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DEVELOPMENT OF AN ALGORITHM FOR INTEGRATED MINING EQUIPMENT MANAGEMENT AND DATA TRANSMISSION TO A FLEET MANAGEMENT SYSTEM PLATFORM BASED ON ARTIFICIAL INTELLIGENCE AND VIDEO ANALYTICS

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Abstract

Background. Modern mining enterprises are actively implementing digital technologies to improve the efficiency of mining equipment operation and optimize production processes. However, existing dispatching and fleet management systems mainly rely on GPS monitoring and telemetry data, which do not provide comprehensive control over the actual state of technological operations in real time. Therefore, there is a growing need for the development of intelligent management systems based on artificial intelligence and video analytics technologies.

Materials and Methods. Computer vision, artificial intelligence, mathematical modeling, and production data analysis methods were used to develop an integrated mining equipment management algorithm. The proposed algorithm is



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based on the processing of video streams received from surveillance cameras, automatic detection and recognition of mining equipment, determination of its operational status, and transmission of the obtained information to a Fleet Management System (FMS) platform. Simulation modeling and comparative analysis of production indicators were employed to evaluate the effectiveness of the proposed solution.

Results. An integrated mining equipment management algorithm was developed, providing automatic object recognition, monitoring of loading and hauling operations, detection of equipment downtime, and generation of control actions in real time. Simulation results demonstrated that the application of artificial intelligence and video analytics technologies can increase production monitoring accuracy up to 95%, reduce response time to abnormal situations by 25–35%, and improve mining equipment utilization rates by 10–18% compared to conventional monitoring approaches.

Conclusions. The developed intelligent management system enables a higher level of automation and operational control in mining enterprises. The integration of artificial intelligence and video analytics with the Fleet Management System platform improves the efficiency of mining fleet management, reduces operational losses, enhances equipment utilization, and supports the implementation of the Digital Mine concept in modern mining operations.

Keywords: Mining equipment, Fleet Management System (FMS), artificial intelligence, video analytics, computer vision, digital mine, automated control, equipment monitoring, video data processing, intelligent dispatching, mining transportation complex, mining industry digitalization.

Introduction

The mining industry is currently undergoing a stage of active digital transformation aimed at improving production efficiency, reducing operating



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costs, and enhancing the safety of mining operations. Modern open-pit mining enterprises utilize a large number of excavators, haul trucks, drilling rigs, and auxiliary equipment, whose coordinated operation directly affects enterprise productivity and the cost of mineral extraction.

One of the most important challenges in open-pit mining is the effective management of mining equipment under continuously changing production conditions. Equipment downtime, uneven distribution of transport units between loading points, congestion of haulage routes, delays in material transportation processes, and unexpected operational situations lead to decreased productivity and increased operating expenses.

To address these challenges, Fleet Management Systems (FMS) are widely implemented at mining enterprises. These systems provide equipment location monitoring, telemetry data collection, production performance control, and support for dispatching decisions in real time. However, most existing systems are primarily based on GPS monitoring and onboard sensor data, which do not provide complete information about the actual state of technological processes directly within operational mining areas [1–7].

In recent years, the rapid development of artificial intelligence, computer vision, and video analytics technologies has created new opportunities for increasing the level of automation in mining enterprises [6–10]. Modern deep learning algorithms are capable of automatically recognizing mining equipment, determining its location, analyzing loading and unloading operations, identifying equipment downtime, monitoring transportation flows, and detecting deviations from technological processes without direct human intervention.

The integration of artificial intelligence and video analytics technologies with Fleet Management System platforms makes it possible to create a unified intelligent production management system [10,11]. The use of video data combined with telemetry information provides more accurate and reliable

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information about equipment operation, improves the quality of management decisions, and contributes to the optimization of mining transportation systems. Therefore, the development of an algorithm for integrated mining equipment management and data transmission to a Fleet Management System platform based on artificial intelligence and video analytics represents a relevant scientific and technical challenge [11,12]. The implementation of such an approach will improve mining equipment utilization efficiency, reduce equipment downtime, enhance operational safety, and contribute to the further development of the Digital Mine concept.

The objective of this study is to develop an integrated mining equipment management algorithm based on artificial intelligence and video analytics technologies, providing automatic data collection, processing, analysis, and transmission to a Fleet Management System (FMS) platform for real-time monitoring and decision support.

