit 3 Banko, PT Bukit Asam Tbk, are carried out using a shovel–haul truck system. In this system, the shovel excavates and loads overburden material into haul trucks. The haul trucks transport the material to the disposal area and return to the loading point, forming a continuous production cycle. The efficiency of this cycle directly influences the total material moved within a given time. The shovel and haul trucks operate in an interdependent manner. The overall efficiency of the system depends heavily on how well the loading capacity of the shovel matches the hauling capacity of the truck fleet. When the number of trucks is not sufficient to keep up with the shovel's loading rate, the shovel will frequently sit idle waiting for the next available truck. This mismatch reduces equipment utilization and directly affects how much overburden can be removed in a single shift. Similar conditions have been observed in many open-pit mining operations where inefficient truck allocation can lead to increased truck queues and shovel idle time, ultimately reducing overall fleet productivity (Pathan et al., 2025).

This interaction can be analyzed using the match factor; in this approach, haul trucks are considered as entities entering a service system, while the shovel acts as the service facility. The balance between truck arrival rate and shovel service rate determines whether the system runs efficiently or experiences idle time and congestion. Since variables such as cycle time and delay time fluctuate under actual field conditions, the system exhibits stochastic behavior. Research on surface mining operations shows that variability in truck cycle time and equipment interaction can significantly influence queue formation and production efficiency, making queue-based system analysis important for evaluating shovel–truck performance (Setiawan et al., 2025).

Operational observations during the study period indicate that overburden stripping activities had not fully achieved the planned production target. This condition suggests that the shovel-haul truck system may not yet be operating optimally under real working conditions. Therefore, a more comprehensive analytical approach is required to evaluate system performance.

The shovel haul truck system is interpreted as a queueing system and analyzed using discrete-event simulation in FlexSim based on actual field data, including cycle time, working hours, delay time, and equipment interaction characteristics. The model is validated using operational data and then used to evaluate alternative operational scenarios. This approach is expected to provide a more realistic assessment of shovel-haul truck productivity in overburden stripping activities at Pit 3 Banko.

The research gap in this research arises from the continued use of conventional calculation methods that rely on average values, such as match factor and cycle time, which are inherently static. Although these methods are commonly applied to evaluate productivity at Pit 3 Banko, they do not fully capture the actual operational conditions in the field.

In practice, shovel–haul truck operations are influenced by various dynamic factors, including fluctuating truck queues, variations in cycle time, and unexpected operational delays. These conditions indicate that the system operates under uncertainty and variability. However, average-based calculation methods assume stable and consistent variables, which often results in discrepancies between calculated productivity and actual production performance.

To overcome this limitation, this research applies a Discrete-Event Simulation approach using FlexSim software. This method enables the shovel-haul truck system to be modeled more realistically by incorporating queuing behavior, time variability, and operational disturbances based on actual field data (Banks et al., 2014). Simulation-based approaches have been widely applied in recent mining studies because they allow production systems to be evaluated under stochastic conditions and provide better support for optimizing fleet size and equipment allocation compared with deterministic methods (Huayanca et al., 2023).

1.2 Research Problem Formulation

Based on the background described previously, the research problems in this study are formulated as follows:

1. How can the shovel and haul truck system at Pit 3 Banko be analyzed using discrete-event simulation to propose the optimal operational configuration under current conditions?
2. How can a discrete-event simulation based on a queueing system approach be applied to improve the performance of the shovel haul truck system and optimize overburden stripping productivity at Pit 3 Banko?

1.3 Research Objectives

The objectives of this research are:

1. To analyze the shovel and haul truck system at Pit 3 Banko using discrete-event simulation and to propose the optimal operational configuration under current operating conditions.
2. To develop and validate a discrete-event simulation model based on a queueing system approach to represent the actual shovel-haul truck interaction. And to evaluate alternative operational scenarios using the validated simulation model and determine the most effective strategy to improve overburden stripping productivity.

1.4 Research Benefits

The following are the benefits expected from this study for several related parties:

1.4.1 Benefit for Students

1. To apply the knowledge acquired during undergraduate studies in the Industrial Engineering Study Program to real conditions in the industrial field, particularly in the analysis of equipment productivity.
2. To enhance the researcher's understanding and practical experience in analyzing the productivity of shovels and haul trucks in overburden stripping operations based on actual field conditions.

1.4.2 Benefit for the University

1. To serve as an additional academic reference, particularly in the field of Industrial Engineering related to productivity analysis and work system evaluation in the mining industry.
2. To contribute to the development of scientific studies that can be utilized by students or future researchers with similar research topics.
3. To strengthen cooperation and academic collaboration between the university and industry partners.

1.4.3 Benefit for PT Bukit Asam (PTBA) Tbk

1. To provide an overview of the productivity conditions of shovel and haul truck operations in overburden stripping activities at Pit 3 Banko based on actual field conditions.
2. To serve as consideration material in evaluating the performance of the loading and hauling equipment work system.
3. To provide recommendations that may be used as a basis for improving the productivity of overburden stripping operations.

1.5 Research Limitations

The following are the limitations of this field work, namely as follows:

1. This study focuses only on the analysis of shovel and haul truck productivity in overburden stripping operations.
2. The research is conducted in the Pit 3 Banko mining area operated by PT Bukit Asam Tbk, located in Tanjung Enim, South Sumatra.
3. This study excludes discussion on cost, financial, or economic aspects, technical design analysis of mining equipment or haul roads.
4. The productivity analysis is based on actual field operational data, including cycle time, effective working time, hauling distance, and haul road conditions.
5. The data used in this study are limited to observations during the research period and do not represent long-term operational performance.

1.6 Systematic Research

This research is organized into six chapters, with the structure and content described as follows:

CHAPTER I INTRODUCTION

This chapter explains the research background, highlighting the importance of overburden stripping productivity in open-pit mining operations and the performance gap observed at Pit 3 Banko. It also includes the formulation of research problems, research objectives, research benefits, research limitations, and the structure of the research. This chapter serves as the foundation that defines the direction and scope of the study.

CHAPTER II LITERATURE REVIEW

This chapter discusses the theoretical foundations that support the research, including concepts of overburden stripping, shovel and haul truck operations, equipment productivity, cycle time analysis, match factor, and discrete-event simulation. The theories presented in this chapter provide the analytical basis for evaluating the actual operational performance and for developing the simulation model used in this study.

CHAPTER III RESEARCH METHODOLOGY

It describes the research approach, research location and time, types and sources of data, data collection techniques, and research variables. This chapter also outlines the procedures used to analyze cycle time, calculate equipment productivity, evaluate match factor, and develop the discrete-event simulation model using FlexSim. In addition, it explains the model verification and validation process to ensure that the simulation represents actual field conditions.

CHAPTER IV DATA PROCESSING AND RESEARCH RESULTS

This chapter describes the operational data collected from Pit 3 Banko and the results of the analysis, including cycle time calculation, effective working time determination, productivity analysis, and match factor evaluation. It also presents the development of the simulation model, validation results, and the outcomes of alternative operational scenarios tested through simulation.

CHAPTER V DISCUSSION

The results obtained from both analytical calculations and simulation are interpreted and evaluated in relation to the research objectives. This chapter discusses system performance, operational inefficiencies, and potential improvements based on the tested scenarios. The discussion connects field conditions with theoretical concepts to provide a comprehensive evaluation of the shovel–haul truck system.

CHAPTER VI CONCLUSION

This chapter summarizes the main findings of the research and answers the research problems formulated in Chapter I. It also provides practical recommendations to improve the productivity and efficiency of shovel and haul truck operations in overburden stripping activities at Pit 3 Banko, as well as suggestions for future research.

CHAPTER II
LITERATURE REVIEW

2.1 Literature Review

Previous studies related to shovel and haul truck productivity in overburden stripping operations have been conducted using various analytical approaches. These studies provide important references for understanding operational factors affecting equipment performance in open-pit mining.

Enkhchuluun et al. (2023) conducted a comprehensive cycle time analysis of haul truck operations in an open-pit coal mine by decomposing the haulage cycle into detailed segments, including loading, loaded travel, dumping, and empty return. The study demonstrated that variations in haul road geometry and operating conditions significantly influenced total cycle time and, consequently, truck productivity. The findings confirmed that cycle time is a reliable indicator for evaluating haul truck performance under actual field conditions and can be used to identify operational bottlenecks in overburden transportation systems.

Manyele (2017) investigated excavator performance in open-pit mining by focusing on loading cycle time as a key productivity parameter. Using a large dataset of dispatch records, the study revealed that excavator productivity is strongly affected by loading delays, equipment positioning, and the compatibility between shovel and haul truck capacities. The results highlighted that even minor increases in loading cycle time can lead to substantial reductions in overall material movement rates, emphasizing the importance of efficient shovel-truck interaction in overburden stripping operations.

Nguyen et al. (2019) analyzed shovel-truck productivity in several open-pit mines by calculating actual production rates and comparing them with theoretical capacities. The study applied match factor analysis to evaluate whether the number of haul trucks assigned to a shovel was optimal. The results showed that improper equipment matching led to excessive truck queuing or shovel idle time, both of which reduced system productivity. This study reinforced the necessity of balancing loading and hauling capacities to achieve efficient overburden removal.

Mnzool et al. (2024) focused on optimizing cycle time in loading and hauling operations through operational adjustments and system-level analysis. Their study demonstrated that improvements in haul road design, reduction of waiting time at loading and dumping points, and optimization of shovel-truck ratios could significantly increase overall productivity. The findings support the use of cycle time analysis as a practical tool for identifying inefficiencies and evaluating improvement scenarios in open-pit mining operations.

Manyele (2017) also examined waste-rock transportation performance by analyzing detailed cycle time components for haul truck operations. The study identified non-productive time, particularly waiting and queuing delays, as the primary contributors to reduced hauling efficiency. The results indicated that minimizing these delays through better operational control and scheduling could substantially improve haul truck productivity in overburden stripping activities.

Several studies have incorporated simulation approaches to evaluate shovel and haul truck systems. A simulation-based study on open-pit mine loading and haulage systems demonstrated that shovel utilization, truck waiting time, and fleet size configuration significantly influence production performance. By simulating different operational scenarios, the study showed that productivity could be improved without additional equipment investment by optimizing operational parameters and dispatch sequences.

Shi Meng et al. (2024) developed an open-source simulation environment to analyze haul truck dispatching strategies in open-pit mining. Although the study focused primarily on dispatching logic, it provided valuable insights into how cycle time variability affects haul truck productivity. The research confirmed that realistic cycle time modeling is essential for accurately representing shovel-truck interactions and evaluating operational performance.

Banerjee et al. (2025) introduced a reinforcement learning-based framework for haul truck dispatch scheduling in open-pit mines. The study demonstrated that adaptive dispatch strategies could reduce waiting time and improve truck utilization under variable operating conditions. While the approach is computational in nature, its findings highlight the importance of understanding cycle time behavior and system dynamics when evaluating productivity in shovel-haul truck operations.

Daduna et al. (2016) approached shovel-truck systems from a theoretical perspective by modeling open-pit mining operations as closed queuing networks. The study provided analytical methods to estimate shovel idle probability and system throughput based on cycle time distributions. The results offer a theoretical foundation for understanding productivity limitations in shovel-haul truck systems and support the empirical findings reported in field-based studies.

Zhang et al. (2022) investigated the optimal configuration of shovel and haul truck fleets using simulation modeling. The study showed that selecting appropriate fleet combinations based on production targets and operating conditions could significantly enhance daily output. The findings emphasize that productivity is not solely dependent on equipment capacity but also on how the equipment is configured and operated within the mining system.

In addition to international research, several national studies published in Indonesian journals have examined shovel and haul truck productivity in overburden stripping operations under local mining conditions.

Tarigan (2025) analyzed the productivity of loading and hauling equipment in overburden stripping activities by comparing actual production rates with planned targets. The study identified effective working time and operational delays as the main factors affecting productivity. The results indicated that improving time management and reducing avoidable delays could significantly increase production performance without major equipment changes.

Taufiq et al. (2024) conducted a productivity analysis of digging, loading, and hauling equipment in overburden removal operations at a coal mining site in Indonesia. The study applied cycle time calculations and match factor analysis to evaluate equipment performance. The findings showed that suboptimal equipment matching and long hauling distances were the primary causes of reduced productivity, reinforcing the importance of integrated system analysis.

Kresno et al. (2022) performed a technical study on shovel and haul truck productivity in overburden stripping operations at a large coal mine. The research demonstrated that actual production was lower than theoretical capacity due to long cycle times and unfavorable haul road conditions. After proposing operational improvements, the study reported a significant increase in monthly production, highlighting the effectiveness of cycle time-based productivity evaluation.

Winarno et al. (2025) examined factors inhibiting the productivity of mechanical equipment in overburden stripping activities. The study emphasized the role of haul road geometry, equipment availability, and operator performance in determining production outcomes. The results suggested that systematic evaluation of these factors is necessary to achieve sustainable productivity improvements.

Hidayat (2019) analyzed the efficiency and productivity of mechanical equipment used in overburden removal. The study concluded that productivity losses were mainly caused by ineffective working time and poor coordination between loading and hauling units. The findings support the application of cycle time analysis as a practical method for identifying inefficiencies in overburden stripping operations.

Table 2.1 The comparison highlights differences

Author	**Year**	**Shovel and Haul Truck**	**Cycle Time Analysis**	**Match Factor**	**Field Data**	**Productivity Analysis**
Enkhchuluun et al.	2023	✓	✓	-	✓	✓
Manyele	2017	✓	✓	-	✓	✓
Nguyen et al.	2019	✓	-	✓	✓	✓
Mnzool et al.	2024	✓	✓	✓	✓	✓
Manyele	2017	✓	✓	✓	✓	✓
Shi Meng et al.	2024	✓	✓	-	-	✓
Banerjee et al.	2025	✓	-	-	-	✓
Daduna et al.	2016	✓	✓	-	-	✓
Zhang et al.	2022	✓	-	-	-	✓
Tarigan	2025	✓	✓	-	✓	✓
Taufiq et al.	2024	✓	✓	✓	✓	✓
Kresno et al.	2022	✓	✓	-	✓	✓
Winarno et al.	2025	✓	-	-	✓	✓
Hidayat. et al	2019	✓	✓	-	✓	✓
Present Study	2026	✓	✓	✓	✓	✓

Based on the comparison presented in Table 2.1, previous studies generally focused on evaluating shovel and haul truck productivity using cycle time analysis, simulation models, or theoretical approaches. Several studies emphasized equipment matching, haul road conditions, and dispatching strategies as key factors influencing productivity.

The present study differs from previous research by concentrating on detailed cycle time analysis based entirely on actual field observations at Pit 3 Banko, PT Bukit Asam Tbk. Unlike simulation-based studies, this research reflects real operating conditions without incorporating cost or financial analysis. Therefore, the present study provides a site-specific evaluation of shovel and haul truck productivity and offers practical insights for improving overburden stripping operations under existing field conditions.

2.2 Theoretical Basis

2.2.1 Coal Mining

Coal mining is the activity of extracting coal deposits from the earth to be used as an energy source and as raw material for industrial purposes. Based on geological conditions and the depth of coal reserves, coal mining methods are generally classified into open-pit mining and underground mining. For coal reserves located near the surface, open-pit mining is more commonly applied because it is more economical and capable of achieving higher production levels.

In open-pit coal mining operations, the mining process is carried out in sequential stages, starting from overburden stripping, followed by coal extraction, and material transportation. Each stage is closely interconnected, meaning that delays or inefficiencies at one stage will directly affect the overall mining operation. Therefore, proper coordination and efficiency at each stage are essential to ensure smooth mining activities.

The success of coal mining operations is strongly influenced by mine planning, appropriate selection of heavy equipment, and effective management of field operations. The use of suitable loading and hauling equipment, along with proper work time management, plays an important role in achieving coal production targets and maintaining operational efficiency

2.2.2 Coal Mining Activites

PT. Bukit Asam mines coal using an open-pit mining system with various shovels and haul trucks. Mining activities at PT. Bukit Asam include:

1. Land Clearing

   Land clearing is the first stage in mining preparation, where the area is cleared of vegetation such as trees, bushes, and roots. This step is needed so the mining area is open and ready to be used for operational activities without obstacles that can disturb equipment movement. After land clearing, the area can be used for several purposes, such as a working area for heavy equipment, topsoil stripping, overburden removal, and the construction of haul roads. Clearing the land also helps improve visibility and safety, making it easier for operators to work and reducing the risk of problems during operations.

Figure 2. 1 Land Clearning

2. Topsoil

   Topsoil stripping is carried out after land clearing to remove the upper layer of soil. This layer contains organic material, so it is separated from other materials to keep its quality. Topsoil removal is needed so the surface is ready for the next mining stage without mixing soil with vegetation. After being removed, the topsoil is usually placed in a designated stockpile area. This material is kept for later use, mainly for land reclamation once mining activities in the area are finished. By separating the topsoil early, the next mining process can run more smoothly and in a more controlled way.

Figure 2. 2 Topsoil

3. Overburden

   Overburden stripping is the process of removing soil and rock layers that cover the coal seam. This stage is carried out after topsoil stripping and is one of the main activities before coal mining can begin. The overburden is excavated using loading equipment and transported by haul trucks to the disposal area. This activity is important because it determines whether the coal seam can be reached according to the mining plan. If overburden stripping does not run well, it can delay coal exposure and affect the overall mining schedule. Therefore, overburden stripping needs to be done in an orderly and consistent manner so that mining operations can continue as planned. The Overburden material itself generally consists of several layers, including:

   a. Soil Layer

      This layer is located below the topsoil and consists of loose soil with fine particles. It is relatively easy to excavate but often has a high moisture content, especially during the rainy season

   b. Clay Material

      This material includes clay and partially weathered rock. It can become sticky when wet and harder to handle, which may affect digging and hauling performance.

c. Rock Material

Deeper overburden layers may consist of harder materials such as sandstone, shale, or siltstone. These materials require more effort during excavation and can influence equipment productivity.

Figure 2. 3 Overburden

d. Material transportation

Transportation activities at PT Bukit Asam Tbk, particularly in the Pit 3 Banko area, are carried out using trucks to transport overburden material from front to the disposal area. The excavated material is loaded by a shovel, then transported via a designated haul road to the disposal site.

Figure 2. 4 Material Transportation

2.2.3 Loading and Transport Equipment

The following are the loading and transport equipment:

a. Shovel PC 3000

A shovel is heavy equipment used in mining operations for digging and loading material. It excavates material at the mining face and directly loads it onto haul trucks, which then transport the material to disposal or processing areas. In open-pit mining, large hydraulic or electric shovels are commonly used to handle overburden and mined material due to their high production capacity.

In the overburden stripping activity at Pit 3 East, Banko Barat, the operation utilizes a Komatsu PC3000 electric shovel as the primary loading unit and a Belaz 75135 rigid truck as the hauling equipment. The PC3000 electric shovel is designed to support high-volume loading operations and maintain stable production rates in large-scale mining environments. Its capacity and cycle time play a significant role in determining overall operational performance. The loading–hauling combination between the PC3000 shovel and the Belaz 75135 rigid truck is intended to optimize overburden removal and support the achievement of production targets efficiently. Proper coordination between these units is essential to minimize idle time and avoid excessive queuing at the loading point.

Figure 2. 5 Shovel PC 3000

b. Haul Truck

A haul truck is a hauling unit used in mining operations to transport excavated material from the loading point to the disposal area. It operates after the material has been loaded by the shovel, making it a critical component in maintaining a continuous hauling cycle. Without proper coordination between loading and hauling units, overall production performance can be significantly affected. In the overburden stripping activity at Pit 3 East, Banko Barat, PT Bukit Asam Tbk, the haul truck used is the Belaz 75135 series. This unit is a rigid dump truck with a high payload capacity, making it suitable for large-scale mining operations. The Belaz 75135 is specifically designed to operate on mine haul roads while carrying heavy loads over relatively long distances.

The primary function of the Belaz 75135 in this operation is to transport overburden material from the mining face to the designated disposal area continuously basis. Its operational performance is influenced by several factors, including payload capacity, haul cycle time, hauling distance, and haul road conditions. In addition, the compatibility between the haul truck capacity and the shovel's loading capacity plays an important role in determining system efficiency. An imbalance between these units can result in idle time at the loading point or excessive queuing, both of which reduce overall productivity in overburden removal activities.

Figure 2. 6 Belaz Rigid 75135

2.2.4 Transportation Road Geometry

The main function of haul roads in mining activities is to support the smooth operation of the mine, particularly in the transportation of materials from the mining front to the disposal area or other areas. The condition and geometry of haul roads greatly affect work safety, transport vehicle speed, cycle time, and transport productivity. Therefore, the geometry of haul roads must be planned and complied with according to standards so as not to cause disturbances or obstacles during operations. Several aspects of haul road geometry that need to be considered in mining activities are as follows:

1. Width of Haul Road on Straight Sections

   The width of the haul road on straight sections needs to be wide enough so haul trucks can pass safely without getting in each other’s way. If the road is too narrow, trucks will have trouble passing and operators usually have to slow down. This often causes queues and makes hauling time longer. A properly sized road allows haul trucks to move more smoothly. Operators can maintain a steady speed, and hauling activities can run without many interruptions. That’s why the width of the haul road on straight sections needs to be considered carefully to keep hauling operations running well.
2. Haul Road Grade

   The gradient of the haul road has a big effect on how haul trucks move. On uphill sections, steep gradients make trucks move more slowly and put more load on the engine. On downhill sections, steep slopes make the truck harder to control, especially when the road surface is slippery. If the road gradient is not suitable, travel time increases and safety risks also go up. Because of that, the haul road gradient needs to be kept within a safe range so hauling activities can be carried out smoothly and safely.

