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Performance Evaluation of a Haul Truck Allocation Model in Sungun Copper Mine

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Abstract

Transportation of materials is the most cost-intensive component in open-pit mining operations. The aim of the allocation models is to manage and optimize transportation activities, leading to reduced wasted time, and ultimately, increasing profitability while reducing operational costs. Given that the implementation of allocation models is one of the essential requirements in Iranian mining operations, this research work focuses on the transportation system in the Sungun copper mine, one of the largest mines in Iran, and highlights the challenges faced by the fixed allocation approach. The aim is to develop and implement a mathematical model to evaluate its performance, and suggest improvements. The allocation model attempts to optimize truck capacity utilization and maximize mining production. Implementing the model in the mine results in a 13.42% increase in total production compared to the conventional method, with a cost increase of 14.7%. The model shows the potential to meet operational and technical constraints to achieve optimal production. Overall, the developed model, with optimized management and improved fleet efficiency, outperforms the traditional haulage method in the mine.

1. Introduction

Open-pit mining activities have been widely acknowledged as essential elements in the global mineral extraction sector. These large-scale mining operations involve the excavation of vast quantities of minerals or ore from open-pit mines. One of the key challenges faced by mining companies in open-pit operations is the efficient allocation of trucks for transporting materials within the mine site. The truck allocation problem in open-pit mines has garnered significant attention from researchers and industry professionals due to its direct impact on operational efficiency, productivity, and cost-effectiveness. Efficient truck allocation plays a vital role in maximizing the overall productivity of open-pit mining operations by ensuring a continuous flow of materials from loading points to processing or stockpiling areas. Therefore, understanding the complexities and nuances of the truck allocation problem in open-pit mines is crucial for mining companies to make informed decisions, optimize resource allocation, improve operational efficiency, and ultimately, enhance the profitability of their mining operations. The complexity of this problem arises from various factors including the dynamic nature of the mining environment, the diverse characteristics of the materials being transported, varying distances between loading and dumping points, and the limited availability of trucks and resources. In the recent years, significant advancements have been made in developing mathematical models to address the truck allocation problem in open-pit mines. In other words, determining the appropriate destination for haul dump trucks is done through operational research techniques (Figure 1). These advancements aim to optimize the allocation of trucks, maximize total mine production, minimize transportation costs, reduce idle time, and enhance the overall productivity of the mining operations. This paper develops a mathematical optimization model for the truck allocation problem in open-pit

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mines. The primary objective is to provide an optimization technique that has been proposed to tackle this challenging problem. Considering that allocation models are not currently employed in Iran's mines, the contribution of this study lies in the implementation of a developed allocation model in a specific case study, located in Iran. The aim is to investigate and evaluate the effectiveness of these models in improving operational efficiency in the context of Iran's mines. This research work encompasses the mathematical model and operational strategy employed in the real-world mining scenario. The model takes into account the key factors influencing truck allocation decisions such as haulage distance, equipment capacities, stripping ratio, truck availability, production targets, and all operational constraints.

In the subsequent sections of this paper, the literature review of the haul truck allocation models is delved. The advantages, weaknesses, and applicability of the developed models are analyzed in mining operations. Next, the detail of the proposed model formulation is presented, and its strengths are stated. Then the model is implemented in a real-world case study to evaluate the performance of the model in the efficiency of the loading and hauling system, and the numerical results are presented and discussed. Finally, a summary of the key findings and recommendations for future research directions to further advance this critical area of study is concluded.

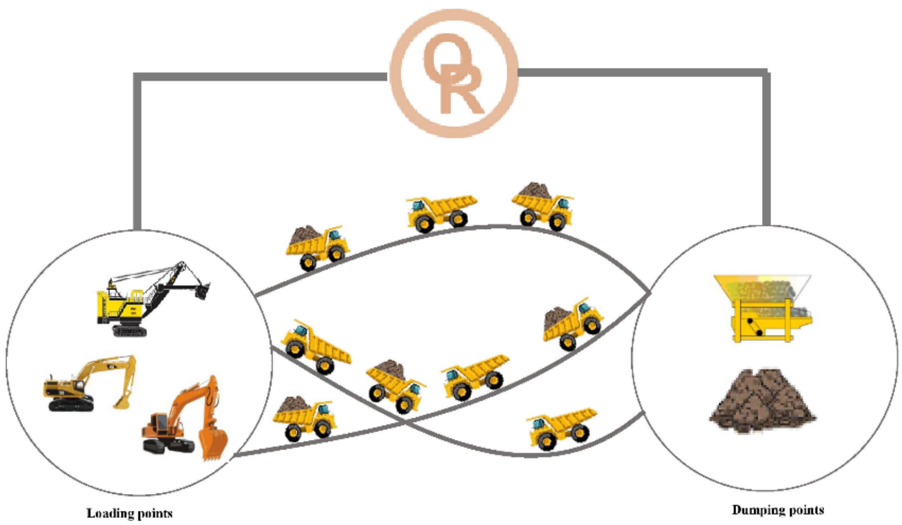

Figure 1. Using operations research techniques in truck allocation problem.

