

Analysis of Land Transportation System Innovation and Technology in the Coal Mining Industry of Indonesia

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ABSTRACT: This study examines the role of land transportation systems in the coal mining industry in Indonesia, with a focus on how technological innovation influences supply chain performance. As a critical component of coal logistics, transportation connects mining operations with processing and distribution networks, yet faces persistent challenges including infrastructure limitations, high operational costs, and coordination complexities. This paper adopts a conceptual approach through an extensive review and synthesis of existing literature on supply chain management, mining logistics, and transportation systems. The analysis highlights the strategic importance of land-based transportation modes, particularly trucks and rail, and explores how emerging technologies such as GPS-based fleet management systems, digital monitoring platforms, and automation can enhance operational efficiency and reliability. The study proposes that the integration of innovation and technology plays a pivotal role in addressing logistical inefficiencies, improving transparency, and strengthening supply chain coordination. This research contributes to the theoretical understanding of transportation system optimization in the mining sector and provides insights for future research and industry application in the context of Industry 4.0.

KEYWORDS: Coal Mining Industry, Land Transportation Systems, Supply Chain Management, Logistics Optimization, Technological Innovation, Indonesia

I. INTRODUCTION

Coal is a flammable black or brownish black sedimentary rock that consists mostly of carbon and hydrocarbons. Coal is a non-renewable energy source because once this resource is used, it will take a very long time to replace it. This is because the energy in coal comes from energy stored by plants that died millions of years ago. In the coal mining industry, the first step in the mining process is to explore and evaluate coal deposits. After the exploration process is complete and a suitable coal deposit is obtained, the extraction process will then be carried out. The coal extraction process can be done in two ways, namely surface mining and underground mining. Surface mining is usually carried out when the coal seam is less than 200 feet below the ground surface, while the underground mining process is carried out when the coal seam is more than 1000 feet below the ground surface. After the coal comes out of the ground, it is usually transported directly via a conveyor belt to the factory at the mining location. The coal will then be processed to remove dirt, ash, dust, sulfur and other unwanted materials so that the calorific value of the coal increases and it can be marketed to the market (Guo et al., 2025) The following is a diagram of the extraction process in the coal industry using surface mining and underground mining methods:

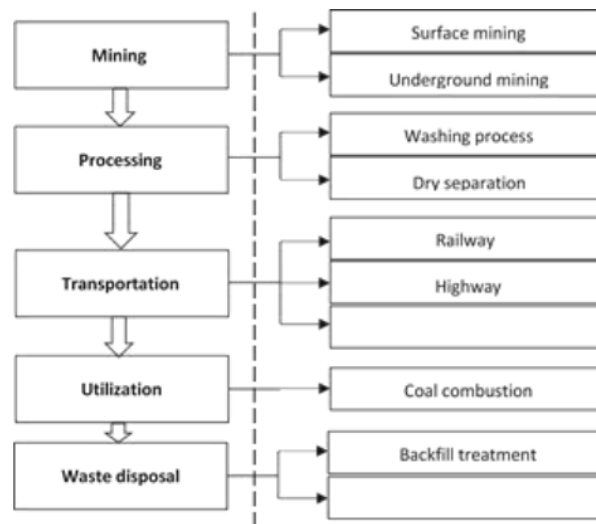


Figure 1. Flow Diagram of the Coal Extraction Process (Guo et al., 2025)

The mining industry in Indonesia itself is an industrial sector that has various important roles. This industry contributed 5-8% of Indonesia's GDP in the last 10 years, of which around 80% came from the coal industry. The mining industry also plays a role in regional development, increasing economic activity, and even opening up job opportunities. According to data from the Ministry of Energy and Mineral Resources, realized coal production in Indonesia in 2020 was 563 million tons, with 134 million tons used for domestic needs and the rest for export needs. This figure will increase in 2021, namely 614 million tonnes (Catur Daminto & Purwanto, 2023). Below is the trend of increasing coal production in Indonesia in the period 2010 to 2021.

