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An Optimization of Shovel-Dumper Combination System in a Surface Mines Project

Abhishek Kumar Tripathi[1], Jannela Yernaidu[2], Durgesh Nandan[3], Sandeep Prasad[4]

[1,2] Department of Mining Engineering, Aditya Engineering College, Surampalem, Andhra Pradesh, India
[3]Department of Electronics and Telecommunication, Symbiosis Institute of Technology, Pune, Maharashtra.
[4] Department of Mining Engineering, AKS University, Satna, India
abhishekkumar@aec.edu.in[1], yernaidu.j@aec.edu.in[2], durgeshnan- dano51@gmail.com[3] , sandeep0908024@gmail.com[4]

Abstract

The optimization of the shovel-dumper combination is one of the major challenging issues during fleet mining equipment management. Optimization of shovel-dumper provides aid in increasing the potential capacity of the overall transportation system. The aim of the present study is to reduce idle time and improve the utilisation of shovel-dumper so that their potential capacity can be increased in a heterogeneous nature of the surface mine conditions. This is achieved in the present paper by applying the queuing theory concept in the operation of shovel-dumper. It is observed that the queuing approach (contains parameters namely waiting time, queue length, shovel utilization, shovel productivity, and other operational properties) helps in identifying the optimal dispatching decisions of the shovel-dumper combination which in turn improves the potential capacity of the respective types of equipment. The formulation of an appropriate queuing model has been undertaken in this study and it has been designed in such a manner so that the best possible combination of shovel-dumper can be achieved for a given surface mines project. Based on this study, it can be concluded that the queuing model can be used as a tool of performance evaluator and equipment selector so that the economic viability of a surface mines project can be improved.

Keywords: *Optimization, Shovel-Dumper, Queueing model, Surface mines*

1. Introduction

All over the world the majority of the economic minerals are mined out by the methods of surface mining due to its ease of operation and less complexity. The surface mining project having many advantages over sub surface mines such as, higher productivity, more safety and flexible in its operation while adapting new technological changes [1]. Many technological advancements are occurred in the various types of HEMMs machinery that enhance the safety and productivity of the surface mines operation [2]. The overall economic of surface mining project largely depends upon the stripping ratio (nothing but the removal of material i.e., overburden and mineral) which involves the various auxiliary unit of operations such as drilling, blasting, loading, hauling and dumping [3]. Among all of these unit operations, hauling and dumping played a significant role in the transportation system of surface mining project. To minimize the material handling costs and the maintenance of haulage roadways cost the optimum selection of haulage-dumper is very necessary [4]. Therefore, the optimum mode of transportation and the right combination of equipment are essential to get optimal results so that the efficient utilization of haul trucks can be achieved in the surface mining project [5]. Many studies stated the optimum combination of shovel and dumper is the best solution for utilizing the haul road efficiently so the better performance can be produced [6,7,8].

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*Author for correspondence

Due to lack of fleet management in haul road, the shovel-dumper combination yet not received optimized results and many researchers attempted various approaches to optimize the results of shovel dumper combination. The queuing model is one of the best possible approaches to select the optimum combination of shovel dumper for surface mining project [9]. However, it is quite difficult to ensure the timely arrival of dumpers to the shovels due to the impact of uncontrollable factors that persist in surface mines. The method of dynamic allocation can be used, in which the dumper, after dumping, is assigned to a free (or a less busy) shovel, based on the selected dispatching criterion [10]. This will significantly reduce the idle time of the cargo-handling equipment and improve its performance. In this paper, an attempt was made, based on queuing model approach, for determining the optimum shovel dumper combination of considered surface mines.