2. Literature Survey

Truck allocation holds great importance in the functioning of open-pit mines, as it aims to optimize the transportation of materials from extraction sites to specific areas within the mine. The effective allocation of trucks plays a crucial role in reducing operational expenses, maximizing productivity, and ensuring the overall success of mining operations. Generally, by strategically assigning trucks and optimizing their movements, open-pit mines can enhance productivity, minimize waiting times, reduce fuel consumption, and ultimately, increase the profitability and sustainability of mining operations. Various research studies and methodologies have been employed to address the challenges and complexities associated with truck allocation in open-pit mines. One prominent area of research in this field focuses on developing mathematical models and optimization algorithms to determine the optimal number of trucks required, their capacities, and the most efficient routes for material transportation. These models consider factors such as haul distances, equipment capacities, fleet cycle times, road conditions, and traffic congestion in the operational constraints. The researchers have employed various optimization techniques including linear programming, mixed-integer programming, stochastic programming, etc. to solve these complex allocation problems. The researchers have proposed different objective functions to these models such as minimizing the total travel distance, minimizing the waiting time at loading and unloading points or maximizing the total material transported within a given time frame. Gamache et al. [1] suggest a comprehensive linear programming model that aimed to optimize the schedule for truck allocation throughout a work shift, taking into account long-term mine production planning. Mena et al. [2] utilize the framework to assign trucks to specific routes based on their operational performance within a truck-shovel system in an open-pit mine. This allocation aims to optimize the fleet's overall productivity and maximize efficiency. Ta et al. [3] formulate a chance-constraint truck allocation model that can accommodate uncertain parameters such as truckload and cycle time. Eivazy and Askari-Nasab [4] create an optimization model for short-term production scheduling in open-pit mines. The proposed multi-destination mixed-integer linear programming model aims to minimize the total cost of mining operations, which includes expenses related to mining, processing, haulage, rehandling, and rehabilitation. Chang et al. [5] utilize a mixed-integer linear programming model to effectively address the truck fleet management problem. The model aimed to maximize the total transport revenue generated by all trucks within the scheduling horizon, while also taking into consideration the probability of shovels being idle. Torkamani and Askari-Nasab [6] introduce a mixed-integer linear programming model to handle the allocation decisions for shovels and trucks in open-pit mines. The primary goal of the model is to minimize the costs associated with truck trips from loading points to various destinations. Bajany et al. [7] introduce an optimization model aimed at minimizing the fuel consumption of dump trucks and shovels for under-trucked open-pit mines. The model ensures that the handling demands of dump sites are effectively fulfilled. Perez et al. [8] focus on optimizing operational efficiency in blasting operations at open-pit mine sites. A framework is introduced that utilizes mathematical programming to minimize truck allocation costs associated with hazardous materials. Manríquez et al. [9] develop an MILP optimization approach to formulate the fleet allocation problem. This approach considered mining sequencing constraints as well as the time and cost involved in moving between phases of each shovel. By optimizing multiple hierarchical objectives, the model generated a short-term production schedule for open-pit mines, enabling crucial decision-making regarding the allocation of trucks and shovels to mining faces.

