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Evaluating the performance of the DISPATCH algorithm, a commercial software, in the Sungun copper mine

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ABSTRACT

Intelligent transportation systems are being widely adopted in open-pit mines worldwide to improve production, achieve planning goals, ensure quality control, monitor equipment, and reduce operational costs. These systems aim to optimize mining processes related to transportation activities, resulting in reduced wasted time, increased profitability, and lower operational costs. In Iran, the transportation system in mining involves fixed allocation and encounters several challenges. Resolving these issues is crucial for the successful implementation of mining fleet management systems in the country. Therefore, this research aims to implement the DISPATCH algorithm, a commercial software, to evaluate and investigate its performance in one of Iran's major mines, the Sungun copper mine. For this reason, a discrete-event simulation model was constructed in Arena software to implement the developed system based on the case study data. The results show that the production rate in the DISPATCH system, with improved fleet efficiency and reduced waiting time, has a growth rate of 17.4 percent compared to the actual dispatching strategy in the mine. In other words, replacing intelligent transportation systems with traditional dispatching methods can manage the loading and hauling process more efficiently with lower costs and higher productivity.

KEYWORDS

real-time truck dispatching, DISPATCH system, discrete-event simulation, Sungun copper mine, open-pit mining

I. INTRODUCTION

Transportation constitutes the most costly aspect of open-pit mining operations (Aarie and Gamache, 2002) (Aarie Gamache, 2002). Enhancing transportation procedures and reducing costs in this sector, even by two to three percent, yields notable savings in mining operational costs. A fleet management system, considering production requirements, controls extraction operations smoothly with the lowest cost. In general, short-term production goals are achieved through the fleet management system. In the fleet management system, dynamic decision-making algorithms are employed to determine optimal or nearly optimal choices for material movement throughout the life of the mine (Moradi Afrapoli et al., 2019). Fig. 1 demonstrates the correlation between open-pit mining operations and the fleet management system (Bao and Zhang, 2020). The fleet management system consists of two key components: hardware and software. The hardware component includes sensors installed on equipment, a wireless network, and a local server situated at the mine. On the other hand, the software component involves dynamic truck management for optimized fleet allocation and dispatching. Using the wireless network (radio network), a global positioning system (GPS), and installed sensors, the position and status of all equipment in the mining network, topological maps, and transportation routes are transferred to the control center and main server and displayed on the dispatcher's screen. After receiving all the information, when the truck operator requests dispatching, the software component of the system runs on the computer and is processed by the system. Finally, the determined truck's path is transferred from the dispatcher's station to the truck driver via a digital message, and the truck driver travels along the designated route (Aarie and Gamache, 2002).

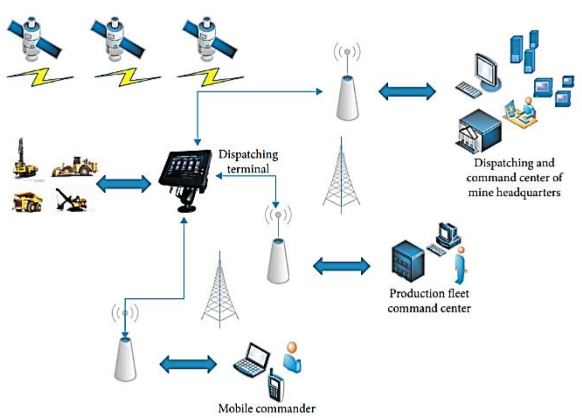

Fig. 1. Fleet operations monitoring and management system

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in open-pit mines (Bao and Zhang, 2020)

