International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 56, No. 1, February, 2023, pp. 43-48
Journal homepage: http://iieta.org/journals/jesa

Evaluation of the Variable Component of Truck Travel Time Based on the Maximum Speed for an Optimal Management of the Fleet, Case of Boukhadra Iron Ore Mine, NE Algeria

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https://doi.org/10.18280/jesa.560106

Received: 4 January 2023
Accepted: 25 January 2023

Keywords:
open pit mining, loading, transport, trucks, speed

ABSTRACT

This work focuses on the loading and haulage works which are crucial operations and of major importance for the mining exploitation and whose costs are very high and represent up to 70% of the total price of the entire supply chain production. It is advisable to make a judicious choice of loading and transport machines and to assign them well to limit waiting times and increase yields, which will of course lead to the realization of the planned production. The allocation of trucks and the number assigned to the shovels is an important work for the operator, in this context the present work concerns the open pit mine of Boukhadra (Tebessa), one of the largest iron deposits in Algeria. Based on truck timing data and the characteristics of excavators, trucks, and roads, an analysis of the current status of loading and transport work was made, which showed high waiting times of the shovel. Based on the performance curves of the CATERPILLAR trucks, we determined the appropriate speeds and therefore the determination of the number of trucks necessary to reduce the waiting times of the excavator.

1. INTRODUCTION

Today with the continuous demand for raw materials for the mining industry, and the diversification of the characteristics of metallic and non-metallic deposits, surface mining techniques vary considerably in terms of size, shape, orientation and depth below the surface [1]. Open pit mining consists of removing the waste rock cover and accessing the deposit from the surface to extract the ore located at a depth less than 150 m, due to the geological arrangement of the ore and the technical requirements related to the extraction, it requires the displacement of a huge quantity of gangue, waste materials, waste or overburden that covers the ore of economic interest [2]. In open pit mining, the process of production includes drilling, blasting, loading and transportation [3]. After the drilling and blasting operations, the fragmented materials must be loaded, and then the waste rock must be moved to the heaps and the ore to the further processing or the stock for marketing, which justifies the importance of the loading and transportation. The equipment is therefore very important to ensure the continuity of mining production [4], moreover in open pit mines the investment and operating costs are influenced by the number and size of the equipment, drilling, blasting, loading and transportation of ore and waste rock [5].

There is a diverse range of loading equipment including shovels which are used for digging, lifting, and moving bulk materials, and loaders which are used to move aside and load.

In open pit mining, transportation predetermines the scheme of opening up, choice of mining method, mining equipment and dumping method. The peculiarities of mining transportation are: the large volume of transported loads, the high intensity of traffic, the steep ascent and descent, the increase of transportation distance as the mining work progresses, the small space for transportation and the rigid dependence of other mining processes on transportation since the latter is the binding link.

There are several means of transport for working in a wide range of natural conditions, the main ones are: trucks, railroads, conveyors. In this article, we consider transport by truck, which has several advantages such as: efficiency of transporting ore and waste rock over the relatively short distance, simplicity of construction, the possibility of overcoming the steep slope and simplicity of organization of the work.

The Shovel-Truck (ST) load-and-carry system is a common practice in surface mining [6-9].

In surface mining, transport costs represent 50–60% of the total cost of production [3-10]; when using truck transport as the main means of transport, these costs can reach up to 50% of the total cost of production [11-13].

In 2013 Chung formulated a model to minimize the number of trucks served by an excavator, taking into account the probability of excavator inactivity, the constraints taken into consideration are throughput and ore grade [14].

In 2021 Isnafitri developed an optimization model to minimize a total cost to determine truck allocation in surface mining to minimize investment costs and transport [4].

The objective of this work is a contribution to the management of the material resources of the open pit mine of Boukhadra, for this we have broken down the travel time of the truck into two components, the first is relatively constant, and the second component is variable and depends not only on the transport distance, but also on the geometry of the transport path and the vehicle speed. In this context, it is proposed to determine the speed of movement according to the performance curves of CATERPILLAR trucks.

System Shovel – Truck

The mining industry is always faced with the challenge of increasing the productivity of mining products with minimal costs. Mining is an expensive and complex activity that aims to develop ore using several complex and expensive processes. The production cycle is composed of drilling, blasting, loading and transport operations. The purpose of the loading and transport process is to load the material previously fragmented by the drilling and blasting process by appropriate equipment which are shovels, then its transport by trucks to the appropriate destinations through a route designed and maintained to accommodate transport trucks [15].