Moniri-Morad et al. [10] examine the problem of allocating trucks by employing a simulation-based optimization method. This method is designed to optimize truck assignments, while taking into account uncertainties that arise during fleet operations. Liu and Chai [11] presents a mixed-integer linear programming model that focuses on minimizing the consumption of transport energy, which varies over time. Benlaajili et al. [12] introduce a model for assigning trucks and shovels, which serves as the initial phase of a mining fleet management system focused on production optimization and allocation planning. The development of this model occurs in two primary stages. The first stage involves modeling the allocation of shovels as a vehicle routing problem. In the second stage, a mixed-integer linear programming model is proposed to determine the optimal number of trips necessary for transporting specific amounts of ore from loading points to dumping sites. Bakhtavar and Mahmoudi [13] propose an approach called scenario-based robust optimization to address the truck-shovel allocation. This approach involves two distinct phases. In the first phase, the uncertainties related to shovel output and crusher capacity are considered. In the second phase, the uncertainties associated with the number of available trucks are included in the model. Shahand and Rehman [14] present a mixed-integer linear programming model for allocating trucks and shovels to mining faces in a cement quarry. The objective is to minimize the operating costs of the trucks and shovels, while adhering to quantity and quality constraints. Mohtasham et al. [15] suggest a chance-constraint goal programming model that is capable of managing the necessary amount and quality of materials needed to fulfill the objectives of the mine's short-term production schedule with complete assurance at all confidence levels of loaders' production. Isnafitri et al. [16] formulate an optimization model to determine the allocation of trucks in open pit mining. The objective of the model is to minimize the total cost, which encompasses both investment and transportation costs. De Melo [17] optimizes the allocation of trucks with the aim of enhancing production, minimizing queue time, and maintaining ore grades within the specified limits. Upadhyay et al. [18] introduce a model for short-term production scheduling. This model efficiently allocates shovels within continuous time frames, effectively managing the size and complexity of the model. These studies collectively emphasize the significance of incorporating various factors such as equipment performance, operational costs, and practical limitations when scheduling fleet allocation. Mohtasham et al. [19] address the truck allocation problem using a mixed-integer linear goal programming model. The model focuses on achieving four primary objectives: (1) maximizing production, (2) minimizing variations in head grade, (3) minimizing variations in tonnage delivered to crushers, and (4) minimizing fuel consumption of mining trucks. Additionally, this study investigates how the prioritization of these objectives can impact the outcomes and efficiency of the mining operation. Mirzaei Nasirabad et al. [20] introduce an integer linear programming model designed to allocate trucks within a truck-shovel system in an open-pit mine based on their operating performances. The primary objective of this research work is to minimize the overall operating cost of the trucks. Wang et al. present a multi-objective optimization algorithm for truck scheduling, considering queuing time, productivity, and financial cost. The algorithm explores the solution space using truck speed and payload as variables. A smart scheduling application is developed to aid users in selecting suitable plans, providing flexible options for managers [21]. Ghasempour-Anaraki and Moradi-Afrapoli present a bi-objective mathematical model that integrates the reduction of carbon emissions into the optimization model for fleet allocation decisions. The model also takes into account various factors that could affect truck allocation decisions including fleet size, truck velocity, truck age groups, and more [22].

The limitations of the proposed models arise from the failure to address specific concerns in production operations and disregarding certain constraints. As a result, the solutions derived from these models do not accurately determine the optimal rates for each route. The following are some important existing limitations that can be outlined:

- Neglecting the number of each truck type
- Ignoring the amount of material available at loading points
- Neglecting the required tonnage of the processing plants and crusher capacity throughout the shift
- Disregarding the cycle time of the fleet
- Neglecting the minimum capacity of shovels

Although shortcomings exist in the modeling of allocation models, allocation models are widely used in most large mines around the world. Considering the similarity of many parameters in large mines in Iran to those in large mines globally, the implementation of these models is strongly felt in the mines of the country. Therefore, the contribution of this study is the implementation of an allocation model in one of the large mines in Iran, the Sungun copper mine, and the evaluation of its performance and efficiency in optimizing the transportation system's productivity. The model attempts to overcome the existing limitations and challenges. Moreover, the proposed mathematical model has not exactly been used with the defined objective function and constraints in the previous studies. In the following, the research work delves into the examination of the model formulation and presents the objective function along with the constraints.

3. Model Formulation

The developed model is a mixed-integer linear programming model with variables, parameters, constraints, and an objective function that collectively describes the allocation problem and guides the analysis. The abbreviations used in the developed allocation model are shown in Table 1.

Table 1. The notation used in the mathematical model.

Set	Defination
i	Unloading points
j	Loading points
h	Truck types
Parameters	**Defination**
T	Duration of the planning (hours) Number of loading points All types of trucks The number of discharge points Number of unloading points Amount of ore available at loading point j (Kiloton) Amount of waste available at loading point j (Kiloton) Grade of the ore material at loading point j (%)
n	Number of loading points All types of trucks The number of discharge points Number of unloading points Amount of ore available at loading point j (Kiloton) Amount of waste available at loading point j (Kiloton) Grade of the ore material at loading point j (%)
H	All types of trucks
m	The number of unloading points
m_r	The number of waste dumping points
O_j	Amount of ore available at loading point j (Kiloton)
W_j	Amount of waste available at loading point j (Kiloton)
b_j	Grade of the ore material at loading point j (%)
R_{max}	The upper acceptable grade limit for the processing plant
R_{min}	The lower acceptable grade limit for the processing plant
Ku_i	The upper limit of production required at unloading point i (kiloton)
Kl_i	The lower limit of production required at unloading point i (kiloton)
d_{ij}	Distance from shovel j to unloading point i (kilometer)
c^h	The capacity of truck types h (kiloton)
N^h	The number of truck types h
G_{ijh}	Cycle time of truck type h from loading point j to unloading point i (seconds)
ρu_i	The maximum amount of extraction for shovel in loading point j (Kiloton)
ρl_i	The minimum amount of extraction for shovels in loading point j (Kiloton)
N^+	Positive integers
Decision variables	**Defination**
X_{ijh}	The total number of full trips of truck type h from loading point j to unloading point i
Y_{ijh}	The total number of empty trips of truck type h from unloading point i to loading point j

