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SELECTION CRITERIA OF MINING TRANSPORT EQUIPMENT IN COMPLEX RELIEF CONDITIONS AND EVALUATION OF THEIR TECHNICAL-ECONOMIC EFFICIENCY

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Abstract. The selection of mining transport equipment in complex terrain conditions is one of the most important engineering tasks in open-pit and underground mining operations. Mountainous and uneven relief significantly affects transportation efficiency, energy consumption, operating costs, and environmental impact. This article analyzes the main criteria for selecting mining transport systems under difficult geological and topographical conditions. Technical and economic indicators of dump trucks, belt conveyors, and ropeway transport systems are comparatively evaluated. Based on productivity, transportation distance, operating costs, energy consumption, and reliability, the most effective transport methods are identified for different mining conditions.

Keywords: mining transport, complex terrain, belt conveyor, dump truck, ropeway transport, technical-economic efficiency, mining engineering.

Аннотация. Выбор горнотранспортного оборудования в сложных рельефных условиях является одной из важнейших инженерных задач в открытых и подземных горных работах. Горный и неровный рельеф существенно влияет на эффективность транспортировки, энергопотребление, эксплуатационные расходы и воздействие на окружающую среду. В данной статье анализируются основные критерии выбора горнотранспортных систем в сложных геологических и топографических условиях. Сравнительно оцениваются технико-экономические показатели самосвалов, ленточных конвейеров и канатной транспортной системы. На основе производительности, расстояния транспортировки, эксплуатационных затрат, энергопотребления и надежности выявляются наиболее эффективные методы транспортировки для различных горных условий.

Ключевые слова: горный транспорт, сложный рельеф, ленточный конвейер, самосвал, канатный транспорт, технико-экономическая эффективность, горная инженерия.

Annotatsiya. Murakkab relyef sharoitlarida kon transporti uskunalarini tanlash ochiq va yer osti kon ishlarida eng muhim muhandislik vazifalaridan biridir. Tog'li va notekis relyef transport samaradorligi, energiya sarfi, foydalanish

xarajatlari va atrof-muhitga ta’siriga sezilarli ta’sir ko‘rsatadi. Ushbu maqolada murakkab geologik va topografik sharoitlarda tog‘-kon transport tizimlarini tanlashning asosiy mezonlari tahlil qilingan. Avtosamosvallar, lentali konveyerlar va kanatli transport tizimlarining texnik-iqtisodiy ko‘rsatkichlari qiyosiy baholanadi. Mahsuldorlik, tashish masofasi, ekspluatatsiya xarajatlari, energiya sarfi va ishonchlilikdan kelib chiqib, turli kon sharoitlari uchun eng samarali tashish usullari aniqlanadi.

Kalit so‘zlar: kon transporti, murakkab relyef, lentali konveyer, avtosamosval, kanat yo‘li transporti, texnik-iqtisodiy samaradorlik, konchilik texnikasi.

INTRODUCTION.

Mining enterprises operating in mountainous and complex terrain face serious transportation challenges. The efficiency of ore transportation directly influences production cost, productivity, and environmental sustainability. Traditional transport systems such as heavy dump trucks may become inefficient on steep slopes and long haulage distances due to increased fuel consumption and maintenance requirements.

Modern mining engineering increasingly considers alternative transport methods including conveyor systems and suspended ropeway transport. Therefore, selecting the optimal transport equipment requires a comprehensive technical-economic analysis.

MATERIALS AND METHODS.

Main Selection Criteria for Mining Transport Equipment. The selection of transport equipment in difficult terrain conditions is based on several major criteria: Transportation capacity; Haulage distance; Terrain slope angle; Capital investment; Operating costs; Energy consumption; Reliability and safety; Environmental impact.

Stage 1 – Analysis of Geological and Relief Conditions At this stage, the following parameters were evaluated:

- Terrain inclination angle;
- Transportation distance;
- Ore production capacity;
- Climatic and operational conditions.