In an open-pit mine, the main production mining equipment, called shovels, are located at different specific locations, allowing the loading of ore or waste rock from the sites for transport to the specific unloading locations, which are the crushers or in the piles for subsequent use or the heaps for waste rock. A shovel is mining equipment used to dig, lift and move fragmented material. The trucks must move towards the shovels using the road network of the mine [16]. The trucks transport the ore from the stopes to the crusher or the ore stockpile, and the waste rock from the stopes to the dump, and they return empty to the loading points to complete a transport cycle.

2. CASE STUDY

This article focuses on the Boukhadra mine, one of the largest iron deposits in Algeria, it is located in the northeast of the country, near the Tunisian border and about 180 kilometers from the Annaba coast (Figure1) headquarters of the El Hadjar iron and steel complex. The first iron mines began in 1927.

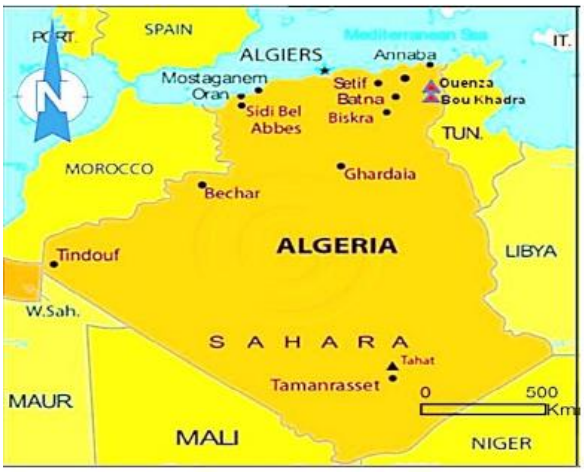

Figure 1. Geographical location of Boukhadra's mine

The Djebel of Boukhadra is located on the Saharan Atlas; it is characterized by a very simple anticlinal geological structure, direction NE-SO, with a periclinal end to N-E. Sediments of the Aptian represent the heart of the structure.

From the litho-stratigraphic point of view, the Boukhadra region consists of Tertiary Mesozoic and partly Quaternary sediments.

From the tectonic point of view, the region of Boukhadra is marked by two important tectonic phases; the folding phase of direction NE-SO and the phase of brittle tectonics have generated base movements, which are at the origin of the formation of the Tebessa-Morsott and Ouled-Boughanem ditches as well as the Boudjaber horst. Other minor faults with minor releases are also reported in the immediate vicinity of the deposit [17]. Mining is carried out according to two modes with open pit and underground, the present work relates to the exploitation with open pit.

The organization of transport is carried out according to the weighted equivalent scheme, using parameters of opening-up method and the calculating of the weighted average Itinerary, a diagram of Boukhadra's mine route is shown in Figure 2. The parameters of the different elements of the route, namely the lengths and the average slopes, are reported in Table 1. Sections, Length (Li) (m) Average slopes of sections (%).

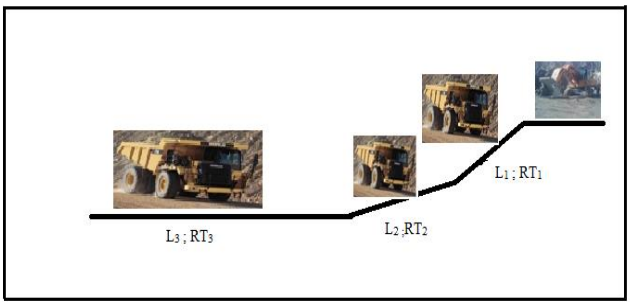

Figure 2. Equivalent diagram of the transport route

Table 1. Plot element settings

No.	Levels	Sections	Length (Li)(m)	Average slopes of sections (%)
1	1045–1030	L_1	310	7
2	1030 – 1015	L_2	225	6
3	1015	L_3	2360	0,6

3. METHODOLOGY

The process production is carried out by drilling and blasting, the loading of the fragmented blocks is done by a KOMATSU hydraulic excavator with a bucket capacity of 6.7m^3 with a cycle time which varies from 30 to 35 seconds.