The objective function and the constraints are defined as follows:

$$\text{Maximize } J_2 = \sum_{h=1}^{H}\sum_{i=1}^{m}\sum_{j=1}^{n}(X_{ij}^{h} * c^h + Y_{ij}^{h} c^h) \tag{1}$$

The objective function J_2 (1) attempts to maximize the total production of the mine by increasing the truck trips from the shovel to the unloading point and that of the return trip.

$$\sum_{h=1}^{H}\sum_{j=1}^{n} c^h X_{ij}^{h} \leq Ku_i \text{ for } i = 1, \ldots, m \tag{2}$$

$$\sum_{h=1}^{H}\sum_{j=1}^{n} c^h X_{ij}^{h} \geq Kl_i \text{ for } i = 1, \ldots, m \tag{3}$$

The unloading points, especially the crusher have specific capacities. If the amount of material delivered is below the minimum crusher capacity, it will result in decreased plant efficiency. Conversely, if the unloading points are overloaded beyond their capacity, it will cause queues at the crushers and waste dumps, as well as additional costs due to material rehandling and reloading. The constraint related to the upper and lower limits of the unloading points' capacity is considered according to Equations 2 and 3, respectively.

$$\sum_{h=1}^{H}\sum_{i=m_r+1}^{m} c^h X_{ij}^h \leq O_j \quad \text{for } j = 1, \ldots, n \tag{4}$$

$$\sum_{h=1}^{H}\sum_{i=1}^{m_r} c^h X_{ij}^h \leq W_j \quad \text{for } j = 1, \ldots, n \tag{5}$$

Each loading point has a specific amount of ore and waste material. Constraints 4 and 5 ensure that the amount of ore and waste transported by trucks should not exceed the amount of material available at the loading points.

$$\frac{\sum_{h=1}^{H}\sum_{j=1}^{n} b_j X_{ij}^h c^h}{\sum_{h=1}^{H}\sum_{j=1}^{n} X_{ij}^h c^h} \leq R_{max} \quad \text{for } i = m_r + 1, \ldots, m \tag{6}$$

$$\frac{\sum_{h=1}^{H}\sum_{j=1}^{n} b_j X_{ij}^h c^h}{\sum_{h=1}^{H}\sum_{j=1}^{n} X_{ij}^h c^h} \geq R_{min} \quad \text{for } i = m_r + 1, \ldots, m \tag{7}$$

Each processing plant has a maximum efficiency within a specific grade range. Typically, the required mineral for the plant is not transported from a mining face, but rather obtained by blending from several mining faces to achieve the desired grade. The upper and lower acceptable limits for the plant are expressed by Equations 6 and 7, respectively.

$$\sum_{h=1}^{H}\sum_{i=1}^{m} c^h X_{ij}^h \geq \rho l_j \quad \text{for } j = 1, \ldots, n \tag{8}$$

$$\sum_{h=1}^{H}\sum_{i=1}^{m} c^h X_{ij}^h \leq \rho u_j \quad \text{for } j = 1, \ldots, n \tag{9}$$

The maximum extraction amount is limited by the maximum capacity of the shovels. Also the extraction quantity for each shovel must align with the mine planning. The minimum and maximum amount of extraction for shovels are restricted by Equations 8 and 9, respectively.

$$\sum_{i=1}^{m}\sum_{j=1}^{n} G_{ij}^h X_{ij}^h c^h \leq 3600 * T * N^h * c^h \quad \text{for } h = 1, \ldots, H \tag{10}$$

To ensure the accuracy of the truck flow rate on each route, it is necessary to determine the quantity of trucks available. This requirement guarantees that the overall operational time of the trucks remains within the intended shift duration. Equation 10 represents this constraint. The cycle time of a truck encompasses various stages such as waiting time for loading, loading time, maneuvering time for loading and unloading, loaded travel time, waiting time for unloading, unloading time, and empty travel time.