A schematic representation of the methodology is shown below.

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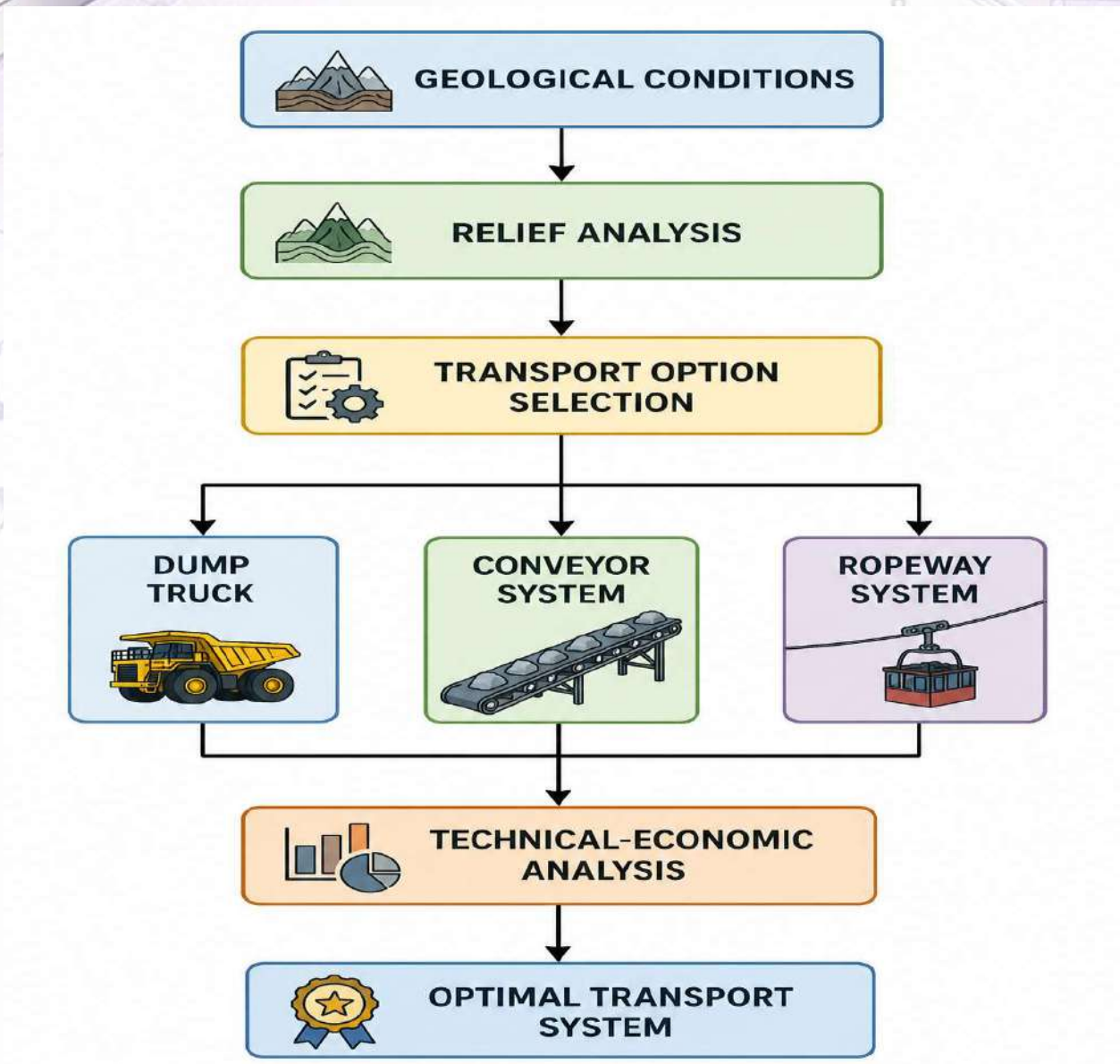


Fig. 1. Methodology for the Selection of Mining Transport Equipment in Complex Relief Conditions

The transportation productivity can be determined by the following formula:

$$Q = \frac{q \cdot n \cdot k}{t}$$

Where: Q — transport productivity (t/h);
q — load capacity (t);
n — number of transport cycles;
k — utilization coefficient;
t — cycle duration (h).
For conveyor systems, the following formula was applied:

$$Q = 3600 \cdot A \cdot v \cdot \gamma$$

Where:
A — material cross-sectional area on the belt (m^2);

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v — belt velocity (m/s);
γ — bulk density of material (t/m^3).

