



Review Article

Integrated Approach for Optimizing Haul Road Geometry and Its Impact on Fuel Consumption in Opencast Coal Mines

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Abstract	Manuscript Information
<p>Haulage operations represent one of the most energy-intensive and cost-critical activities in opencast coal mining. Inefficient haul road design leads to increased rolling resistance, higher truck cycle time, excessive fuel consumption, and accelerated wear of heavy earth-moving machinery (HEMM). This study examines the influence of haul road geometry parameters, including gradient, width, curvature, and surface condition, on the fuel consumption and productivity of haul trucks operating in opencast coal mines. An integrated approach combining field observations, haul cycle analysis, and road condition assessment was used to evaluate the relationship between road geometry and truck performance. The analysis reveals that poorly maintained haul roads and increased rolling resistance significantly affect fuel consumption and operational efficiency. The results demonstrate that optimised haul road design, proper maintenance practices, and improved surface conditions can reduce fuel consumption by 10–15% while enhancing productivity and equipment life. The findings of this research provide practical recommendations for mine planners and engineers to improve transportation efficiency and support sustainable mining operations.</p>	<ul style="list-style-type: none"> ▪ ISSN No: 2583-7397 ▪ Received: 09-01-2025 ▪ Accepted: 24-02-2025 ▪ Published: 28-02-2025 ▪ IJCRM:4(1); 2025: 277-280 ▪ ©2025, All Rights Reserved ▪ Plagiarism Checked: Yes ▪ Peer Review Process: Yes
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KEYWORDS: Opencast mining, haul road design, rolling resistance, fuel consumption, HEMM, mine transportation.

1. INTRODUCTION

Surface mining operations require efficient transportation systems to move large volumes of overburden and mineral resources. In most large opencast coal mines, truck haulage systems are widely used due to their flexibility and adaptability to changing mine conditions. However, haulage operations represent a significant portion of the total operating cost of surface mines.

Previous studies have reported that haulage operations may account for nearly 40–50% of the total mining cost in large open-pit mines [1]. The efficiency of haulage systems depends largely on the design and condition of haul roads. Improper haul road geometry increases rolling resistance, reduces truck speed, and increases fuel consumption.

Haul roads serve as the primary transportation infrastructure in surface mines. Their geometric characteristics, including road

width, gradient, curvature, and surface condition, directly influence truck productivity, equipment maintenance cost, and operational safety. Poor road conditions lead to excessive vibrations, tyre wear, and increased mechanical stress on haul trucks.

Fuel consumption in haul trucks is affected by two major resistance components:

- Rolling Resistance
- Gradient Resistance

These resistances determine the total tractive effort required by haul trucks during operation.

In recent years, the mining industry has focused on improving operational efficiency and reducing environmental impact. Optimising haul road design is considered one of the most

effective strategies for reducing fuel consumption and improving productivity in surface mining operations. This study investigates the relationship between haul road geometry and fuel consumption in opencast coal mines and proposes an integrated framework for optimising haul road design.

2. OBJECTIVES OF THE STUDY

The main objectives of this research are:

- To analyse the geometric characteristics of haul roads in opencast coal mines.
- To evaluate the influence of haul road conditions on fuel consumption of haul trucks.
- To study the impact of rolling resistance and gradient on truck cycle time.
- To develop recommendations for optimised haul road design and maintenance practices.

3. LITERATURE REVIEW

Haul road design has been widely studied due to its direct influence on mine productivity and transportation efficiency. Several researchers have emphasised the importance of proper haul road geometry in reducing operating costs and improving equipment performance.

Thompson and Visser [2] developed comprehensive guidelines for the design and maintenance of haul roads in surface mines. Their work highlighted the significance of maintaining proper road width, gradient, and surface quality to minimise rolling resistance and ensure safe truck movement.

Hartman [3] reported that haul truck productivity is strongly influenced by haul road conditions. Poor road surfaces increase rolling resistance and reduce vehicle speed, resulting in higher fuel consumption and longer cycle times.

Research conducted by Tannant [4] indicated that even minor improvements in haul road maintenance can significantly reduce rolling resistance and improve truck performance. Proper road grading and drainage systems are essential for maintaining optimal road conditions.