$$\sum_{j=1}^{n} X_{ij}^h = \sum_{j=1}^{n} Y_{ij}^h \quad \text{for } i = 1, \ldots, m \;\&\; h = 1, \ldots, H \tag{11}$$

$$\sum_{i=1}^{m} X_{ij}^h = \sum_{i=1}^{m} Y_{ij}^h \quad \text{for } j = 1, \ldots, n \;\&\; h = 1, \ldots, H \tag{12}$$

Equations (11) and (12) are implemented to ensure a balance in the flow rate of each truck type at every service point within the mine including loading and dumping points.

$$X_{ij}^h \in N^+, Y_{ij}^h \in N^+ \tag{13}$$

Equation 13 states that the decision variables are positive integers.

4. Model Implementation in Sungun Copper Mine

The Sungun copper mine is located in northwestern Iran, in East Azerbaijan Province. It is situated approximately 130 kilometers northeast of Tabriz, 75 kilometers northwest of Ahar, and 30 kilometers north of Varzaqan. The mine is in proximity to the neighboring Republics of Azerbaijan and Armenia. In the mine, the loading system is typically carried out by loaders and excavators, and the transportation is done by dump trucks with capacities of 30, 55, 60, 100, and 135 tons. The specifications of the available trucks are mentioned in Table 2. The unloading points generally include crushers, waste dumps, oxide dumps, low-grade material dumps, and mineral stockpiles. The required data and information for optimizing the transportation system are collected through direct measurements and the mine support office. The necessary data consists of two parts: operational data including fleet cycle time, loader capacity, crushers' capacity, etc., collected directly; and planning-related data including ore grade and stripping ratio, collected by the mine's support office. Data related to the cycle time of loaders and trucks has been collected through recording the waiting time for loading, loading time, empty travel time, loaded travel time, waiting time for unloading, and unloading time of trucks during a complete shift. The cycle time of trucks from various loading points to the dumping locations has been collected using a chronometer. Additionally, the actual hourly capacity of the crusher has been determined by recording its capacity over the course of two full shifts. During the shift under consideration, oxide and low-grade materials are absent. In this shift, there are 14 loading points, consisting of 9 waste loading points and 5 ore loading points. The operational specifications of the loading points are stated in Table 3.

Table 2. The specifications of the available trucks in the desired shift.

Truck type (ton)	Model	Practical payload capacity	Total number
30 (5)	Komatsu HD-325	24	6
55 (4)	BelAZ-7555B	44	6
60 (3)	Komatsu HD-605	48	11
100 (2)	Komatsu HD-785	80	32
135 (1)	BelAZ-75131	105	2

Table 3. The operational specifications of the loading points in the desired shift.

Loading point	Bench level	Type of material	Loader model	Maximum production bound (ton)	Minimum production bound (ton)	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	1350	0.42
5	2187.5	Waste	Komatsu- PC 850	7000	3500	-
6	2187.5	Waste	Komatsu- PC 850	6600	3300	-
7	2250	Waste	Komatsu- PC 800	3000	1500	-
8	1937.5	Ore	Komatsu- PC 850	7000	2700	0.9
9	2000	Ore	Komatsu- PC 850	7000	2300	0.51
10	2012.5	Ore	Komatsu- PC 800	7000	3600	0.42
11	2250	Waste	Komatsu- WA 800	8400	4200	-
12	2287.5	Waste	Komatsu- PC 850	7000	3500	-
13	2200	Waste	Komatsu- WA 700	7700	3800	-
14	2250	Waste	Komatsu- PC 1250	7700	3800	-

In the Sungun copper mine, there is an oxide dump and a crusher. Waste materials are transported to the waste dump, low-grade and oxide materials are transported to the oxide dump, and ore materials are transported to the crusher. The minimum and maximum capacity of the crusher are 14,000 and 12,500 tons, respectively. The minimum, maximum, and desired quality of the ore material in the crusher for the considered shift are 0.60, 0.62, and 0.61, respectively. The processing plant consists of two phases with the same capacities. The minimum capacity of the plant is 1,600 tons per hour, and the maximum capacity is 2,000 tons per hour. The stripping ratio for the specified shift is a minimum of 2.5 and a maximum of 3.5. The implemented allocation strategy in the mine is of the fixed allocation type. In this shift, a total of 49,476 tons of material (36,516 tons of waste and 12,960 tons of mineral) have been produced with a total cost of 2,162,360 rials. Generally, in this shift, a minimum of 12,500 tons of ore material and 32,500 tons of waste material must be extracted based on the mine schedule. It is worth mentioning that these data were collected in 2019.