2.2.5 Loading Pattern

To achieve production results that meet the planned targets, the loading pattern is one of the important factors influencing overburden stripping activities. In this process, the loading equipment excavates the material and loads it into the haul truck. Once the haul truck is fully loaded, it immediately transports the material to the disposal area and is replaced by the next haul truck to ensure that the loading process continues without interruption. The loading pattern can be identified based on the condition and position of the haul truck during the loading process. Loading Pattern Based on the Position of the Haul Truck Relative to the Shovel. Based on the relative position of the haul truck to the shovel during loading, there are two types of loading patterns:

a. Top loading

Top loading occurs when the shovel is positioned on a higher bench, while the haul truck is located on a lower bench. In this pattern, loading time tends to be shorter because the material does not need to be lifted to a high elevation. In addition, the haul truck body is more clearly visible to the operator, allowing the loading process to be carried out more easily and efficiently. (Figure 2.7)

Figure 2. 7 Top loading

(Source: “Surface Mining Primary Loading Tool”. Selection Guide. Caterpillar.)

b. Bottom loading

Bottom loading occurs when both the shovel and the haul truck are positioned on the same bench level. In this pattern, the shovel bucket must be lifted higher to load the material into the haul truck body, which generally results in longer loading time compared to top loading. (Figure 2.8)

Figure 2. 8 Bottom loading

Loading Pattern Based on the Number of Haul Truck Positions. Based on the number of haul truck positions relative to the shovel, loading patterns are classified into two types:

a. Single Side Loading

Single side loading is a loading pattern in which haul trucks are loaded from only one side of the shovel. In this pattern, the shovel operates with a relatively fixed loading direction and minimal repositioning. This pattern is considered safe and easy to apply; however, it may lead to waiting time when the number of available haul trucks is limited. (Figure 2.9)

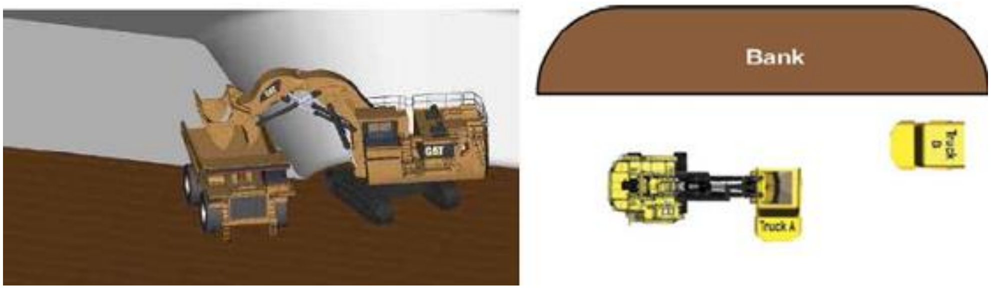


Figure 2. 9 Single sided loading

b. Double Sided Loading

   Double side loading is a loading pattern in which haul trucks are loaded from two sides of the shovel. With this pattern, the next haul truck is already positioned and ready while the previous haul truck is still being loaded, thereby reducing waiting time and increasing productivity. However, this pattern requires good operational control due to a higher safety risk. (Figure 2.10)

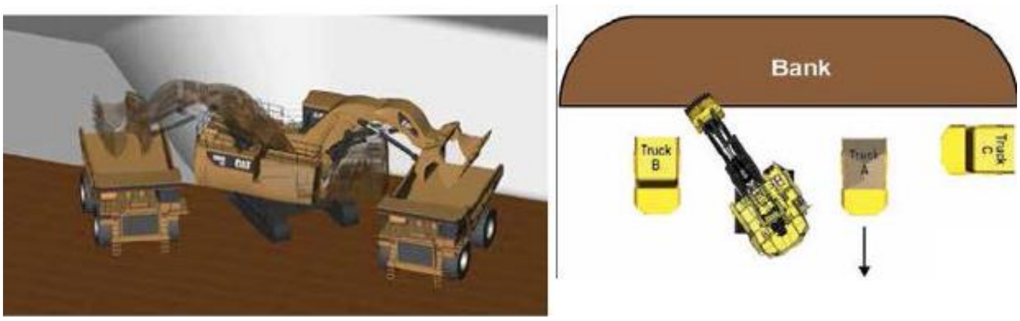


Figure 2. 10 Double sided loading

Loading Pattern Based on Shovel Position Relative to the Mining Face. Based on the position of the shovel relative to the excavation face and the haul truck position, there are three common loading patterns:

a. Frontal Cuts

   In the frontal cuts pattern, the shovel faces directly toward the excavation face. Haul trucks are positioned alternately on the left and right sides of the shovel. This pattern requires a relatively wide working area because the shovel swing angle is relatively large. (Figure 2.11)

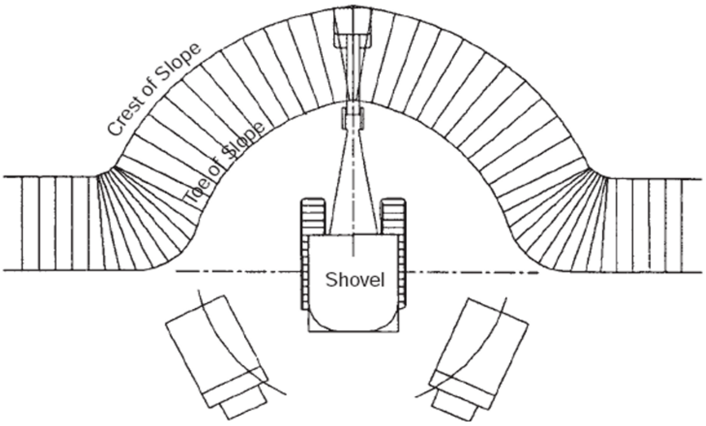


Figure 2. 11 Frontal cuts

b. Drive-by Cuts

Drive-by cuts are a loading pattern in which the shovel operates parallel to the excavation face. This pattern offers good operational efficiency because the shovel swing angle is smaller and haul truck positioning is easier to manage, resulting in shorter loading time. (Figure 2.12)

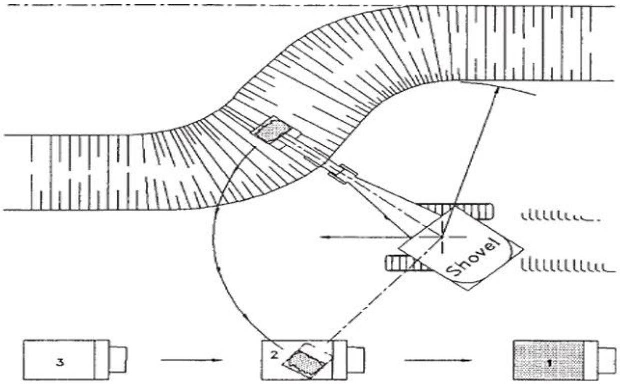


Figure 2. 12 Drive-by cuts

c. Parallel Cuts

Parallel cuts are a loading pattern where the shovel works parallel to the excavation face. This pattern consists of two methods, namely single spotting and double spotting. In the double spotting method, the next haul truck is already in position before the previous haul truck leaves the loading area, allowing the shovel to operate more continuously and reducing waiting time

1) Parallel Cuts with Single Spotting of Truck

The second hauling unit waits until the loading unit has completed loading the first hauling unit. After the first hauling unit leaves the loading area, the second hauling unit performs a turning and reversing maneuver to take the loading position. While the second hauling unit is being loaded, the third hauling unit arrives and waits for the next loading cycle, and so on (Figure 2.13)

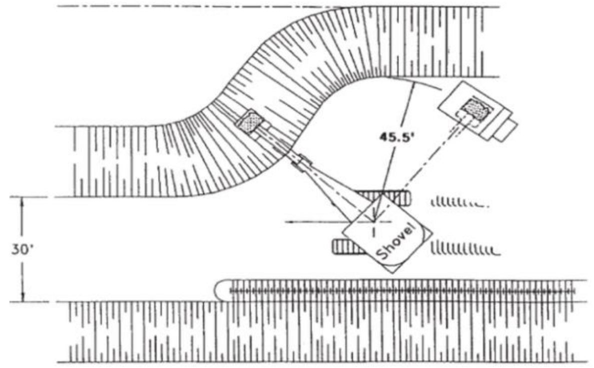


Figure 2. 13 Parallel Cuts with Single Spotting of Truck

2) Parallel Cuts with Double Spotting of Truck

In this method, while the first hauling unit is being loaded, the second hauling unit has already maneuvered by turning and reversing to position itself on the opposite side of the first hauling unit. After the first hauling unit departs from the loading area, the loading unit can immediately continue loading the second hauling unit without waiting for additional maneuvering. With this pattern, the waiting time of the loading unit can be minimized, thereby increasing the efficiency of the loading process. (Figure 2.14)

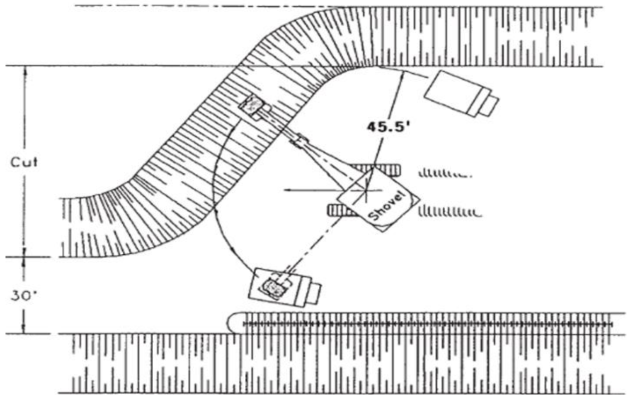


Figure 2. 14 Parallel Cuts with Double Spotting of Truck

2.2.6 Time Study

Time study is a method used to determine the actual working time of an operational activity through direct observation in the field. This method is carried out by recording the time required for each stage of equipment operation during one operating cycle. Through this approach, the working time obtained reflects the real conditions in the field, including waiting time, delays, and operational disturbances.

In overburden stripping activities, shovel and haul truck operations are repetitive and follow a relatively consistent working pattern. Therefore, the use of time study is considered appropriate as it can describe the duration of each activity, starting from loading, hauling, dumping, until the equipment returns to the loading point. The collected time data are then used to determine the operating cycle time of the equipment.

The application of time study in this research aims to obtain actual cycle time data as the basis for calculating the productivity of loading and hauling equipment. By using time data obtained from direct field observations, productivity calculations can be carried out more realistically and in accordance with actual operating conditions, so that the results can represent the actual performance of the equipment.

2.2.7 Swell Factor

Swell in soil or rock occurs when the material is excavated or removed from its original condition. The excavation process causes the material structure to become less compact, creating voids between particles that result in an increase in volume compared to its original condition in the ground. Material that has been excavated is in a loose condition, while material before excavation is in its original or in-situ condition. This change in condition is important in mining activities, particularly in overburden stripping operations, because the volume handled by excavation and hauling equipment is the volume in the loose condition.

The swell factor is a parameter that represents the ratio between the volume of material in the loose condition and its volume in the original condition. The value of the swell factor is influenced by the type of material, the degree of compaction of the soil or rock, and the excavation method used. More compact materials generally have lower swell factor values compared to less compact materials. According to Peurifoy (2006), the swell factor can be determined based on the ratio between the density of the material in the loose condition and the density of the material in the original condition.

2.2.8 Bucket Fill Factor

Swell occurs in soil or rock when the material is excavated or blasted from its original location. These activities create spaces or pores that cause an increase in volume from the original state (compacted) in the field, resulting in a loss of material. The swell factor is the percentage of the volume of material in its original state compared to the volume of the material in its loose state (Nichols, 1999).

2.2.9 Work Efficiency

Work efficiency is used to calculate the actual production of operational activitie. Work efficiency is an assessment of the performance of a job or a comparison between the time spent working and the time available (Alvarizzy & Nuh, 2024). The factors that affect work efficiency are as follows:

1. Mining Work Time

   Mining work time is the amount of work time used to carry out excavation, loading, and transportation activities. Work efficiency will be greater if the amount of work time is closer to the amount of work time available. The tme available is closely related to effective working hours. Effective working hours are the hours during which mechanical equipment is in production. Effective working hours are obtained from the available working hours minus any obstacles that occur during the production process, including equipment repairs and maintenance.
2. Avoidable obstacles

   Avoidable obstacles are obstacles that occur due to deviations from the scheduled working hours. These obstacles include:
   a. Stopping work before break time
   b. Arriving late after break time
   c. Stopping work early at the end of the shift
   d. Operator needs
3. Unavoidable obstacles

   Unavoidable obstacles are obstacles that occur during working hours, causing loss of working time due to natural conditions or routine activities that must be carried out. These obstacles include:
   a. Daily preparations

- b. Checking and warming up equipment
- c. Refueling
- d. Moving equipment
- e. On-site equipment damage and repairs
- f. Rain and slippery conditions
- g. Breaks

2.2.10 Match Factor

The ability to accurately predict the production of shovels and haul trucks is an important aspect of operational planning and control in mining activities. Accurate production estimates are needed to ensure that both types of equipment operate in a balanced and efficient manner, allowing the loading and hauling process to run smoothly(Michel et al., 2024).

The match factor is used as a parameter to evaluate the compatibility between the working capacities of shovels and haul trucks within an operating system (Morgan, 1968). This parameter indicates the level of work balance between the loading and hauling equipment and is also used to assess the efficiency of the equipment combination at the mining front. Proper matching between shovels and haul trucks directly affects material flow and the effective utilization of working time.

A well-balanced operation between shovels and haul trucks can reduce waiting time, minimize queuing, and improve operational continuity. Therefore, the match factor can be used as a basis for evaluating the performance of the loading and hauling system and for identifying opportunities to improve overall productivity (Morgan, 1968).

2.2.11 Cycle Time

Cycle time is a fundamental parameter used to evaluate the performance of loading and hauling systems in open-pit mining operations. It represents the total time required for a piece of equipment to complete one full operational cycle and return to its initial position. In shovel–haul truck systems, cycle time reflects the efficiency of material movement from the loading area to the dumping point and is widely used as a key indicator for assessing operational performance in overburden stripping activities (Manyele, 2017).

In haul truck operations, cycle time generally consists of several sequential components, including loading time, loaded hauling time, dumping time, and empty return time. Loading time is influenced by shovel bucket capacity, number of passes, swing angle, and operator skill, while hauling time is affected by hauling distance, road gradient, road surface condition, and traffic conditions (Pt et al., 2025). Studies have shown that variations in these components can significantly increase total cycle time, leading to reduced haulage efficiency and lower productivity (Enkhchuluun et al., 2023).

Cycle time analysis is widely applied because it provides a direct representation of actual field conditions. By measuring and breaking down each cycle component, operational delays such as queuing, waiting time, and maneuvering inefficiencies can be clearly identified. Several studies emphasize that reducing non-productive cycle time through operational improvements and better coordination between shovel and haul truck units can substantially improve system performance in overburden stripping operations (Mnzool et al., 2024).

2.2.12 Heavy Equipment Productivity

Heavy equipment productivity refers to the amount of material that can be moved by mechanical equipment within a given period under specific operating conditions. In open-pit coal mining, productivity is commonly expressed in bank cubic meters per hour or tons per hour and serves as a primary indicator of operational efficiency. The productivity of shovel and haul truck systems is particularly critical in overburden stripping operations, as it directly affects mine scheduling and coal exposure rates (Nguyen et al., 2019).

The productivity of heavy equipment is influenced by various factors, including equipment capacity, cycle time, effective working time, and operating conditions(Zulfar et al., 2025). Technical aspects such as bucket size, payload capacity, and engine power determine theoretical productivity, while operational factors such as equipment availability, operator performance, and haul road conditions largely determine actual productivity. Research has shown that even when equipment capacity is sufficient, poor coordination and long cycle times can significantly reduce realized production rates (Kresno et al., 2022).

In shovel–haul truck systems, productivity should be evaluated as an integrated system rather than as individual equipment performance. Imbalances between shovel capacity and the number of haul trucks often lead to shovel idle time or excessive truck queuing, both of which reduce overall productivity. Several studies conclude that productivity improvement efforts should focus on optimizing cycle time, improving haul road conditions, and ensuring proper equipment matching to achieve efficient and sustainable overburden stripping operations (Taufiq et al., 2024).

2.2.13 Discrete Event Simulation (DES)

Discrete-event simulation is a modeling method used to represent systems in which changes occur at specific points in time due to certain events. In this approach, the system state changes only when an event happens, such as the start or completion of loading, hauling, or dumping activities.

This method is suitable for analyzing operational systems that involve sequential processes and interaction between multiple resources. In shovel and haul truck operations, each unit performs repetitive cycles that are influenced by time variability and equipment availability. Because of these dynamic interactions, system performance cannot be fully represented by fixed or average calculations alone.

Discrete-event simulation allows operational parameters such as loading time and travel time to be modeled with variability, so the system can be evaluated under more realistic conditions(Adan & Egberto, 2026). It is commonly used to analyze system performance, measure equipment utilization, and test alternative operational scenarios without disrupting actual field operations. In this research, discrete-event simulation is applied to model the shovel and haul truck system at Pit 3 Banko in order to evaluate operational performance and identify potential productivity improvements (Adan & Egberto, 2026).

The application of discrete-event simulation in this research is justified by the inherent stochastic and dynamic characteristics of the shovel-haul truck system operating at Pit 3 Banko. In surface mining operations, the shovel-haul truck system does not operate under fixed, predetermined conditions. Instead, each operational cycle is influenced by a combination of factors that vary continuously throughout the shift, including the physical properties of the overburden material at the mining face, haul road surface conditions along different segments of the haul route, the performance of individual operators, and the occurrence of both planned and unplanned delays such as equipment inspection, refueling, and adverse weather conditions. As a result, cycle time components such as loading time, travel time to the dump site, dumping time, and return travel time are not constant values but rather random variables that follow statistical probability distributions.

Because of this inherent variability, deterministic analytical methods that rely solely on average cycle time values, such as the conventional match factor calculation, are insufficient to fully represent actual system behavior. Deterministic methods assume that all operational parameters remain constant and equal to their mean values throughout the entire shift. Under this assumption, the effects of queue buildup when multiple trucks arrive at the loading point simultaneously, shovel idle time when the next truck has not yet returned, and the cascading impact of individual delays on overall system throughput cannot be properly captured. The result is that productivity estimates derived from deterministic calculations often deviate from actual production performance observed in the field, as evidenced by the discrepancy between the calculated theoretical productivity and the actual overburden removal output recorded during the study period at Pit 3 Banko.

Discrete-event simulation directly addresses these limitations by modeling the system as a sequence of discrete events, each of which causes a state change in the system at a specific point in simulated time. In this framework, each operational parameter is represented not as a fixed value but as a probability distribution fitted to actual field observation data. Loading time, travel time, dumping time, and delay durations are all sampled stochastically from their respective fitted distributions during each simulation replication, allowing the model to generate a range of possible system outcomes that reflect the natural variability of real operations. Furthermore, the queuing dynamics of the shovel-haul truck system, including truck waiting time at the loading point, shovel idle time between consecutive truck arrivals, and the influence of fleet size on queue length and equipment utilization, are explicitly captured within the simulation model structure (Banks et al., 2014). This makes discrete-event simulation a more appropriate and comprehensive analytical method for evaluating shovel-haul truck productivity and for testing the operational performance of alternative fleet configurations under realistic field conditions, without requiring any disruption to actual mining operations.

CHAPTER III
RESEARCH METHOD

3.1 Research Objects

The object of this research is the shovel–haul truck system used in overburden stripping operations at Pit 3 Banko, PT Bukit Asam Tbk, which consists of a shovel as the loading equipment and haul trucks as the hauling equipment operating in an integrated and continuous manner. In this system, the shovel loads overburden material into the haul trucks, which then transport the material to the disposal area before returning to the loading point for the next cycle, forming an interdependent operational process. The performance of each unit is closely related, as delays or inefficiencies in loading time, maneuvering, hauling, or dumping activities can lead to waiting time, queuing, and idle equipment, thereby reducing overall operational efficiency. Consequently, the productivity of overburden stripping is strongly influenced by the coordination and balance between the shovel and haul trucks, making cycle time and productivity analysis essential to evaluate actual equipment performance under field conditions and to identify operational inefficiencies within the shovel–haul truck system.

3.2 Collection Data Method

3.2.1 Study Literature

The literature study was conducted to obtain theoretical references that support this research. The literature sources were collected from related institutions, textbooks, journals, technical reports, and other relevant documents. These sources discuss topics such as queueing theory, productivity of loading and hauling equipment, and work efficiency analysis in mining operations. The literature study serves as a reference to understand the basic concepts, calculation methods, and practical applications that are relevant to analyzing and improving the productivity of loading and hauling equipment.

3.2.2 Observation

Observations were conducted through direct monitoring in the field at PIT 3 Banko, PT Bukit Asam, to obtain actual data related to the productivity of heavy equipment and transport trucks in overburden removal activities. Observations focused on the operational performance of loading and transportation equipment during working hours under normal operating conditions.

Several aspects were observed directly in the field, including the interaction between excavators and haul trucks, loading patterns, equipment cycle times, and others. In addition, observations were made on mining front conditions, road conditions, and operational constraints that could affect equipment productivity, such as delays during loading, maneuvering times, and waiting times.

All observed data were recorded systematically to ensure accuracy and consistency. The results of these observations were used to describe the actual field conditions and support further analysis of the productivity of shovel and haul trucks in the overburden removal operation at PIT 3 Banko.

3.2.3 Interviews

Interviews were conducted to obtain direct information related to operational activities and factors affecting the productivity of loading and hauling equipment. This method was used to complement field observations and to gain practical insights from personnel involved in overburden stripping operations. The interviews were conducted with:

a. Loading and hauling equipment operators (2 persons), responsible for operating shovels and haul trucks and directly involved in loading efficiency, cycle time, and operational delays.
b. Field foremen (2 persons), responsible for supervising daily operations and coordinating loading and hauling activities in the field.
c. Head of Mining Engineering (KTT) (1 person), responsible for overseeing mining operations and determining technical and production-related policies.