In the software section, the first step involves employing optimization techniques to determine the shortest available routes between loading and unloading points (White and Olson, 1986). Various researchers, including Soumis and Elbrond (1987), Soumis (1989), and He and Yegulalp (1993), have applied different algorithms to address the shortest problem between shovels and dumping stations. This problem depends on the current position of the shovels in the mining system and is updated as the shovels' positions change. Once the shortest routes are identified, fleet management systems have the option to employ two methods for real-time truck dispatching: single-stage and multi-stage approaches. In the single-stage method, truck dispatching is carried out without considering the optimal production rate of routes (Forsman et al., 1993; Kolonja et al., 1993; Fioroni et al., 2008; Jaoua et al., 2009; Souza et al., 2010; Asenovski and Kaikov, 2020; de Carvalho and Dimitrakopoulos, 2021). Most common mining fleet management systems operate based on the multi-stage approach. In this method, the optimal production rate of routes is determined in the first stage using operational research methods (Lizotte and Bonates, 1987; Li, 1990 ; Temeng et al., 1998; Ta et al., 2005 ; Topal and Ramazan, 2010; Eivazy and Askari-Nasab, 2012 ; Chang, et al., 2015; Matamoros and Dimitrakopoulos, 2016; Upadhyay and Askari-Nasab, 2019 ; Both and Dimitrakopoulos, 2020.). In the second stage, employing an optimization algorithm, the real-time dispatching of trucks is fulfilled to achieve the production rates specified in the first stage (Subtil et al., 2011; Afrapoli et al., 2018; Yeganejou et al., 2022; Mohtasham et al., 2022). Eventually, before implementing the fleet management system in actual mining operations, a precise evaluation of the approaches' performance is crucial. Due to the stochastic nature of mining operations, this evaluation is a challenging task. Research indicates that simulation is an appropriate tool for examining and analyzing management concerns and operational decision-making in fleet management systems (Tarshizi et al., 2015; Tiile et al., 2016; Kaba et al., 2016; Baafi and Zeng, 2019). In this regard, this study aims to implement the dispatch algorithm of the well-known commercial system DISPATCH using discrete-event simulation in a case study to investigate its performance and efficiency in the productivity of the mining and operational fleet system.

II. COMMERCIAL FLEET MANAGEMENT SYSTEMS AVAILABLE IN THE MARKET

Currently, numerous mining and software companies worldwide have developed mining fleet management systems. Table 1 outlines some of the prominent providers of these systems. Among these systems, DISPATCH stands out as the most successful, widely used, and recognized fleet management system, which performs the material transportation process with the least wasted time (Moradi Afrapoli et al., 2015). Since the algorithms and models used in each fleet management system are proprietary, companies do not have a desire to disclose them publicly due to business competition. Therefore, comparing approaches and the level of optimization of employed solutions is not feasible. However, Modular Mining is an exception, as it has disclosed the logic behind its management system. The algorithms and models presented by White and Olson (1986) and Olson et al. (1993), which are publicly available, serve as the fundamental basis for the DISPATCH system.

Table 1: Summary of Some Commercial Mining Fleet Management Systems (Moradi Afrapoli et al., 2015)

Fleet Management System	Company	Number of Mines in Use
DISPATCH®	Modular Mining Systems	236
Jmineops	Leica Geosystems	More than 130
Wencomine	Wenco Mining Systems	Around 70
CAT® MINESTAR™ FLEET	Caterpillar	Not available
Pitram	Micromine	Not available
Dynamine	TATA	Not available

III. THE METHODOLOGY EMPLOYED IN THE COMMERCIAL DISPATCH SYSTEM

The DISPATCH system employs a multi-step method for real-time truck dispatching. Firstly, the shortest paths between all points in the mining road network are determined using Dijkstra's algorithm. The second stage comprises two components, beginning with an overall optimization process. In the second stage, maximization of production is carried out aiming to minimize the number of trucks required to cover the loading production. However, the allocation model employed in this commercial system has limitations. It overlooks various mining objectives and doesn't fully cover the technical and operational constraints of the mine. To address these shortcomings, a comprehensive multi-objective model developed by Mahtasham et al. (2021a) is utilized for the allocation stage. In the third phase, before dispatching the trucks, two lists are prepared: one for the mining routes and another for the trucks. In the route list, the routes are sorted based on the time required for dispatching. Routes with production rates that vary more from their optimal rates (determined by the first stage) are prioritized at the top of this list. The time needed for route i is determined by Eq. (1):

$$need-time_i = \quad L_j + \frac{F_{ij}\left(A_j - R_j\right)}{P_i} \qquad (1)$$

Where $need - time_i$ represents the expected time required for assigning a truck to route *i* (hours), L_j is the time of the last truck assigned to shovel *j* (hours), P_i denotes the optimal flow rate of route *i* based on the allocation plan (LP model) (cubic meters per hour), A_j is the total determined allocation until time L_j to shovel *j* (cubic meters), R_j stands for the remaining transportation allocations for shovel *j* (cubic meters), and F_{ij} is the current flow rate of route *i* over the total flow rate of shovel *j* determined by the allocation plan.