The mode of haulage chosen and used in this mine is transport by CATERPILLAR trucks; they feed the crushing station and are also used for dumping waste rock. The crushed ore will be loaded into wagons and transported by rail to the El-Hadjar Annaba steel complex (Figure 3). The selection of trucks was made according to the productivity of the mine, the characteristics of the loads to be transported, the type of loading machinery and the transport distance. Caterpillar trucks are the most popular vehicles of the different brands used in the mining industry. Based on the power of vehicle, mine productivity, haul truck capacity and other parameters, CAT 775F was selected for the analysis presented in this study.

Cycle time is the time taken by a piece of equipment to complete an operating cycle. For a truck, this includes time to spot and load, to get to the dump site; maneuvering, locating, unloading and returning to the loading point, and also predictable, unpredictable delays and waiting times [18, 19].

The time between the start of loading of 2 successive trucks is called truck loading time. The time t=0 is taken at the instant when the loading machine begins to empty the first bucket. The determination of the time required by the vehicle for its complete haulage cycle includes loading, hauling, dumping, returning, and spotting times, as shown in Eq. (1) [20]:

$$\text{Ttruck}=\text{Load time}+\text{Full haul}+\text{Dump time}+\text{Empty haul}+\text{Spotting} \quad (1)$$

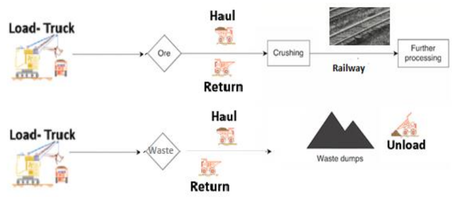

Figure 3. Boukadra's mine production system

Table 2. CATERPILLAR 775 truck haulage cycle time timekeeping

Number Truck	Load time(min)	Full hall(min)	Dump(min)	Empty hall(min)	Spotting(min)	Ttruck(min)
CAT775F-1	3.7	9.3	0.91	8.5	0.79	23.2
CAT775F-1	3.6	9.15	1	8.66	0.71	23.12
CAT775F-1	3.53	8.93	1.06	8.2	0.83	22.55
CAT775F-1	2.8	8.98	0.95	9.26	2.27	24.26
CAT775F-1	3.45	8.73	1.11	8.78	2.35	24.42
CAT775F-1	3.58	9.08	0.96	8.45	0.89	22.96
CAT775F-2	2.63	8	1.21	8.71	0.96	21.51
CAT775F-2	3.11	8.18	1.01	9.15	0.72	22.17
CAT775F-2	2.81	8.91	0.95	8.33	1.77	22.77
CAT775F-3	3.91	8.1	1.08	8.76	0.69	22.54
CAT775F-3	2.96	8.2	0.81	9.25	2.36	23.58
CAT775F-3	3.26	10.03	0.95	8.96	0.79	23,99
CAT775F-3	3.86	8.95	0.83	9.05	0.92	23.61
CAT775F-3	3.3	8.96	1.03	8,81	0.73	22.83
Average	3.32	8.82	0.99	8.78	1.20	23.11

The average of truck travel cycle time is Ttruck=23.11 min, the average of loading cycle time is Load time=3.32 min according to Table 2. The number of trucks is determined by Eq. (2) [21, 22]:

$$\text{Number of trucks} = \frac{\text{Ttruck}}{\text{Load time}} \quad (2)$$

According to the results of timing carried out at the Boukhadra mine, the number of trucks required is 23.11/3.32=7, plus a reserve truck, the total number of trucks is 8, which far exceeds the current means of the mine composed of a shovel and 3 trucks, knowing that the speed of movement of the truck is not taken into consideration. A representation of successive cycles of truck times (Figure 4) helps to show excavator waits are estimated at 13.15 min.

To solve this problem an evaluation of the travel time of the truck is essential, for this we have broken down this time into two components, one constant and the other is variable.

It is proposed to determine the variable part according to the speed of the truck, which will allow better use of the trucks. The speed of the truck will be estimated from the performance curves of CATERPILLAR trucks.