The research object includes mining transport systems used in open-pit mining operations under mountainous and uneven terrain conditions. The following transport methods were analyzed: Heavy dump trucks; Belt conveyor systems; Suspended ropeway transport systems.

The study considered transportation conditions characterized by: Steep slopes; Long haulage distances; Variable Road conditions;

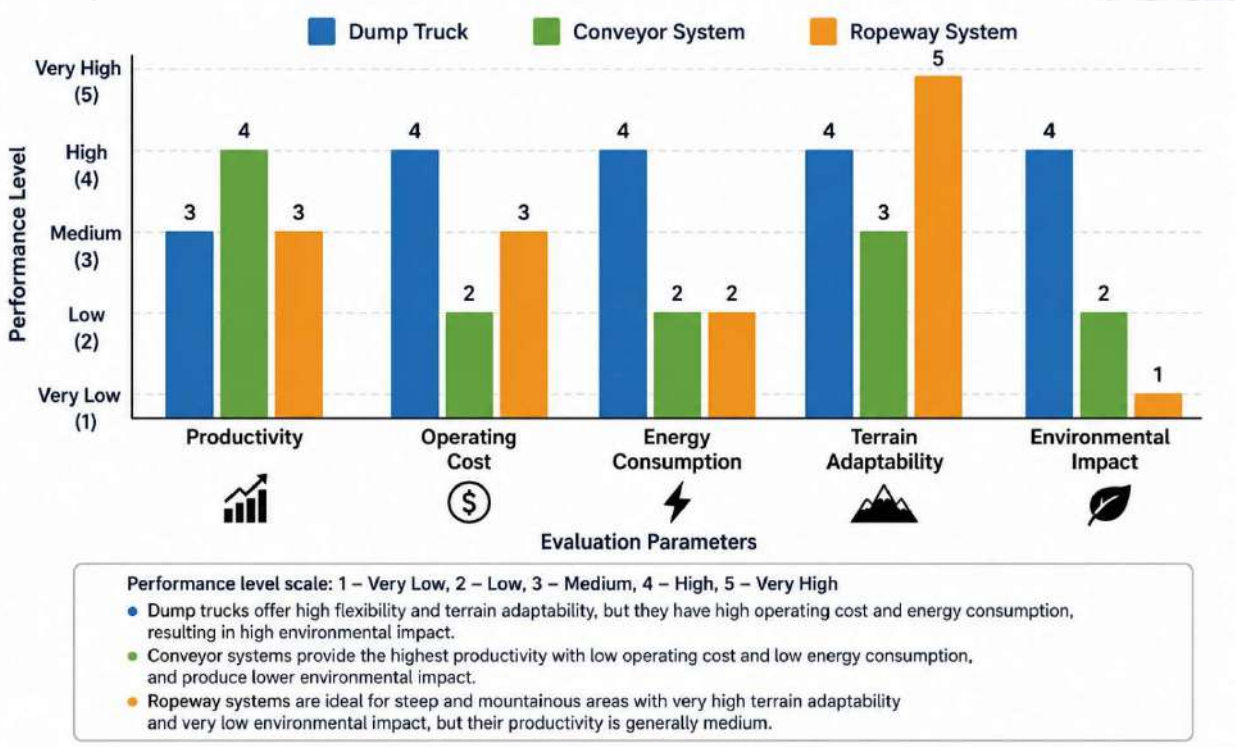


Fig. 2. Comparative Analysis of Mining Transport Systems in Complex Relief Conditions

Figure 2 presents a comparative analysis of the main mining transport systems used under complex relief conditions. The comparison was performed based on five key evaluation parameters: productivity, operating cost, energy consumption, terrain adaptability, and environmental impact. The performance level of each transport system was assessed using a scale from 1 to 5, where 1 represents very low performance and 5 represents very high performance.