The definition makes it evident that assigned routes tend to have higher flow rates (P_i). Additionally, shovels whose production rates fall short of their plans (A_j–R_j), where (A_j–R_j) is smaller or negative, tend to prioritize earlier truck allocation times. The route with the minimum required time is selected as the neediest route. The truck list includes all trucks stationed at unloading locations or currently en route to unloading destinations. Trucks are dispatched by selecting the most suitable match between the truck and the route, aimed at enhancing the scheduling efficiency of that route. The best truck is identified based on cost minimization, where costs are determined by factors such as shovel idle time, truck waiting time, the additional time a truck spends traveling to a selected shovel instead of the nearest one, and the material flow rate on each route determined from the first stage. The determination of the best truck involves the utilization of the concept of "lost tons," as defined in equation (2).

$$lost - tones = TC\ \frac{TR}{RT}(TI + ET) \times (SR * SI) \qquad (2)$$

Where TC is the ratio between the allocated truck capacity and the average truck capacity, TR is the total drilling rate of all shovels available in the mine (tons per hour), RT is the total number of trucks required (results of the allocation program), TI is the expected waiting time of the truck, the time it is allocated to the neediest route, ET is the maximum travel time of an empty truck on the neediest route, SR is the sum of all route rates terminating at the most needy shovel, and SI is the expected idle time of the shovel if the truck is allocated to the neediest route.

A truck with the lowest lost tons from the truck list is chosen as the best truck. After selecting the best truck and the neediest route, that truck is removed from the truck list, and the desired route is moved to the end of the route list. Then, the lists are updated and the route that is higher than all other routes in the route list is chosen as the next most needy route, and the best truck that has not been allocated is selected from the truck list. This process repeats until all trucks in the truck list are allocated to shovels (Munirathinam and Yingling, 1994).

IV. CASE STUDY

To assess the effectiveness and efficiency of the DISPATCH algorithm in a real mining operation, the Sungun copper mine is considered as a case study. In the mine, the loading system is typically handled by loaders and excavators, while material haulage is carried out by dump trucks of 30, 55, 60, 100, and 135-ton capacities. Various discharge points are present, including crushers, waste dumps, oxide dumps, low-grade material dumps, and mineral stockpiles. Three companies, Mobin, Ahan Ajin, and Noavaran, are responsible for the mining transportation operations. Each company operates independently without any interference with each other, and their activities are entirely separate. The required data consists of operational data, including cycle time, loader capacity, crusher capacity, etc., collected directly, and planning data, including ore grade and stripping ratio, collected through the mine support office. In this shift, there are 14 loading points, including 9 waste loading points and 5 mineral loading points (Ahan Ajin operates 2 waste loading points and 2 mineral loading points, Mobin operates 3 waste loading points and 3 mineral loading points, and Noavaran operates 4 waste loading points). In this research, operational data from Ahan Ajin company is utilized. The operational specifications of the loading stations dedicated to Ahan Ajin company are presented in Table 2. In this operational shift, 15 trucks of 100 tons capacity and 4 trucks of 30 tons capacity are involved in the transportation operations. Fig. 2 depicts a schematic picture of the transportation operations of Ahan-Ajin's Company. Based on our previous study (Mohtasham et al., 2021b) and by implementing an optimization-based simulation method, an appropriate and optimal number of trucks for mining operations is estimated to be 24 trucks, including 18 trucks with 100 tons capacity and 6 trucks with 30 tons capacity. The stripping ratio for the target shift ranges from a minimum of 2.5 to a maximum of 3.5. The mine's allocation strategy is fixed allocation. In this shift, the company has produced a total of 19,312 tons of materials (12,640 tons of waste and 6,672 tons of ore) using the fixed allocation strategy.