2. Design of Queuing Model

The queuing model formulation requires some stochastic features and assumption. The model is designed in accordance with truck arrival pattern, service pattern, size of truck fleet, queue size and cost of idling to arrival and service unit are to be made realistic. The arrival rate of dumper is considered as random which is described by Poisson's distribution whereas the service rate of shovel is considered as exponential distributions in the proposed queuing model. The queuing theory consists of various parameters namely waiting time, queue length, shovel utilization, shovel productivity per hour, and other properties. In the present case study, the queuing model (M/M/S) along with finite calling population is considered to evaluate the performance of fleet equipment deployed. In queuing model, which is in the form of (M/M/S):(FIFO/K/K), M/M Poisson arrival and exponential service distribution whereas the S represent the number of parallel servers. In the present case study, the only one operating server is considered. The service operation of this queuing model is based on first in first out (FIFO). The size population of dumpers and ultimate queuing capacity is presented by K/K. Queuing model helps in making sound decision policy by providing easy means of asset evaluation when compared to heuristic approach [11]. The over dumping and under dumping of the system can be planned in the queuing model by the knowledge of waiting time in line and system. The fleet management of dumper (truck) can be performed by removing or adding a dumper in order to optimize the material transportation. The idle time of the dumper can be utilized by analyzing time spent of dumper in the system so that an optimum combination of the shovel and dumper can be employed in a considered site. In the queuing model of (M/M/S):(FIFO/K/K) some performance parameters need to evaluate for solving the optimum combination of shovel and dumper. For the designing the queuing model, following important performance parameters calculated are as follows:

(a) Traffic intensity (ℓ)

$$e = \frac{\lambda}{\mu}$$

(for the single shovel case) here, $\ell < 1$, otherwise queue will be going on increasing increasing

(b) Probability of 'n' dumpers in the system (P_n)

$$P_n = \frac{K!}{(K-n)!s!s^{n-s}}\left(\frac{\lambda}{\mu}\right)^n P_o \quad \text{, n= 1, 2, ...k } (s \le n \le K)$$

where,

$$P_o = \left[\sum_{n=o}^{e-1} \frac{K!}{(K-n)!n!}\left(\frac{\lambda}{\mu}\right)^n + \sum_{n=s}^{k} \frac{K!}{(K-s)!s!s^{n-s}}\left(\frac{\lambda}{\mu}\right)^n\right]^{-1}$$

(c) Expected number of dumper in the queue, i.e., length of queue (L_q)—

$$L_q = \sum_{n=s}^{k}(n-s)P_n$$

(d) Expected number of dumpers in the system, (L_s)

$L_s = L_q$ + number of trucks being loaded

$$L_s = \sum_{n=o}^{k} nP_n$$

Or,

(e) Most expected value of dumper arrival rate (λ^-)

$$\lambda^- = \sum_{n=o}^{k} \lambda(K-n)P_n = \lambda(K - L_s)$$

(f) Expected time that a dumper spends in the queue (Wq)

$$W_q = \frac{L_q}{\lambda} \text{, where } \lambda(K - L_s)$$

(g) Expected time that a dumper spends in the system (W_s)

$$W_s = \frac{L_s}{\lambda}$$

(h) Shovel utilization (η_s)

$$\eta_s = 1 - P_o$$

(i) Dumper utilization, (η_t)

$$\eta_t = 1 - \frac{W_q}{W_q + t_1 + t_t + t_d}$$

Where, t_1 = loading time, t_1 is the total travelling time (loaded dumper travel time + empty dumper travel time), td is the dumping time and W_q is the waiting time of dumper in queue.

3. Field Data

The formulated queuing model was tested for a surface mine which is situated at the geographical coordinates of 14° 8' 55.4928" N, 76° 40' 1.1424" E in the Karnataka state of India. The mines having a shovel and dumper combination for loading and hauling the excavated material. To determine the optimum combination of shovel and dumper a queuing model approach is performed in this paper. The shovel capacity of 3.6 cubic meter with 45 tonne per discharge of dumper is considered in the present study. The aim of proposed model is to provide the optimum combination of shovel and dumper by reducing the idle and waiting time of dumper in queue. The data collected from field is presented in Table 1.

Table 1. The field data observations in shovel-dumper combination

	Parameter	Notations	Values
1.	Arrival rate	λ	7 dumper/hr.
2.	Service rate	μ	14 dumper/hr.
3.	Traffic Intensity	e	0.5
4.	Number of shovels	S	1

4. Results and Discussion

There are some important queuing parameters need to find in order to formulate the queuing model for optimum combination of shovel and dumper. Thus, the important parameters are evaluated based on the field collected data (as mentioned in Table 1). The various possible dumper combination is considered on the calculation of queue length, waiting time, shovel utilization approximate production and on the total operating cost. These parameters were calculated based on the formulae of queuing model design (which is mentioned in the section 2 of this paper). The results of queuing model are shown in Tables 2 and 3. Table 2 indicates the effect of dumper fleet on the queuing parameters and the cost of operation per tonne is shown in Table 3.

