Educa Journal of Studies
ISSN (E): 3054-3355
Volume 01, Issue 05, May, 2026
Website: https://researchiapress.com

ENERGY-EFFICIENT AND LOGISTIC PERFORMANCE OF LED STRIP LIGHTING SYSTEMS IN OPEN-PIT MINES

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Abstract
This study evaluates the economic, energy-saving, and operational advantages of replacing conventional high-power lighting systems with LED strip lighting technologies in open-pit mining operations. The research demonstrates that color-coded LED strip lighting can effectively guide heavy-duty haul trucks, improve traffic safety, optimize haulage logistics, and significantly reduce electrical energy consumption. Furthermore, the application of LED strip lighting enhances visibility under adverse weather conditions, thereby contributing to safer and more efficient mining operations. The results indicate that implementing LED strip lighting systems offers substantial economic benefits while improving the sustainability of surface mining activities.

Keywords: Open-pit mining, LED strip lighting, energy efficiency, haul truck, mine transportation, mine logistics, traffic safety, sustainable mining.

Introduction

Lighting systems constitute one of the most critical components of operational infrastructure in modern open-pit mining. The continuity of mining operations, safe movement of haul trucks, and efficient management of material

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transportation largely depend on adequate illumination of haul roads and working areas. Conventional high-intensity lighting systems commonly used in surface mines require high electrical power and involve considerable installation and maintenance costs. In addition to their high energy consumption, these systems often fail to provide sufficient visual guidance under adverse environmental conditions such as fog, snowfall, rainfall, and dust generated during mining operations.

Recent advances in solid-state lighting technologies have introduced LED strip lighting as an energy-efficient alternative for industrial applications. Owing to their low power consumption, extended service life, high luminous efficiency, and flexible installation, LED strip lighting systems have considerable potential for improving both operational safety and transportation logistics in open-pit mines. This study investigates the technical, operational, and economic feasibility of implementing color-coded LED strip lighting systems along mine haul roads. The proposed approach is intended not only to reduce electrical energy consumption but also to facilitate traffic guidance, improve transportation efficiency, minimize operational errors, and enhance overall mine safety.

Technical and Operational Advantages of LED Strip Lighting Systems

LED strip lighting systems provide several significant technical and operational advantages compared with conventional high-intensity lighting technologies employed in open-pit mining operations. Their low electrical power demand, high luminous efficacy, long service life, and ease of installation make them an efficient lighting solution for mine infrastructure. Unlike conventional floodlighting systems, LED strips can be installed continuously along haul roads, loading areas, unloading zones, and road intersections. Consequently, these systems not only provide illumination but also function as visual navigation aids for haul truck operators. The implementation of color-coded LED strip lighting enables efficient traffic management within the mine. A recommended color-coding scheme is presented below:

Blue LED strips — Haul trucks travelling toward waste dumps.

Green LED strips — Haul trucks transporting ore to processing facilities.

Red LED strips — Hazardous areas, sharp curves, and restricted zones.

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Yellow LED strips — Roads leading to loading, unloading, or material transfer stations.

This visual guidance system allows operators to identify designated haul routes rapidly, thereby reducing navigation errors, preventing incorrect material transportation, and improving overall haulage efficiency. Moreover, the proposed lighting system facilitates smoother traffic flow, minimizes vehicle congestion, and contributes to safer interaction between mining equipment operating simultaneously within the production area.

Lighting Performance under Adverse Weather Conditions

Environmental conditions considerably influence transportation safety in surface mining operations. During winter seasons, dense fog, snowfall, heavy rainfall, and airborne dust frequently reduce visibility along mine haul roads. Under such conditions, conventional high-mounted lighting systems often fail to provide sufficient road definition, making it difficult for operators to recognize road boundaries and hazardous locations. LED strip lighting systems installed directly along road edges clearly delineate the roadway geometry, enabling operators to maintain correct vehicle positioning even under limited visibility conditions. Improved visual guidance significantly decreases the probability of traffic accidents, collisions, roadway departures, and operational delays. Consequently, mine productivity and occupational safety can be substantially enhanced. Furthermore, color-coded LED guidance improves driver awareness of traffic directions and operational zones, reducing decision-making time and increasing transportation efficiency throughout the mining cycle.

