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AUTOMATED CONTROL SYSTEMS FOR OPEN PIT MINING TRANSPORT EQUIPMENT: CURRENT STATE AND DEVELOPMENT PROSPECTS

Makhmudov Sherzod Azamatovich
Associate Professor, Navoi State Mining and Technology University
Ismatov Adkhamjon Alibekovich
Senior Lecturer, Navoi State Mining and Technology University
Rakhimova Nozanin Allayor kizi
Student, Group 29A-25 TMO

Annotation. This paper examines automated control systems (ACS) for open pit mining transport equipment, analyzing centralized and decentralized management approaches. The study reviews leading international systems including Wenco, Modular Mining, VIST Group, Leica Geosystems, and Caterpillar solutions. Special attention is given to autonomous haulage systems (AHS) developed by Komatsu, Caterpillar, and Hitachi, which eliminate human drivers and utilize GPS navigation, obstacle detection, and centralized dispatching. Analysis shows that ACS implementation increases productivity by over 20% and equipment utilization by 25% while reducing operational costs. The research demonstrates that modern mining requires integrated robotic systems functioning within comprehensive mine development frameworks, enabling centralized control and coordination with all mining operations and personnel for enhanced efficiency and safety.

Key words: automatic control system, road transport, technology, trucking, quarry.

Аннотация. В статье рассматриваются автоматизированные системы управления (АСУ) карьерным автотранспортом, анализируются централизованные и децентрализованные методы управления. Проведен обзор ведущих международных систем: Wenco, Modular Mining, VIST Group, Leica Geosystems и Caterpillar. Особое внимание уделено автономным системам транспортировки (AHS) компаний Komatsu, Caterpillar и Hitachi, исключающим присутствие водителей и использующим GPS-навигацию, обнаружение препятствий и централизованную диспетчеризацию. Анализ показывает, что внедрение АСУ повышает производительность более чем на 20%, использование оборудования на 25% при снижении эксплуатационных затрат. Исследование демонстрирует, что современная добыча требует интегрированных роботизированных систем, функционирующих в рамках комплексных систем разработки месторождений, обеспечивающих централизованное управление и координацию со всеми горными операциями для повышения эффективности и безопасности.

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Ключевые слова: система автоматического управления, автомобильный транспорт, технология, грузоперевозки, карьер.

Annotatsiya. Maqolada ochiq konlar avtotransporti uchun avtomatlashtirilgan boshqaruv tizimlari (ABT) ko'rib chiqiladi, markazlashtirilgan va markazlashmagan boshqaruv usullari tahlil qilinadi. Wenco, Modular Mining, VIST Group, Leica Geosystems va Caterpillar kabi yetakchi xalqaro tizimlar o'rganilgan. Komatsu, Caterpillar va Hitachi kompaniyalarining avtonom tashish tizimlari (AHS) alohida e'tibor qaratilgan bo'lib, ular haydovchilarni istisno qiladi, GPS navigatsiya, to'siqlarni aniqlash va markazlashtirilgan dispetcherlikdan foydalanadi. Tahlil shuni ko'rsatadiki, ABT joriy etilishi unumdorlikni 20% dan ortiq, uskunadan foydalanishni 25% oshiradi va ekspluatatsiya xarajatlarini kamaytiradi. Tadqiqot zamonaviy kon ishlab chiqarishi samaradorlik va xavfsizlikni oshirish uchun barcha kon operatsiyalari bilan markazlashtirilgan boshqaruv va muvofiqlashtiruvchi kompleks robotlashtirilgan tizimlarni talab qilishini ko'rsatadi.

Kalit so'zlar: avtomatik boshqaruv tizimi, yo'l transporti, texnologiya, yuk tashish, karer

INTRODUCTION

The management of open pit mining operations represents one of the most complex challenges in modern mining engineering, characterized by the coordination of numerous interacting elements distributed across vast spatial areas with significant operational variability. The technological process of material haulage by dump trucks encompasses four critical stages: planning, process organization, process implementation, and control. Each stage requires meticulous monitoring of operational parameters including execution time of loading and transportation operations, number of trips completed, weight of transported cargo, fuel consumption levels, driver performance quality, and other key performance indicators that directly impact overall mining efficiency.

The emergence and rapid advancement of automated control systems (ACS) has fundamentally transformed the landscape of open pit mining operations. Modern ACS must provide real-time operational information regarding the location and movement of road transport equipment and associated working components, enabling mining companies to optimize their haulage operations with unprecedented precision. The integration of advanced microprocessor technology, sophisticated information systems, and satellite navigation platforms such as GPS and GLONASS has catalyzed a qualitative leap in the development and deployment of automated control systems specifically designed for road transport equipment in open pit mining environments [1,2,3].