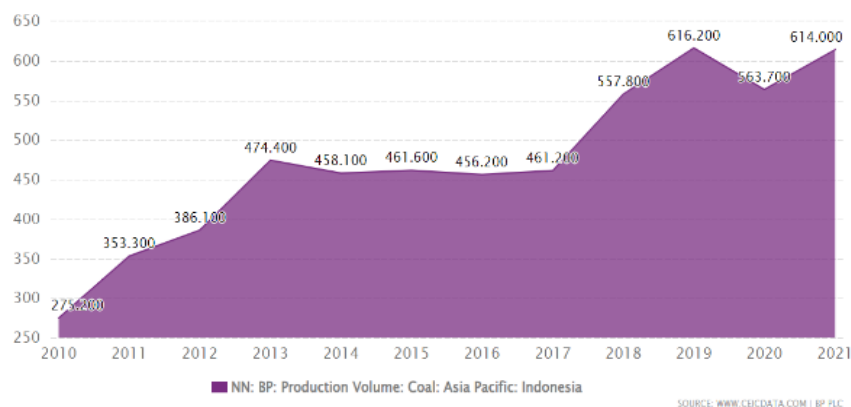


Figure 2. Coal Production Trends: Asia Pacific: Indonesia 2010 – 2021

In Indonesia itself, the 5 provinces that contribute the largest coal production are East Kalimantan, South Kalimantan, South Sumatra, North Kalimantan and Central Kalimantan. According to data from the Ministry of Energy and Mineral Resources, in 2020, these 5 provinces will be able to contribute around 534 million tons of coal production from Indonesia.

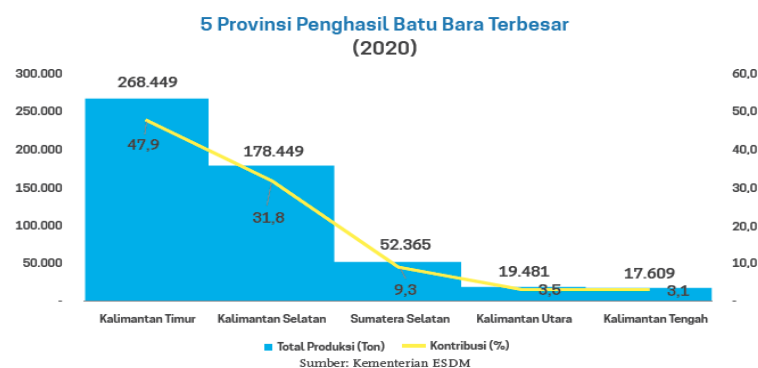


Figure 3. Contribution of Indonesian Coal Producing Provinces in 2020

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This coal commodity from Indonesia is one of the well-known producers abroad, such as China, India and the United States. Seeing the high global market demand for coal from Indonesia, local companies need to create strategies to increase production to meet the increasing demand for coal, one of which is by optimizing the coal transportation performance process. An effective and efficient distribution process for mining products is certainly one of the main factors in a supply chain in the mining industry. Lack of infrastructure will be an obstacle for coal mining activities. Apart from that, transporting coal from mining areas using trucks is also an activity that is difficult to control, because there are many variables that influence the journey of a coal transport truck, starting from the behavioral characteristics of the truck driver which influences many factors, the main one being the speed to the required travel time (Yuniar et al., 2020). This characteristic of driver behavior is a variable that is difficult to control in travel, because it cannot be monitored directly. The transportation process in the mining industry is generally outsourced to third party logistics service providers (3PL Third Party Logistics) so that responsibility for ensuring cost efficiency and customer satisfaction can be shared among all supply chain players. This is a challenge for companies providing transportation services to be able to provide services in accordance with customer requests. In this industrial era 4.0, with the very rapid development of innovation and technology, it can be the answer for companies providing transportation services to help optimize and work efficiency.