Table 3. Effect of dumper fleet on the cost of operation of shovel and dumper

Dumper fleet size	(Estimated) Production Qn tons/hr.	Total cost of operation money unit /ton		
		Cost of loading	Cost of hauling	Total cost
2	307	8.14	6.51	17.10
3	460	5.43	6.95	13.69
4	614	4.07	7.32	15.96
5	768	3.25	8.07	15.49
6	920	2.71	8.91	17.5
7	1075	2.32	9.48	18.8
8	1228	2.03	10.42	19.66

Table 2. Effect of dumper fleet on the parameters of Queuing model

Dumper fleet size	Queue length		Waiting time		Shovel utilization (%)
	Length of queue Lq (Dumpers)	Length of system Ls (Dumpers)	Waiting time in queue Wq (Minute)	Waiting time in queue Ws (minute)	
2	0.2	0.8	0.86	3.42	60.0
3	0.63	1.42	2.70	6.08	78.0
4	1.28	2.19	5.48	9.38	91.5
5	2.11	3.07	9.04	13.15	96.3
6	3.03	4.02	12.98	17.23	98.7
7	4.01	5.00	17.18	21.43	99.6
8	5.00	6.00	21.43	25.72	99.9

The relation between the number of dumpers and the length of queue, is presented in Figure 1. By observing the figure it can be easily concluded that, the relationship is almost linear and increase in proportion is in the positive direction.

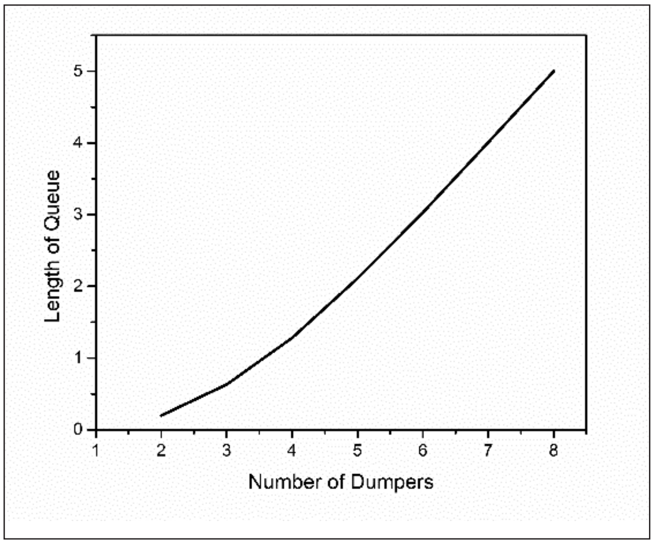

Fig.1: Plot between number of dumpers and length of queue

The relation between number of dumpers and waiting time in queue is presented in Fig. 2, from which it can be clearly deducted that, the waiting time increases with the increase in number of dumpers.

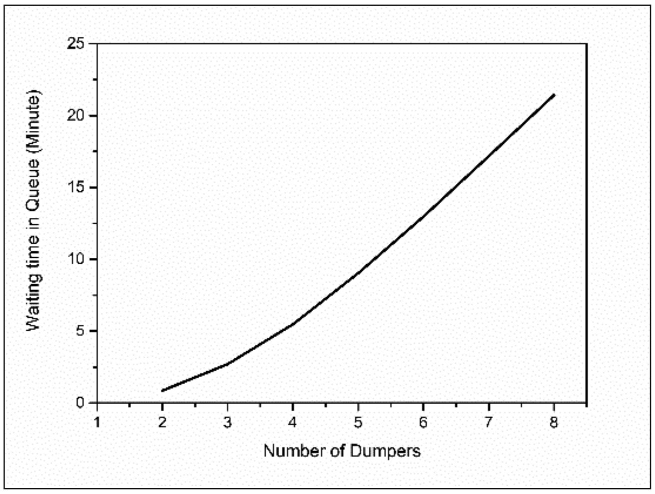

Fig.2: Plot between number of dumpers and waiting time in queue

The shovel utilization percentage is plotted against the number of dumpers in Figure 3, from which it is evident that, the shovel utilization percentage, although, increases with increase in the number of dumpers, but, after a certain number, it becomes constant after reaching maximum utilization capacity.