The information obtained from the interviews was used to support the analysis of shovel and haul truck productivity at PIT 3 Banko, PT Bukit Asam Tbk.

3.3 Collection Data

Data collection was carried out in the research area, located at PIT 3, PT Bukit Asam Tbk. The data required in this study consist of primary data and secondary data, as described below.

3.3.1 Primary Data

The following are the primary data of this research:

a. Mining Front Conditions

Mining front condition data were collected to identify the actual working conditions at the loading area, including bench conditions, material characteristics, and operational constraints that may affect loading and hauling productivity.

b. Loading Patterns

Loading pattern data were collected to understand the interaction between shovels and haul trucks during loading activities, including truck positioning, loading sequence, and the number of passes required for each haul truck.

c. Match Factor and Bucket Fill Factor

Bucket fill factor data were collected to see how well the shovel bucket was filled during loading activities. This data shows how effective the loading process was and how much material was actually loaded in each cycle. Match factor data were collected to look at the balance between the shovel and haul truck operations in the field. This was done to see whether the number of haul trucks was too many, too few, or already suitable for the shovel capacity. The results were used to understand the working conditions at the loading area, especially related to waiting time and truck queuing during overburden stripping activities

d. Cycle Time of Haul Truck and Shovel

Cycle time data were collected to measure the duration of one complete operating cycle of haul trucks and shovels. This data is used to analyze equipment performance and to calculate productivity.

3.3.2 Secondary Data

The following are the secondary data of this research:

a. Equipment Specifications

Equipment specification data were obtained to provide technical information on the loading and hauling equipment used in the operation, which is required for productivity analysis.

b. Rainfall Data

Rainfall data were collected to identify weather conditions that may affect road conditions, equipment operation, and overall productivity.

3.4 Research flow

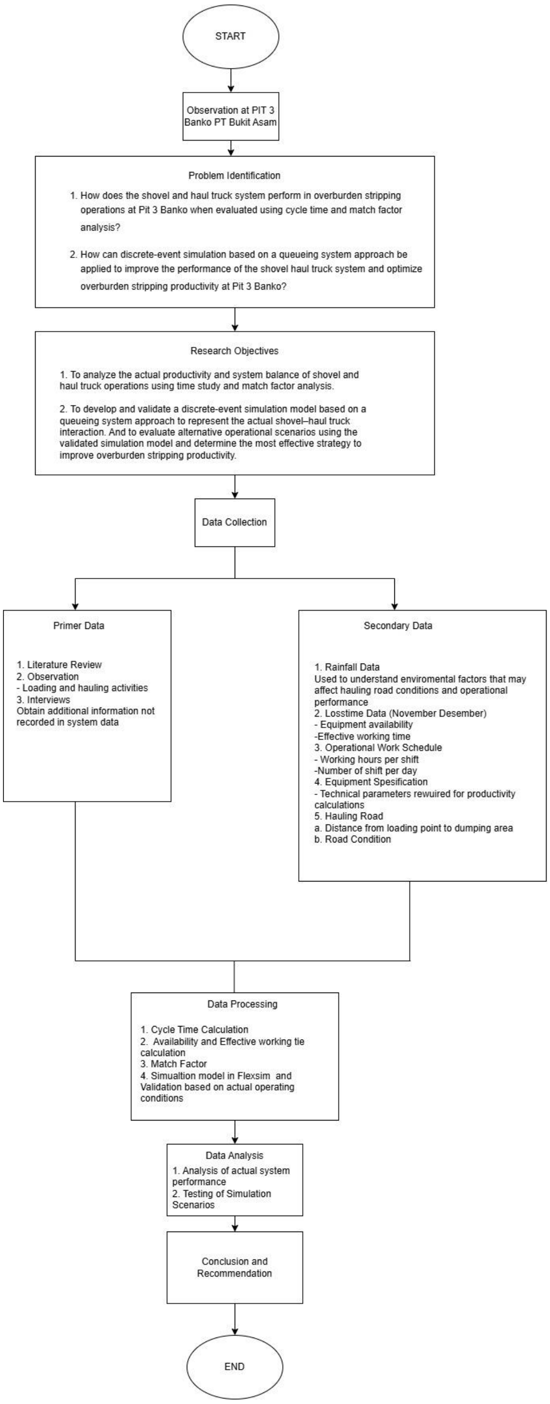


Figure 3. 1 Research flow

Based on the research flow presented in Figure 3.1, the following are the explanations of each research stage:

a. Start

This stage represents the beginning of the research process. At this stage, the overall research direction is determined, including the scope of study, research focus, and expected outcomes. The research is focused on evaluating the productivity of shovel and haul truck operations in overburden stripping activities at Pit 3 Banko, PT Bukit Asam Tbk.

b. Field Observation

Field observation is conducted to directly observe loading and hauling activities during overburden stripping operations. This stage aims to understand actual working conditions in the field, including operational flow, haul road characteristics, environmental conditions, and equipment interaction. Observation results serve as the basis for identifying productivity-related problems and determining relevant data requirements.

c. Problem Identification

Based on field observation and operational performance records, problems related to shovel and haul truck productivity are identified. The main issue identified is the gap between production target and actual realization. This stage ensures that the research focuses on measurable productivity performance and system efficiency.

d. Research Objectives

After identifying the problems, research objectives are formulated to provide clear analytical direction. The objectives include calculating actual cycle time, measuring work efficiency, analyzing the balance between loading and hauling systems, and testing alternative hauling unit composition scenarios using simulation modeling.

e. Data Collection

Data collection consists of primary and secondary data acquisition. Primary data are obtained through direct observation, time study of loading and hauling cycles, and interviews with operators and supervisors. These data include shovel cycle time, haul truck cycle time, and operational delay information.

Secondary data include rainfall data to evaluate environmental influences, loss time data for calculating equipment availability and effective working time, operational schedules including working hours and number of shifts, equipment specifications required for productivity calculation, and haul road data such as distance between loading and dumping areas and road condition characteristics.

f. Data Processing

The collected data are processed to obtain analytical parameters. Cycle time calculation is performed to determine the duration of each operational cycle component. Equipment availability and effective working time are calculated based on loss time data to determine actual utilization levels. Match factor is calculated to evaluate the balance between loading and hauling capacity.

In addition to analytical calculations, a simulation model is developed using FlexSim software based on actual operating conditions. The simulation model represents the shovel–haul truck interaction, haul road distance, and working schedule to evaluate system behavior under alternative fleet configurations.

g. Data Analysis

Data analysis is conducted in two stages. First, the actual system performance is evaluated based on calculated productivity, work efficiency, and match factor results. This stage identifies whether the shovel–haul truck system operates under balanced or imbalanced conditions. Second, simulation scenarios are tested to analyze the impact of alternative hauling unit compositions on productivity performance. The simulation results are compared with actual system performance to determine potential improvements.

Operational factors such as rainfall influence, haul road condition, equipment availability, and fleet coordination are considered during analysis to ensure that conclusions reflect real operating conditions.

h. Conclusion and Recommendation

The final stage of the research is drawing conclusions based on analytical and simulation results. Conclusions summarize the actual productivity level, system balance condition, and operational factors influencing performance. Based on these findings, recommendations are formulated to improve shovel and haul truck productivity in overburden stripping operations at Pit 3 Banko.

i. End

This stage marks the completion of the research process after all analytical stages and recommendations have been finalized.

3.5 Cycle Time Analysis

Cycle time analysis is conducted to determine the duration of one complete operating cycle for both shovel and haul trucks. The cycle time values are obtained through direct field observation using a time study approach. The purpose of this analysis is to measure the operational performance of loading and hauling equipment under actual working conditions.

3.5.1 Shovel Cycle Time

The shovel cycle time is defined as the time required by the loading equipment to complete one full digging and loading cycle. The working cycle consists of digging, swinging the loaded bucket toward the haul truck, dumping material into the truck body, and swinging back to the initial digging position.

The shovel cycle time is calculated using the following equation:

$$CT_m = t_{dig} + t_{swing\_loaded} + t_{dumping} + t_{swing\_empty}$$

Where:

CT_m = shovel cycle time (minutes)
t_{dig} = digging time
t_{swing_loaded} = loaded swing time
$t_{dumping}$ = dumping time
t_{swing_empty} = empty swing time

The cycle time values are recorded in seconds during observation and converted into minutes for productivity calculation purposes. The average cycle time is determined to represent the service time of the shovel within the operational system.

3.5.2 Haul Truck Cycle Time

The haul truck cycle time represents the total time required for one complete hauling cycle. This cycle begins when the haul truck maneuvers toward the loading area and ends when it returns to the loading point after dumping material.

The haul truck cycle consists of several sequential activities, including:

a. Maneuvering to the loading position
b. Loading time
c. Loaded travel time
d. Maneuvering at the dumping area
e. Dumping time
f. Empty return travel time

The haul truck cycle time is expressed mathematically as:

$$CT = T_{ml} + T_l + T_{tl} + T_{md} + T_d + T_r$$

Where:

CT = haul truck cycle time (minutes)

T_{ml} = maneuvering time at the loading area (minutes)

T_l = loading time (minutes)

T_{tl} = loaded travel time (minutes)

T_{md} = maneuvering time at the dumping area (minutes)

T_d = dumping time (minutes)

T_r = empty return travel time (minutes)

The cycle time data obtained from field observations are recorded in seconds and then converted into minutes by dividing each time value by 60. The cycle time calculation is performed using the total cycle time for each haul truck trip, as expressed by the following equation:

$$CT = \frac{T_{total}}{60}$$

This calculation is carried out for all observed data, and the average cycle time value is then determined to represent the actual haul truck cycle time of the Belaz 75135 under field operating conditions.

3.6 Work Efficiency Analysis

Work efficiency analysis is conducted to evaluate the effective use of equipment during available working hours. This research examines whether machines, such as shovels and haul trucks, operate at their full potential or experience idle times that reduce overall productivity.

The research considers factors like operating time, waiting time, delays, and breakdowns. By comparing actual working time with total available time, efficiency percentages for each piece of equipment can be calculated. This analysis helps managers identify underused equipment, workflow bottlenecks, and opportunities to improve productivity, ensuring that all resources are utilized effectively during each shift.

3.6.1 Available Working Time

Based on the working hour arrangement, the working time used for overburden stripping activities was 12 hours per day, from 07.00–19.00 WIB. This working time represents the available working time, which was then used as the basis for calculating effective working time and the productivity of mechanical equipment, as shown in Table 3.1

Table 3. 1 Working Time

Day	Working Time	Break
Monday	07.00 – 19.00	12.00-13.00
Tuesday	07.00 – 19.00	12.00-13.00
Wednesday	07.00 – 19.00	12.00-13.00
Thrusday	07.00 – 19.00	12.00-13.00
Friday	07.00 - 19.00	11.00-14.00
Saturday	07.00 – 19.00	12.00-13.00
Sunday	07.00 – 19.00	12.00-13.00

3.6.2 Delay Time

Delay time represents the portion of working time during which equipment cannot operate effectively due to operational interruptions. In this study, delay time is classified as unavoidable delay (Wtd), which includes activities that cannot be eliminated under normal operating conditions. Unavoidable delays may include preparation time, inspection and warming-up, front preparation, equipment breakdown and repair, weather-related conditions, and rest time.

The total unavoidable delay is calculated as the sum of all identified delay components. The effective working time is then determined by subtracting the unavoidable delay from the available working time.

3.6.3 Effective Working Time and Work Efficiency

Effective working time (We) is calculated as:

$$We = Wt - Wtd$$

Where:

We = effective working time (minutes)

Wt = available working time (minutes)

Wtd = unavoidable delay time (minutes)

Work efficiency (Ek) is calculated using the following equation:

$$Ek = \frac{We}{Wt} \times 100\%$$

This value represents the percentage of time during which the equipment operates effectively within the total available working time.

3.7 Match Factor Analysis

Match factor analysis is used to evaluate the balance between loading and hauling operations in the shovel–haul truck system. The match factor describes the relationship between the service capacity of the shovel and the hauling capacity of the haul trucks.

The match factor is calculated using the following equation:

$$MF = \frac{N_a \times CT_m}{N_m \times CT_a}$$

Where:

MF = match factor

N_a = number of haul trucks (units)

CT_m = shovel cycle time (minutes)

N_m = number of shovels (units)

CT_a = haul truck cycle time (minutes)

The interpretation of match factor values is defined as follows:

a. MF = 1 indicates a balanced working system between loading and hauling operations.
b. MF < 1 indicates that the shovel experiences idle time due to insufficient hauling capacity.
c. MF > 1 indicates that haul trucks experience waiting time due to excess hauling capacity.

This indicator is used to evaluate whether the shovel–haul truck system operates in a balanced condition before further analysis through simulation modeling.

3.8 Simulation Modeling Using FlexSim

In the input modeling stage, all parameters used in the FlexSim simulation model were determined based on actual operational data obtained from field observations at Pit 3 Banko, PT Bukit Asam. These data were processed and then used as inputs for the simulation model so that the simulated system could represent the real operating conditions.

The input modeling process started with collecting cycle time data from the main components of the shovel–haul truck system, specifically the loading time and unloading time. These data were obtained through direct observation in the field using a time study method, where each operational activity of the truck and shovel was recorded during the working process. The collected data were then used as the basis for building the simulation parameters.

After the raw data were collected, the next step was distribution fitting using ExpertFit software. ExpertFit was used to determine the statistical distribution that best represents the pattern of the actual field data (Law,2015). This step is important because, in real operations, process times such as loading and dumping are not constant and usually vary depending on several factors, such as material conditions, road conditions, and operator performance. Therefore, using probability distributions in the simulation allows the model to represent the variability of the real system more realistically.

The results of the ExpertFit analysis showed that the loading time is best represented by the Johnson Bounded distribution, while the unloading time follows the Pearson Type 6 distribution. These distributions were selected because they provided the best goodness-of-fit results compared to other candidate distributions tested in ExpertFit. The selected distributions were then directly implemented as the processing time parameters for the loading and unloading objects in the FlexSim model.

Another important parameter used in the simulation is the simulation time. In this study, the simulation time was set to 43,200 seconds or 12 hours, which represents one full operational shift in the mining activity. Using one full shift allows the simulation to capture the system performance over a complete operational period.

The simulation model also includes the number of haul trucks as scenario variables. The actual condition in the field uses 3 haul trucks, while two additional scenarios were tested in the simulation using 6 trucks and 7 trucks. These scenarios were designed to evaluate how changes in the number of trucks affect the balance of the system between the loading equipment and the hauling equipment.

Another parameter included in the model is the haul truck speed during operation. Based on the operational conditions, the speed of a loaded truck is approximately 20 km/h, while the speed of an empty truck ranges between 30 and 40 km/h. This difference in speed is included in the simulation because trucks carrying material move slowermore slowly than when they travel back empty to the loading area.

The model also considers operational delays or unavoidable delays, which represent the time when equipment cannot operate effectively. These delays include activities such as equipment preparation, inspection, refueling, maintenance, weather conditions, and operator breaks. Based on the operational data collected from the field, the total unavoidable delay for the haul trucks is 375 minutes per day, and this value is used in the analysis of operational efficiency.

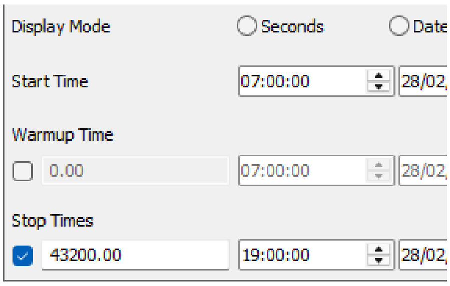
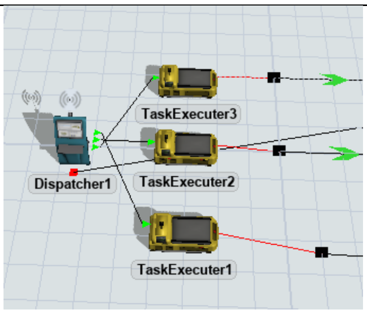
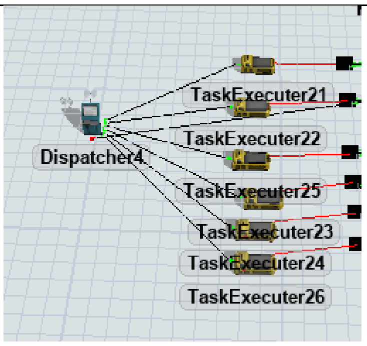
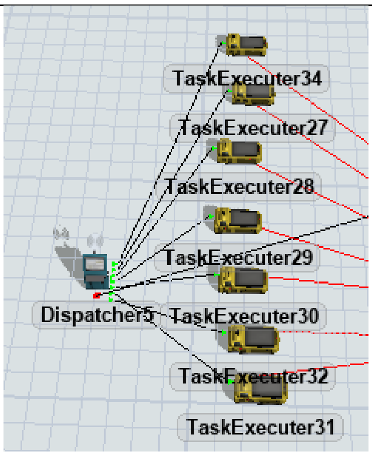
In the simulation model, the truck operation follows the actual working cycle. The truck arrives at the loading area, waits ifuntil the shovel is not currently serving another truck, then undergoes the loading process. After loading, the truck travels to the dumping area, performs the unloading process, and then returns to the loading area to start the next cycle. By modeling this complete cycle, the simulation can represent the interaction between the shovel and haul trucks realistically.

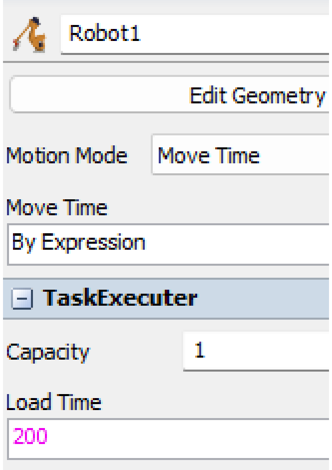
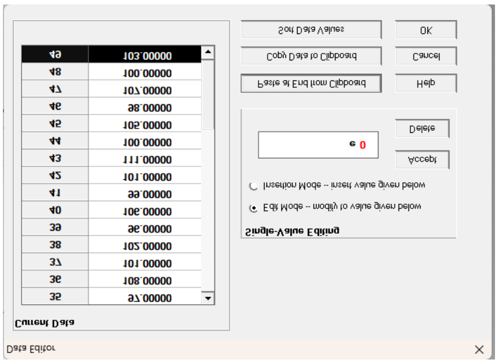
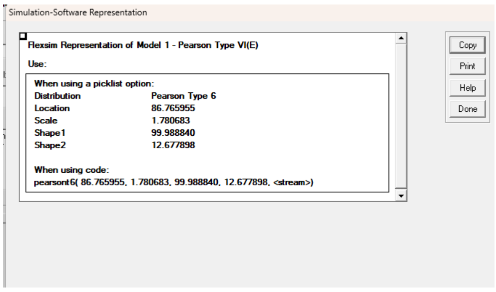
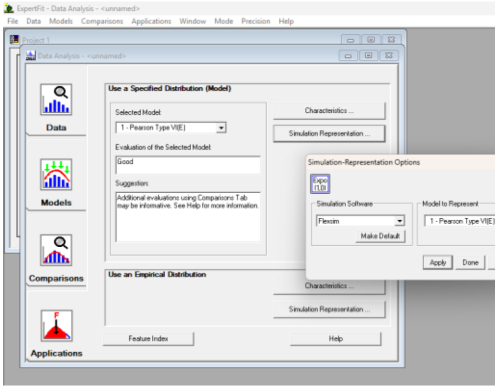
The main output observed from the simulation model is the number of truck trips or haul cycles, which is counted every time a truck completes the dumping process at the disposal area. This value is used to evaluate the system performance and to compare the simulation results with the actual conditions in the field.

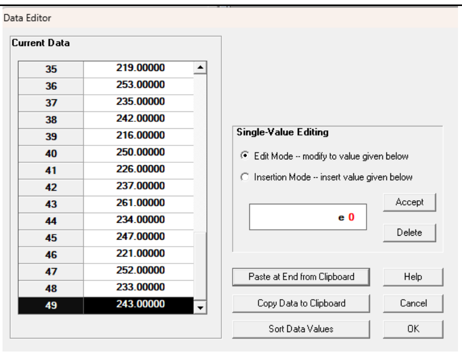
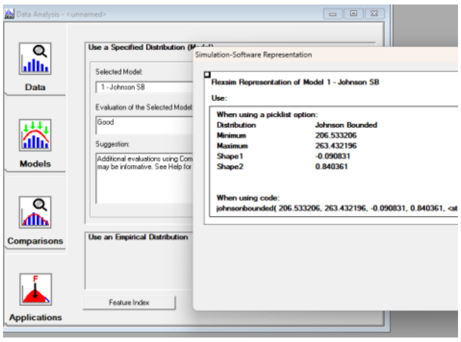
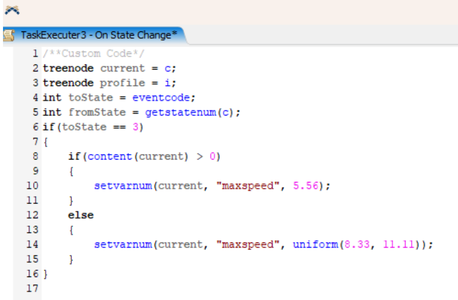
By using all these input parameters derived from actual field data and statistical distribution analysis, the FlexSim simulation model can represent the behavior of the shovel–haul truck system close to the real operating conditions. The model is then used to analyze different truck scenarios and determine the most optimal number of haul trucks to improve overburden stripping productivity at Pit 3 Banko.

The simulation model requires several input parameters derived from field observations and historical operational data. These parameters include simulation time, truck capacity, loading and unloading time distributions, truck speed, queue strategy, and operational delays. The detailed input parameters used in the simulation model are presented in Table 3.2.