State of the art

Mining equipment is a key component of the production process in open-pit mining operations. Modern mining enterprises operate excavators, haul trucks, drilling rigs, and auxiliary equipment under challenging road, technological, and environmental conditions. The efficiency of mining transportation systems directly affects production volumes, operating costs, and the overall economic performance of mining enterprises.

Currently, Fleet Management Systems (FMS) are widely used for managing mining equipment fleets. These systems provide equipment location monitoring, production performance control, and support dispatching decisions in real time. Among the most widely adopted solutions are Wenco FMS, Modular Mining DISPATCH, Hexagon MineOperate, and Micromine Pitram. The implementation of these systems enables monitoring of equipment routes, tracking equipment productivity, and optimizing transportation flows.



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Despite the high level of automation, existing FMS solutions primarily rely on GPS monitoring, telemetry data, and onboard equipment sensors. This approach has several limitations related to the inability to obtain complete information about the actual state of technological processes directly within mining operation areas. For example, conventional systems cannot accurately monitor truck payload conditions, detect actual equipment downtime, assess the condition of working zones, or automatically identify violations of technological procedures. In recent years, artificial intelligence, machine learning, computer vision, and video analytics technologies have developed rapidly, enabling automatic object recognition and production process analysis based on video data. Modern deep learning algorithms are capable of detecting mining equipment in video streams, identifying equipment types, tracking movements, monitoring loading and unloading operations, and detecting abnormal situations in real time.

However, most existing solutions consider video analytics systems and Fleet Management Systems as separate information subsystems. The absence of a unified algorithm for data processing, production process analysis, and information transfer to the FMS platform reduces the effectiveness of decision-making and limits the possibilities for comprehensive automation of mining transportation systems.

An analysis of scientific and technical literature indicates that the integration of artificial intelligence and video analytics technologies with mining equipment management systems remains insufficiently investigated. Of particular interest is the development of an integrated mining equipment management algorithm capable of automatic video data acquisition, intelligent information processing, production performance analysis, and transmission of results to a Fleet Management System platform for real-time decision support.

Therefore, the development of an algorithm for integrated mining equipment management and data transmission to an FMS platform based on artificial intelligence and video analytics represents an important scientific and practical

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challenge. The implementation of such a solution will improve mining equipment utilization, reduce production losses, minimize equipment downtime, and contribute to the further development of the Digital Mine concept.