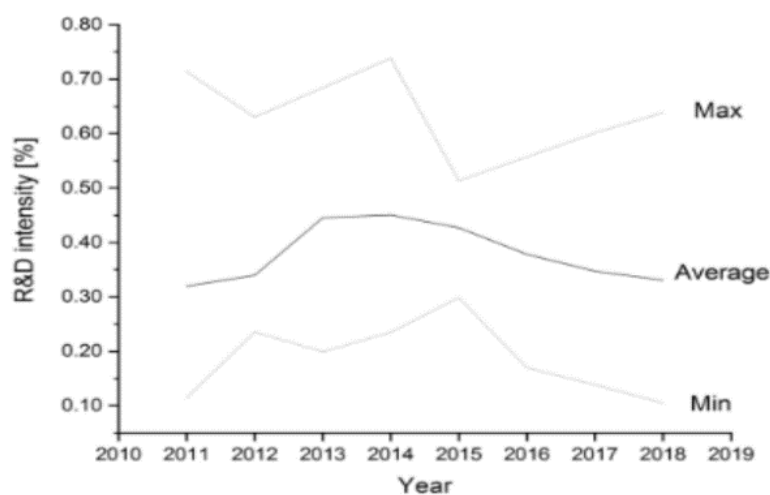


Figure 4. Research and Development Intensity Level in the Mining Industry

The level of research & development intensity in the mining industry sector at 0.4% is very low when compared to the pharmaceutical industry sector at 25.1% and the information and communications industry sector at 24.7%. This is because the mining industry's supply chain system collaborates and relies on heavy equipment suppliers and transportation service providers, where the process of developing and utilizing technology is more extensive compared to coal companies. For example, developing systems for heavy equipment and then innovating technology for monitoring transportation equipment using GPS trackers and so on. In contrast to most mining companies, the supplier sector has a high priority on the innovation agenda. A survey conducted on 432 companies from Mining Equipment, Technology & Services (METS) in Australia, in 2015, revealed that for 63% of these companies, innovation was their core business strategy, primarily driven by a vision focused on customers, the need to stay ahead of the competition and direct solutions to the requirements of their customers (Sánchez & Hartlieb, 2020). This will certainly be an encouragement for transportation service providers, especially in Indonesia, to be more sensitive to technological developments so that they can survive and compete and not be eroded by the rapid development of technology in the digital era. Based on this description, this research will analyze the role of transportation activities in the supply chain cycle in the coal mining industry as well as the impact of the role of innovation and technology on the transportation process in the coal mining industry.

This research analyzes the role of transportation activities in the coal mining industry, specifically focusing on land transport modes such as trucks and trains, while examining how innovation and technology influence operational and financial processes within this sector. The study is limited to the transportation phase of the coal supply chain and seeks to address key questions regarding the role of these activities in the industry cycle and the impact of technological advancements on both operational efficiency and financial outcomes. Ultimately, the research aims to assess the transportation process, identify obstacles in distribution, review the current fleet, and explore how innovations and technology can be leveraged to overcome challenges and improve overall performance. To guide this research, the study proposes the following research question:

RQ: *How do technology and innovation in land-based transportation modes impact the operational efficiency and financial performance of the coal mining supply chain?*

II. LITERATURE REVIEW

Supply Chain Management

The term Supply Chain Management was first proposed by Oliver and Weber, explaining that if the supply chain is a physical network, namely companies involved in supplying raw materials, producing goods, or sending it to the end user, then supply chain management is a method, tool, and management approach (Lambert et al., 1998; Oliver & Webber, 2012). Supply Chain Management is a method or approach for managing product flows, information flows and money flows in an integrated manner involving parties, from upstream to downstream consisting of suppliers, factories and distribution and service activities (Ashraf et al., 2025). In the coal mining industry, supply chain management has a very important role, such as information transparency and collaboration, both between internal company functions and with external company parties (Luo et al., 2017). In general, the supply chain flow in the coal industry can be described as follows:

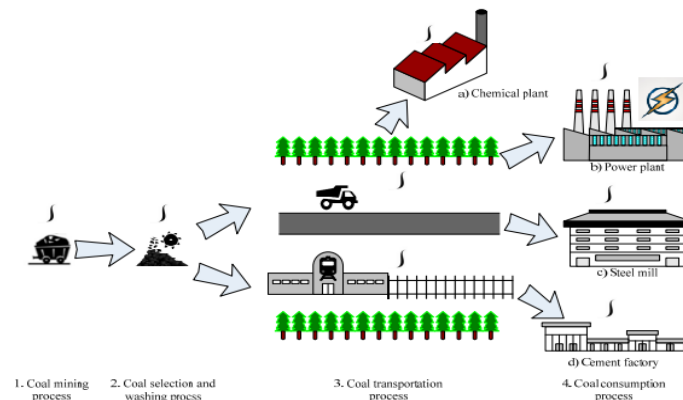


Figure 5. Coal Mining Industry Supply Chain Flow (Luo et al., 2017)

The coal extraction process can be done in two ways, namely surface mining and underground mining. Surface mining is usually carried out when the coal seam is less than 200 feet below the ground surface, while the underground mining process is carried out when the coal seam is more than 1000 feet below the ground surface. Then, the coal is selected and washed. At this stage, the coal will be selected and cleaned to remove dirt, ash, dust, sulfur and other unwanted materials so that the calorific value of the coal increases. After the cleaning process is complete, the coal will then be transported to the plant to be processed according to further needs. The coal will then be processed in the plant for various industrial needs such as the power generation industry, chemical industry, steel industry and cement industry.