Table 3.2 Input Modeling

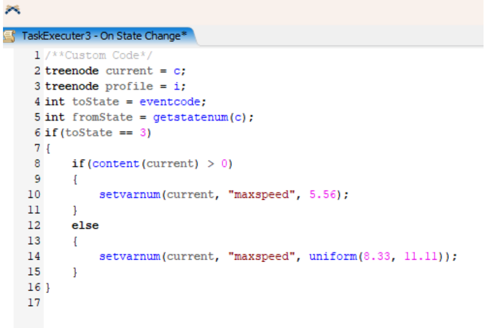
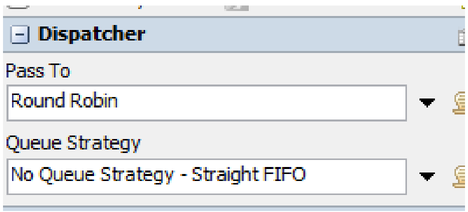
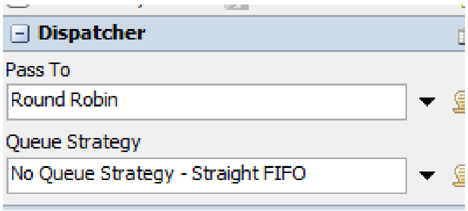
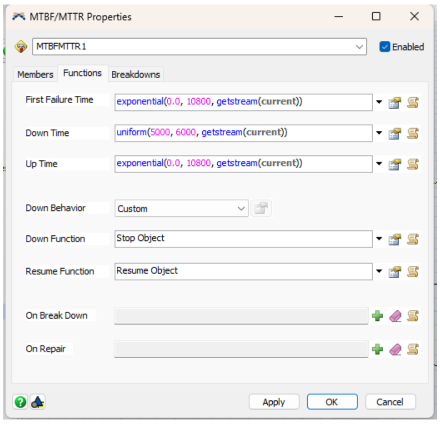
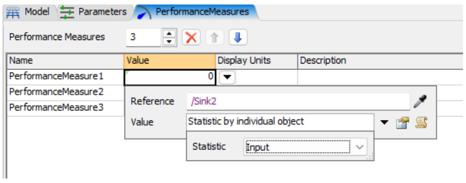
Component	**Parameter**	**Value/Distribution**	**Description**
Simulation Time	Simulation Time	720 minutes (43.200 seconds)	Represents one operational shift  Display Mode ○ Seconds ○ Date Start Time 07:00:00 28/02, Warmup Time ☐ 0.00 07:00:00 28/02, Stop Times ☑ 43200.00 19:00:00 28/02,
Number of Trucks	Scenario 1	3 units	
	Scenario 2	6 units	
	Scenario 3	7 units	
Shovel (Robot)	Load Time	Distribution obtained from ExpertFit based on	Represents the shovel loading time

Component	Parameter	Value/Distribution	Description
		49 actual data samples (3–4 minutes / 200–240 seconds)	 Robot1 Edit Geometry Motion Mode: Move Time Move Time: By Expression TaskExecuter Capacity: 1 Load Time: 200
Truck	Unload Time	Distribution obtained from ExpertFit based on actual dumping data	Represents the material dumping time  Data Editor Current Data 49 103.00000 48 100.00000 47 107.00000 46 98.00000 45 105.00000 44 100.00000 43 111.00000 42 101.00000 41 99.00000 40 106.00000 39 96.00000 38 102.00000 37 101.00000 36 108.00000 35 97.00000 Single-Value Editing ● Edit Mode -- modify to value given below ○ Insertion Mode -- insert value given below 0  Simulation-Software Representation Flexsim Representation of Model 1 - Pearson Type VI(E) Use: When using a picklist option: Distribution: Pearson Type 6 Location: 86.765955 Scale: 1.780683 Shape1: 99.988840 Shape2: 12.677898 When using code: `pearsont6( 86.765955, 1.780683, 99.988840, 12.677898, <stream>)`  ExpertFit - Data Analysis - <unnamed> Use a Specified Distribution (Model) Selected Model: 1 - Pearson Type VI(E) Evaluation of the Selected Model: Good Suggestion: Additional evaluations using Comparisons Tab may be informative. See Help for more information. Simulation-Representation Options Simulation Software: Flexsim Model to Represent: 1 - Pearson Type VI(E)

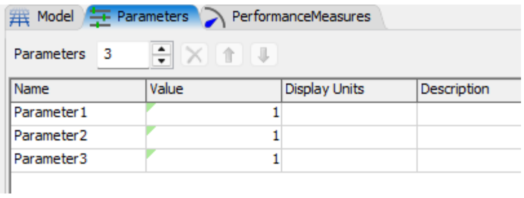
Component	Parameter	Value/Distribution	Description
Truck	Load time	Distribution obtained from ExpertFit based on actual loading data	 Data Editor Current Data 35 219.00000 36 253.00000 37 235.00000 38 242.00000 39 216.00000 40 250.00000 41 226.00000 42 237.00000 43 261.00000 44 234.00000 45 247.00000 46 221.00000 47 252.00000 48 233.00000 49 243.00000 Single-Value Editing ● Edit Mode -- modify to value given below ○ Insertion Mode -- insert value given below e 0  Selected Model: 1 - Johnson SB Evaluation of the Selected Model: Good Suggestion: Additional evaluations using Com may be informative. See Help for Simulation-Software Representation Flexsim Representation of Model 1 - Johnson SB Use: When using a picklist option: Distribution Johnson Bounded Minimum 206.533206 Maximum 263.432196 Shape1 -0.090831 Shape2 0.840361 When using code: johnsonbounded(206.533206, 263.432196, -0.090831, 0.840361, <st
Truck Speed (Loaded)	Loaded Speed	5,56 m/s (≈ 20 km/h)	 Custom Code  TaskExecuter3 - On State Change*
Truck Speed (Empty)	Empty Speed	Uniform (8.33 – 11.11 m/s) ≈ 30–40 km/h	Defined through script  Custom Code

Truck Speed (Loaded):

```
/**Custom Code*/
treenode current = c;
treenode profile = i;
int toState = eventcode;
int fromState = getstatenum(c);
if(toState == 3)
{
    if(content(current) > 0)
    {
        setvarnum(current, "maxspeed", 5.56);
    }
    else
    {
        setvarnum(current, "maxspeed", uniform(8.33, 11.11));
    }
}
```

Component	Parameter	Value/Distribution	Description
			 TaskExecuter3 - On State Change*
Queue System	Queue Strategy	FIFO (First In First Out)	Trucks that arrive earlier are served first  **Dispatcher** Pass To: Round Robin Queue Strategy: No Queue Strategy - Straight FIFO
Dispatcher	Task Allocation	Round Robin	Truck tasks are assigned sequentially  **Dispatcher** Pass To: Round Robin Queue Strategy: No Queue Strategy - Straight FIFO
Operational Delay	Non-Efficiency Downtime	375 minutes (22.500 seconds)	Based on truck non-effective time data  MTBF/MTTR Properties MTBFMTTR1 ☑ Enabled Members / Functions / Breakdowns First Failure Time: exponential(0.0, 10800, getstream(current)) Down Time: uniform(5000, 6000, getstream(current)) Up Time: exponential(0.0, 10800, getstream(current)) Down Behavior: Custom Down Function: Stop Object Resume Function: Resume Object On Break Down: On Repair: Apply / OK / Cancel
Model Output	Throughput Sink	Number of trips (ritase)	Each unloading is counted as one trip  Model / Parameters / PerformanceMeasures Performance Measures: 3 Name / Value / Display Units / Description PerformanceMeasure1: 0 PerformanceMeasure2 PerformanceMeasure3 Reference: /Sink2 Value: Statistic by individual object Statistic: Input

```
/**Custom Code*/
treenode current = c;
treenode profile = i;
int toState = eventcode;
int fromState = getstatenum(c);
if(toState == 3)
{
    if(content(current) > 0)
    {
        setvarnum(current, "maxspeed", 5.56);
    }
    else
    {
        setvarnum(current, "maxspeed", uniform(8.33, 11.11));
    }
}
```

Component	**Parameter**	**Value/Distribution**	**Description**
CT Calculation	Cycle Time	Simulation Time / Throughput Sink	Calculates the average trip cycle time based on simulation output (3 parameters / 3 scenarios) 

Parameters 3

Name	Value	Display Units	Description
Parameter1	1		
Parameter2	1		
Parameter3	1		

CHAPTER IV
DATA COLLECTION AND PROCESSING

4.1 Data Collection

This section presents the operational data collected during field observation at Pit 3 Banko, PT Bukit Asam Tbk, which are used as the basis for productivity and system balance analysis.

4.1.1 Equipment Configuration

The equipment configuration used in this study consisted of one loading and unloading unit and three transport units that were actively operating during the observation period. Details of the equipment configuration are presented in Table 4.1.

Table 4. 1 Calculation of Productivity

No	Unit	Bucket Capacity	Total
1	Shovel Komatsu-PC 3000	±15 m³	1
2	Belaz 75135 Rigid	±135 ton	3

The work system observed during the study was a configuration of one shovel unit serving three dump truck units. The productivity analysis in this study was based entirely on actual conditions in the field, and only units that were actively operating during the observation period were included in the calculations.

4.1.2 Working Time

Based on the working hour arrangement, the working time used for overburden stripping activities was 12 hours per day, from 07.00–19.00 WIB. This working time represents the available working time, which was then used as the basis for calculating effective working time and the productivity of mechanical equipment, as shown in Table 4.2

Table 4. 2 Working Time

Day	Working Time	Break
Monday	07.00 – 19.00	12.00-13.00
Tuesday	07.00 – 19.00	12.00-13.00
Wednesday	07.00 – 19.00	12.00-13.00
Thrusday	07.00 – 19.00	12.00-13.00
Friday	07.00 - 19.00	11.00-14.00

Day	Working Time	Break
Saturday	07.00 – 19.00	12.00-13.00
Sunday	07.00 – 19.00	12.00-13.00

4.1.3 Delay Time

Delay time represents the portion of working time during which equipment cannot operate effectively due to unavoidable operational interruptions. Although it does not directly generate production output, this time component is still included in the total daily working time and affects equipment efficiency. In this research, delay time is classified as an unavoidable delay (Wtd), which refers to delays that cannot be eliminated because they are part of normal operational procedures in the field. The uUnavoidable delays include activities such as equipment positioning, work coordination, routine pre-operation checks, and minor temporary technical interruptions. In general, the components of equipment working time can be expressed as follows:

$$W_t = W_e + W_{td}$$

where:
W_t= Total working time
W_e= Effective working time
W_{td}= Unavoidable delay time

Work efficiency can be calculated using the following equation:

$$Efficiency(\%) = \frac{We}{Wt} \; x \; 100\%$$

From this equation, it can be seen that an increase in delay time W_{td}will reduce the effective working time W_e , which consequently lowers equipment efficiency and productivity.

4.1.3.1 Unavoidable Delay of Komatsu PC3000

The unavoidable delays for the Komatsu PC3000 shovel are presented in Table 4.3. These delays consist of daily preparation activities, equipment inspection and warming-up, front preparation, equipment breakdown and repair, weather-related conditions, and rest time.

Table 4. 3 Unavoidable Delay of the Shovel

Type of Delay	Times (minutes/day)
Unavoidable Delay Time (Wtd)	
Daily preparation	30
Equipment inspection and warming up	25
Front preparation	20
Equipment breakdown and repair	15
Rain and slippery conditions	110
Rest time	150
Total unavoidable delay (Wtd)	350

4.1.3.2 Unavoidable Delay of Belaz 75135

The unavoidable delays for the Belaz 75135 haul truck are shown in Table 4.4 Compared to the shovel, additional delay components such as refueling activities are included. Weather conditions also contribute significantly to the total delay time.

Table 4. 4 Unavoidable Delay of Belaz 75135

Type of Delay	Times (minutes/day)
Unavoidable Delay Time (Wtd)	
Delay preparation	25
Equipment inspection and warming up	20
Refueling	15
Front preparation	15
Equipment breakdown and repair	20
Rain and slippery conditions	130
Rest time	150
Total unavoidable delay (Wtd)	375

4.2 Cycle Time Analysis

Cycle time analysis is conducted to determine the duration of one complete operating cycle for both shovel and haul trucks. The cycle time values are obtained through direct field observation using a time study approach.

4.2.1 Shovel Cycle Time

The shovel cycle time represents the time required by the Komatsu PC3000 loading equipment to complete one full digging and loading cycle. The operating cycle consists of digging the material, swinging the loaded bucket toward the haul truck, dumping the material into the truck body, and swinging back to the initial digging position. The average duration of each activity component was obtained through direct field observation and is presented in Table 4.5.

Table 4. 5 Cycle time shovel

No	Loading Group	Average Time (min)
1	Group 1	3.39
2	Group 2	3.55
3	Group 3	3.48
4	Group 4	3.63
5	Group 5	3.6
6	Group 6	3.22
7	Group 7	3.23
Total Average		**3.44**

4.2.2 Haul Truck Cycle Time

The haul truck cycle time represents the total time required by a Belaz 75135 haul truck to complete one full hauling cycle. The cycle begins when the truck maneuvers toward the loading point and ends when it returns to the loading area after dumping the material. The cycle consists of loading time, loaded hauling time, dumping time, empty hauling time, and waiting time. The average cycle time components for Fleet 3007 are presented in Table 4.6.

Table 4. 6 Cycle Time Haul Truck

Activity	Average Time (sec)
Manuver Load	67.27
Load	236.72
Travel (Loaded)	415.00
Manuver Dumping	42.72
Dumping	102.53

Activity	Average Time (sec)
Return	390.16
Total (sec)	**1,254.40**

Converted into minutes:

$$CT_{a,3007} = \frac{1{,}254.40}{60} = 20{,}9 \text{ minutes}$$

4.3 Work Efficiency Analysis

Work efficiency analysis evaluates the effectiveness of equipment utilization during the available working time.

Table 4. 7 Effective Working Time of Komatsu PC3000 and Belaz 75135

Equipment	Wt (min)	Wtd (min)	We (min)
Shovel	720	350	370
Haul Truck	720	375	345

$$Ek = \frac{We}{Wt} \times 100\%$$

Table 4. 8 Work Efficiency of Komatsu PC3000 and Belaz 75135

Equipment	Work Efficiency (%)
Shovel	51.39
Haul Truck	47.92

Based on the work efficiency analysis, both the shovel and haul truck are operating well below the industry benchmark of 75–83%. The shovel achieves only 51.39% efficiency, while the haul truck reaches 47.92%. The primary contributor to this low efficiency is the high total unavoidable delay time, particularly rain and slippery conditions (110 minutes/day for shovel, 130 minutes/day for haul truck) and rest time (150 minutes/day for both). These delays significantly reduce effective working time from the 720-minute total shift. To improve work efficiency in future operations, it is recommended that delay time be minimized through better scheduling of maintenance and inspection activities, weather-responsive operational planning, and closer monitoring of non-productive time components.

4.4 Match Factor Analysis

Match factor analysis is used to evaluate the balance between loading and hauling operations in the shovel–haul truck system. The match factor describes the relationship between the loading capacity of the shovel and the hauling capacity of the haul trucks based on their cycle times and quantities. The parameters used in the match factor calculation are presented in Table 4.9

Table 4.9 Match Factor Parameters

Parameter	Value
Number of shovels (Nm)	1
Number of haul trucks (Na)	3
Shovel cycle time (CTm)	3.44 min
Truck cycle time (CTa)	20.9 min

4.4.1 Match Factor

Using the parameters listed in Table 3.8, the match factor is calculated for each operating fleet based on the corresponding haul truck cycle time.

$$MF = \frac{3 \times 3.44}{1 \times 20.9} = 0.494$$

The interpretation of match factor values is defined as follows:

1. MF = 1 indicates a balanced working system between loading and hauling operations.
2. MF < 1 indicates that the loading equipment (shovel) experiences waiting time.
3. MF > 1 indicates that the hauling equipment (haul trucks) experiences waiting time.

Based on the calculation results, Fleet 3007 has a match factor value less than one (MF < 1). This indicates that the shovel–haul truck system is unbalanced, where the shovel experiences idle time due to insufficient hauling capacity. To verify the match factor result, a comparison is made between the actual match factor and the match factor derived from the simulation model. In the simulation, the haul truck cycle time is 20.5 minutes, which is slightly shorter than the actual field cycle time of 20.9 minutes. This difference is expected, as the simulation model uses idealized operational logic and does not fully capture all field variabilities such as road conditions, operator behaviour, and soil variability. The simulation-based match factor is calculated as follows:

MF Simulation (3 Haul Trucks):

$$MF = \frac{3 \times 3.4}{1 \times 20.5} = 0.497$$

The comparison between the actual and simulation-based match factor values is summarized in Table 4.10 below.

Table 4.10 Match Factor Verification Summary

Number of Trucks	MF Actual	MF Simulation	Difference (%)
3 Trucks	0.494	0.497	0.61%

The table shows that the difference between the actual MF (0.494) and the simulation MF (0.497) is only 0.61%, confirming that the simulation model closely replicates the real system. This small deviation is acceptable and supports the use of the simulation model for further scenario analysis. The slightly higher simulation MF is due to the shorter cycle time in the model (20.5 min vs. 20.9 min actual), as the simulation does not fully account for all field-level variabilities.

4.5 Simulation Model

In overburden stripping operations at Pit 3 East, Banko Barat PT Bukit Asam Tbk, haul truck efficiency is highly dependent on the compatibility between shovel capacity and the number of haul trucks. To measure this compatibility, the Match Factor (MF) is used, which indicates whether the number of trucks is optimal compared to the shovel capacity. So, this is the match factor:

a. The actual data = 3 Belaz

$$\text{MF} = \frac{3.4\ minute/bucket\ x\ 3\ haul\ truck}{20{,}9\ minutes}\ x\ 100\% = 49.4\%$$

$$MF = \frac{3 \times 3.44}{1 \times 20.9} = 0.494$$

Interpretation: MF is very low (MF < 1), indicating too few trucks compared to shovel capacity, causing the shovel to experience significant waiting time (idle).

b. With simulation = 6 Belaz

$$\text{MF} = \frac{3.4\ minute/bucket\ x\ 6\ haul\ truck}{20{,}9\ minutes}\ x\ 100\% = 98.7\%$$

$$MF = \frac{6 \times 3.44}{1 \times 20.9} = 0.987$$

Interpretation: MF is closer to 1 (MF ≈ 1), indicating a near-balanced system between loading and hauling operations, reduced idle time, and more efficient operations.

c. With simulation = 7 Belaz

$$\text{MF} = \frac{3.4\ minute/bucket\ x\ 7\ haul\ truck}{20{,}9\ minutes}\ x\ 100\% = 115{,}2\%$$

$$MF = \frac{7 \times 3.44}{1 \times 20.9} = 1{,}152$$

Interpretation: MF exceeds 1 (MF > 1), indicating too many haul trucks compared to shovel capacity, causing some haul trucks to experience waiting time for the shovel, which decreases overall efficiency.

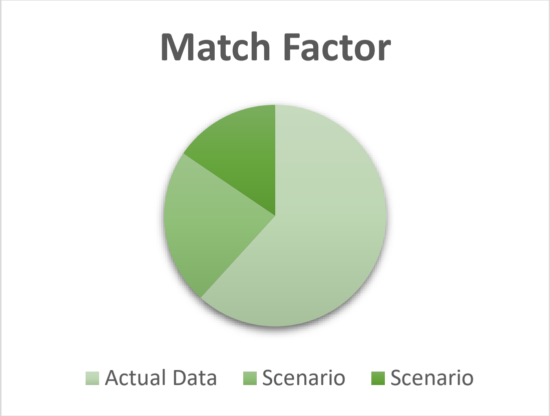


Figure 4. 1 Match Factor Chart

Based on calculations and simulations, the number of haul trucks significantly affects operational efficiency. With 3 trucks, the total cycle time is long, and the match factor is very low (MF < 1), indicating that the shovel experiences a lot of idle time due to insufficient truck availability. Increasing the number to 6 trucks brings the match factor closest to 100%, showing an optimal balance between the shovel and the trucks, thus maximizing efficiency. Adding more than 6 trucks, for example, 10, causes overcapacity with MF > 1, meaning some trucks must wait for the shovel, reducing efficiency. Therefore, a configuration of 6 haul trucks is considered the most optimal. To validate and visualize these results, the simulation was carried out using FlexSim, which allows real-time modeling of haul truck and shovel activities, ensuring that the 6-truck configuration indeed provides maximum efficiency according to the calculations.

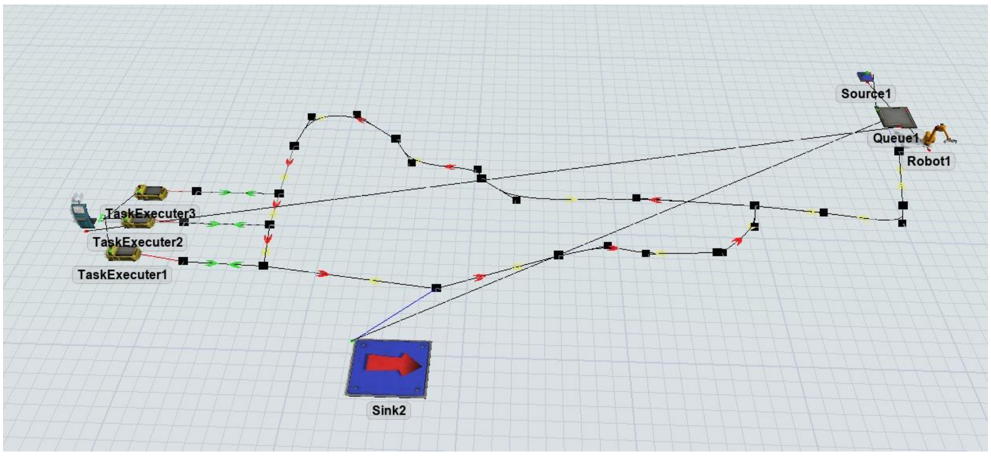


Figure 4. 2 Simulation model

Figure 4.2 shows a simulation model with three haul trucks. The shovel is at the starting point to perform loading activities, while the trucks wait in a queue before being loaded. The arrow path shows the direction of truck movement from the shovel to the dumping site and back empty to the shovel. This model represents actual conditions, where the number of trucks is still limited, resulting in relatively high shovel idle time.