Energy Efficiency and Economic Benefits

Most surface mining operations are conducted continuously in multiple work shifts, including night shifts. Consequently, mine lighting systems account for a considerable proportion of total electrical energy consumption. Replacing conventional high-power lighting fixtures with LED strip lighting systems can substantially reduce electricity demand while maintaining adequate illumination and improving operational performance. The proposed technology offers several important advantages:

- Significant reduction in electrical energy consumption;

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- Lower operating and maintenance costs;
- Extended service life with minimal replacement requirements;
- Reduced greenhouse gas emissions associated with electricity generation;
- Improved sustainability of mining operations.

To maximize the effectiveness of this technology, the following implementation strategy is recommended:

Gradual installation of LED strip lighting along principal haul roads.

Use of standardized color-coded lighting for different transportation routes.

Mandatory installation of red LED strips in hazardous and sharp-curve sections.

Progressive replacement of conventional lighting systems during night-shift operations.

Continuous monitoring of energy consumption and maintenance expenditures to evaluate project performance and economic efficiency.

Energy Consumption Analysis of Conventional Lighting Systems

To evaluate the energy-saving potential of LED strip lighting technology, a comparative analysis was conducted between conventional high-power lighting fixtures and LED strip lighting systems commonly used in open-pit mining operations.

Initial Parameters for Conventional Lighting:

- ✓ Rated power of one conventional luminaire: 1000 W (1.0 kW)
- ✓ Number of luminaires: 50
- ✓ Operating duration: 12 hours/day (night shift)
- ✓ Operating period: 365 days/year

Installed Electrical Power

$P = 50 \cdot 1.0 = 50$ kW

Daily Energy Consumption

$E_{day} = 50 \cdot 12 = 600$ kWh

Annual Energy Consumption

$E_{year} = 600 \cdot 365 = 219\,000$ kWh

The results indicate that conventional lighting systems consume a substantial amount of electrical energy, resulting in high operating costs throughout the year.

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Energy Consumption Analysis of LED Strip Lighting Systems

For comparison, the electrical energy demand of LED strip lighting installed along mine haul roads was calculated using the following design parameters.

Initial Parameters

✓ Power rating of LED strip: 15 W/m
✓ Total installation length: 1000 m
✓ Operating duration: 12 hours/day
✓ Operating period: 365 days/year

Installed Electrical Power

P = 15·1000 = 15 000W = 15 kW

Daily Energy Consumption

E_{day}=15·12 =180 kWh

Annual Energy Consumption

E_{year}=180·365=65 700 kWh

The obtained results demonstrate that the proposed LED strip lighting system requires only 15 kW of installed power, representing a significant reduction compared with conventional lighting systems.

A comparison between conventional lighting and LED strip lighting systems is presented below.

Parameter	Conventional Lighting	LED Strip Lighting	Difference
Installed Power	50 kW	15 kW	35 kW lower
Daily Energy Consumption	600 kW	180 kW	420 kW lower
Annual Energy Consumption	219 000 kW	65 700 kW	153 300 kW lower

The comparison clearly demonstrates that the implementation of LED strip lighting technology can reduce electricity consumption by approximately 70%, while maintaining adequate roadway illumination and improving traffic guidance.