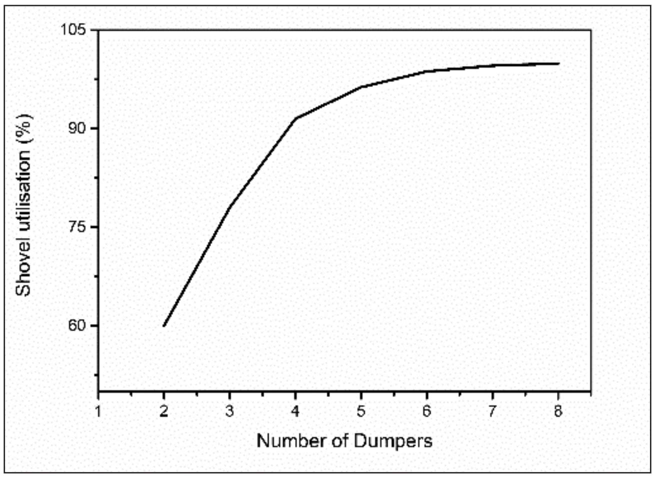

Fig.3: Plot between number of dumpers and shovel utilization

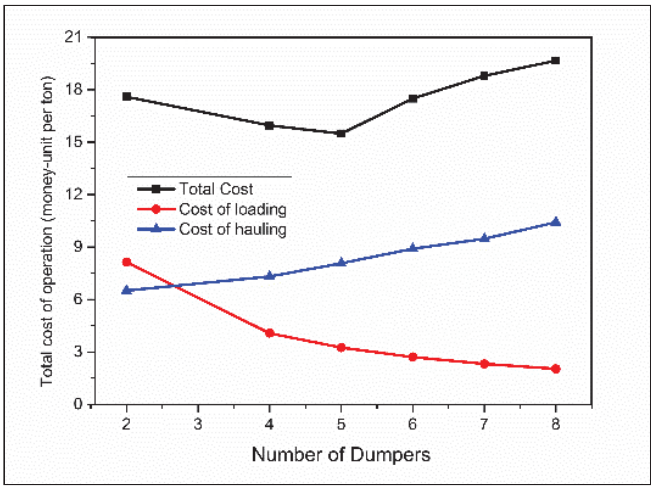

Fig.4: Plot between number of dumpers and total cost of operation

In Fig. 4, the total operating cost and the number of dumpers is plotted. From that it can be seen that, the cost of hauling increases with the number of dumpers, whereas, the cost of loading decreases with number of dumpers. As shown in Figure 4, the total cost exhibits a null optimum cost point. This null point is called the optimum point of shovel-dumper combination. This point must be obtained in order to calculate the optimum number of dumper with the specified capacity of shovel.

5. Conclusion

Shovel and dumper are the two most important equipment used in any surface mines. The optimum combination of shovel and dumper help in improving the production of the surface mines. This paper is focused on the queuing model approach to reduce idle time and improve the utilization of shovel-dumper by providing optimum combination. The queuing approach (contains various operational parameters) helps in identifying the optimal dispatching decisions of the shovel-dumper combination which in turn improves the potential capacity of the shovel. The queueing model, (M/M/C/*M): (FIFO/K/K), of single server and finite pattern is used in this paper. The length and waiting time in que are related to the number of dumpers in shovel-dumper combination. Therefore, the knowledge of optimum combination is very much necessary so that the overall production of shovel can be increased. In the total cost of shovel-dumper combination the null point was obtained for the combination of 5 dumpers and 1 shovel. Thus, this point exhibits the optimum combination of shovel and dumper for the considered site.

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