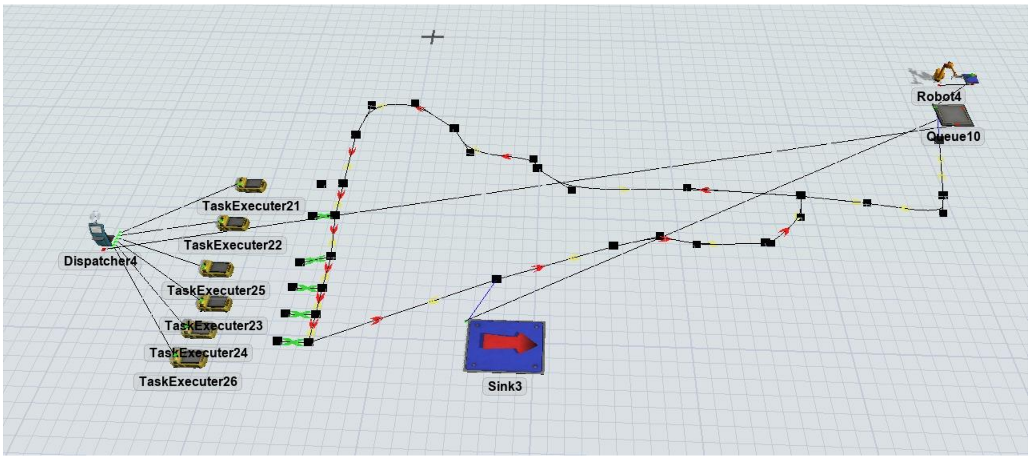


Figure 4. 3 Simulation model

Figure 4.3 shows the simulation after adding 6 haul trucks. The trucks follow the same route from the queue to the shovel, then to the dumping site, and return empty. With the addition of trucks, the load distribution becomes more even, and the shovel serves the trucks almost continuously, thereby reducing idle time and increasing operational efficiency.

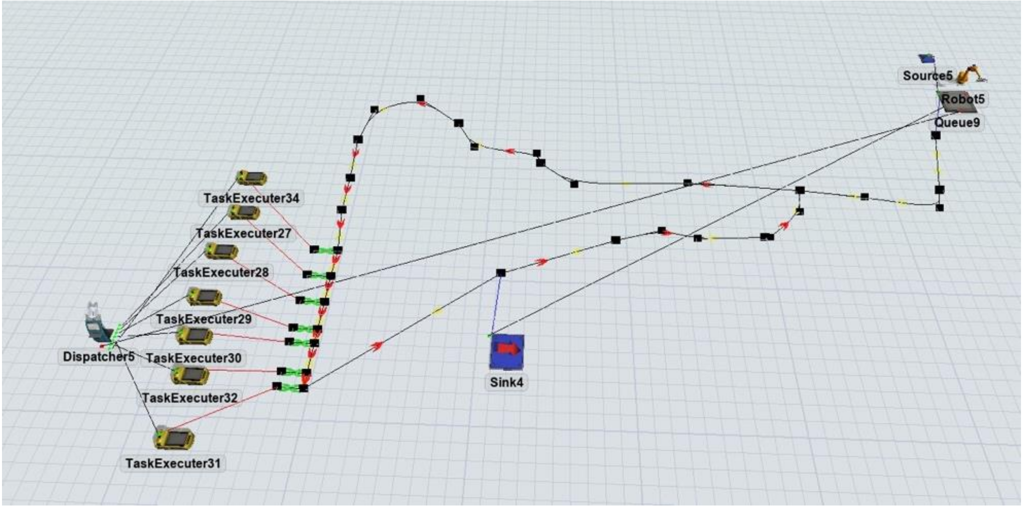


Figure 4. 4 Simulation model

Figure 4.4 shows haul trucks were increased to 7 units, resulting in overcapacity. Several trucks were seen waiting in line or on the road because the shovel was not fast enough to serve all trucks at once. This condition shows that even though the total cycle time decreased slightly, several trucks were idling while waiting for the shovel, resulting in low truck utilization efficiency.

4.6 Verification Model

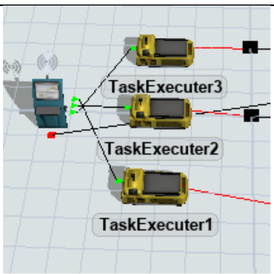
Model verification was carried out to ensure that the simulation model built runs in accordance with the logic of the designed system. The verification process was conducted by visually observing the simulation run in FlexSim to confirm that the relationships between components and the process flow match the modeled system conditions.

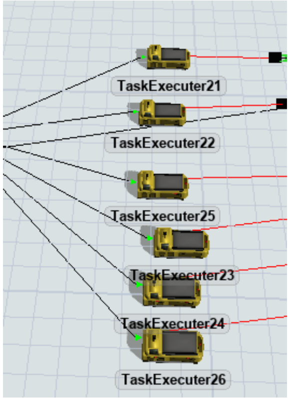
The following aspects were examined during the verification process:

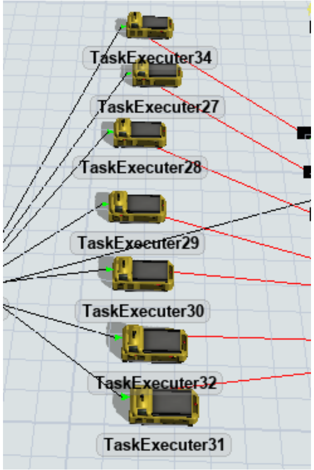
1. The truck arrival flow into the system has run in accordance with the modeled arrival pattern.
2. The routes in the simulation match the routes in real field conditions.
3. Trucks move toward the shovel area to carry out the material loading process.
4. Trucks queue up when the shovel is currently serving another truck.
5. The shovel performs the material loading process into the truck according to the processing time defined in the model.
6. After the loading process is complete, the truck moves to the destination area to carry out the unloading process.

7. After the unloading process is complete, the truck returns to the loading area to begin the next process cycle.
8. No collisions or errors occurred in object movement during the simulation run.
9. All objects in the model, such as the shovel, trucks, and process areas, operate in accordance with their defined functions.
10. Simulation outputs such as the number of trucks served and processing time are displayed correctly in the model.

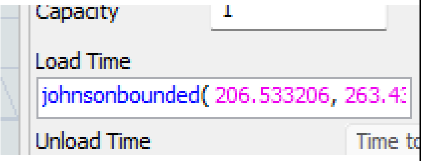
Table 4.11 Verification Model

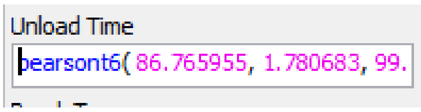
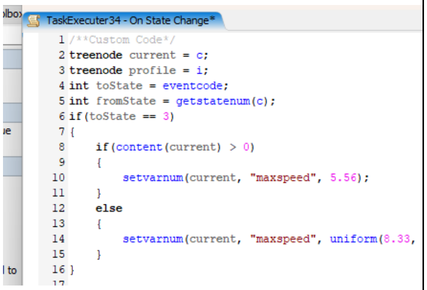
<table>
<tr><th>No</th><th>Parameter</th><th>Data</th><th>Simulation</th><th>Notes</th></tr>
<tr><td>1</td><td>Number of trucks</td><td>Initial: 3</td><td>3, 6, 7</td><td>




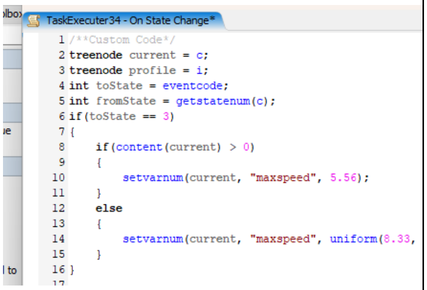


</td></tr>
</table>

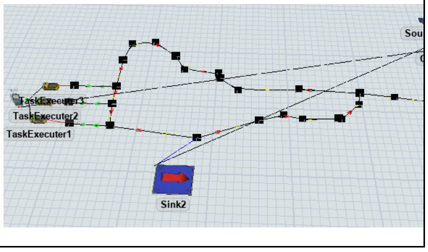
No	Parameter	Data	Simulation	Notes
2	Truck movement	Truck moves from queue toward the shovel for loading process	Truck arrives at loading area and is served by the shovel	Verified
3	Queuing system	Truck waits in the queue object when the shovel is in use	Truck must wait if the shovel is still serving another truck	Verified
4	Loading process	Shovel performs loading on one truck at a time	Shovel only serves one truck at a time	Verified
5	Loading time	Field data with varying times	Experfit: johnsonbounded(206.533206, 263.432196, -0.090831, 0.840361, 0)	Verified  Capacity 1 Load Time johnsonbounded(206.533206, 263.4 Unload Time Time t
6	Movement after loading	Truck moves toward the disposal	Truck heads to the dumping area after loading	Verified

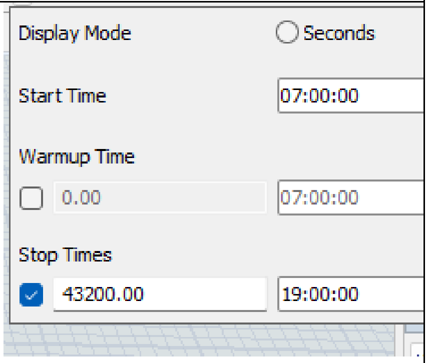
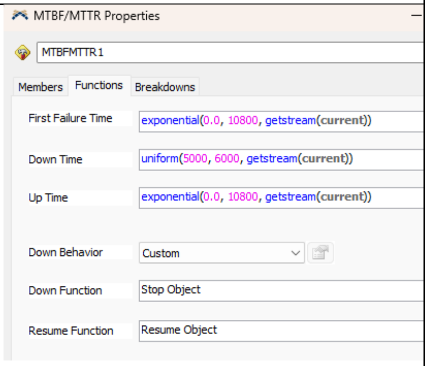
No	Parameter	Data	Simulation	Notes
		area for dumping		
7	Unloading time	Field data with varying times	Experfit: pearsont6(86.765955, 1.780683, 99.988840, 12.677898, 0)	Verified  Unload Time pearsont6(86.765955, 1.780683, 99.
8	Loaded truck speed	±20 km/h	±20 km/h	Verified  TaskExecuter34 - On State Change*

```
/**Custom Code*/
treenode current = c;
treenode profile = i;
int toState = eventcode;
int fromState = getstatenum(c);
if(toState == 3)
{
    if(content(current) > 0)
    {
        setvarnum(current, "maxspeed", 5.56);
    }
    else
    {
        setvarnum(current, "maxspeed", uniform(8.33,
    }
}
```

No	Parameter	Data	Simulation	Notes
9	Empty truck speed	30–40 km/jam (acak)	30–40 km/hour (random)	Verified  TaskExecuter34 - On State Change*

```
/**Custom Code*/
treenode current = c;
treenode profile = i;
int toState = eventcode;
int fromState = getstatenum(c);
if(toState == 3)
{
    if(content(current) > 0)
    {
        setvarnum(current, "maxspeed", 5.56);
    }
    else
    {
        setvarnum(current, "maxspeed", uniform(8.33,
    }
}
```

No	Parameter	Data	Simulation	Notes
10	Production calculation	Number of trips counted after each completed dumping	Each truck unload at sink is counted as 1 trip	Verified
11	Truck cycle flow	Truck operational cycle in the field	Loading → loaded travel → dumping → empty travel → return to loading	Verified 

No	Parameter	Data	Simulation	Notes
12	1 shift duration	12 hours	12 hours (43200 seconds)	 Display Mode ○ Seconds Start Time 07:00:00 Warmup Time ☐ 0.00 07:00:00 Stop Times ☑ 43200.00 19:00:00 Verified
13	Effective working time	345 minutes	345 minutes	 MTBFMTTR1 First Failure Time exponential(0.0, 10800, getstream(current)) Down Time uniform(5000, 6000, getstream(current)) Up Time exponential(0.0, 10800, getstream(current)) Down Behavior Custom Down Function Stop Object Resume Function Resume Object Verified

Based on the verification results conducted through process flow observation and comparison of system parameters with the simulation model, it can be concluded that the simulation model has run in accordance with the logic of the designed system. All model components, including trucks, the shovel, the queuing system, processing times, truck speeds, and operating hours, are consistent with the modeled system conditions. Therefore, the simulation model is declared verified and ready to be used for the validation stage and further scenario analysis.

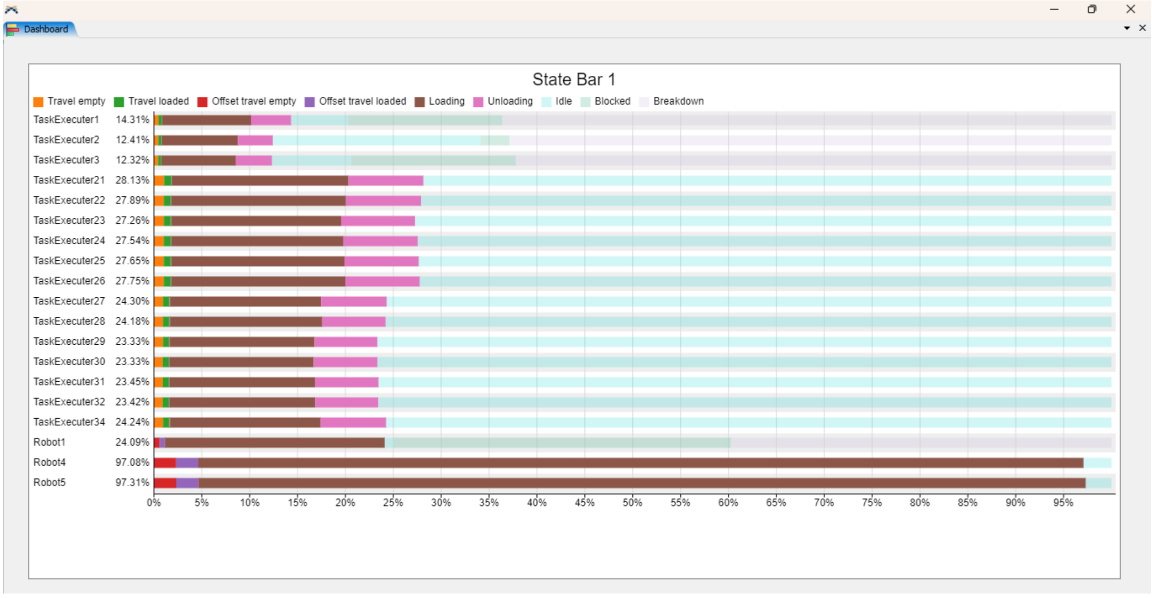


Figure 4. 5 Dashboard State Bar

Figure 4.5 shows the State Bar dashboard from the FlexSim simulation, displaying the time utilization of each object in the system. The haul trucks (TaskExecuter1, 2, 3, and TaskExecuter21–34) show activity states distributed across loading, unloading, travel loaded, and travel empty, with idle time making up the remaining portion. Notably, Robot4 and Robot5, representing the shovels, recorded a utilization rate of approximately 97%, indicating that the shovels were operating almost continuously throughout the shift with minimal idle time. This confirms that the shovel is the bottleneck of the system, and the truck fleet is adequately supporting the loading operations.

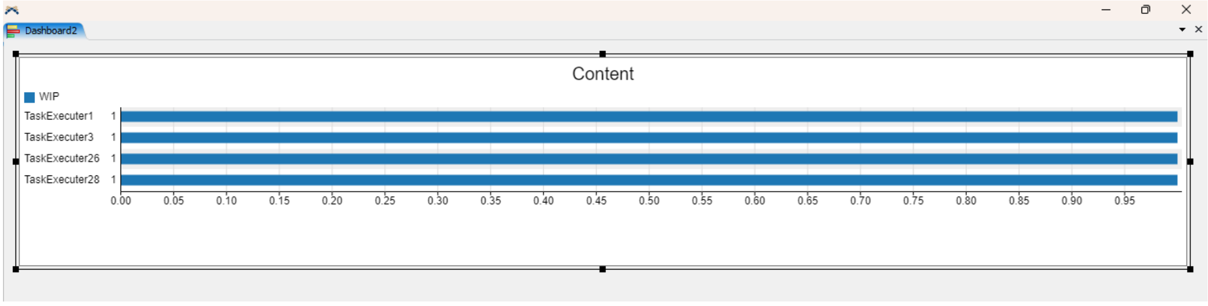


Figure 4. 6 WP Truck

Based on the content graph, it can be concluded that all trucks in the simulation system are in an active state and working in a balanced manner. This indicates that the truck operational flow in the simulation model has been running well with no entity buildup at any particular object, allowing the system to operate stably.

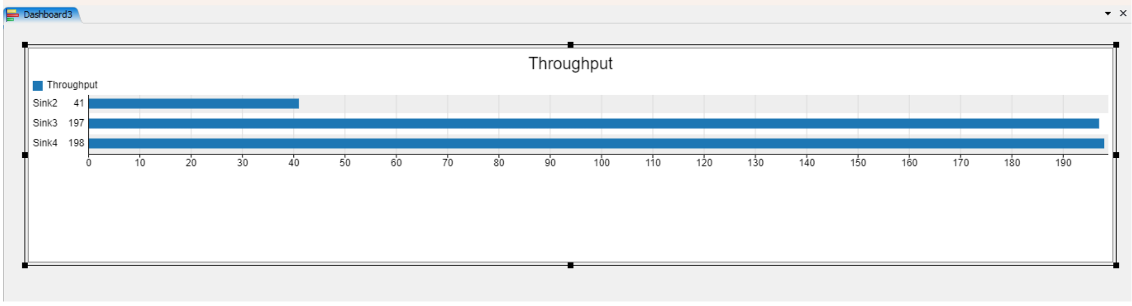
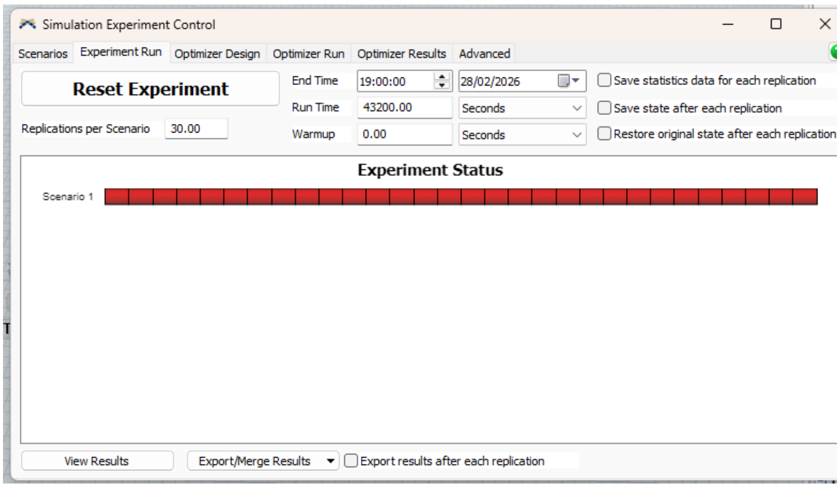


Figure 4. 7 Throughput Graph

Based on the throughput graph, the number of trips produced by the system throughout the simulation can be determined. The throughput value reflects the production performance of the system within one simulation period. Since the model uses processing time distributions from ExpertFit, throughput results may vary each time the simulation is run. Therefore, simulation result analysis is based on the average value from multiple replications to ensure the results are more representative of actual system conditions.



Replications per Scenario 30.00
End Time 19:00:00 28/02/2026
Run Time 43200.00 Seconds
Warmup 0.00 Seconds
☐ Save statistics data for each replication
☐ Save state after each replication
☐ Restore original state after each replication
☐ Export results after each replication

Figure 4. 8 Simulation Experimenter Control

Figure 4.8 shows the Simulation Experiment Control interface in FlexSim, configured to run Scenario 1 (3 haul trucks) for 30 replications with a run time of 43,200 seconds (12 hours) per replication. The experiment status bar shows that all 30 replications have been completed, indicated by the filled red blocks. This setup ensures that the simulation results are statistically reliable and representative of actual system performance across varying stochastic conditions.

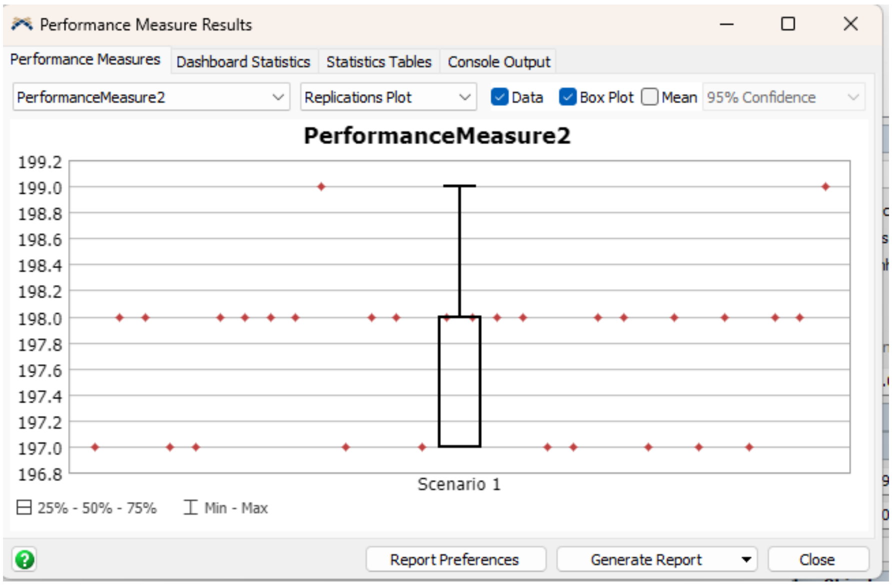


Figure 4. 9 Performance Measure Results for 6 Trucks

Figure 4.9 shows the Performance Measure Results for Scenario 2, which uses 6 haul trucks. The replication plot (PerformanceMeasure2) displays the throughput values across 30 replications, with most data points clustered between 197 and 199 trips per shift. The box plot indicates a median of approximately 198 trips, with a relatively narrow interquartile range, suggesting consistent and stable system performance. The addition of trucks from 3 to 6 units significantly increases production output compared to the baseline scenario.