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Contemporary approaches to process control can be categorized into two primary methodologies: centralized and decentralized systems. In centralized control architectures, a control center aggregates data from individual mobile units, allowing dispatch services to monitor operational data continuously and regulate vehicle movements dynamically based on evolving field conditions. Conversely, decentralized approaches accumulate data at individual vehicle level over designated time periods before transmission to the central control facility. Regardless of the chosen methodology, both systems employ automated data processing algorithms to generate comprehensive reports that inform decision-making processes and facilitate timely adjustments to operational procedures.

The global mining industry has witnessed the emergence of several prominent automated control system manufacturers, including Wenco International Mining Systems (Hitachi), Modular Mining (Komatsu), VIST Group, Leica Geosystems (Hexagon Geosystems), Devex (Hexagon Geosystems), and Caterpillar. These industry leaders have leveraged extensive computer technology integration and implemented sophisticated optimization algorithms based on linear and dynamic programming theories to solve complex destination problems inherent in trucking operations. The widespread adoption of radio communication systems has further enhanced operational capabilities by ensuring immediate connectivity between dispatchers and dump truck operators.

Recent years have seen a paradigm shift toward autonomous haulage systems (AHS) that completely eliminate human operators from dump truck operations. Leading equipment manufacturers are developing and deploying robotic mining excavators and autonomous dump trucks that promise substantial improvements in operational efficiency, equipment productivity, and personnel safety while simultaneously reducing operating costs and minimizing human presence in hazardous mining environments. According to industry experts, automated control of mining and transport equipment can increase overall productivity by more than 20% and enhance the efficiency of excavators and dump trucks by approximately 25%.

This paper examines the current state of automated control systems for open pit mining transport equipment, analyzes the technological capabilities and operational characteristics of leading international systems, and explores the development prospects of autonomous haulage technologies that represent the future of surface mining operations.

MATERIALS AND METHODS

Currently, there are several varieties of automated control systems for road transport equipment on the market.

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Advances in microprocessor technology, information technology, GPS and GLONASS satellite navigation systems have had a qualitative impact on the development of automated control systems for road transport equipment in open pit mining [4,5].

The analysis of automated control systems for transport equipment [3,6,7] has revealed the following manufacturers to be the most widespread among the mining companies in the world: Wenco International Mining Systems (Hitachi), Modular Mining (Komatsu), VIST Group, Leica Geosystems (Hegsagon Geosystems), Devex (Hegsagon Geosystems), Caterpillar. The three companies mentioned above are directly related to the production of quarrying equipment and the creation of robotic systems.

A peculiarity of foreign ACSs used in open-pit mining is that they were developed with extensive use of computer technology, and as an algorithm for optimal management of trucking were used solutions on a computer of the destination problems using the theory of linear and dynamic programming. Radio communication is widely used in the systems to ensure operative communication between the dispatcher and dump truck drivers [8].

One of the first automated control systems of open-pit motor transport in which for optimisation of dumper trucks distribution procedure by excavators the algorithm of solving on computer of linear programming tasks with variable factors was used (introduced on the big copper open-cast mine (Tucson, USA). Actually it was dispatching system with time allocation, i.e. the computer worked in a dialogue mode with the dispatcher. The open-circuit control of the open-circuit dump trucks has increased haulage productivity by more than 20%.

Leica Geosystems Mining has developed a comprehensive mining control system, Jigsaw, which includes: basic mining equipment monitoring and control modules. A special feature of the Jigsaw automation system is that it is based on the same type of unified on-board equipment and has three control levels: open pit truck control (Leica Jfleet systems), high precision positioning (Leica J2 guidance) and autonomous systems (Leica J3 autonomous).

The flexibility, scalability and integration of the Jigsaw system enables it to be customized to your individual requirements. Based on an analysis of the information on the Leica website, the Jigsaw system has been implemented in more than 100 different mining operations worldwide [9].

In developed countries with a mining industry, a number of companies are now considering the introduction of promising unmanned technologies based on remote-controlled equipment and autonomous haulage systems using robotic excavators and dump trucks for open-pit mining. Compared to existing mining

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technologies, unmanned technologies ensure higher efficiency of open pit mining operations, equipment productivity and personnel safety, reduce operating costs and minimise the presence of people at the face. According to foreign experts, automated control of mining and transport equipment in open pit mines can increase productivity by more than 20% and increase the efficiency of excavators and dumper trucks by 25%. The pioneer in the field of automatic control systems for quarry dump trucks is Unite Rig Equipment, which manufactures the Lextra Hol dump trucks (USA).