The proposed model was solved using IBM ILOG CPLEX Optimization version 12.6 on a laptop computer equipped with an Intel i7 CPU and 12GB of RAM. Based on the actual data from a shift in the mine, the developed mathematical model was implemented. The model was solved by CPLEX in under a minute, achieving an optimal solution with a zero percent gap. Table 4 illustrates the delivered production of materials based on the presented allocation model for the desired shift at the Sungun copper mine. Also the number of loaded and empty truck trips based on the developed allocation model for the desired shift are presented in Tables 5 and 6, respectively.

Table 4. The amount of the transported materials using the developed allocation model in the considered shift.

Type of material	Production (ton)	Transportation cost (Rial)
Waste	42121	
Ore	13998	2,481,750,000
Total	56119	

Table 5. The number of loaded truck trips from loading points to dumping sites in the desired shift.

Dumping point	**1**																					
Loading point	1			2		5			6			7			11				12	13		14	
Truck type	1	2	3	2	4	1	2	4	2	3	5	3	4	8	1	2	3	4	2	2	4	2	4
Trips number	23	52	1	47	1	1	42	1	40	1	3	1	2	57	1	27	124	4	44	47	1	95	1

Dumping point	2													
Loading point	3		4				8				9			10
Truck type	4	5	1	2	3	4	2	3	4	5	3	4	5	3
Trips number	42	85	2	15	1	1	7	3	41	8	21	29	1	75

Table 6. The number of empty truck trips from dumping sites to loading points in the desired shift.

Dumping point	**1**																						
Loading point	1			2		3	4		5	6		7			9	10		11			12	13	14
Truck type	1	2	3	2	4	5	1	2	2	2	3	3	4	5	4	2	4	1	2	3	2	2	2
Trips number	23	52	1	47	1	3	1	15	42	40	1	1	2	57	1	22	1	1	27	124	44	47	73

Dumping point	2																		
Loading point	3		4			5		6	8			9			10	11	13	14	
Truck type	4	5	1	3	4	1	4	5	3	4	5	3	4	5	3	4	4	2	4
Trips number	42	82	1	1	1	1	1	3	3	34	8	21	29	1	75	4	1	22	1

5. Result and Discussion

The objective of the allocation model is to maximize the utilization of all available trucks' capacities to increase mining production. In this model, the objective is to increase the total mine production, without any consideration for the cost of material transportation. As shown in Figure 2, the total production increases by 13.42% compared to the traditional method (mine's strategy), while costs increase by 14.7%. In conclusion, the developed allocation model satisfies all constraints and effectively reduces fleet wasting time, leading to an increase in mining production.

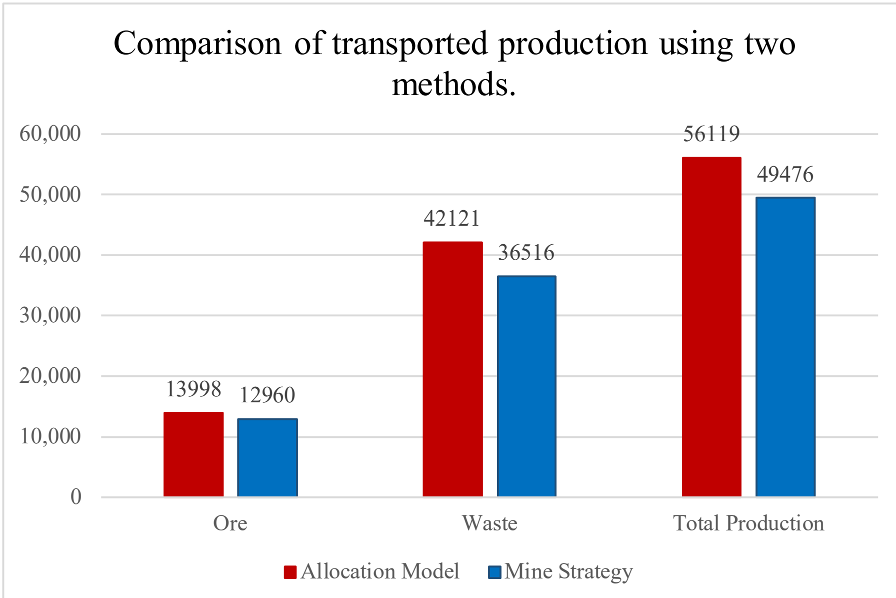

Figure 2. Performance comparison of allocation model and mine's strategy.