The analysis indicates that conveyor systems provide the highest productivity among the evaluated transport methods. Due to their continuous transportation process, conveyor systems are highly effective for large-scale mining operations and long-distance material transportation. In addition, conveyors demonstrate relatively low operating costs and reduced energy consumption, which significantly improves their economic efficiency. Their

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environmental impact is also lower compared to dump truck transportation because they minimize fuel usage and reduce dust emissions.

Dump truck transport systems showed high terrain adaptability and operational flexibility. They are capable of operating in various mining conditions and can easily adjust transportation routes according to changing mining layouts. However, dump trucks have high operating costs and high energy consumption due to fuel requirements, tire wear, and frequent maintenance needs. Furthermore, truck transportation creates considerable environmental impact through exhaust emissions, noise, and road degradation.

Ropeway transport systems demonstrated very high adaptability in mountainous and steep terrain conditions. These systems are particularly suitable for areas where road construction is technically difficult or economically inefficient. Ropeway systems also showed low energy consumption and very low environmental impact because they require minimal ground infrastructure and produce less environmental disturbance. Nevertheless, their productivity remains moderate compared to conveyor systems.

Overall, the comparative analysis confirms that the selection of mining transport equipment should depend on geological conditions, transportation distance, production capacity, and economic requirements. Conveyor systems are more suitable for continuous large-volume transportation, dump trucks are effective for flexible short-distance operations, and ropeway systems are advantageous in steep mountainous regions with difficult access conditions.

The economic efficiency of each transport system was evaluated through a comprehensive analysis of technical and operational expenditures associated with mining transportation processes. The assessment considered several important economic indicators, including capital investment required for equipment installation, fuel and energy consumption during operation, maintenance and repair costs, labor expenses, and the transportation cost per ton of mined ore. These parameters play a critical role in determining the long-term feasibility and sustainability of transport systems operating under complex relief conditions.

Capital investment includes the initial costs associated with purchasing transport equipment, construction of haul roads or conveyor infrastructure, installation works, and supporting facilities. Fuel and energy consumption were analyzed because they directly influence operational expenses, especially in mountainous regions where transportation resistance and slope gradients increase power demand. Maintenance costs were also considered, as mining equipment operating under difficult terrain conditions experiences higher mechanical stress and more frequent wear of components.

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Labor costs include operator salaries, technical personnel expenses, and workforce requirements for maintaining continuous transportation operations. Additionally, the transportation cost per ton of ore was used as a key indicator for comparing the economic performance of different transport systems under identical production conditions.

To evaluate the overall economic performance of the transport systems, the efficiency coefficient was calculated using the following equation:

$$E = \frac{P}{C}$$

Where: E — economic efficiency coefficient;
P — transportation productivity;
C — total operational cost.

This coefficient represents the relationship between transport productivity and total operating expenses. A higher value of the efficiency coefficient indicates that the transport system provides greater productivity with lower operational costs, making it more economically advantageous. Therefore, systems with higher E values were considered more suitable for mining operations in complex terrain conditions.

COMPARATIVE ANALYSIS.

A comparative analysis of the selected mining transport systems was carried out to determine their technical and economic effectiveness under complex relief conditions. The evaluation focused on the operational characteristics of dump trucks, conveyor systems, and ropeway transport systems. Each transport method was analyzed according to several important parameters, including productivity, operating cost, energy consumption, terrain adaptability, and environmental impact.