Logistics in the Coal Industry

Logistics is a series of efforts that include the effectiveness of planning, implementation, and supervision of a process of moving goods or services, energy or other resources, from the starting point to the user point. Logistics management, together with transportation and warehousing components, are key components that are the foundation for industrial and economic development in the current era (Dadzie & Richard, 2025). Logistics have the following relationship pattern:

Logistics = Materials Management + Distribution

Supply Chain = Suppliers + Logistics + Customers

Logistics in the coal industry means covering the process of transporting coal from origin to destination via single or multimodal transportation modes and includes storage, the process of loading or unloading coal for delivery to power plants, the steel industry, the cement industry sector and various other industrial sectors. Coal logistics infrastructure consists of nodes and connections, often identified as ports, railway stations, warehouses, coal yards, temporary storage areas, and other coalfield areas connected by roads, railways, shipping, pipelines, conveyors, used by various mining operators (Pandey et al., 2025). In the coal mining industry, logistics management is very important to ensure that the process of moving coal from the mine until it can be distributed to users can be controlled properly. Logistics operations in mining companies are largely outsourced to third party logistics service providers (3PL Third Party Logistics). Therefore, responsibility for ensuring cost efficiency and customer satisfaction can be shared among all supply chain players (Yaping & Bossman, 2021).

Transportation Systems in the Coal Industry

Transportation is a process or method for moving people, goods, or other items from one place to another. Transportation management is an important component in the coal mining industry (Zhang et al., 2024). To be able to develop a good transportation system in the mining industry, good planning is needed covering all activities, from exploration, development, exploitation to distribution of mining products, requiring transportation facilities from various modes to reduce transportation

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costs. Mining and transportation are inseparably linked (Ávila et al., 2025; Xu et al., 2024). Raw materials need to be distributed to target markets, which may be very far from the mining location. Therefore, different transportation modes are needed to be able to support the distribution process to various locations or places (Xu et al., 2024). The transportation process for transporting mining products is generally more complex and expensive. The cost of transporting mineral products from the mine to the factory is an important component of the total costs. Data shows that the contribution to transportation costs fluctuates significantly from time to time (Ávila et al., 2025).

Transportation constitutes a structurally significant and highly variable component of mineral supply chain costs, with its share of total operating expenditure varying substantially by mining method, operational scale, and geographic context. In underground operations, access and haulage systems represent a “relevant” and strategically determined portion of total OPEX, with deepening mines exhibiting distinct cost trajectories across different modal choices (Cardozo & Petter, 2025). For open-pit mines, the cost burden of material movement is equally pronounced; optimization research demonstrates that intelligent path planning for truck fleets can reduce transportation expenditures by 18.54% compared to unoptimized operations, a savings magnitude that implicitly confirms haulage as a dominant cost category warranting rigorous analytical intervention (Liu et al., 2025). The continued dominance of truck-shovel systems is increasingly contested by in-pit crushing and conveying (IPCC) configurations, which offer substantial advantages as haul distances grow with mine depth, conveyor-based systems reduce fuel consumption, maintenance, and carbon intensity while stabilizing cost trajectories that otherwise escalate with extended haulage profiles (Khajvandsany et al., 2025).

Modal choice and distance operate as interdependent determinants of logistics cost structures. While rail remains the backbone of long-distance bulk mineral transport, its cost efficiency is contingent upon infrastructure access, volume guarantees, and network integration, conditions frequently absent in remote mining jurisdictions (Pandey et al., 2025). Truck haulage, despite its flexibility, exhibits diseconomies at distance and is optimally confined to intra-complex movement or short-haul transshipment roles (Liu et al., 2025). Critically, these modal cost differentials are amplified by the global resource paradox: high-quality mineral deposits are increasingly situated in infrastructure-poor, logistically marginal regions, while consumption centers and processing facilities remain concentrated in industrialized economies. This geographic decoupling is most starkly illustrated in lithium supply chains, where Australia supplies 33% of global raw spodumene yet over 97% is refined in China, a separation that renders transoceanic logistics not merely a support function but the essential connective tissue of the entire production network (Hayes et al., 2025).