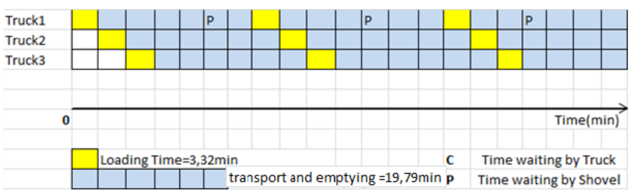

Figure 4. Successive truck cycles as a function of time

The cycle time for a unit operation can be divided into two primary components. The first component consists of those tasks that have a relatively constant duration from one application to the next. This includes such tasks as turning, spotting, dumping, and loading. Estimates of the time required for each of these fixed components of the cycle are generally available from equipment manufacturers. These estimates are based upon experience and are given for specific equipment models operating over a range of job conditions. The variable component of the cycle time is associated with the travel time for mobile equipment and the swing time for fixed-base equipment. Swing time is controlled primarily by the swing angle. Travel time for mobile equipment is much more variable. It is dependent not only upon the haul distance but also the geometry of the haul path and the speed of the vehicle, which is itself a function of available power, total resistance, and load [23].

The spotting time at the loading position also depends upon the type of haulage unit and the operating conditions. The average values are given in Table 3. We choose 0.3min for average conditions and rear dump.

Table 3. Spot at loading machine (min)

Operating conditions	Bottom-dump tractor-traiter	Rear-dump	Side-dump semitrailer
Favorable	0.15	0.15	0.15
Average	0.50	0.30	0.50
Unfovarble	1.0	0.50	1.0

Table 4. Turning-spotting-dumping time (min)

Operating conditions	Bottom-dump tractor-traiter	Rear-dump	Side-dump semitrailer
Favorable	0.3	1.0	0.7
Average	0.6	1.3	1.0
Unfovarble	1.5	1.5-2.0	1.5

Turning, spotting, and dumping time depends upon the type of unit and the specific operating conditions. As a guide, average values for the different types of haulage units under the indicated conditions are shown in Table 4. We choose 1.3min for average conditions and rear dump.

4. RESULTS AND DISCUSSION

To determine the speed at which a vehicle will negotiate a particular slope having a certain rolling resistance (total resistance), it is suggested to refer to the performance curves of the vehicle manufacturer; rolling resistance is the amount of rimpull or tractive effort required to overcome the retarding effect between the tires and the ground. It includes the resistance caused by the tire penetration into the ground, by the flexing of the tires under the load, and (to a degree) by the friction in the wheel bearings (Figure 5). It is normally expressed as pounds pull per ton of vehicle weight, or as a percentage of vehicle weight. For typical haul roads, the rolling resistance is 2% if the road is hard and well maintained; on the bench and close to the dump end, the road quality deteriorates it is expected to increase to 3%; during wet periods when the road conditions are worsened, the rolling resistance might increase to 4%; finally, under very poor conditions, it may rise to 10–16%, however, this would only be over very small sections of the haul road and for short periods of truck operations. The typical values for rolling resistance are presented in Table 5.

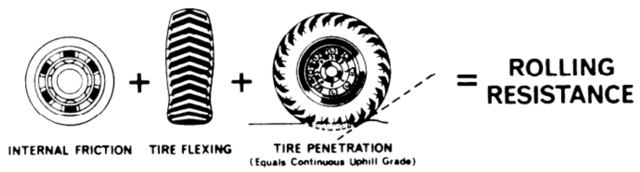

Figure 5. Rolling resistance created by tire penetration, tire flexing, and internal resistance in final drive set. Indicated as pounds pull per ton of vehicle weight [19]

Table 5. Typical values for rolling resistance (%)

Road condition	Rolling resistance
Bitumen, concrete	1.5
Dirt-smooth, hard, dry and well maintained	2.0
Gravel-well compacted, dry and free of loos material	2.0
Dirt-dry but not firmly packed	3.0
Gravel-dry not firmly compacted	3.0
Mud-with firm base	4.0
Gravel or sand-loose	10.0
Mud-with soft spongy base	16.0

A reminder of the principles of development and use of performance curves is required.

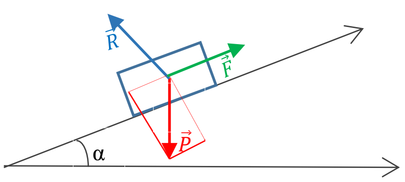

Figure 6. Balance of forces on an inclined plane

By bringing the truck back to its center of gravity, we will have a balance of forces, as shown in Eq. (3):

$$\sum \text{Forces} = Km\vec{\gamma}, \text{ so } \vec{F} + \vec{P} + \vec{R} = km\vec{\gamma} \quad (3)$$

where, F: the driving force (traction force (rim force) or resistance provided by the engine or the retarder of the truck; P: is the weight of the truck; R: is the reaction of the ground, and is decomposed in Rn: normal reaction, RT: tangential reaction, always opposed to the movement, it is the rolling resistance; m and ɣ are the mass and the acceleration of the truck; K: coefficient taking into account the inertia of the truck (K varies from 1.04 to 1.15), for the present work we take K=1.

