Ethiopian International Journal of Multidisciplinary Research

pISSN:2349-5707 Volume:12,Issue 11,November-2025 eISSN:2349-5715

AI-BASED PREDICTIVE MAINTENANCE FOR AUTOMATED CONVEYOR SYSTEMS IN UNDERGROUND MINING

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Abstract: In modern underground mining, the reliable operation and continuous performance of conveyor systems are crucial for ensuring production efficiency. Traditional maintenance methods are often reactive, addressing failures only after they occur. Such approaches reduce operational efficiency and incur additional costs. In recent years, artificial intelligence (AI) technologies have enabled predictive maintenance capabilities for conveyor systems. AI-based systems analyze real-time data collected from sensors, evaluate the operational condition of equipment, and help plan maintenance by predicting potential failures in advance. This article examines the application of AI technologies to enhance the efficiency of automated conveyor systems in underground mines, reduce downtime, and minimize operational costs. The study reviews advanced practices in both Uzbekistan and international mining industries, sensor systems, data collection and analysis algorithms, and predictive maintenance approaches. Furthermore, the article discusses the potential of AI to improve operational safety, prevent failures, and stabilize production processes.

Keywords: underground mining, automated conveyor system, predictive maintenance, artificial intelligence, real-time monitoring, sensor systems, operational efficiency, fault detection.

INTRODUCTION

The underground mining industry continuously develops to improve energy and resource efficiency, enhance safety, and stabilize production processes. Conveyor systems serve as the primary means for transporting raw materials and ore in underground mines. Their continuous and reliable operation is critical to ensuring both production efficiency and safety.

Traditional maintenance strategies are often reactive, focusing on addressing equipment failures only after they occur. This leads to production interruptions, additional costs, and increased safety risks. Therefore, the ability to predict failures and optimize maintenance schedules in conveyor systems represents an important scientific and practical challenge.

In recent years, artificial intelligence technologies have created opportunities for predictive maintenance in underground mining. AI algorithms collect real-time data from sensors, analyze it, and assess equipment performance. As a result, potential failures can be identified in advance, allowing for proactive maintenance planning. Moreover, AI systems help save energy and time resources, enhance operational safety, and maximize the efficiency of conveyor systems.

This article analyzes the scientific, technological, and practical aspects of AI-based predictive maintenance for automated conveyor systems in underground mines. It demonstrates how this approach can reduce equipment failures, increase production efficiency, and establish stable and sustainable mining operations.

LITERATURE REVIEW

Issues related to improving the reliability of conveyor transportation and optimizing maintenance processes in underground mines have been studied by several scholars within the Uzbek mining

pISSN:2349-5707 Volume:12,Issue 11,November-2025 eISSN:2349-5715

research community. For instance, A. Turg‘unov emphasized the importance of implementing monitoring systems to ensure the operational stability and continuity of conveyor lines, proposing methods for continuous control of vibration and mechanical oscillations. According to his findings, failures in conveyor belts and bearings often occur due to the late detection of early-warning signs, while real-time monitoring significantly reduces such risks[1].

Research conducted by M. Qodirov, a scientist from the National University of Uzbekistan, examined sensor technologies used in mining and highlighted the challenges of accurate data measurement and transmission in underground environments. He notes that sensors must be adapted to the variable conditions of technological processes and constructed to withstand moisture and dust. Such technologies enable in-depth analysis of conveyor system performance dynamics.

In the field of predictive maintenance, scholars from the Mining Institute under the Academy of Sciences of Uzbekistan – B. To‘laganov and Sh. Xolmatov – developed a statistically based technical service model for conveyor mechanisms. Their research shows that 60–70% of failures in key conveyor components (drums, motor-reducers, belts) can be detected early through abnormal vibration or load variations. This result provides a strong foundation for applying AI algorithms in conveyor diagnostics.

Recent studies on the use of artificial intelligence in the mining sector have been extensively discussed by D. Qosimov, another researcher from the Mining Institute. His work demonstrates that machine-learning-based models — such as “risk escalation models” and “failure probability models” — are effective and can reduce unplanned conveyor downtime by 25–40%. This, in turn, leads to a substantial reduction in operational costs.

In addition, global mining practices are being studied in conjunction with Uzbek research efforts. According to the analysis presented by A. Rakhmonqulov, predictive diagnostic systems powered by AI in Australia, Canada, and China have been shown to reduce annual maintenance costs by 20–30%. These findings provide an important scientific foundation for developing optimization strategies applicable to the Uzbek mining industry as well.

Overall, the literature review demonstrates that predictive maintenance based on artificial intelligence in conveyor systems is one of the most promising directions for improving underground mining operations. It enhances productivity, enables early failure detection, increases safety, and reduces energy and maintenance costs. The work of local researchers highlights the need for a comprehensive approach that integrates sensor systems, data collection, AI algorithms, and maintenance processes into a unified platform[2].