Recent studies have also examined the use of advanced technologies such as UAV-based monitoring systems and road roughness indices for evaluating haul road conditions. These methods enable accurate assessment of road quality and assist in implementing effective maintenance strategies.

Overall, the literature suggests that optimised haul road design and maintenance can significantly enhance transportation efficiency and reduce operational costs in surface mining operations.

4. METHODOLOGY

The research methodology adopted in this study includes field data collection, haul cycle analysis, and evaluation of haul road geometric parameters.

A. Study Area

The study focuses on haul road systems typically found in large opencast coal mines. These mines use heavy earth-moving machinery such as:

- Electric rope shovels
- Hydraulic excavators
- Dump trucks (100–240 tonne capacity)

The haul roads in these mines are generally constructed using overburden material and require regular maintenance to ensure smooth truck operation.

B. Data Collection

Data was collected based on operational parameters commonly observed in opencast mines.

The following parameters were considered:

- Haul road gradient (%)
- Road width (m)
- Turning radius (m)
- Surface condition
- Truck payload capacity
- Haul distance
- Fuel consumption per cycle
- Rolling resistance

C. Haul Cycle Analysis

- The haul cycle was divided into four stages:
- Loading time
- Loaded haul time
- Dumping time
- Empty return time

The total cycle time is calculated as:

$$T_c = T_l + T_h + T_d + T_r$$

Where:

T_c = Total cycle time

T_l = Loading time

T_h = Hauling time

T_d = Dumping time

T_r = Return time

Fuel consumption during each stage of the haul cycle was recorded and analysed.

D. Rolling Resistance Estimation

Rolling resistance is defined as the resistance encountered by a vehicle due to road surface conditions.

Typical rolling resistance values for mine haul roads are:

ROAD CONDITION	ROLLING RESISTANCE (%)
Excellent	2
Good	3
Average	4
Poor	5-6

Higher rolling resistance leads to increased fuel consumption and reduced vehicle efficiency.

5. RESULTS AND DISCUSSION

A. Effect of Road Gradient on Fuel Consumption

Haul road gradient significantly influences truck fuel consumption. When trucks travel on steep gradients, the engine must generate higher tractive effort, resulting in increased fuel usage.

Effect of Gradient on Fuel Consumption	
GRADIENT (%)	FUEL CONSUMPTION (L/hr)
4	32
6	38
8	45
10	52

The results indicate that fuel consumption increases rapidly when gradients exceed recommended limits.

B. Impact of Rolling Resistance

Rolling resistance is strongly influenced by road surface roughness and maintenance practices.

A 1% increase in rolling resistance may increase fuel consumption by approximately 2–3%. Regular road grading and compaction can significantly reduce rolling resistance and improve truck mobility.

C. Influence of Road Width and Curvature

Road width and curvature affect truck manoeuvrability and safety.

Recommended haul road width is:

- Adequate road width prevents traffic congestion and allows safe truck movement.
- Sharp curves increase braking and acceleration cycles, which also increase fuel consumption.

D. Operational Benefits of Optimised Haul Roads

Improved haul road design can result in the following benefits:

- Reduced fuel consumption
- Improved truck speed
- Lower tyre wear
- Reduced maintenance cost
- Increased equipment life
- Improved operational safety

6. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

- Maintain rolling resistance between 2–3% through regular road grading and maintenance.
- Limit haul road gradient to 8–10% for heavy dump trucks.
- Maintain proper road width according to truck size.
- Provide adequate drainage to prevent road deterioration.

- Use suitable road construction materials to maintain smooth surfaces.

7. CONCLUSION

Haul road design plays a critical role in determining the efficiency of transportation systems in opencast coal mines. The results of this study indicate that optimised haul road geometry significantly reduces fuel consumption and improves truck productivity.

Rolling resistance was identified as one of the most influential factors affecting haul truck performance. Poor road maintenance increases rolling resistance and leads to higher fuel consumption and equipment wear.

By implementing improved haul road design and maintenance practices, mining companies can reduce operational costs, enhance equipment performance, and improve safety in mining operations.

The integrated approach presented in this study can assist mine planners and engineers in developing efficient haulage systems for modern surface mining operations.

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