Table 2. Operational specifications of loading points for Ahan Ajin company in the considered shift

Loading points	Bench level (m)	Type of material	Loading equipment	Maximum production rate (ton/shift)	Minimum production rate (ton/shift)	Average grade (%)
1	2275	waste	Komatsu-PC 2000	10000	5000	-
2	2237.5	waste	Komatsu- PC 1250	7700	3800	-
3	1900	ore	Komatsu- PC 1250	7700	2800	0.75
4	2150	ore	Komatsu- PC 1250	7700	3000	0.42

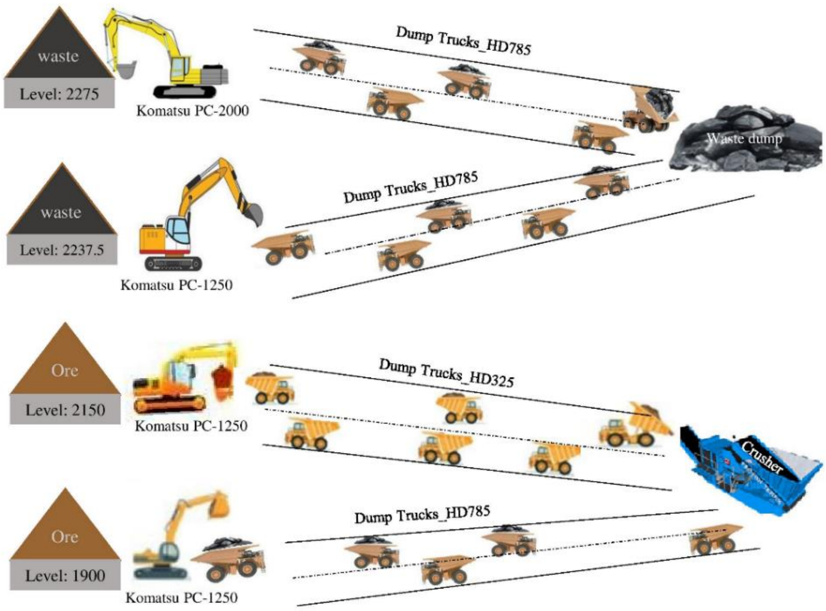

Fig. 2. Schematic picture of the mining operation of Ahan-Ajin's company.

V. Results and Evaluation

To implement the DISPATCH system in the Sungun copper mine, simulating the mine transportation system during the considered shift is essential. Since the cycle time of the truck-shovel system is stochastic, the behavior and distribution functions of these data need to be analyzed for incorporation into the simulation model. For this purpose, in Arena software, distribution functions for all data have been obtained from experimental data using the Kolmogorov-Smirnov test with the least squares error. The logic employed in designing the simulation model involves utilizing the closed cycle of trucks in operation. At first, data related to the number and type of active trucks in each subsystem were determined. Then, the cycle times of trucks were applied based on the fitted distribution functions for each mining face. Finally, the simulated model was run with 100 iterations for a shift of 5.6 hours. To validate the simulation model, the truck cycle time was considered as a key performance indicator. According to Table 3, it can be concluded that the model is reliable for future simulation models at a 95% confidence level.

By implementing the optimization allocation model (Mahtasham et al., 2021), a total of 24,000 tons of materials (16,000 tons of waste and 8,000 tons of minerals) need to be transported. Based on the results of this model, the DISPATCH algorithm was implemented. Fig. 2 illustrates the amount of materials transported using the DISPATCH algorithm and the mine's strategy. As evident from the Fig. 2, the algorithm performs well compared to the current mine policy (fixed allocation strategy). This performance improvement is achieved through enhanced equipment utilization with dynamic fleet management. In this algorithm, real-time dispatch decisions of trucks have been made with the least deviation from the allocation stage production rates. The production of waste and ore material in the DISPATCH system has increased by approximately 21.2% and 10.3%, respectively, compared to the allocation system used in the mine. Overall, the total system efficiency has increased by approximately 17.4% using the DISPATCH algorithm compared to the mine's strategy. The improvements in the truck fleet management system and the reduction in waiting times for trucks are the primary contributors to this outcome. The DISPATCH system effectively enhances fleet efficiency and minimizes wasted time by directing trucks along appropriate routes. This optimization leads to a notable increase in the overall efficiency of the mining system.

Table 3. Comparison of recorded and simulated truck cycle times in the considered shift.