The analysis showed that dump truck transport systems provide high operational flexibility and adaptability in mining areas with changing transportation routes. Dump trucks are capable of operating in difficult geological conditions and can easily transport ore over short and medium distances. However, their operating costs are relatively high due to significant fuel consumption, tire wear, and frequent maintenance requirements. In addition, heavy truck transportation creates considerable environmental impact through exhaust gas emissions, dust generation, and road deterioration.

Conveyor transport systems demonstrated the highest productivity among the analyzed transport methods. Conveyor systems ensure continuous transportation of ore materials with relatively low operating costs and reduced energy consumption compared to truck haulage systems. They are especially effective for long-distance transportation in large-scale mining enterprises.

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Furthermore, conveyor systems produce lower environmental pollution because they reduce fuel usage and minimize dust emissions. Nevertheless, conveyor systems have limited flexibility and require substantial capital investment for installation and infrastructure development.

Ropeway transport systems showed excellent adaptability under mountainous and steep terrain conditions where conventional road construction becomes difficult or economically inefficient. Ropeway systems are capable of transporting materials across valleys, slopes, and elevated areas with minimal environmental disturbance. Their energy consumption is relatively low, and they generate very little environmental impact compared to truck transportation. However, their productivity is generally lower than conveyor systems, and maintenance of cable structures and suspended equipment may increase technical complexity.

Table 1

The comparative evaluation results are summarized in the Table 1below.

Parameter	Dump Truck	Conveyor System	Ropeway System
Productivity	Medium	High	Medium
Operating Cost	High	Low	Medium
Energy Consumption	High	Low	Low
Terrain Adaptability	High	Medium	Very High
Environmental Impact	High	Low	Very Low

Based on the comparative analysis, conveyor systems were identified as the most economically efficient option for continuous large-volume transportation over long distances. Dump trucks remain suitable for flexible short-distance operations, while ropeway systems are particularly advantageous in mountainous regions with difficult access and steep relief conditions. Therefore, the selection of transport equipment should be based on the specific geological, technical, and economic conditions of the mining enterprise. Engineering calculations and technical-economic comparisons were performed using analytical methods and mining engineering standards. The obtained results were compared to determine the most efficient transportation system for complex terrain mining conditions. The overall research methodology ensured reliable assessment of transport system performance under different mining conditions.

CONCLUSION.

The selection of mining transport equipment in complex relief conditions is a critical factor influencing the overall efficiency, productivity, and economic viability of mining operations. This study demonstrated that transportation systems play a decisive role in determining operational costs, energy

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consumption, environmental impact, and production continuity in both open-pit and mountainous mining environments.

The comparative analysis of dump trucks, conveyor systems, and ropeway transport systems showed that each transport method has its own advantages and limitations depending on geological and operational conditions. Dump truck systems provide high flexibility and adaptability, making them suitable for short-distance and variable mining routes. However, they are characterized by high fuel consumption, increased maintenance requirements, and significant environmental impact.

Conveyor systems were identified as the most efficient option for large-scale and continuous mining operations. They offer high productivity, low operating costs, and reduced energy consumption, which makes them economically attractive for long-distance material transportation. Additionally, their environmental impact is relatively low due to reduced emissions and minimized fuel usage.

Ropeway transport systems demonstrated superior performance in steep and mountainous terrain conditions where conventional road construction is difficult or economically impractical. Their low energy consumption and minimal environmental disturbance make them a sustainable alternative for specific geological conditions, although their productivity remains moderate compared to conveyor systems.

The results of this study confirm that no single transport system is universally optimal. Instead, the selection of mining transport equipment must be based on a comprehensive evaluation of terrain characteristics, production capacity, transportation distance, and economic factors. The developed methodological approach ensures a balanced technical-economic assessment for selecting the most suitable transport system in complex relief mining conditions.

In conclusion, the integration of appropriate transport technologies significantly enhances mining efficiency, reduces operational costs, and improves environmental sustainability. Future research should focus on the development of hybrid transport systems and digital optimization models to further improve decision-making in mining logistics.

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