6. Conclusions

The truck allocation in open-pit mines is a critical aspect of efficient operations. Through the utilization of advanced techniques such as operational research, the task of determining appropriate destinations for trucks is optimized. These techniques take into account various factors such as distance, payload capacity, traffic congestion, and operational constraints to make informed decisions. By effectively allocating trucks to their destinations, open-pit mines can enhance productivity, minimize transportation costs, and streamline overall operations. In fact, the use of these approaches and continuous improvement in truck allocation processes can further optimize the efficiency and effectiveness of mining operations in open-pit mines. With a closer look at the realities of transportation systems in Iranian mines and a more detailed study and observation of two or three major mines in our country, it will be found that the transportation system in these mines follows a fixed allocation approach that faces numerous challenges. Addressing these challenges is essential and requires the implementation of allocation models in the country. Therefore, the aim of this research work is to develop and implement an optimized mathematical model for evaluating the performance of the model in one of the major mines in Iran, the Sungun copper mine, and provide insights into potential improvements in the transportation system of the mine. The objective of the allocation model is to optimize the utilization of the available truck capacities in order to enhance mining production to its maximum potential. Implementation of the model in the Sungun copper mine shows that the total production experiences a 13.42% increase when compared to the conventional method (mine's strategy), accompanied by a cost increase of 14.7%. The results indicate that the model has a good potential to fulfill operational and technical constraints to achieve desirable and optimal production. In summary, the developed model with optimized management, leading to increased fleet efficiency, demonstrates better performance compared to the traditional haulage method in the Sungun copper mine. Future work could expand the model by incorporating additional objectives and constraints such as the age of trucks, fleet availability, etc. in mining operations. Also, the model could be expanded for shovel allocation problems in the mining operation.

References

[1]. Gamache, M., Desaulniers, G., and Hébert-Desgroseilliers, L. (2009). A generic linear program for an optimal mine production plan. *Groupe d'études et de recherche en analyse des décisions.*

[2]. Mena, R., Zio, E., Kristjanpoller, F., and Arata, A. (2013). Availability-based simulation and optimization modeling framework for open-pit mine truck allocation under dynamic constraints. *International Journal of mining science and Technology, 23(1)*, 113-119.

[3]. Ta, C. H., Kresta, J. V., Forbes, J. F., and Marquez, H. J. (2005). A stochastic optimization approach to mine truck allocation. *International journal of surface mining, reclamation and environment, 19(3)*, 162-175.

[4]. Eivazy, H. and Askari-Nasab, H. (2012). A mixed integer linear programming model for short-term open pit mine production scheduling. *Mining Technology, 121(2)*, 97-108.

[5]. Chang, Y., Ren, H., and Wang, S. (2015). Modelling and optimizing an open-pit truck scheduling problem. *Discrete Dynamics in nature and Society,* 2015.

[6]. Torkamani, E. and Askari-Nasab, H. (2015). A linkage of truck-and-shovel operations to short-term mine plans using discrete-event simulation. *International Journal of Mining and Mineral Engineering, 6(2),* 97-118.

[7]. Bajany, D. M., Xia, X., and Zhang, L. (2017). A MILP Model for Truck-shovel scheduling to minimize fuel consumption. *Energy Procedia, 105*, 2739-2745.

[8]. Pérez, J., Maldonado, S., and González-Ramírez, R. (2018). Decision support for fleet allocation and contract renegotiation in contracted open-pit mine blasting operations. *International Journal of Production Economics, 204*, 59-69.

[9]. Manríquez, F., González, H., and Morales, N. (2019, May). Short-term open-pit mine production scheduling with hierarchical objectives. *In Min Goes Digit: Proc 39th Int Symp Appl Comput Oper Res Miner Ind APCOM* , 443-451.

[10]. Moniri-Morad, A., Pourgol-Mohammad, M., Aghababaei, H., and Sattarvand, J. (2019). A methodology for truck allocation problems considering dynamic circumstances in open pit mines, case study of the sungun copper mine. *Rudarsko-geološko-naftni zbornik, 34(4).*

[11]. Liu, G. and Chai, S. (2019). Optimizing open-pit truck route based on minimization of time-varying transport energy consumption. *Mathematical Problems in Engineering*, 2019.

[12]. Benlaajili, S., Moutaouakkil, F., Chebak, A., Medromi, H., Deshayes, L., and Mourad, S. (2020). Optimization of truck-shovel allocation problem in open-pit mines. *In Smart Applications and Data Analysis: Third International Conference*, SADASC 2020, Marrakesh, Morocco, June 25–26, 2020, Proceedings 3 (pp. 243-255). Springer International Publishing.