The purpose of developing this system is to eliminate dump truck drivers altogether. The system includes control devices mounted on the dump truck, guiding transport equipment based on an underground cable with a depth of 0.45 m and control units along the quarry route, and a central control panel [10].

The economic efficiency of this system was tested in a copper ore quarry, where 10 excavators and 54 dump trucks were operated. There was a halving of the manual control time of the dump trucks and a 25% increase in the utilisation rate of the dump trucks, while operating costs were reduced by 25% [11].

In 2004, a Komatsu Autonomous truck automated driving control system was developed in Japan for Komatsu dump trucks when driving on quarry roads with gradients up to 12%. The system was installed on Komatsu's small and medium-sized dump trucks (HD-785, HD-465, HD325) with a payload of 32 to 80 tonnes. The Autonomous truck system operates in three modes: automatic, radio control and manual control and includes the following autonomous subsystems [12, 13]: GMS (Global Monitoring System); NS (Navigation System); ODS (Obstade Detection System); VMS (Vehicle Monitoring System). Dumper movement was monitored automatically from the loading machine. Remote control of dump truck movement at loading point is carried out in semi-automatic mode, or under full control by means of special radio remote control. The Autonomous truck system was most effective when three Komatsu dump trucks were operating simultaneously at speeds of up to 30 km/h forward and 10 km/h reverse.

Leading quarry equipment manufacturers are developing and implementing Autonomous Haulage Systems (AHS) based on robotic mining excavators and dump trucks. The AHS system eliminates the human factor in dump truck operation, and ensures not only the truck's travel on the highway between the loading and unloading points, but also maneuvering in the unloading points. Komatsu Ltd., which has partnered with Modular Mining to develop an autonomous trucking system called Front Runner. The system was first put into operation in 2008 at Rio Tinto's West Angelas mine, the East Pilbara mine in Western Australia. Since 2009, mining equipment has been controlled from a single

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control centre located 1,300 km from the mine site. The Front Runner system was also put into operation at Codelco's copper mines in Chile. Front Runner equipment was initially installed on five KOMATSU dump trucks based on a 930E model with electric drive. The autonomous trucks are driven in difficult field conditions without a driver under control of a computerized dispatcher. The general concept of the Front Runner autonomous haulage system is shown in Figure 1.

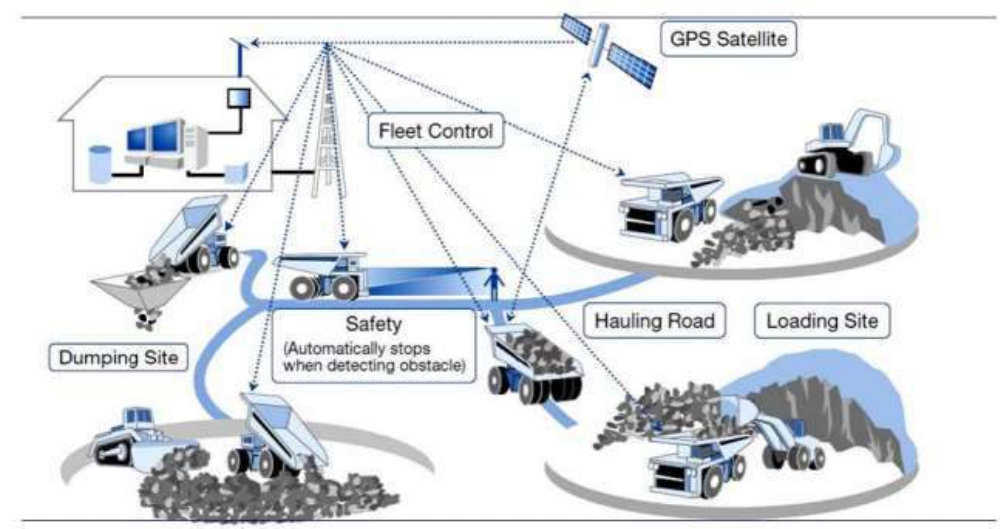


Fig. 1. - Front Runner autonomous trucking system concept

The computer-controlled dispatcher uses wireless data transmission to route and speed the driverless dump trucks, while the global positioning system establishes their position. For loading, the dump trucks are automatically guided to the same location as the bucket, the coordinates of which are determined by a GPS navigator integrated into the hydraulic excavator or wheel loader mechanism. The computer-controlled dispatcher also relays the dump truck's course data to the unloading point. In terms of safety, the control system ensures that the dumper trucks do not collide with each other or with any other equipment in the field. If another vehicle or person is in the line of sight of the obstacle detection system, the autonomous hauler machines will slow down or stop immediately.