By projection on the axis of displacement and considering that α is small (then: sin (α)=tan (α)=α(radians) and by expressing RT as a function of P (RT=r*P, knowing that r is the coefficient of rolling resistance, function of the state of the ground).

The Eq. (3) becomes:

$$Km\, \gamma = F - mg\, (\alpha + r) \quad (4)$$

The usable fraction of F (driving or braking force, as the case may be) is limited by the grip of the vehicle on the ground. The maximum force available will be Fmax=f ∑Pi; where f represents the coefficient of friction (or adhesion) of the wheels on the ground and ∑Pi the weight on the driven or braked wheels. In the acceleration phase, ɤ gradually decreases (as the speed increases), until it reaches a zero value for F0=mg (α+r). The driving force is then just sufficient to overcome the resisting forces. The acceleration is zero and the speed reaches its maximum. This has been translated into curves called performance curves.

Uphill: These are the engine performance curves.

Downhill: These are the curves of the retarder, depending on the length of the slope. The chart in Figure 6 only makes sense if the total equivalent slope is positive. The equivalent slope is α+r if the slope is uphill and α-r if it is downhill. r and α are counted in absolute value [22].

The weight of the empty truck is 45.620 tons and the weight of the truck is 106.37 tons when loaded.

Downhill (step to crusher)

Equivalent slope=α-r; %; the total truck weight 106.37 tons. For L_1: α=7%, for L_2: α=6%, for L_3: α=0.6. The rolling resistance coefficient is: r=3%. Equivalent slope: α-r. Section L_1: α-r=4%, Section L_2: α-r=3%, Section L_3: α-r=-2.4%.

Uphill (from crusher to the bench).

For the ascent the weight of the empty truck is 45,620 tons; the slopes are of order: L_1: α=7%, L_2: α=6%, L_3: α=0.6. The rolling resistance coefficient is: r=3%. Equivalent slope: α+r. Section L_1: α+r=10%, Section L_2: α+r=9%, Section L_3: α+r=3.6%.

Starting from the weight of the vehicle and going down to the percentage of equivalent slope. From the point of intersection, we draw a line horizontally to the curve, then we descend vertically on the speed scale to obtain the maximum speed (Figure 7), we obtain the results mentioned in Table 6.

The results of the projection of the downhill performance curve for the total length (L_1+L_2+L_3) by applying α-r=4% we obtain a speed of 37 km/h.

Time for Full haul is determined by:

$$\frac{\sum L_i}{\sum V\, max} = \frac{0.31 + 0.225 + 2.36}{37} = 4.69\; min$$

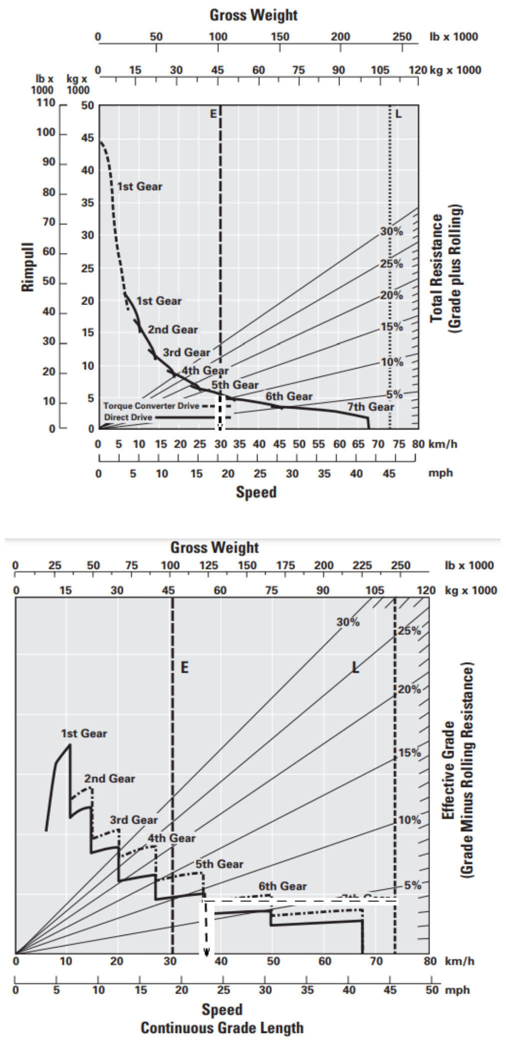

Figure 7. Performance curve for the CATERPILLAR 775F truck

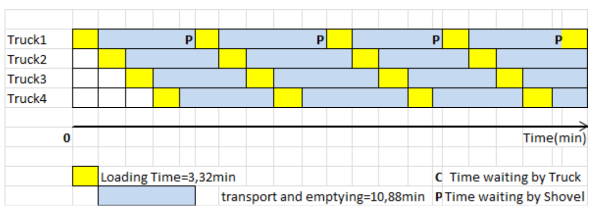

Figure 8. Successive truck cycles as a function of time

Table 6. Maximum speeds on the different sections of the route according to the performance curve

	Maximum Speed (V max) (Km/h)			
	Equivalent slope (%)	Empty (Km/h)	Equivalent slope (%)	full (Km/h)
L_1	10	30	4	37
L_2	9	31	3	37
L_3	3,6	40	-2.4	-

Time Empty haul is determined by:

$$\frac{\sum L_i}{\sum V\,max} = \frac{0.31}{30} + \frac{0.225}{31} + \frac{2.36}{40} = 4.59\ min$$

The time required by the truck for its complete haulage is calculated from the sum of loading, hauling, dumping, returning, and spotting times. Spotting time is evaluated according to Table 3 and Table 4, so Truck=14.2min.

Therefore, the number of trucks assigned to the shovel is 4 referring to formula (2), as shown in Figure 8. The waiting time of the shovel for the 2nd run of the truck is 0.92min compared to the current working method with 13.15min, the coefficient of use of the shovel will increase and therefore the yield per shift will increase systematically.

Given the difficulties in determining the overall productivity of the site, operators prefer from experience to use the absolute coefficient of use to calculate the yield of the excavator expressed in m^3/h, as shown in Eq. (5) [24]:

$$D = D' * CUA \qquad (5)$$

where, D': theoretical yield of the excavator (m^3/h); CUA: absolute coefficient of use of the shovel calculated by Eq. (6):

$$CUA = \frac{HUE}{HP} \qquad (6)$$

where, HP: theoretical time of work. It represents the total of possible hours in a given period. We consider 1 shift=8 hours; HEU: These are the hours actually worked by the machines assigned to the operation.

It is obvious that when the waiting times decrease, the HUE increases and therefore the yield of the shovel increases.

5. CONCLUSIONS

Based on the analysis of the loading and transportation works in the Boukhadra open pit mine with a fleet of one KOMATSU excavator and three CATERPILLAR775 trucks, the results of the calculations and their analysis led to the conclusion that the time shovel waiting time is high, which systematically reduces the utilization coefficient of the shovel during the shift. The breakdown of the truck's cycle time into two components: the first, which has a relatively constant duration and is estimated by equipment manufacturers; the second is variable and depends only on the transport distance, the geometry of the transport path and the speed of the vehicle, which is itself a function of the power available, and of the total resistance.

REFERENCES

[1] William, H., Mark, K., Randall, M. (2006). Open pit mine planning&design, Volume 1–Fundamentals. 3rd Edition. A Balkema book.

[2] Luisa, F.M.H. (2017). Open pit mine loading and haulage simulation. Thesis Master of Science. Department of Civil and Environmental Engineering University of Alberta. https://doi.org/10.7939/R3B27Q386

[3] Ghaziania, H.H., Monjezi, M., Mousavi, A., Dehghani, H., Bakhtavar, E. (2021). Design of loading and transportation fleet in open-pit mines using simulation approach and metaheuristic algorithms. Journal of Mining and Environment, 12(4): 1177-1188. https://doi.org/10.22044/jme.2022.11450.2131