The strategic salience of transportation is therefore accelerating. Coal logistics, as a mature and high-volume subsystem, exemplifies the complexity inherent in modern mineral supply chains: fragmented multi-modal networks spanning trucks, trains, and ships require real-time data integration, centralized visibility platforms, and advanced analytics to mitigate bottlenecks and reduce cost uncertainty (Pandey et al., 2025). Concurrently, geopolitical fragmentation and concentrated ownership of critical mineral assets introduce new layers of supply chain vulnerability, wherein transportation corridors become sites of strategic leverage and potential disruption (Lapeyronie et al., 2025). The convergence of physical distance, modal constraints, and geoeconomic risk has fundamentally repositioned transportation management—no longer an operational afterthought, but a determinative design variable in mine project viability and supply chain configuration.

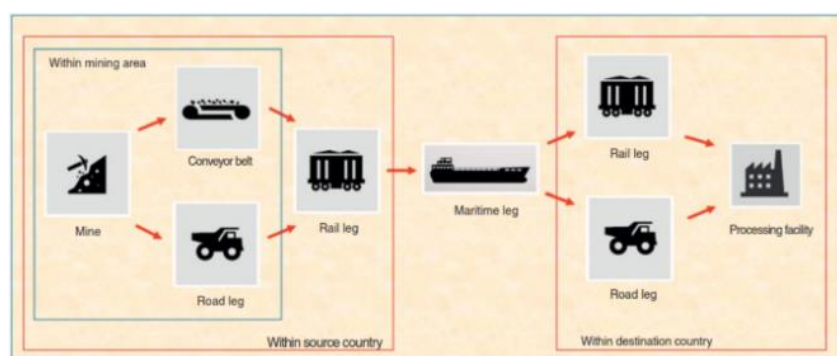


Figure 6. Transportation in The Mining Industry Supply Chain (Daly et al., 2022)

Land Transportation Process in Mining Areas

In the process of hauling or moving mining products to mining areas, mining companies generally use heavy equipment that has a large capacity. This is done to speed up the mining process and cost efficiency. There are two types of Off Highway dump trucks that are often used, namely rigid rear dump trucks and articulated dump trucks. Off Highway Dump Truck is a heavy truck used to transport materials in mining areas. This dump truck has a vessel that can move up and down hydraulically to unload or remove material.



Figure7. Off Highway Dumptruck (Komatsu, 2025)

The following are several types of off-highway dump trucks used in mining areas based on their specifications:

No	Type	Brand	Specification	Max Payload	Vessel
1	Rigid Dump truck	Komatsu	HD465-7	55 Tons	34.2 m ³
2	Rigid Dump truck	Komatsu	HD785-7	91 Tons	60 m ³
3	Rigid Dump truck	Komatsu	HD1500-8	140 Tons	78 m ³
4	Rigid Dump truck	Komatsu	730E	186 Tons	111 m ³
5	Rigid Dump truck	Komatsu	830E-AC	221 Tons	147 m ³
6	Articulated Dump truck	Komatsu	HM400-3R	40 Tons	24 m ³

Figure 8. Dump Truck Specifications Based on Type and Capacity Source (Komatsu, 2025)

Land Transportation Process Outside Mining Areas

Land transportation using Dump Truck

In the transportation process of transporting coal mining products outside the mining area, mining companies will generally collaborate with Third Party Logistic companies. This aims to outsource work and share the risks that will be faced in the material delivery distribution process. The transportation process outside the mining area and via public roads or access must take into account the regulations that apply on public roads which are regulated by the Ministry of Transportation, Directorate General of Land Transportation. Through the Regulation of the Director General of Land Transportation Number: KP.4413/AJ.307/DRJD/2020 concerning Bulk Goods Transport Dimensions in article 3b regulates regulations regarding the use of goods cars that transport non-dangerous special goods in the form of bulk transport which must comply with the motor vehicle dimensions provisions as follows (Tampubolon et al., 2025), for dump truck type open trucks:

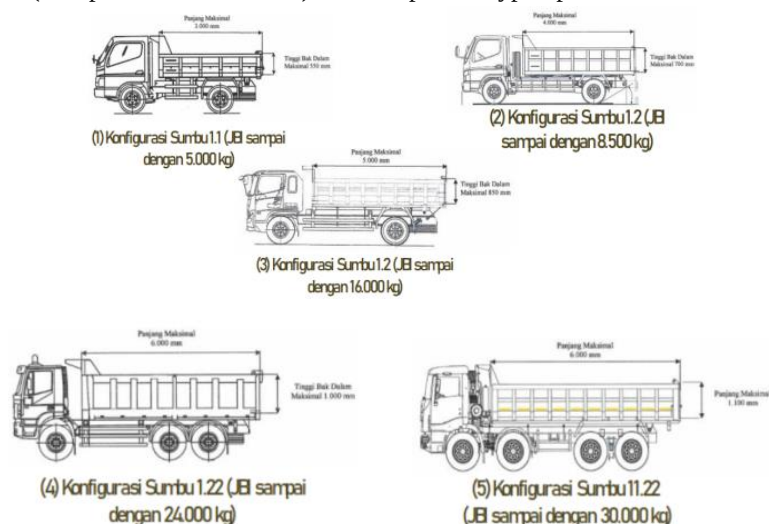


Figure 9. Dimensions Dump Truck (Tampubolon et al., 2025)

Based on applicable regulations, the process of land transportation activities using dump trucks will be limited to a maximum load size of 30,000 kg. The following are examples of vehicles or means of transportation used in the land transportation process outside the mining area.



Figure 10. Hino 500 Series Brand Dump Truck (HINO, 2026)

This type of dump truck vehicle is generally used by companies providing logistics services to support mining companies to fulfill mining product distribution work. With a carrying capacity of up to 26,000 kg, this type of equipment is quite effective and does not violate land transportation regulations on highways or public roads.

Rail Transportation

The transportation of coal in Indonesia relies heavily on rail, which offers significant advantages over truck haulage in terms of volumetric efficiency and infrastructure preservation. Coal trains operating in South Sumatra, such as the Babaranjang (long-train coal train), utilize consists of 60 to 70 open-system carriages, enabling the movement of large tonnages in a single journey (Tama, 2024). In contrast, over 5,000 coal trucks traverse South Sumatra's public roads daily, with overloaded vehicles accelerating infrastructure deterioration and imposing substantial repair costs on local governments. Public opposition to truck transport intensified following the collapse of the Muara Lawai Bridge in June 2025, prompting provincial authorities to ban coal trucks from public roads effective January 1, 2026 (Pratama, 2025). Rail transport avoids public road congestion and damage, but faces its own infrastructure constraints. The railway network in Sumatra, managed by PT Kereta Api Indonesia (Persero), plays a strategic role in coal distribution, connecting mines such as PT Bukit Asam Tbk's (PTBA) operations in Tanjung Enim to port facilities at Tarahan and Keramasan (Junida, 2024). However, rail infrastructure remains unevenly developed (Wijaya, 2022). While feasibility studies for coal rail development in Kalimantan continue, operational lines have not yet been established (Maulani et al., 2018).

PT Kereta Api Indonesia, in collaboration with mining companies including PT Bukit Asam Tbk, has undertaken significant capacity expansion. In 2024, PTBA began constructing new coal handling facilities, including train loading stations and conveyor systems, to increase rail transport capacity by 20 million tons annually on the Tanjung Enim-Keramasan route (Jati et al., 2021; Junida, 2024). Concurrently, KAI Logistics (KALOG) is investing in 54 new locomotives and over 2,000 wagons, targeting coal transport volume of 85.9 million tons by 2028, a substantial increase from the 27.8 million tons transported in 2017 (Setyaji et al., 2024). These developments position rail as an increasingly attractive option for mining companies seeking reliable, high-capacity transport amid tightening restrictions on road haulage.

Data Teknis		Komponen Utama	
Kapasitas Muat Max	: 50 ton	Rangka Dasar	: Mild Sheet
Kecepatan Max	: 80 km/jam	Bogie	: Jenis Barber S2 HD
Lebar Sepur	: 1067 mm	Sistem Pengereman	: UIC 540, Air Brake
Beban Gandar	: 18 ton	Alat Perangkai	: Automatic Coupler, Tipe F, Rotary dan Fixed, AAR No, 10A
Panjang Gandar Ujung Gerbong	: 14062 mm	Twist Lock	:
Lebar Gerbong	: 3080 mm	Alat Pengaturan Tekanan	:
Tinggi Lantai Dari Atas Rel	: 1089 mm	Empty Load Device	: Pengereman - Salah Satu Bogie
Jarak Antar Pusat Bogie	: 10676 mm	Mekanisme Loading	: Rotary Dumper 180 derajat
Tinggi Pusat Alat Perangkai Dari Atas Rel	: 770 mm	Unloading	:
Berat Kosong (maximum)	: 22000 kg		