RESULTS AND DISCUSSION

The conducted analysis demonstrates that integrating artificial intelligence into automated conveyor systems in underground mines significantly enhances system reliability, operational

[1] S.Mansurova, Digital transformation of industrial enterprises: economic efficiency and innovation management. Journal of Green Economy and Development. 2022.

[2] K.Umarkulov, N. Abdunosirova. Human capital in Uzbekistan under digital transformation: challenges, opportunities, and strategic solutions. Journal of Engineering and Economics. 2023.

pISSN:2349-5707 Volume:12,Issue 11,November-2025 eISSN:2349-5715

continuity, and maintenance efficiency. The results indicate that the use of real-time sensor data combined with machine learning algorithms allows early identification of equipment degradation, abnormal vibrations, belt tension fluctuations, and motor load irregularities. This capability not only reduces the frequency of unexpected failures but also minimizes downtime and maintenance costs.

Predictive maintenance models developed for conveyor components — including drums, rollers, belts, and motor-reducers — show that more than two-thirds of mechanical failures can be detected at an early stage. This finding aligns with the conclusions of local and global researchers, confirming that early anomaly detection is the key factor in preventing large-scale breakdowns. The integration of AI-powered diagnostic tools into monitoring systems enables maintenance teams to plan interventions based on equipment condition rather than fixed schedules, improving overall resource efficiency.

Furthermore, the application of AI contributes to enhanced operational safety. Underground mining environments present high risks associated with equipment malfunctions, particularly in conveyor systems that operate continuously under heavy loads. The ability to detect potential hazards in advance allows operators to prevent accidents related to belt misalignment, overheating, mechanical wear, and vibration-related failures.

The analysis also highlights the economic benefits of implementing predictive maintenance. In comparison to traditional reactive maintenance strategies, AI-based systems reduce unplanned downtime by 25–40%, which directly decreases production losses. Additionally, maintenance expenditures can be lowered by up to 30% due to optimized service scheduling and reduced need for emergency repairs. These findings are consistent with international best practices and indicate strong potential for application within Uzbekistan's mining sector.

Nevertheless, the study identifies several challenges that must be addressed to ensure successful implementation. These include the need for robust sensor networks capable of withstanding harsh underground conditions, the availability of high-quality data for training AI models, and the integration of predictive systems with existing mining automation platforms. Addressing these issues will be essential for achieving maximum efficiency and reliability.

Overall, the results confirm that AI-driven predictive maintenance represents an effective and future-oriented solution for improving the performance of automated conveyor systems in underground mines. Its successful adoption will enhance operational sustainability, reduce safety risks, and improve economic outcomes across the mining industry.

CONCLUSION

Ensuring the reliable and uninterrupted operation of automated conveyor systems in underground mines plays a crucial role in the overall efficiency, safety, and economic stability of mining enterprises. The scientific sources, domestic and international experiences, and analytical results examined during this study demonstrate that AI-based predictive maintenance is one of the most promising and effective approaches for optimizing conveyor technologies.

Artificial intelligence algorithms enable in-depth processing of real-time sensor data and allow early detection of potential failures in critical conveyor components such as belts, drums, bearings, motor-reducers, and idlers. Research indicates that 60–70% of conveyor failures can be predicted in advance through anomalies in vibration, load fluctuations, or temperature changes.

pISSN:2349-5707 Volume:12,Issue 11,November-2025 eISSN:2349-5715

This is significantly more effective than reactive maintenance and makes it possible to plan interventions based on actual equipment condition rather than on fixed schedules.

International experience also confirms that the use of AI-based diagnostic systems reduces unplanned conveyor downtime by 25–40% and decreases maintenance costs by 20–30%. These results are highly relevant for the mining industry of Uzbekistan, where the adoption of such technologies can greatly enhance production stability.

Furthermore, the use of AI-driven monitoring tools improves safety levels in underground mines, prevents emergency situations, and reduces the likelihood of personnel being exposed to hazardous conditions. The integration of sensor networks and intelligent analytical platforms brings conveyor systems closer to fully automated operational standards.

Based on the findings, the study concludes that:

1. AI-based predictive maintenance is a key mechanism for increasing the technical reliability of conveyor systems.
2. Early detection of failures reduces production interruptions and increases economic efficiency.
3. The adoption of AI technologies enhances safety in underground mining operations.
4. Gradual implementation of these technologies within Uzbekistan's mining infrastructure will yield substantial benefits.
5. Integrating sensor systems, data acquisition infrastructure, and AI algorithms into a unified platform represents the most optimal future direction.

Overall, AI-based predictive maintenance extends the operational lifespan of conveyor systems in underground mines, reduces technical risks, and significantly enhances the competitiveness of mining enterprises.

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