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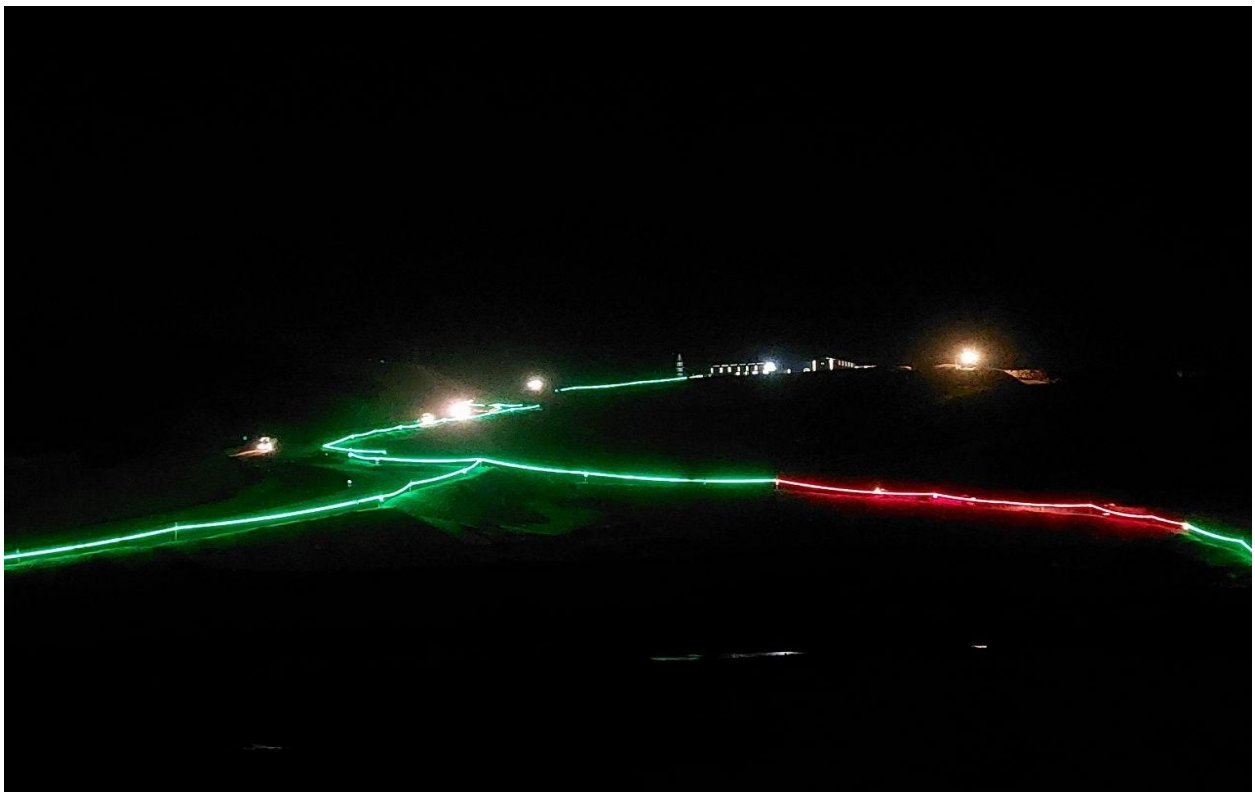

Figure 1. Proposed LED Strip Lighting System for Open-Pit Mine Haul Roads

Figure 1 illustrates the proposed application of LED strip lighting systems along haul roads in an open-pit mine. The continuous installation of LED strips along road edges provides clear visual guidance for haul truck operators while improving roadway visibility during both day and night operations. The proposed color-coded lighting system enables operators to identify designated transportation routes rapidly, thereby minimizing navigation errors and improving haulage efficiency. Furthermore, the lighting system enhances operational safety by clearly identifying hazardous areas, sharp curves, loading points, and waste dump access roads. The implementation of LED strip lighting contributes not only to energy conservation but also to intelligent traffic management within surface mining operations.

Practical Advantages for Mine Operations

The proposed LED strip lighting system provides several operational advantages:

✓ Improved visibility along haul roads.

✓ Enhanced traffic safety during night-time operations.