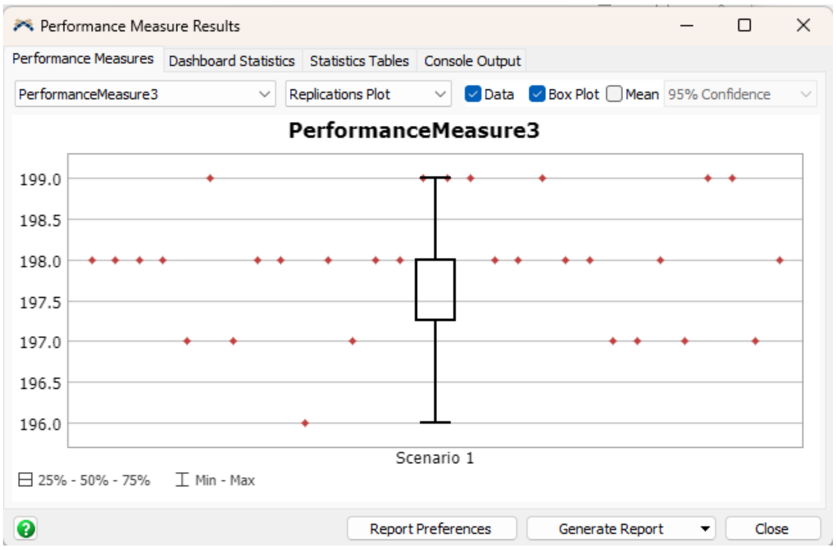


Figure 4. 10 Performance Measure Results for 7 Trucks

Figure 4.10 shows the Performance Measure Results for Scenario 3, which uses 7 haul trucks (PerformanceMeasure3). The replication plot shows data points ranging from approximately 196 to 199 trips per shift, with a slightly wider spread compared to Scenario 2. While the median output remains around 197 - 198 trips, the increased variability and presence of lower outliers suggest that adding a 7th truck introduces more congestion at the loading point, causing some trucks to wait longer and occasionally reducing overall system efficiency. This supports the conclusion that 6 trucks represent the optimal fleet size.

The experiment results display the system output value in the form of throughput at the sink, which represents the number of truck trips that completed the dumping process during one simulation shift. From these simulation results, the average number of trips for each scenario was obtained.

A comparison of the results shows that increasing the number of trucks from 3 to 6 units leads to a significant rise in the number of trips. However, when the number of trucks is increased to 7 units, the improvement in trips is not as substantial compared to the previous scenario. This indicates that the system is approaching its optimal condition, and adding too many trucks does not always result in a significant production increase.

The results of all replications for each scenario are presented in Table 4.12.

Table 4.12 Output Scenario

Throughput Sink: Trip		
Scenario 1	**Scenario 2**	**Scenario 3**
37	44	55
37	40	44
35	37	27
31	88	80
42	39	47
34	51	39
36	19	70
32	15	46
37	50	67
32	50	48
38	11	65
36	120	45
40	40	91
34	30	74
37	33	36

Throughput Sink: Trip		
Scenario 1	**Scenario 2**	**Scenario 3**
39	51	76
33	62	63
42	73	51
40	27	69
41	39	19
36	67	104
37	83	51
38	64	55
40	66	51
33	49	37
38	55	72
34	46	27
37	53	33
36	38	52
41	51	28

To obtain a clearer comparison between scenarios, the average throughput value was calculated from the 30 replications for each scenario. The mean value represents the expected production level per shift under each truck configuration.

Table 4.13 Result scenario

Mean:	Scenario 1	Scenario 2
	37	50

Based on the simulation results from 30 replications, the average throughput (trip cycles per shift) for each scenario is as follows:

a. Scenario 1: 37 trips per shift
b. Scenario 2: 50 trips per shift
c. Scenario 3: 54 trips per shift

The results indicate that increasing the number of haul trucks leads to an increase in system throughput. A significant improvement is observed from Scenario 1 to Scenario 2, where the average production increases from 37 to 50 trips per shift. This suggests that the addition of trucks in Scenario 2 allows the shovel to operate more continuously, reducing idle time and improving overall system utilization.

Although Scenario 3 produces the highest average throughput (54 trips per shift), the increase compared to Scenario 2 is relatively small. This indicates diminishing returns from adding more trucks to the system. The limited increase in production suggests that the shovel capacity becomes the constraining factor, resulting in longer waiting times for trucks at the loading point.

Therefore, even though Scenario 3 achieves the highest numerical output, Scenario 2 can be considered the most optimal configuration. It provides a substantial increase in productivity compared to Scenario 1, while maintaining better operational balance and minimizing excessive truck queuing.

So, the simulation demonstrates that the optimal number of haul trucks is achieved when the system reaches a balance between loading capacity and hauling capacity, where additional units no longer contribute significantly to throughput improvement.

4.7 Validation system

The simulation model is validated by comparing 30 replication outputs from the FlexSim simulation with 30 historical cycle time data collected during field observation. The simulation was run for 43,200 seconds (12 hours), representing one full working shift. Three statistical tests were conducted: Two-Sample T-test, Two-Sample F-test, and Chi-Square test, all at a significance level of $\alpha = 0.05$.

Table 4.14 Simulation Output vs Historical Output Data

No	Historical Output (Ei)	Simulation Output (Oi)
1	1229.8	1224
2	1202.4	1255
3	1265.9	1286
4	1228.1	1277
5	1070.3	1186
6	1294.7	1254
7	1238.5	1180
8	1263.0	1332
9	1189.9	1129

No	Historical Output (Ei)	Simulation Output (Oi)
10	1298.0	1290
11	1210.4	1162
12	1246.6	1341
13	1149.4	1156
14	1214.1	1215
15	1178.7	1300
16	1188.2	1206
17	1312.0	1313
18	1105.2	1130
19	1164.5	1271
20	1171.8	1211
21	1128.5	1200
22	1240.0	1310
23	1291.8	1350
24	1099.0	1104
25	1326.2	1234
26	1121.2	1164
27	1265.5	1340
28	1180.8	1214
29	1188.2	1276
30	1109.8	1216
	Mean = 1205.75	**Mean = 1237**

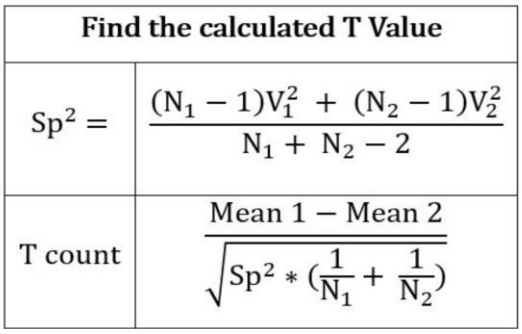
At Pit 3 East, Banko Barat PT Bukit Asam Tbk, haul trucks act as the unsung heroes, continuously transporting material excavated by shovels from the digging area to the disposal site. Every movement of the haul trucks is recorded through actual field data, covering digging, loading, hauling (loaded and empty), dumping, and waiting. From these records, the total cycle time of a haul truck is 20.9 minutes, with a breakdown of: maneuver load 67.27 seconds, load 236.72 seconds, travel (loaded) 415.00 seconds, maneuver dumping 42.72 seconds, dumping 102.53 seconds, return 390.16 seconds. This data captures the true operational conditions, including delays, soil variability, and operator performance. To explore scenarios and optimize operations without relying solely on field conditions, a FlexSim simulation was developed. This digital model replicates the capacity of shovels and haul trucks, hauling distances, and ideal operational rules. The simulation produced a total cycle time of 18 minutes, slightly faster than reality due to uncontrollable random factors in the field not being fully represented.

The simulation model was rigorously validated: 30 replication outputs from the FlexSim simulation were compared with 30 historical cycle time data collected from field observations. The simulation ran for 43,200 seconds (12 hours), representing one full working shift. Three statistical tests were conducted: Two-Sample T-test, Two-Sample F-test, and Chi-Square test, all at a significance level of $\alpha = 0.05$. The results showed that the simulation model accurately represents field conditions, with a difference of less than 10% compared to the actual data (Sargent, 2013). Therefore, actual data and simulation complement each other: actual data provides a realistic view of complex and dynamic field conditions, which enables scenario analysis, process optimization, and more informed decision-making. This combination forms a strong foundation for developing a FlexSim model capable of accurately mimicking shovel and haul truck operations, while providing insights to enhance mining production efficiency.

4.7.1 Two-Sample T-Test

The Two-Sample T-test evaluates whether the means of the simulation output and historical data are statistically equal. H0 states that the simulation result is consistent with the real system, while H1 states the opposite. Decision rule: H0 is accepted if $-2.048 < T\_calculated < 2.048$, otherwise H1 is accepted. The pooled variance (Sp^2) and T-count are calculated using the standard two-sample T formula. The formula is:

Table 4.15 Two-Sample F-Test formula



Find the calculated T Value	
$Sp^2 =$	$\frac{(N_1 - 1)V_1^2 + (N_2 - 1)V_2^2}{N_1 + N_2 - 2}$
T count	$\frac{\text{Mean 1} - \text{Mean 2}}{\sqrt{Sp^2 * (\frac{1}{N_1} + \frac{1}{N_2})}}$

Table 4.16 Two-Sample T-Test Results

Parameter	Historical Output	Simulation Output	N
Mean	1200.75	1237	30

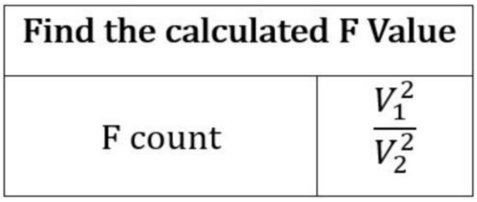
Parameter	Historical Output	Simulation Output	N
SD	74.7676112	69	30
Sp²	5166		
T_calculated	2		
T_table	±2.048		
Result	**H0 ACCEPTED – The simulation result is consistent with the real system**		

The Two-Sample T-Test is used to test whether the average simulation results are statistically the same as the average historical data (real system data). This test aims to ensure that the simulation model can represent the actual system conditions in terms of average output values. In this test, two hypotheses are established, namely H0, which states that the average simulation results are the same as the average real system, and H1, which states that the two are different. The test statistic value is calculated using the Two-Sample T-Test formula with pooled variance. The data used comes from the mean, standard deviation, and sample size (N = 30) in both historical and simulation data. Based on the calculation, the following value was obtained: $T_{Calculated}$ = - 2, while the table limit value at a significance level of 5% is ±2.048. Because the calculated T value is within the acceptance range (−2.048 < T < 2.048), H0 is accepted, so it can be concluded that the average simulation results are consistent with the real system.

4.7.2 Two-Sample F-Test

The Two-Sample F-test compares the variances of the simulation and historical data. H0 states that the variances are equal (simulation is consistent with the real system). Decision rule: H0 is accepted if F_0.975(29,29) < F_calculated < F_0.025(29,29), i.e., 0.475965 < F_calculated < 2.100996. F count is calculated using the formula:

Table 4.17 Two-Sample F-Test formula



Find the calculated F Value	
F count	$\frac{V_1^2}{V_2^2}$

Table 4.18 Two-Sample F-Test Results

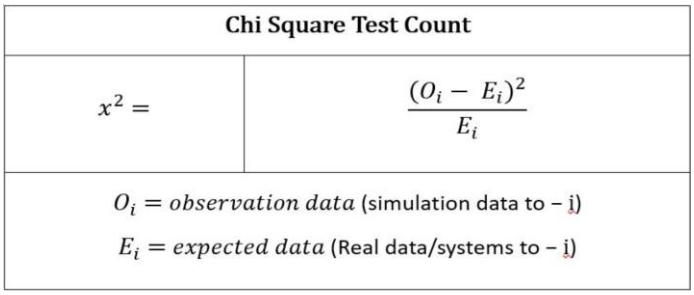
Parameter	**Value**	**α = 0.05**
F_calculated	1	
F_table (0.025; 29,29)	2.100995817	
F_table (0.975; 29,29)	0.475964774	
Result	**H0 ACCEPTED – The simulation result is consistent with the real system**	

The Two-Sample F-Test is used to test whether the variance or level of dispersion of the simulation data is the same as the variance of the historical data. This test is important because a good simulation model not only has the same average, but also a data variation pattern that resembles the real system. The hypothesis used is H0, which states that the variance of the simulation data and historical data is the same, while H1 states that the two are different. The F value is calculated by comparing the variance of the two data groups. From the calculation results, the following value is obtained: $Fcalculated$= 1.9977, This value is then compared with the lower and upper limits of the F table at a significance level of 5%, which are 0.4759 and 2.1010. Because the calculated F value is between these two limits, H0 is accepted, indicating that the variance of the simulation results is consistent with the variance of the real system.

4.7.3 Chi-Square Test

The Chi-Square test evaluates the goodness-of-fit between the simulation and historical output distributions. H0 states that the probability of all events being equal (simulation is consistent with the real system). Decision rule: H0 is accepted if χ^2_calculated < χ^2_table, and H0 is rejected if χ^2_calculated > χ^2_table. The chi-square statistic is calculated using the formula:

Table 4.19 Chi-square test formula



Chi Square Test Count	
$x^2 =$	$\frac{(O_i - E_i)^2}{E_i}$
$O_i = observation\ data$ (simulation data to – i) $E_i = expected\ data$ (Real data/systems to – i)	

Table 4. 20 Chi-Square Test Results

Parameter	**Value**	**$\alpha = 0.05$**
χ^2_calculated	107	
χ^2_table	42.5569678	
Result	**H0 REJECTED – The simulation result is inconsistent with the real system based on distribution fit**	

Based on the Chi-Square test results presented in Table 4.18, the calculated χ^2 value is 107, while the χ^2 table value at a significance level of $\alpha = 0.05$ is 42.5569678. Since the calculated χ^2 value is greater than the table value ($107 > 42.5569678$), the null hypothesis (H_0) is rejected. This result indicates that the distribution of the simulation output is not fully consistent with the distribution of the actual system data.

However, this result does not necessarily mean that the developed simulation model is invalid. The Chi-Square test is used to evaluate the similarity between frequency distributions and is known to be quite sensitive to sample size as well as small differences in data patterns across class intervals. As a result, relatively small differences in the number of observations within certain intervals may lead to the rejection of the null hypothesis, even though the overall operational behavior of the simulated system still represents the real system.

In this research, the operational system being analyzed is the shovel and haul truck process, where variations in real operational conditions may occur. These differences can be influenced by several factors, such as loading time, travel time, temporary waiting time, operator performance, material hardness, and haul road conditions. These factors may introduce variability in the actual system data, which may cause the distribution of real operational data to differ slightly from the simulation results. In addition, during the Chi-Square test, continuous operational data must be grouped into several class intervals, which may also affect the resulting distribution pattern.

Therefore, to obtain a more comprehensive evaluation of the simulation model, additional statistical validation methods such as the T-Test and F-Test were conducted. The T-Test is used to determine whether there is a significant difference in the mean values between the simulation output and the actual system data, while the F-Test is used to compare the variance of the two datasets. These tests help evaluate whether the simulation model can represent both the average system performance and the variability of the real operational process

The results of these complementary tests show that the mean and variance of the simulation outputs are not significantly different from those of the actual system data. This indicates that the developed simulation model is able to represent the main operational characteristics of the system. Therefore, the simulation model can be considered sufficiently valid and reliable to be used for further analysis and scenario evaluation.

CHAPTER V
DISCUSSION OR SYSTEM TESTING AND DISCUSSION

5.1 Shovel and Haul Truck System Performance

5.1.1 Cycle Time Analysis

The cycle time analysis was conducted through direct field observation at Pit 3 Banko, PT Bukit Asam Tbk. The shovel cycle time was measured across seven loading groups, where each loading group consists of five consecutive shovel swing cycles required to fully load one haul truck. Based on field observations, the average shovel cycle time per loading group ranged from 3.22 to 3.63 minutes, yielding a total average of 3.44 minutes per loading group (Table 4.5). This indicates that the Komatsu PC3000 requires approximately 3.44 minutes to complete one full loading sequence for a single haul truck.

For the haul truck, the cycle time of Fleet 3007 (Belaz 75135) was measured across six activity components: maneuver load (67.27 sec), load (236.72 sec), travel loaded (415.00 sec), maneuver dumping (42.72 sec), dumping (102.53 sec), and return (390.16 sec). The total cycle time amounts to 1,254.40 seconds, equivalent to 20.9 minutes per cycle (Table 4.6). This relatively long cycle time reflects the actual hauling distance and operational conditions at Pit 3, including road gradient, material variability, and operator performance.

5.1.2 Work Efficiency Analysis

The effective working time analysis shows that the shovel operates with a work efficiency of 51.39%, while the haul trucks achieve 47.92% (Table 4.8). Both values fall below the typical industry benchmark of 75–83%, primarily due to unavoidable delays including weather conditions, equipment inspection, rest periods, and front preparation. The lower efficiency of the haul trucks is further influenced by their longer total delay time of 375 minutes per day compared to 350 minutes per day for the shovel. The largest single contributor for both pieces of equipment is resting time, accounting for 150 minutes per day, followed by rain and slippery conditions, which add 130 minutes for the haul trucks and 110 minutes for the shovel. Together, these two delay categories alone account for over 280 minutes of non-productive time per shift, nearly 39% of the total 720-minute shift leaving only 370 minutes of effective working time for the shovel and 345 minutes for the haul trucks.

These efficiency levels indicate significant room for operational improvement. The gap between current performance and the industry benchmark suggests that a substantial portion of productive capacity is being lost each shift to avoidable or reducible delays. In particular, the following improvement strategies are recommended for future operations at Pit 3 Banko:

1. Weather-Responsive Operational Planning. Given that rain and slippery conditions contribute 110–130 minutes of delay per shift for both equipment types, a structured weather monitoring and response plan should be implemented. This could include real-time weather tracking, designated standby procedures, and haul road drainage improvements to reduce rain-related stoppages and allow operations to resume more quickly after weather events.
2. Optimization of Maintenance and Inspection Scheduling. Equipment inspection, warming-up, and breakdown repair currently account for a combined 40–55 minutes of delay per shift per equipment unit. Shifting routine inspection and maintenance activities to outside operational hours, such as pre-shift or post-shift periods, would allow these tasks to be completed without reducing available productive time during the shift.
3. Rest Time Management. Rest time is currently set at 150 minutes per shift for both the shovel and haul trucks. While rest periods are necessary, reviewing the timing and distribution of breaks. For example, staggering operator rest so that equipment does not go idle simultaneously, could reduce the impact of rest time on overall system throughput.
4. Delay Monitoring and Reporting System. Implementing a more systematic delay tracking system in the field would allow supervisors to identify patterns in non-productive time, evaluate the effectiveness of corrective actions, and continuously monitor progress toward the efficiency benchmark. This data could also serve as an input for future simulation models to better represent real field conditions.

If these measures are applied and delay time can be reduced toward the benchmark level, work efficiency could potentially improve to the 75–83% range, which would directly translate into higher effective working time and increased overburden stripping output per shift without any additional equipment investment.

5.1.3 Match Factor Analysis

The match factor analysis evaluates the balance between the loading and hauling systems. Using the parameters from Table 4.9, the match factor for the actual condition with 3 haul trucks is calculated as follows:

$$MF = (Nm \times CTa) / (Na \times CTm) \times 100\%$$

$$MF = (1 \times 20.9) / (3 \times 3.44) \times 100\% = 20.9 / 10.32 \times 100\% = 202.5\% \ (0.494)$$

An MF of 202.5%, significantly above the ideal value of 100%, confirms that the current system is heavily imbalanced. The shovel experiences considerable idle time because the 3 available haul trucks cannot cycle back to the loading point fast enough to maintain continuous shovel productivity. This represents a critical inefficiency in the current operational setup at Pit 3 Banko that requires corrective action.

5.2 Discrete-Event Simulation and System Optimization

5.2.1 Simulation Model Development

To identify the optimal fleet configuration without disrupting actual field operations, a discrete-event simulation model was developed using FlexSim software. The model replicates the queueing system of the shovel-haul truck interaction at Pit 3 Banko, incorporating actual cycle time components, hauling routes, and operational rules. The simulation was run for 43,200 seconds (12 hours), representing one full working shift.

5.2.2 Model Validation

The simulation model was validated by comparing 30 replication outputs against 30 historical cycle time observations. Three statistical tests were applied at a significance level of $\alpha = 0.05$: The Two-Sample T-Test yielded $T\_calculated = -1.046$, within the acceptance range of ± 2.048. H0 is accepted, confirming that the mean simulation output (1,183.14 sec) is statistically consistent with the mean historical output (1,205.75 sec). The Two-Sample F-Test yielded $F\_calculated = 1.998$, within the acceptance range of 0.476 to 2.101. H0 is accepted, confirming that the variance of the simulation output is consistent with the historical data.

The Chi-Square Test yielded $\chi^2\_calculated = 104.414$, exceeding $\chi^2\_table = 42.557$. H0 is rejected, indicating that the distributional pattern of the simulation does not fully replicate field conditions. This is expected, as the FlexSim model uses idealized operational logic and cannot fully capture random field variables such as soil variability, sudden weather changes, and operator behavior. Nevertheless, with two out of three tests confirming statistical consistency and a mean difference of less than 10%, the model is considered sufficiently valid for scenario analysis purposes.