Under an agreement between Komatsu and RioTinto, 150 autonomous Komatsu 930E-B haulers are to be commissioned at the Yandicoogina mine in Western Australia.

Another leading manufacturer of mining equipment, Caterpillar, has developed the Caterpillar Mine Star autonomous mine management system with plans for commercial use at a control centre in Edmonton, Canada, to manage 8 mining operations in North America and Canada [14]. Each of the plants has approximately 35 autonomous, remotely operated dump trucks. The distance from the most distant quarry to the control centre is more than 1000 km. The Caterpillar Mine Star autonomous system includes two main subsystems: Minestar Fleet

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Commander and Minestar Health, with the first subsystem allowing to monitor and optimize all cargo flows, control all stages of dump truck operation, and visualize all incoming information. Minestar Health, on the other hand, monitors and manages all events in real time.

Japan's Hitachi is also planning to develop a full-process AHS autonomous haulage system based on Hitachi AC powered mining trucks in close cooperation with Wenco International Mining Systems Ltd [15,17,18].

The Leica J3 autonomous control subsystem of the Leica Geosystems mining automated control system Jigsaw, in partnership with Autonomous Solutions Inc. (ASI), has developed a versatile hardware and software platform (Figure 2) that is not tied to a specific machine type and manufacturer, allowing for any level of autonomy for the trucking equipment [16,19,20,21].

Leica J3 autonomous system includes: Haul truck convoy control subsystem; remote operator control subsystem outside the cab using a handheld remote control within line of sight; semi-autonomous control subsystem (remote operator work from the control point using video surveillance and digital map of the pit with full automation of the work cycle part).

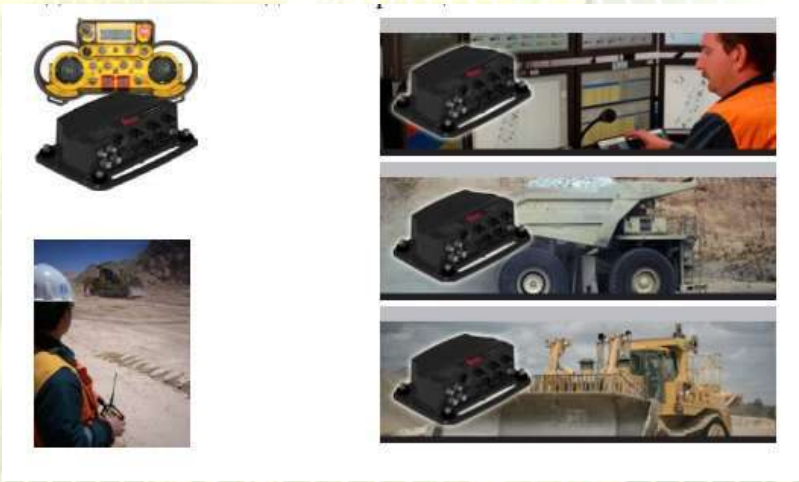


Fig. 2. - Hand-held remote control and on-board equipment of the Leica J3 autonomous system

RESULTS AND CONCLUSIONS

The conducted analysis of the modern state and prospects of development of automation of surface mining shows that the most important features and a necessary factor in the development of production organization and management during mining works at the present stage is the use of automated control systems of transport equipment, allowing to significantly increase the efficiency of mining production: labour productivity and safety of mining works.

The degree of development of communication technologies, navigation and software allows to automate control and management of mining equipment with

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application of standard control principles. The next step in improving the productivity of road transport equipment could be a step aimed at reducing non-technological downtime and removing humans from the direct control of mining equipment.

The analysis has shown that the current competition, development of new solutions and ways to improve the efficiency of road transport equipment has led to the development and implementation of automated mining method in the leading mining companies of the world. And with appropriate modernisation of ACS and refinement of software, there should be a phased transition to the creation of ACS with the use of robotic haulage systems.

Existing technology for mining and transportation equipment that can move remotely or autonomously along process roads is no longer satisfactory to mining companies. What is needed is for the mining equipment to function as part of an entire mine development system, interacting with every piece of equipment and every person in the mining operation, i.e. for the robotic transport equipment to be part of the ASU system and also to be centrally controlled, not in isolation from the rest of production.

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