System (mining face)	Recorded			Simulated			
	Average	Minimum	Maximum	Average	Half-width	Minimum	Maximum
1	22.4	20.3	23.7	22.3	0.02	20	24.3
2	32.5	29.9	33.7	32.9	0.01	28.6	34.4
3	18.3	16.5	19.9	18.8	0.03	16.6	22.3
4	24	23.4	24.6	24	0.01	23.2	25.3

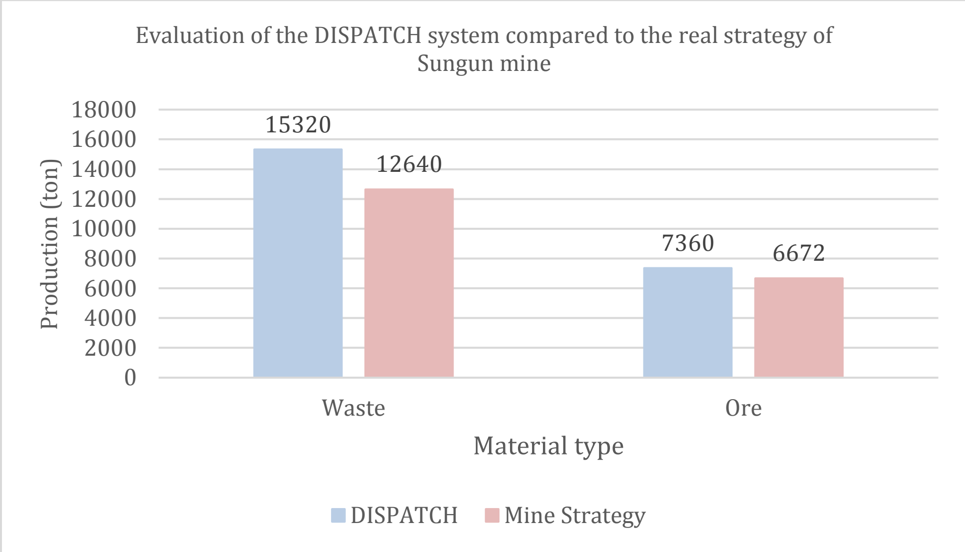

Fig. 2. Comparison of the delivered tonnage using the DISPATCH algorithm and the mine's strategy in the considered shift

VI. Conclusion

Fleet management systems serve as crucial components for the efficient operation and optimal control of fleet resources in various industries. These systems, utilizing advanced technologies and powerful software, assist companies and organizations in increasing the efficiency and effectiveness of their fleets while reducing costs. Fleet management encompasses planning, monitoring, supervising, and actively controlling fleet-related activities. Through the utilization of these systems, it becomes feasible to accurately monitor the location, status, and performance of equipment in real time and take necessary actions to optimize their performance. Since transportation systems represent one of the most costly components in open-pit mining operations, utilizing equipment control and monitoring systems, along with destination management, can lead to significant reductions in operational costs. Over the past few decades, various commercial fleet management systems have been introduced to the market. These systems, utilizing their specific algorithms, perform the material transportation process with the least wasted time. Among these systems, the DISPATCH management software is the most widely used fleet management system, employed in over 200 mines worldwide. The absence of advanced fleet management systems in Iran's mines, despite the similarity of many parameters with large mines worldwide, is strongly felt. Hence, this article aims to implement and evaluate the performance and efficiency of the DISPATCH system in one of Iran's large mines, the Sungun copper mine, using discrete-event simulation. To achieve this, the real mine transportation system was simulated and validated using Arena software. Then, a multi-objective allocation model was utilized, and based on the results of this model, the DISPATCH system algorithm was implemented in the simulation model. The results demonstrated that the DISPATCH algorithm has a good potential to meet operational and technical objectives and constraints in achieving desirable and optimal production. The productivity of the system using the DISPATCH algorithm has increased by approximately 17.4% compared to the traditional mining strategy. The DISPATCH algorithm, with its optimized management leading to increased fleet efficiency, outperforms the conventional haulage method in the Sungun copper mine. Therefore, it can be concluded that changing the mining haulage strategy towards intelligent fleet management in Iran mines could lead to significant improvements in mining system efficiency.

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