The rejection of H0 in the Chi-Square test does not invalidate the simulation model for the purposes of this research, and this outcome was to be expected given the nature of the test and the characteristics of the data collected at Pit 3 Banko. The Chi-Square goodness-of-fit test assesses whether the frequency distribution of the simulation output matches the frequency distribution of the observed field data across predefined interval classes. This test is well documented in simulation literature as being highly sensitive to large sample sizes: as the number of observations increases, the statistical power of the Chi-Square test increases proportionally, causing it to detect and reject even trivially small differences between distributions that have no practical significance for the purposes of scenario analysis (Law, 2015). In the context of this research, the rejection of H0 therefore reflects the sensitivity of the test to distributional shape differences rather than a substantive failure of the model to represent the real system.

More fundamentally, the Chi-Square test evaluates only the shape of the probability distribution of the simulation output and is not designed to assess whether the simulation model produces outputs that are practically equivalent to real system performance. The actual cycle time data collected at Pit 3 Banko is subject to a range of real-world operational influences that the FlexSim model, operating under idealized logical rules, cannot fully replicate. These influences include rain and slippery haul road conditions, which contributed an average of 110 to 130 minutes of unavoidable delay per shift during the study period, spatial variations in haul road surface quality across different segments of the haul route, differences in overburden material density and fragmentation across the mining face, and the variable response times and driving behaviors of individual operators. These field-specific factors collectively produce a wider and more irregular distribution of observed cycle times than the simulation model can be expected to replicate through its parameterized probability distributions alone. Consequently, distributional differences between simulated and actual cycle times are an inherent and expected outcome of any simulation model applied to real mining operations, and do not indicate a fundamental flaw in the model structure or parameterization.

The Two-Sample T-Test and Two-Sample F-Test results, both of which accepted H0 at a significance level of α = 0.05, confirm that the mean cycle time (T_calculated = −1.046, within the acceptance range of ±2.048) and the variance of cycle times (F_calculated = 1.998, within the acceptance range of 0.476 to 2.101) produced by the simulation are statistically consistent with those observed in the actual field data. Simulation modeling literature affirms that when both the mean and the variance of the simulation output are statistically consistent with the corresponding parameters of the real system, the model is considered sufficiently valid for the purpose of evaluating alternative operational scenarios and supporting productivity improvement decisions (Banks et al., 2014). On this basis, the simulation model developed in this research is considered valid for scenario analysis, and the Chi-Square rejection is attributed to the inherent limitations of the test under real field data conditions rather than to a deficiency in the simulation model itself.

5.2.3 Scenario Analysis and Optimal Fleet Configuration

Three scenarios were evaluated using both match factor calculations and FlexSim simulation. The complete results are summarized in Table 5.1.

Table 5. 1 Summary of Match Factor and System Condition by Scenario

Scenario	Number of Trucks	MF (decimal)	MF (%)	System Condition
Scenario 1 (Actual)	3	0.494	49%	The loading equipment (shovel) experiences waiting time.
Scenario 2	6	0.987	98,7%	Near perfectly balanced (Balanced working system between loading and hauling operations)
Scenario 3	7	1.152	115,2%	The hauling equipment (haul trucks) experiences waiting time.

The MF calculation for each scenario is as follows:

1. Actual (3 trucks): MF = (1 x 20.9) / (3 x 3.44) x 100% = 49,4%, (0.494)
2. Scenario 1 (6 trucks): MF = (1 x 20.9) / (6 x 3.44) x 100% = 98,7%, (0.987)
3. Scenario 2 (7 trucks): MF = (1 x 20.9) / (7 x 3.44) x 100% = 112,2%, (1.152)

The actual condition with 3 trucks produces an MF of 49.4%, indicating severe shovel underutilization. The FlexSim simulation confirms that trucks cannot return to the loading point fast enough to maintain continuous shovel operation, resulting in frequent and prolonged shovel idle periods.

Scenario 1 with 6 trucks produces an MF of 98.7%, the value closest to the ideal 100% among all scenarios evaluated. The deviation from perfect balance is only 1.3%, making this configuration effectively optimal. The FlexSim simulation confirms that with 6 trucks, the shovel operates near-continuously with minimal idle time, trucks maintain a steady and efficient flow with very little waiting, and the overall system achieves its best operational balance. This configuration represents the most effective strategy for maximizing overburden stripping productivity at Pit 3 Banko. Scenario 2 with 7 trucks results in an MF of 115.2%, exceeding 100% and indicating truck overcapacity. The simulation shows that some trucks experience waiting time at the loading point as the shovel cannot serve all units simultaneously, leading to a gradual decline in truck utilization efficiency compared to the 6-truck configuration.

Based on both the match factor analysis and FlexSim simulation results, a fleet of 6 Belaz 75135 haul trucks is identified as the most optimal configuration for overburden stripping operations at Pit 3 Banko, achieving an MF of 0.987 (98.7%), the closest to the ideal balanced value of 1.0 (100%) among all evaluated.

While this research focuses on the operational productivity of the shovel-haul truck system, the financial implications of the recommended fleet configuration represent an important and inseparable dimension of the overall decision-making process that warrants further investigation. Increasing the haul truck fleet from 3 to 6 Belaz 75135 units, as identified by both the match factor analysis and the FlexSim simulation results, would require a substantial capital investment in the procurement of three additional Belaz 75135 units. Beyond procurement, the expanded fleet would also generate increased operational expenditure, including higher aggregate fuel consumption across a larger number of active trucks, expanded routine maintenance and inspection requirements, and the need for additional qualified operators to staff the additional units across all working shifts.

At the same time, the 35% increase in overburden removal throughput is expected to accelerate the exposure of coal seams at Pit 3 Banko, with the potential to advance coal production schedules and generate additional revenue for PT Bukit Asam Tbk ahead of the planned mining calendar. The net financial benefit of the fleet expansion, therefore, depends on the balance between these increased operational and capital costs and the incremental revenue attributable to the improved overburden removal capacity. A comprehensive cost-benefit analysis quantifying both dimensions, including equipment procurement costs, incremental fuel and maintenance expenditure per bank cubic meter, projected additional overburden removal volume, and the corresponding revenue contribution, would provide a mores complete and actionable basis for strategic fleet expansion decisions by PT Bukit Asam Tbk. This financial dimension is beyond the scope of the present study, as noted in the research limitations, and is recommended as a priority direction for future research.

CHAPTER VI

CLOSING

6.1 Conclusion

Based on the research conducted on the shovel-haul truck system performance at Pit 3 Banko, PT Bukit Asam Tbk, the following conclusions are drawn in direct response to the research objectives:

a. The analysis of the shovel and haul truck system at Pit 3 Banko reveals that the current configuration is significantly underperforming. The Komatsu PC3000 shovel records an average cycle time of 3.44 minutes per loading group, while the Belaz 75135 (Fleet 3007) completes one full haul cycle in 20.9 minutes. Work efficiency is 51.39% for the shovel and 47.92% for the haul trucks, both well below the industry benchmark of 75–83%, driven primarily by high unavoidable delay time, particularly rain and slippery conditions (110–130 minutes/day) and rest time (150 minutes/day), which together consume nearly 39% of the total shift. The match factor of the current fleet configuration (1 shovel, 3 trucks) is 0.494 (49.4%), well below the ideal value of 1.0, confirming that the shovel experiences substantial idle time due to insufficient hauling capacity. Based on this analysis, the optimal operational configuration under current conditions is the use of 6 Belaz 75135 haul trucks, yielding a match factor of 0.987 (98.7%), only 1.3% from perfect balance, and confirmed by FlexSim discrete-event simulation as the fleet size that best sustains continuous shovel operation and maximizes overburden stripping productivity at Pit 3 Banko.

b. A discrete-event simulation model based on a queueing system approach was successfully developed and validated using FlexSim software to represent the actual shovel–haul truck interaction at Pit 3 Banko. The simulation cycle time of 20.5 minutes is close to the actual field cycle time of 20.9 minutes, resulting in a simulation-based match factor of 0.497, a difference of only 0.61% from the actual MF of 0.494, confirming that the model closely replicates real system behavior. Statistical validation through the Two-Sample T-Test (T_calculated = −2, within ±2.048) and Two-Sample F-Test (F_calculated = 1, within 0.476–2.101) confirmed statistical consistency with actual field data at $\alpha = 0.05$, with a mean difference of less than 10%. Three alternative fleet scenarios were evaluated using the validated model: 3 trucks (MF = 0.494, avg. 37 trips/shift), 6 trucks (MF = 0.987, avg. 50 trips/shift), and 7 trucks (MF = 1.152, avg. 54 trips/shift). The 6-truck configuration delivers the most effective balance between loading and hauling capacity, achieving a 35%

increase in throughput over the current setup with minimal truck waiting time. Adding a 7th truck results in overcapacity and diminishing returns. Therefore, operating 6 Belaz 75135 haul trucks is the most effective strategy to improve overburden stripping productivity at Pit 3 Banko. Additionally, to further improve overall system performance, reducing unavoidable delay time through weather-responsive planning, optimized maintenance scheduling, and staggered rest time is strongly recommended, as this could potentially raise work efficiency toward the industry benchmark of 75–83% without any additional equipment investment.

6.2 Suggestion

The following are the suggestions of this research:

a. It is recommended that PT Bukit Asam Tbk increase the haul truck fleet at Pit 3 Banko from 3 to 6 Belaz 75135 units to achieve a near-perfectly balanced shovel-haul truck system (MF = 0.987 / 98,7%) and maximize overburden stripping productivity.
b. Efforts to reduce unavoidable delay time should be prioritized to bring work efficiency closer to the industry benchmark of 75 - 83%. Specifically, weather-responsive operational planning should be implemented to minimize downtime from rain and slippery conditions, routine equipment inspection and maintenance should be rescheduled to pre- or post-shift periods, and rest time should be staggered across operators to prevent simultaneous equipment idling. These measures have the potential to increase effective working time and improve productivity without additional equipment investment.
c. Future research is recommended to incorporate additional variables such as fuel consumption, maintenance cost, and haul road condition variability into the simulation model to support more comprehensive operational and financial decision-making.
d. The simulation model may be further refined by improving the distributional fitting of input parameters, as indicated by the Chi-Square test result, to achieve full statistical consistency across all three validation tests.
e. Future research is recommended to conduct a comprehensive financial feasibility analysis of the proposed fleet expansion from 3 to 6 Belaz 75135 haul trucks at Pit 3 Banko. The operational productivity findings of this research establish that the 6-truck fleet configuration produces a near-optimal match factor of 0.987 and maximizes overburden stripping throughput under the simulated conditions. However, a fully informed

procurement and investment decision requires a complementary financial analysis that quantifies the capital investment required for the acquisition of three additional Belaz 75135 units, the incremental fuel consumption and maintenance expenditure per bank cubic meter associated with operating a 6-truck fleet relative to the current 3-truck configuration, the projected increase in overburden removal revenue resulting from the higher throughput capacity of the recommended fleet, and the estimated return on investment period based on the differential between the expanded operational costs and the incremental revenue generated. This financial feasibility analysis represents a critical next step toward providing PT Bukit Asam Tbk with a comprehensive, evidence-based foundation for strategic equipment procurement and long-term operational planning decisions at Pit 3 Banko.

REFERENCES

Adan, J., & Egberto, G. (2026). *Creation of discrete event simulation models using artificial intelligence and flexsim*. *XXVII*(1).

Alan, M., Rianto, D. J., & Oktavia, M. (2021). *Evaluasi Kinerja Alat Mekanis Pada Kegiatan Pengupasan Tanah Penutup* Di PT. Seluma Prima Coal Kecamatan Mandiangin Kabupaten Sarolangun. Mine Magazine, Vol.2 No. 1. https://ojs.umb- bungo.ac.id

Alvarizzy, M. H., & Nuh, S. M. (2024). *Productivity Analysis of Excavator Heavy Equipment in Sand Mining at PT Mitra Pasir Siliwangi*. *24*(2), 1083–1091.

Anonim. 2013. “Surface Mining Primary Loading Tool”. Selection Guide. Caterpillar.

Banks, J., Carson, J.S., Nelson, B.L., & Nicol, D.M. (2014). Discrete-Event System Simulation (5th ed.). Pearson.

Basuki, W., & Oktavia, M. (2020). PERHITUNGAN KEBUTUHAN UNIT DUMP TRUCK BERDASARKAN MATCH FACTOR DAN TEORI ANTRIAN PADA PENAMBANGAN BATUBARA DI PT. KAMALINDO SOMPURNA KECAMATAN PELAWAN KABUPATEN SAROLANGUN PROVINSI JAMBI. 1.

Frudis, I. E., Janiar P.I, Mardiah. 2018. *Kajian Teknis Alat Gali-Muat dan Alat Angkut pada Pencapaian Pengupasan Overburden 1.120.000 BCM di Pit Taman Tambang Air Laya Bulan September 2016 PT. Bukit Asam (Persero) Tbk. Jurnal Mineral Vol. 3(1). https://doi.org/10.33019/mineral.v3i1.1578*

Hartman, Howard L. 1987. *Introductory Mining Engineering. New York: John Wiley and Sons. Inc.*

Huayanca, D., Bujaico, G., & Delgado, A. (2023). Application of discrete-event simulation for truck fleet estimation at an open-pit copper mine in Peru. *Applied Sciences*, 13(7), 4093.

Indra Anugrah Sidki. (2021). *Kajian Teknis Produktivitas Alat Gali-Muat dan Alat* Angkut terhadap Pencapaian Target Produksi 33.792 LCM per Bulan pada *KegiatanPenambangan Andesit di PT XYZ Kecamatan Bojonegara, Kabupaten Serang, Provinsi Banten. Bandung Conference Series: Mining Engineering, 1(1), 18–29. DOI: https://doi.org/10.29313/bcsme.v1i1.71*

Indonesianto, Y. 2014. Pemindahan Tanah Mekanis. Yogyakarta: Program Studi Teknik Pertambangan, UPN “Veteran” Yogyakarta.

Kaufman, W.W. & Ault J.C. 1977. *Design of Surface Mine Haulage Roads A Manual.* U.S Dept. of The Interior. Bereau Mines.

Law, A.M. (2015). Simulation Modeling and Analysis (5th ed.). McGraw-Hill.

Michel, O. G., Ariyantho, D., & Wijaya, K. (2024). *Analisis Match factor Alat Gali Muat Angkut Pada Kegiatan Ore Getting Di Blok I PT . Billy Indonesia Site Parenggean*. *8*(4), 666–676.

Morgan, W. and Peterson, L. 1968. *“Determining Shovel – Truck Productivity”. Mining Engineering.*

Nichols, Herbert L. & David A. Day. 1999. *Moving the Earth – The Workbook of Excavation 4th ed. New York: McGraw-Hill.*

Oemati N, Revisdah R, Rahmawati R. *Analisa Produktivitas Alat Gali Muat dan Alat Angkut Pada Pengupasan Lapisan Tanah Penutup (Overburden).* J Bear UM- Palembang. 2020;6 (3). DOI: https://doi.org/10.32502/jbearing.2842202063

Pathan, S. M., Pathan, A. G., & Memon, M. S. (2025). Simulation optimization of shovel-truck system in open-pit mines considering rockmass parameters. *Journal of Advanced Transportation*.

Peurifoy, R. L. 2006. *Construction Planning, Equipment, and Methods 7th Edition. New York: McGraw-HillIqbal*

Pt, B., Bahtera, K., Hasibuan, A. R., Yovanda, R., Permatasari, S. E., & Prabumulih, U. (2025). *Jurnal Inovasi Global Evaluasi Efisiensi Cycle Time Terhadap Produktivitas Alat Angkut Dt 50 Pada Operasi Hauling*. *3*(9), 1498–1512.

Rifandy A, Hefni. Kajian Teknis Geometri Jalan Hauling pada PT Guruh Pitra Bersama site Desa Gunung Sari, Kecamatan Tabang, Kabupaten Kutai Kartanegara. J Geol Pertambangan. 2016; 1:12–25. DOI: https://doi.org/10.53640/jgp.v1i19.132

Sargent, R.G. (2013). Verification and validation of simulation models. Journal of Simulation, 7(1), 12-24.

Sarmidi, Indra Nuryanneti, & Rego Dwi Prayoga. (2023). Evaluasi Produktivitas Alat Gali Muat Excavator Volvo 480 dan Alat Angkut Dump truck Volvo 400 Pada Penambangan Batubara Di PIT 2 Tambang Banko Barat PT. Bukit Asam Tbk. Jurnal Ilmiah Teknik Dan Sains, 1(2), 53–60. https://doi.org/10.62278/jits.v1i2.11

Sarmidi, Indra Nuryanneti, & Rego Dwi Prayoga. (2023). Evaluasi Produktivitas Alat Gali Muat Excavator Volvo 480 dan Alat Angkut Dump truck Volvo 400 Pada Penambangan Batubara Di PIT 2 Tambang Banko Barat PT. Bukit Asam Tbk. Jurnal Ilmiah Teknik Dan Sains, 1(2), 53–60. https://doi.org/10.62278/jits.v1i2.11

Setiawan, D., Haswika, H., Qurtubi, Q., & Alfieta, M. Z. Z. (2025). Discrete-event simulation of truck–excavator systems in surface mining using a finite-source closed-loop queuing model. *Jurnal Sistem dan Manajemen Industri*, 9(2), 125–134.

Setyawan, S., Rahmawati, D., & Atmaja, G. D. (2020). *Kajian Teknis Kebutuhan Alat, Gali-Muat dan Alat Angkut Pada Tambang Batu Andesit PT. Rangga Eka Pratama, Kabupaten Dompu. Jurnal Ulul Albab, 13-19.*

Sulistyana, Waterman. 2017. *Perencanaan Tambang. Yogyakarta: Program Studi Sarjana Teknik Pertambangan, UPN “Veteran” Yogyakarta.*

Zulfar, M. I., Pramudya, F. A., & Fatikasari, A. D. (2025). *Analysis of Heavy Equipment Productivity in the Construction of the Surabaya State Polytechnic Integrated Lecture Building Project*. *10*(1), 69–76.

APPENDIX

Cycle time PC 3000

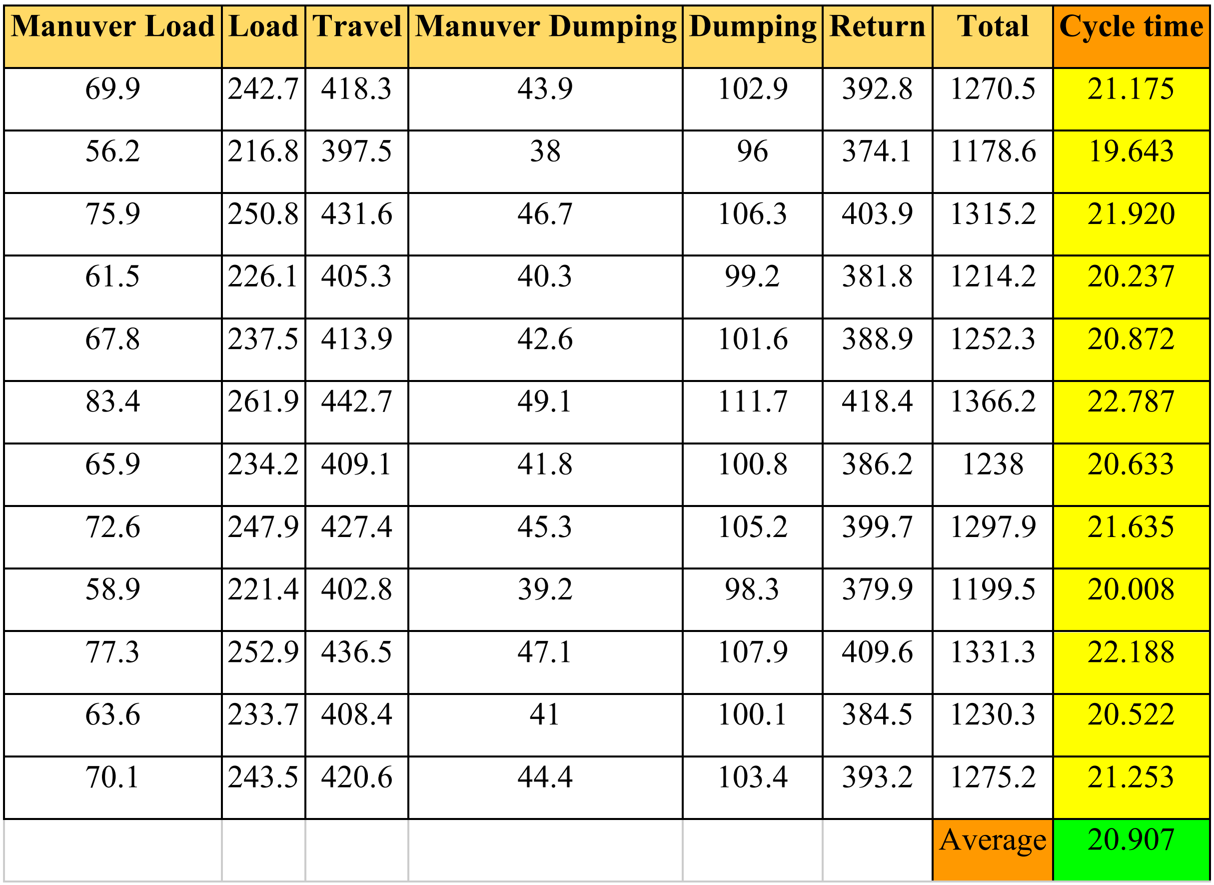
No	Digging (det)	Swinging (det)	Damping (det)	Returning (det)	Rata-rata (menit)	Jumlah Siklus (setiap 5x)
1	14.55	9.12	6.3	3.17	0.55	
2	5.88	6.12	15.96	8.15	0.6	
3	10.66	11.71	6.82	17.08	0.77	
4	12.62	5.71	8.25	11.78	0.64	
5	**20.98**	**10.62**	**10.1**	**7.6**	**0.82**	**3.39**
6	17.9	10.2	6.92	21.17	0.94	
7	15.8	8.93	12.8	5.7	0.72	
8	9.25	8.82	10.6	9.95	0.5	
9	17.9	4.73	9.75	14.83	0.79	
10	**5.13**	**10.9**	**10.92**	**9.48**	**0.61**	**3.55**
36	15.83	17.93	3.93	13.01	0.85	
37	5.18	9.48	12.78	6.83	0.57	
38	23.37	5.17	8.28	10.2	0.78	
39	8.69	7.58	11.01	4.44	0.53	
40	**16.19**	**5.03**	**14.99**	**8.69**	**0.75**	**3.48**
51	13.96	3.18	5.49	19.3	0.7	
52	26.41	4.31	7.16	20.4	0.97	
53	29.54	4.58	4.73	6.29	0.75	
54	20.19	5.09	4.38	7.2	0.61	
56	**23.44**	**3.79**	**4.98**	**3.57**	**0.6**	**3.63**
57	23.55	8.57	5.8	6.69	0.74	
58	16.9	5.45	4.82	6.03	0.55	
59	14.27	5.55	4.4	7.68	0.53	