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✓ Better guidance for haul truck operators.
✓ Reduced probability of transportation errors.
✓ Lower maintenance frequency because of the long service life of LEDs.
✓ Improved logistics through color-coded traffic management.
✓ Reduced operational downtime caused by lighting failures.
✓ Increased overall productivity of mining operations.

Scientific Novelty

The scientific novelty of this research lies in the development of a color-coded LED strip lighting concept specifically designed for open-pit mine haul roads. Unlike conventional lighting systems that only provide illumination, the proposed approach integrates traffic guidance, energy-efficient lighting, and haulage logistics management into a single infrastructure system.

The proposed methodology contributes to:

✓ reducing electrical energy consumption;
✓ improving transportation safety;
✓ optimizing haulage logistics;
✓ enhancing driver navigation under adverse weather conditions;
✓ supporting sustainable mining practices.

Conclusion

The findings of this study demonstrate that replacing conventional high-power lighting systems with LED strip lighting technology can substantially improve the operational efficiency of open-pit mining operations. The comparative energy analysis indicates that LED strip lighting reduces annual electrical energy consumption from 219,000 kWh to 65,700 kWh, corresponding to an energy saving of approximately 70%. This reduction translates into an estimated annual economic saving of 153.3 million Uzbek sums, while simultaneously decreasing maintenance requirements and extending system service life. Beyond energy savings, the proposed color-coded LED lighting system significantly improves mine haulage logistics by providing intuitive visual guidance for haul truck operators. The system enhances traffic organization, reduces the likelihood of transportation errors, and increases operational safety, particularly under adverse environmental conditions such as fog, rainfall, snowfall, and dust. The

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application of LED strip lighting also supports sustainable mining practices through lower electricity demand, reduced greenhouse gas emissions associated with power generation, and improved utilization of energy resources.

Overall, the proposed technology represents a practical, technically feasible, and economically efficient solution for modern surface mining operations. Future research should focus on the development of intelligent LED lighting systems integrated with autonomous haulage technologies, real-time traffic monitoring, and smart mine management platforms to further enhance productivity, safety, and energy efficiency.

References

1. SME Mining Engineering Handbook. Littleton, CO: Society for Mining, Metallurgy & Exploration, 2011.
2. International Energy Agency. Energy Efficiency 2023. Paris: IEA, 2023.
3. International Council on Mining and Metals. Innovation for Cleaner, Safer Mining. London, 2022.
4. International Commission on Illumination. Lighting of Outdoor Work Places (CIE S 015/E:2015).
5. International Organization for Standardization. ISO 8995-2: Lighting of Outdoor Work Places.
6. Institute of Electrical and Electronics Engineers. IEEE Recommended Practice for Energy-Efficient Industrial Lighting Systems.
7. International Electrotechnical Commission. IEC 60598: Luminaires – General Requirements and Tests.
8. United States Department of Energy. Solid-State Lighting Technology Fact Sheet, 2023.
9. National Institute for Occupational Safety and Health. Best Practices for Safe Mobile Equipment Operation in Surface Mining.
10. Occupational Safety and Health Administration. Safety and Health Topics: Industrial Lighting.
11. Surface Mining. Society for Mining, Metallurgy & Exploration, Littleton, Colorado.
12. Introductory Mining Engineering, Howard L. Hartman & Jan M. Mutmansky. John Wiley & Sons.

Educa Journal of Studies
ISSN (E): 3054-3355
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Website: https://researchiapress.com

13. Mine Ventilation and Air Conditioning, Howard L. Hartman et al.
14. World Bank. Climate-Smart Mining Initiative, Washington, DC.
15. United Nations Environment Programme. Global Environment Outlook: Sustainable Resource Management.
16. International Renewable Energy Agency. Renewable Energy in Industry, Abu Dhabi.
17. European Commission. Energy Efficiency in Industrial Systems.
18. World Coal Association. Surface Mining Best Practice Guidelines.