[13]. Bakhtavar, E. and Mahmoudi, H. (2020). Development of a scenario-based robust model for the optimal truck-shovel allocation in open-pit mining. *Computers & Operations Research, 115,* 104539.

[14]. Shah, K., & Ur Rehman, S. (2020). Modeling and optimization of truck-shovel allocation to mining faces in cement quarry. *Journal of Mining and Environment, 11(1)*, 21-30.

[15]. Mohtasham, M., Mirzaei-Nasirabad, H., and Alizadeh, B. (2021). Optimization of truck-shovel allocation in open-pit mines under uncertainty: a chance-constrained goal programming approach. *Mining Technology, 130(2),* 81-100.

[16]. Isnafitri, M. F., Rosyidi, C. N., and Aisyati, A. (2021, March). A truck allocation optimization model in open pit mining to minimize investment and transportation costs. *In IOP Conference Series: Materials Science and Engineering, 1096(1)*, 012024. IOP Publishing.

[17]. de Melo, W. B. (2021). Optimization of truck allocation in open pit mines using differential evolution algorithm. *International Journal of Innovation and Research, 9(8),* 338-350.

[18]. Upadhyay, S. P., Doucette, J., and Askari-Nasab, H. (2021). Short-term production scheduling in open pit mines with shovel allocations over continuous time frames. *International Journal of Mining and Mineral Engineering, 12(4)*, 292-308

[19]. Mohtasham, M., Mirzaei-Nasirabad, H., Askari-Nasab, H., and Alizadeh, B. (2021). A multi-objective model for fleet allocation schedule in open-pit mines considering the impact of prioritising objectives on transportation system performance. *International Journal of Mining, Reclamation and Environment, 35(10),* 709-727.

[20]. Mirzaei-Nasirabad, H., Mohtasham, M., and Rahimzadeh-Nanekaran, F. (2023). Evaluating the Effect of Fleet Management on the Performance of Mining Operations Using Integer Linear Programming Approach and Two Different Strategies. *Iranian Journal of Management Studies, 16(1),* 139-155.

[21]. Wang, Y., Liu, W., Wang, C., Fadzil, F., Lauria, S., and Liu, X. (2023). A Novel Multi-Objective Optimization Approach with Flexible Operation Planning Strategy for Truck Scheduling. *International Journal of Network Dynamics and Intelligence.*

[22]. Anaraki, M.G. and Afrapoli, A. M. (2023). Sustainable open pit fleet management system: integrating economic and environmental objectives into truck allocation. *Mining Technology, 132(3),* 153-163.

ارزیابی عملکرد یک مدل تخصیص کامیون در معدن مس سونگون

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چکیده:

حمل‌ونقل مواد پرهزینه‌ترین بخش در عملیات معدن‌کاری روباز است. هدف مدل‌های تخصیص، مدیریت و بهینه‌سازی فعالیت‌های موجود در بخش حمل‌ونقل است که منجر به کاهش زمان‌های تلف شده و در نهایت افزایش سودآوری و کاهش هزینه‌های عملیاتی می‌شود. با توجه به اینکه پیاده‌سازی مدل‌های تخصیص کامیون یکی از نیازهای اساسی در عملیات معدنی ایران است، این پژوهش بر سیستم حمل‌ونقل معدن مس سونگون، یکی از بزرگ‌ترین معادن ایران، تمرکز دارد و چالش‌هایی که در روش تخصیص ثابت وجود دارد را برجسته می‌کند. هدف این مطالعه، توسعه و پیاده‌سازی یک مدل ریاضی برای بررسی و ارزیابی عملکرد آن و راهکارهای بهبود عملیات است. مدل تخصیص سعی می‌کند تا از ظرفیت بهینه کامیون‌ها استفاده کند و تولید معدن را به حداکثر برساند. پیاده‌سازی مدل در معدن مورد مطالعه، منجر به افزایش ۱۳/۴۲ درصدی در تولید کل معدن و افزایش ۱۴/۷ درصدی در هزینه‌های عملیاتی نسبت به روش معمولی (تخصیص ثابت) می‌شود. این مدل پتانسیل خوبی برای برآورده کردن محدودیت‌های عملیاتی و فنی برای دست‌یابی به تولید بهینه دارد. به طور کلی، مدل توسعه‌یافته، با مدیریت بهینه و بهبود کارآیی ناوگان، از روش حمل‌ونقل سنتی در معدن بهتر عمل می‌کند.

کلمات کلیدی: معدن‌کاری روباز، تخصیص کامیون، بهینه‌سازی، کارآیی عملیاتی، بهره‌وری.