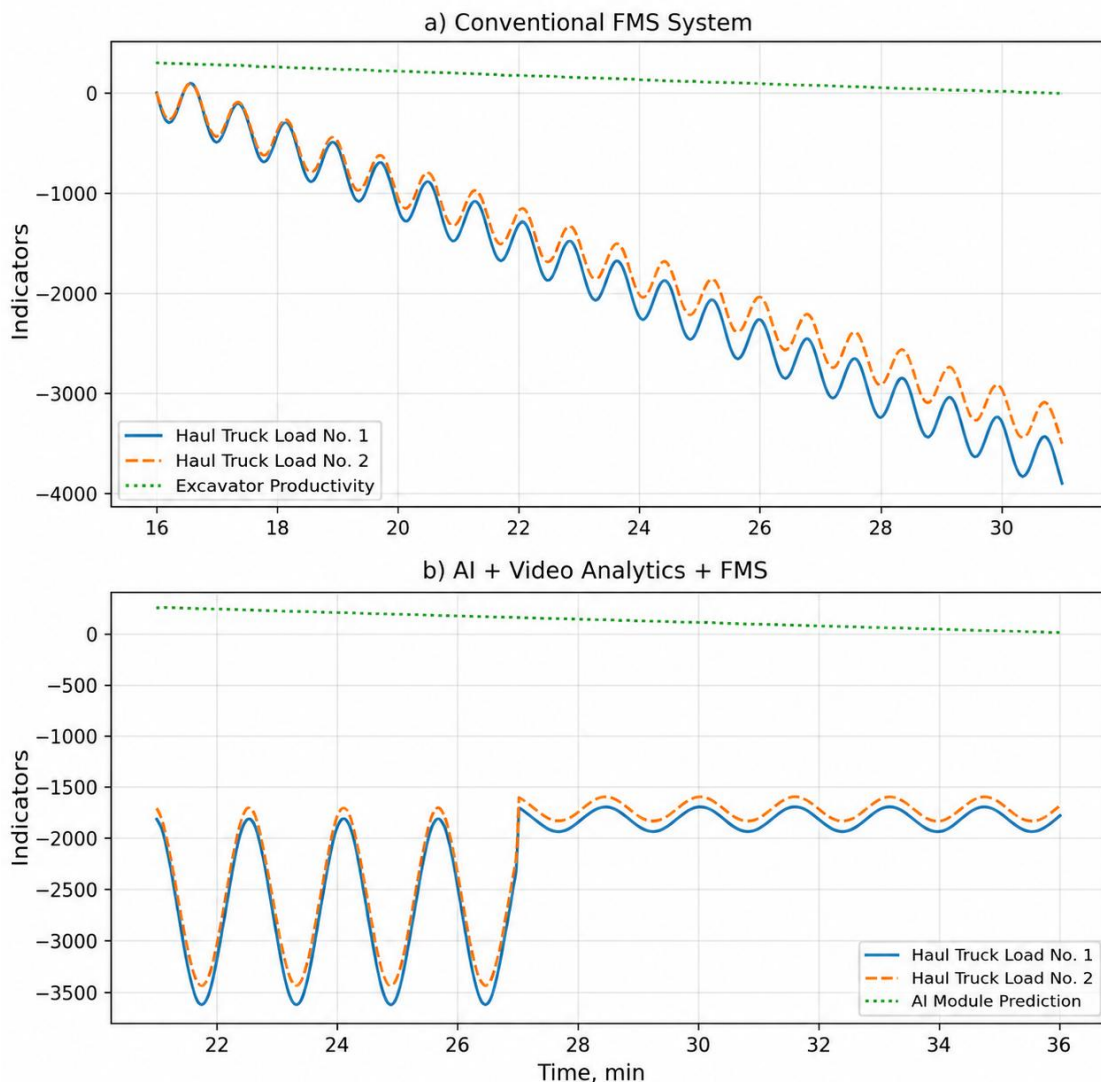


Fig. 1. Comparison of mining equipment performance indicators using a conventional Fleet Management System (FMS) and an intelligent management system based on artificial intelligence and video analytics.

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Figure 1 presents the simulation results of a mining transportation system operating under different management approaches. Graph (a) illustrates the performance of a conventional Fleet Management System (FMS), while graph (b) demonstrates the results achieved using the proposed AI-based video analytics algorithm integrated with the FMS platform. The results indicate improved equipment utilization, reduced downtime, and enhanced operational stability when artificial intelligence and video analytics technologies are applied.

Conclusions

As a result of the conducted research, an algorithm for integrated mining equipment management and data transmission to a Fleet Management System (FMS) platform based on artificial intelligence and video analytics technologies was developed. The proposed approach provides automated acquisition, processing, and analysis of video data obtained from open-pit mining operations, followed by the transmission of analytical results to the dispatching and fleet management system.

The analysis of existing mining fleet management systems demonstrated that conventional FMS solutions mainly rely on GPS monitoring and telemetry data, which limits the ability to monitor the actual state of technological processes. The integration of computer vision and artificial intelligence technologies significantly extends the functionality of existing systems through automatic equipment recognition, monitoring of loading and hauling operations, detection of equipment downtime, and identification of abnormal situations in real time.

Simulation results showed that the proposed algorithm improves production monitoring accuracy, reduces response time to operational events, and increases mining equipment utilization efficiency. The combined use of video analytics and the FMS platform ensures more stable operation of the mining transportation system, reduces the impact of the human factor on decision-making processes, and increases the reliability of production data.

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The practical significance of the research lies in the possibility of implementing the developed algorithm at operating mining enterprises without substantial modifications to the existing monitoring and dispatching infrastructure. The proposed solution can improve mining equipment utilization, reduce operating costs, minimize equipment downtime, and support the further development of the Digital Mine concept.

Future research should focus on expanding the functionality of the proposed system through the implementation of predictive machine learning models, predictive maintenance technologies, and integration with autonomous mining equipment management systems.

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