[4] Isnafitri, M.F., Rosyidi, C.N., Aisyati, A. (2021). 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. https://doi.org/10.1088/1757-899X/1096/1/012024
[5] O'Hara, T.A., Suboleski, S.C. (1992). Costs and cost estimation. SME Mining Engineering Handbook, 1: 405-424.
[6] Krause, A.J. (2006). Shovel-truck cycle simulation methods in surface mining. University of Witwatersrand: Johannesburg, South Africa.
[7] Abbaspour, H., Drebenstedt, C., Dindarloo, S.R. (2018). Evaluation of safety and social indexes in the selection of transportation system alternatives (Truck-Shovel and IPCCs) in open pit mines. Safety Science, 108: 1-12. https://doi.org/10.1016/j.ssci.2018.04.020
[8] Ercelebi, S.G., Bascetin, A. (2009). Optimization of shovel-truck system for surface mining. Journal of the Southern African Institute of Mining and Metallurgy, 109(7): 433-439.
[9] Nasirabad, H.M., Mohtasham, M., Omidbad, M. (2018). A comparison between various dispatching strategies for truck-shovel productivity optimization in open pit mines. International Journal of Mining and Geo Engineering. https://doi.org/10.22059/IJMGE.2018.255973.594731
[10] Zhang, Y., Zhao, Z., Bi, L., Wang, L., Gu, Q. (2022). Determination of truck–shovel configuration of open-pit mine: A simulation method based on mathematical model. Sustainability, 14(19): 12338. https://doi.org/10.3390/su141912338
[11] Zhang, Y.D. (2003). Development and prospect of mining system engineering. Metal Mine, 1: 1-3.
[12] Zhang, Y.D., Wang, Y.J. (1989). Open pit mining system engineering. Coal Industry Press, Beijing, China.
[13] Liu, G., Chai, S. (2019). Optimizing open-pit truck route based on minimization of time-varying transport energy consumption. Mathematical Problems in Engineering, 2019: 6987108. https://doi.org/10.1155/2019/6987108
[14] Ta, C.H., Ingolfsson, A., Doucette, J. (2013). A linear model for surface mining haul truck allocation incorporating shovel idle probabilities. European journal of Operational research, 231(3): 770-778. http://dx.doi.org/10.1016/j.ejor.2013.06.016
[15] Aguayo, I.A.O., Nehring, M., Ullah, G.W. (2021). Optimising productivity and safety of the open pit loading and haulage system with a surge loader. Mining, 1(2): 167-179. https://doi.org/10.3390/mining1020011
[16] Hébert-Desgroseilliers, L. (2009). Conception d'un plan de production minière avec rétroaction ,mémoire de maîtrise, École Polytechnique de Montréal. PolyPublie. https://publications.polymtl.ca/216/
[17] Hezaimia, I., Boukelloul, M.L., Merah, C., Berrah, Y., Hamdane, A., Benghazi, Z., Kahoul, I. (2019). Selection of new appropriate mining method: case of Boukhadra iron ore mine, NE Algeria. Arabian Journal of Geosciences, 12: 1-13. https://doi.org/10.1007/s12517-019-4641-4
[18] Coronado, P.P.V., Tenorio, V. (2015). Optimization of open pit haulage cycle using a KPI controlling alert system and a discrete-event operations simulator. Conference: 37th International Symposium on the application of computers and operations research in the mineral industry.
[19] Lineberry, G.T. (1985). Optimizing off-highway truck characteristics for minimum haulage cost. International Journal of Mining Engineering, 3(4): 295-310. https://doi.org/10.1007/BF00880840
[20] Bishop, T.S. (1972). Trucks, Surface Mining, Chap. 9.2, E.P. Pfleider, ed., AIME, New York, pp. 553–588.
[21] Kovalenko, V., Ambartsoumian, N., Lahmer, K.M. (1986). Exploitation des carrières. Office des publications universitaires.
[22] Bourgine, B. (1986). Modélisation de la politique d'exploitation et dimensionnement des équipements miniers dans le cadre de simulations d'exploitations minières à ciel ouvert. Thèse de doctorat, Institut des matériaux et des gisements miniers, Ecole des mines d'Ales.
[23] Sweigard, R.J. (1992). Materials handling: Loading and haulage. Chapter 9, pp. 761-782. SME Mining Engineering Handbook.
[24] Kamulete Mudianga, N. (2014). Cours d'exploitation des mines à ciel ouvert. Université de Lubumbashi Faculté Polytechnique Département des mines, pp. 254.