Figure 11. Open Carriage Specification Data (Coal Carriage) (PT. KAI, 2025)

Transportation Challenges in the Coal Mining Industry

The Indonesian coal mining industry faces intensifying operational challenges driven by both market dynamics and regulatory pressures. While global demand fluctuations create uncertainty, domestic market obligations now legally require mining companies to prioritize local supply before exports, adding complexity to production planning and logistics (Anggawira et al., 2025; Chandrarin et al., 2022). In response, companies must implement innovative strategies to enhance efficiency, reduce costs, and improve service reliability. Digital transformation has emerged as a critical enabler: real-time data integration, centralized visibility platforms, and advanced analytics can significantly reduce operational costs while improving delivery performance (Ayeisha & Anggoro, 2024; Damayanti & Khairunnisa, 2023; Yulianti et al., 2025). Empirical evidence shows autonomous haulage systems (AHS) increased transportation capacity by about 40% and reduced costs by 15% in open-pit mining contexts (Zhao & Bi, 2020).

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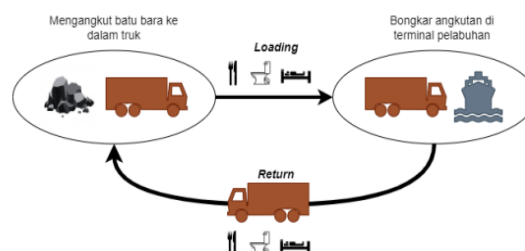
The coal distribution process itself presents serious challenges due to the inherently complex nature of multi-modal transportation. Coal moves through fragmented networks involving trucks, trains, and ships, where lack of integration creates inefficiencies and bottlenecks (Nugroho et al., 2025). Truck transport from mining areas is particularly difficult to optimize, as driver behavioral characteristics such as speed choices, route decisions, and fuel management practices introduce significant performance variability. Studies indicate that driver habits can affect fuel consumption by eight to fifteen percent (Ashqar et al., 2024; Mohammadnazar et al., 2024). Although historically difficult to monitor in remote mining environments, digital fleet management systems now enable real-time monitoring of vehicle performance, route adherence, and fuel efficiency (Hazrathosseini & Afrapoli, 2023). Autonomous and semi-autonomous haulage systems have been introduced in open-pit mining operations as a means of improving operational consistency and safety. Peer-reviewed studies on autonomous truck control systems indicate improved collision avoidance performance and enhanced route optimization through algorithm-based motion planning and sensor fusion technologies (Ge et al., 2022). While precise safety improvement rates vary across studies and operational contexts, the literature consistently finds that automation reduces human-error-related variability and enhances operational reliability. In Indonesia's major coal-producing regions, including Sumatra and Kalimantan, infrastructure constraints and road-use conflicts further complicate coal logistics. Academic research documents road degradation, congestion, and social impacts associated with coal transport corridors, underscoring structural limitations that affect supply chain efficiency (Nasir et al., 2026).

Transportation System Innovation in the Coal Mining Industry

The main reasons for transport innovation in the mining sector are efficiency through reduced costs, improved operations or reduced mileage and safety factors through reduced risks and improved working conditions. Efficiency through cost reduction is a key driver of transportation innovation. This factor involves any action, investment or new process to reduce production costs and increase mine competitiveness. The drive to increase efficiency aims to achieve cheaper direct costs (for example lower fuel costs) or indirect costs such as reducing vehicle energy consumption through optimizing routes and distance traveled. Safety factors and working conditions are other fundamental considerations in mining operations to make the mining process safer and more sustainable. Thus, measures that can reduce the risk of accidents and eliminate factors such as driver fatigue in mining areas are starting to be developed through the introduction of automation and sensors/radar. Innovation aims to improve the working conditions of miners so as to increase the attractiveness of this industrial sector by reducing the high risk level of workers in the mining industry. In this industrial era 4.0, the development of technological innovation will have a significant influence on every mining work process. This is in line with Sancez et al. (2020) who explain that innovation plays a crucial role in the mining industry, namely as a tool to increase process efficiency, reduce costs and increase social and environmental awareness.