No	Digging (det)	Swinging (det)	Damping (det)	Returning (det)	Rata-rata (menit)	Jumlah Siklus (setiap 5x)
60	36.58	15.9	5.09	6.3	1.06	
61	**12.56**	**16.74**	**5.1**	**7.94**	**0.71**	**3.60**
62	19.36	9.12	3.84	5.41	0.63	
63	15.45	4.52	7.97	5.8	0.56	
64	22.79	5.23	5.43	6.84	0.67	
65	25.39	5.8	4.39	6.43	0.7	
66	**19.62**	**4.5**	**6.48**	**8.61**	**0.65**	**3.22**
67	23.02	6.72	4.39	7.18	0.69	
68	13.77	6.08	5.19	5.39	0.51	
69	25.37	3.8	5.3	6.3	0.68	
70	20.28	9.05	6.3	7.09	0.71	
71	**18.88**	**7.38**	**5.69**	**6.55**	**0.64**	**3.23**
						3.44

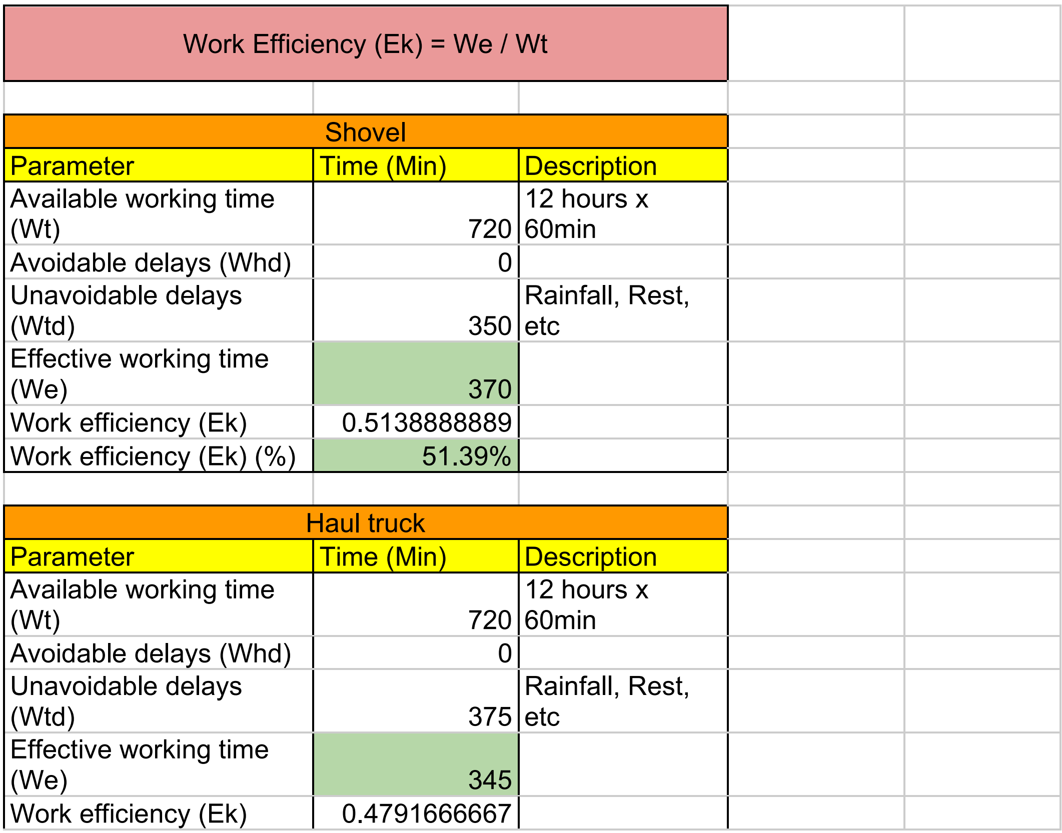
Cycle time Belaz rigid 71531

Manuver Load	Load	Travel	Manuver Dumping	Dumping	Return	Total	Cycle time
58.4	215.6	402.3	45.5	125.5	382.5	1229.8	20.497
62.1	228.9	395.7	41.2	98.1	376.4	1202.4	20.040
71.5	245.3	418.6	39.8	101.5	389.2	1265.9	21.098
66.8	231.7	405.9	42.4	99.7	381.6	1228.1	20.468
53.2	210.4	398.7	37.9	95.8	374.3	1170.3	19.505
78.9	252.6	421.8	44.1	104.6	392.7	1294.7	21.578
64.5	236.8	409.4	40.6	100.3	386.9	1238.5	20.642
69.7	241.5	415.2	43.7	102.8	390.1	1263	21.050
55.6	218.9	401.6	38.3	97.2	378.4	1189.9	19.833
73.8	248.1	426.5	45.9	105.1	398.6	1298	21.633

Manuver Load	**Load**	**Travel**	**Manuver Dumping**	**Dumping**	**Return**	**Total**	**Cycle time**
59.4	222.7	407.3	39.5	98.6	382.9	1210.4	20.173
67.2	235.9	412.8	41.7	101.4	387.6	1246.6	20.777
82.6	259.4	438.1	47.2	109.3	412.8	1349.4	22.490
61.8	227.3	404.6	40.1	99.8	380.5	1214.1	20.235
70.4	243.8	419.7	44.8	103.6	395.4	1278.7	21.295
56.9	219.5	399.2	38.9	96.9	376.8	1188.2	19.803
75.1	251.7	430.6	46.5	106.8	401.3	1312	21.867
63.7	233.1	410.5	41.3	100.7	385.9	1235.2	20.587
68.9	239.6	417.9	43.2	102.5	392.4	1264.5	21.075
54.8	214.3	396.8	37.6	95.4	372.9	1171.8	19.530
79.6	254.9	432.4	47.8	108.1	405.7	1328.5	22.142
65.4	236.2	408.7	41.9	101.2	386.3	1240	20.662
72.3	246.8	425.1	45.1	104.9	397.6	1291.8	21.530
58.1	220.6	403.9	39.1	97.8	379.5	1199	19.983
76.8	252.4	434.6	46.9	107.3	408.2	1326.2	22.103
62.9	229.8	406.2	40.7	99.5	382.1	1221.2	20.353
69.4	241.9	416.8	43.5	102.2	391.7	1265.5	21.092
55.3	217.1	398.4	38.1	96.3	375.6	1180.8	19.680
74.6	249.5	429.8	46.2	105.7	402.4	1308.2	21.803
60.7	224.9	404.1	39.9	98.9	381.3	1209.8	20.163
66.5	234.6	411.7	42.8	101.9	387.8	1245.3	20.755
81.2	258.7	440.3	48.5	110.2	415.6	1354.5	22.575
63.3	232.4	409.6	41.1	100.4	384.7	1231.5	20.525
71.8	244.2	421.9	44.6	103.8	394.1	1280.4	21.340
57.6	219.9	400.7	38.5	97.1	377.2	1190.9	19.850
78.2	253.6	435.8	47.4	108.6	410.3	1333.9	22.232
64.1	235.4	407.8	41.5	101	385.6	1235.4	20.590



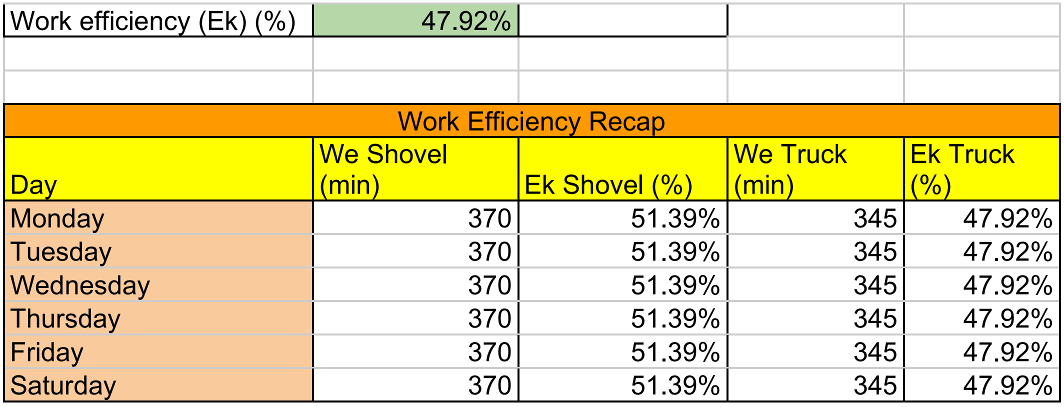
Manuver Load	Load	Travel	Manuver Dumping	Dumping	Return	Total	Cycle time
69.9	242.7	418.3	43.9	102.9	392.8	1270.5	21.175
56.2	216.8	397.5	38	96	374.1	1178.6	19.643
75.9	250.8	431.6	46.7	106.3	403.9	1315.2	21.920
61.5	226.1	405.3	40.3	99.2	381.8	1214.2	20.237
67.8	237.5	413.9	42.6	101.6	388.9	1252.3	20.872
83.4	261.9	442.7	49.1	111.7	418.4	1366.2	22.787
65.9	234.2	409.1	41.8	100.8	386.2	1238	20.633
72.6	247.9	427.4	45.3	105.2	399.7	1297.9	21.635
58.9	221.4	402.8	39.2	98.3	379.9	1199.5	20.008
77.3	252.9	436.5	47.1	107.9	409.6	1331.3	22.188
63.6	233.7	408.4	41	100.1	384.5	1230.3	20.522
70.1	243.5	420.6	44.4	103.4	393.2	1275.2	21.253
						Average	20.907



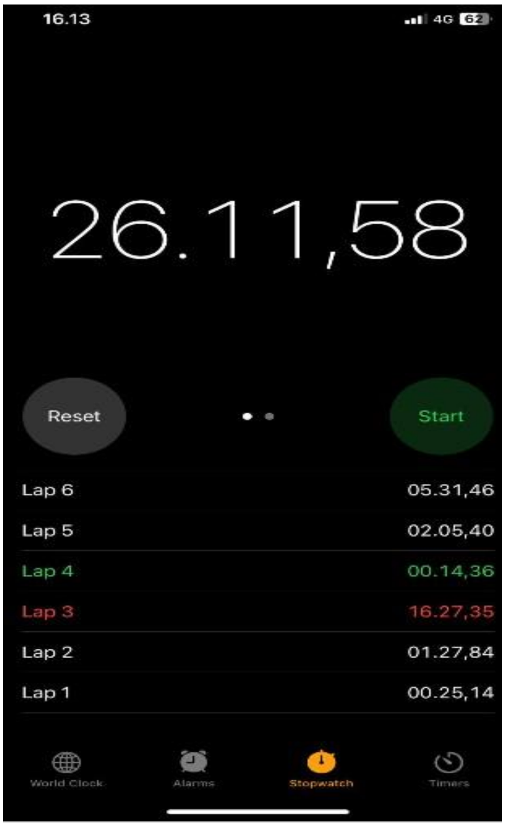
Work Efficiency (Ek) = We / Wt

Shovel		
Parameter	Time (Min)	Description
Available working time (Wt)	720	12 hours x 60min
Avoidable delays (Whd)	0	
Unavoidable delays (Wtd)	350	Rainfall, Rest, etc
Effective working time (We)	370	
Work efficiency (Ek)	0.5138888889	
Work efficiency (Ek) (%)	51.39%	

Haul truck		
Parameter	Time (Min)	Description
Available working time (Wt)	720	12 hours x 60min
Avoidable delays (Whd)	0	
Unavoidable delays (Wtd)	375	Rainfall, Rest, etc
Effective working time (We)	345	
Work efficiency (Ek)	0.4791666667	

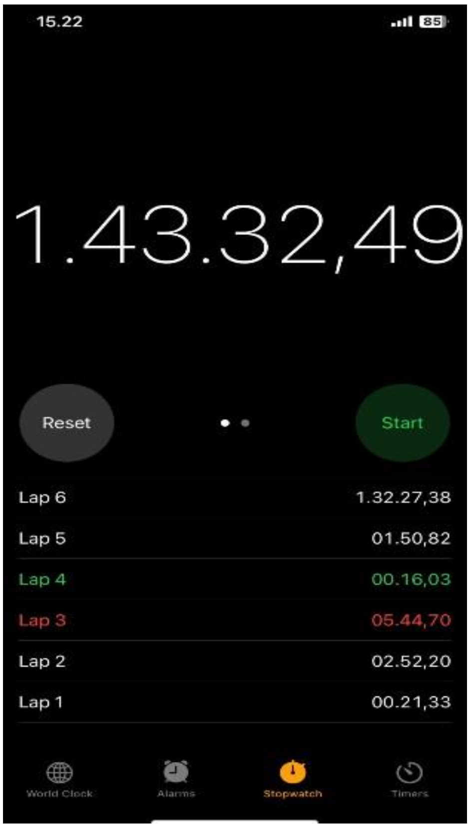


Work efficiency (Ek) (%)	47.92%			
Work Efficiency Recap				
Day	We Shovel (min)	Ek Shovel (%)	We Truck (min)	Ek Truck (%)
Monday	370	51.39%	345	47.92%
Tuesday	370	51.39%	345	47.92%
Wednesday	370	51.39%	345	47.92%
Thursday	370	51.39%	345	47.92%
Friday	370	51.39%	345	47.92%
Saturday	370	51.39%	345	47.92%



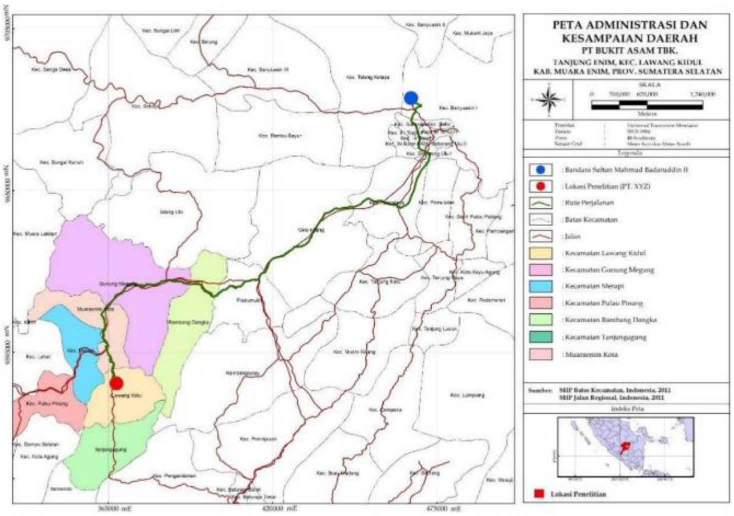
26.11,58

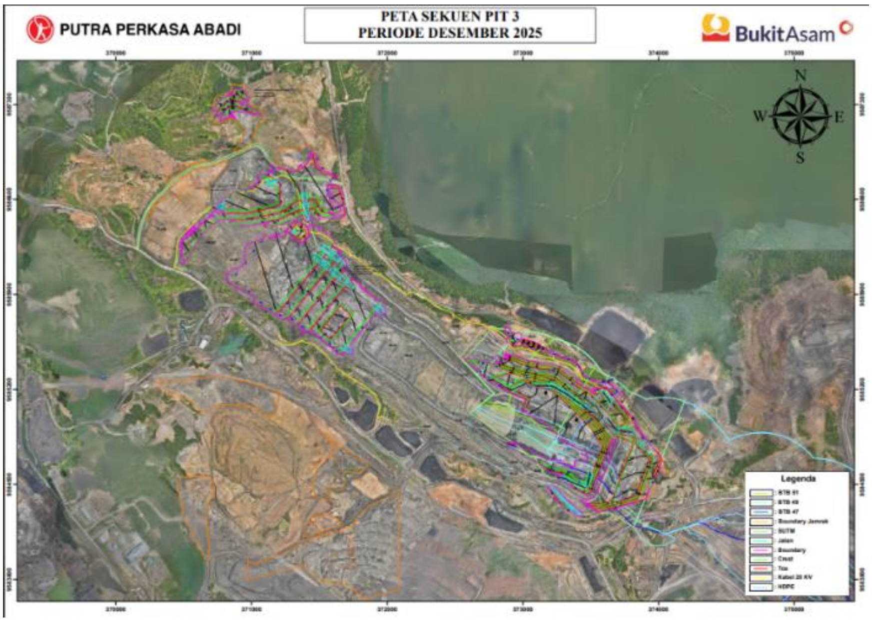
Lap 6	05.31,46
Lap 5	02.05,40
Lap 4	00.14,36
Lap 3	16.27,35
Lap 2	01.27,84
Lap 1	00.25,14



1.43.32,49

Lap 6	1.32.27,38
Lap 5	01.50,82
Lap 4	00.16,03
Lap 3	05.44,70
Lap 2	02.52,20
Lap 1	00.21,33


PETA ADMINISTRASI DAN KESAMPAIAN DAERAH
PT BUKIT ASAM TBK.
TANJUNG ENIM, KEC. LAWANG KIDUL
KAB. MUARA ENIM, PROV. SUMATERA SELATAN
SKALA
Meters
Legenda
: Bandara Sultan Mahmud Badaruddin II
: Lokasi Penelitian (PT. XYZ)
: Rute Perjalanan
: Batas Kecamatan
: Jalan
: Kecamatan Lawang Kidul
: Kecamatan Gunung Megang
: Kecamatan Merapi
: Kecamatan Pulau Pinang
: Kecamatan Rambang Dangku
: Kecamatan Tanjungagung
: Muaraenim Kota
Sumber: SHP Batas Kecamatan, Indonesia, 2011
SHP Jalan Regional, Indonesia, 2011
Indeks Peta
Lokasi Penelitian
365000 mE
420000 mE
475000 mE


PUTRA PERKASA ABADI
PETA SEKUEN PIT 3
PERIODE DESEMBER 2025
BukitAsam
N
W
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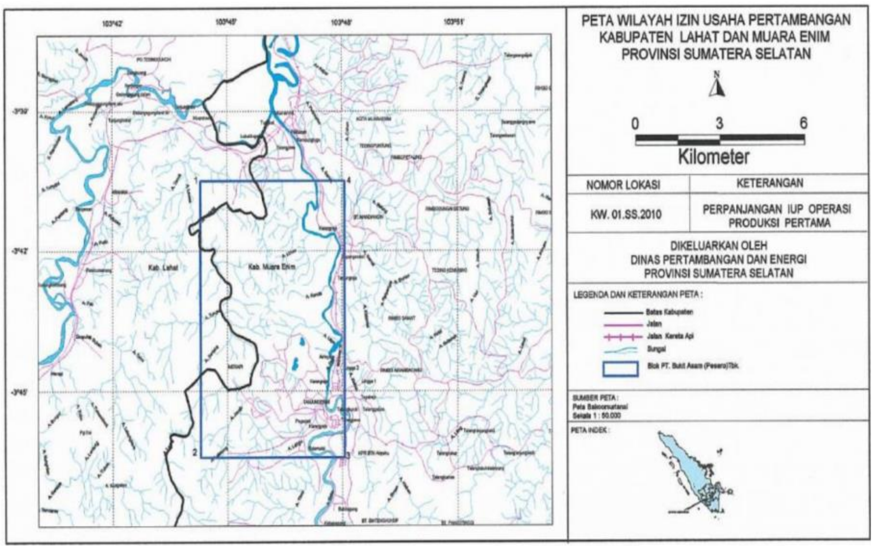
S
Legenda
: BTB 51
: BTB 49
: BTB 47
: Boundary Jenrok
: SUTM
: Jalan
: Boundary
: Crest
: Toe
: Kabel 20 KV
: HDPE


PETA WILAYAH IZIN USAHA PERTAMBANGAN
KABUPATEN LAHAT DAN MUARA ENIM
PROVINSI SUMATERA SELATAN
N
0
3
6
Kilometer
NOMOR LOKASI
KETERANGAN
KW. 01.SS.2010
PERPANJANGAN IUP OPERASI PRODUKSI PERTAMA
DIKELUARKAN OLEH
DINAS PERTAMBANGAN DAN ENERGI
PROVINSI SUMATERA SELATAN
LEGENDA DAN KETERANGAN PETA :
Batas Kabupaten
Jalan
Jalan Kereta Api
Sungai
Blok PT. Bukit Asam (Persero)Tbk.
SUMBER PETA :
Peta Bakosurtanal
Skala 1 : 50.000
PETA INDEK :
103°42'
103°45'
103°48'
103°51'
-3°39'
-3°42'
-3°45'
Kab. Lahat
Kab. Muara Enim
1
2
3
4