Smart GPS Tracker Innovation on Trucks

To determine truck travel patterns in coal transportation activities, from the mining area to the next terminal port, one innovation that can be used is the Smart GPS tracker, which is a device based on a fleet management system, to determine the variables of coal transportation trips. Among these are the speed of the truck when passing a route along with the location of the truck when it is operating or in transit or stopping to rest. According to Yuniar et al. (2020), the average speed of trucks carrying coal in coal mines located in Rantau District, South Kalimantan Province, from the stockpile to the sea port and after delivery, is 23 km/hour to 37 km/hour. The upper speed limit for trucks transporting dangerous goods, including coal, is 60 km/hour for trips outside the city and 40 km/hour for trips within the city. Referring to the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 111 of 2015, concerning Procedures for Determining Speed Limits, the speed of coal trucks can still be optimized. The use of a Smart GPS Tracker based on a fleet management system can help vehicle owners or coal mining business owners find out or track detailed activities of their coal trucks, using very detailed activity variables, starting from transporting coal from the stockpile to dropping goods at harbor. This can make it easier to monitor whether the vehicle is performing as optimally as possible or whether there are still wasteful activities that can be optimized.



Sumber: Yuniar et al. (2020)

Figure 12: Coal Transportation Activities (Yuniar et al., 2020)

III. METHODOLOGY

This research employs a mixed-method approach, combining descriptive qualitative and quantitative methods to analyze transportation processes in the coal mining industry. The qualitative aspect utilizes literature studies and field surveys, including a topographic survey and a one-month observation using GPS trackers installed on trucks, to gain an in-depth understanding of the transportation process, driver behavior, and road infrastructure. Data is collected through a questionnaire focusing on variables influencing driver behavior such as motivation, health, and weather and perceptions of travel time using indicators like discipline and road conditions. This qualitative data, along with the GPS and survey data, is then analyzed using quantitative methods; specifically, driver behavior and its impact on travel time are examined using a statistical approach with multiple linear regression, while topographic and infrastructure data are analyzed using software such as Smart GPS tracker system and Google Earth Pro. The research progresses through stages including introduction, sampling, variable preparation, data collection, validation, analysis, and finally, the drawing of conclusions and recommendations.

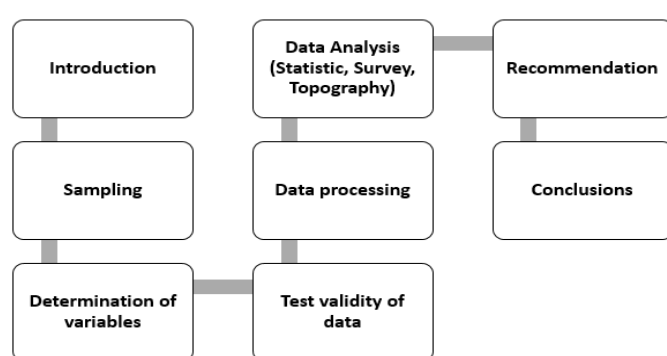


Figure 13. Research Flow Model for Analysis of the Impact of Innovation on the Coal Transportation System

IV. CONCLUSIONS

This study underscores the critical role of land transportation systems as a key enabler of supply chain performance in the coal mining industry. Through a conceptual analysis of existing literature, it is evident that transportation activities, particularly those involving trucks and rail systems, significantly influence cost structures, operational efficiency, and distribution reliability. Despite their importance, these systems are often constrained by infrastructural limitations, regulatory complexities, and operational variability. The discussion highlights that technological innovation represents a crucial pathway for addressing these challenges. The adoption of digital solutions such as GPS-based monitoring systems, fleet management technologies, and data-driven decision-making tools has the potential to enhance visibility, improve coordination, and reduce inefficiencies across transportation operations. Furthermore, the increasing relevance of automation and smart systems reflects a broader transformation aligned with Industry 4.0, where transportation is no longer viewed solely as an operational function but as a strategic component of supply chain integration. In conclusion, this research emphasizes that the effective integration of innovation and technology into land transportation systems is essential for improving the overall performance of the coal mining supply chain. Future research is encouraged to further develop conceptual models and explore the practical implications of advanced transportation technologies, as well as to examine policy and infrastructure development that supports integrated and sustainable logistics systems in Indonesia.

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