APPLICATION OF QUEUING THEORY IN ANALYSING SHOVEL-TRUCK HAULAGE SYSTEM IN VIET NAM SURFACE MINE

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Abstract- Haulage system in ore and waste material transportation plays an important role in most open pit mines. Queueing theory presents a promising method to account for idle time caused by trucks waiting to be served at either the loading or dumping point. This paper deals with the analysis shovel-truck system performance using queuing model (M/M/1) in Viet Nam surface mine. The outputs of the model show relationships between truck fleet size with the length queue, waiting time in queue, shovel utilization and production. Analysis of operating costs while varying the number of truck to find out the optimized point at which the system works with minimal cost.

Keywords- Haulage system, Queuing theory, trucks, shovel, optimized

I. INTRODUCTION

Currently many open pit coal mines in Viet Nam are in the period of operating at greater depth. This leads to increase haul distances from the working faces to the mine surface, introduces longer cycle time for the hauling units and can also generate lower production rates. Hauling becomes a critical parameter and therefore an effective choice of haulage methods becomes an important factor in mine production optimization for deep open pit mines.

In an open pit operation the trucks move from the shovels to the dumping site and back. Occasionally the trucks have to wait at the shovel, at the dumping site, at the repair shop or at the fueling station when there already is a truck being loaded at the shovel or being fueled. These waiting times reduce the capacity of the operation. Waiting time estimation is an important task in the design and equipment selection for a new open pit operation or when changes in an existing operation are being considered.

The queuing theory offers an interesting approach to the estimation of waiting times because of its calculation speed and its relative simplicity compared with simulation using a large number of random numbers to generate a modelsuch as Monte Carlo simulation [3]. Queuing theory gained popularity as a method of fleet selection and haul cycle analysis. FLSELECTOR module for equipment fleet selection using the form (M/E/c)/K was developed in 2002 by El-Moslmani allows for an optimum fleet to be selected based on least cost, maximum production [1]. Ercelevi and Bascetin also gave out a computational study in optimization of shovel-truck system for surface mining using a model based on the closed queuing network theory which has potential to be useful for mine operators in mine planning at the stage of equipment procurement [2]. Recently, an (M/M/c) queuing model was developed by Meredith to model truck and shovel relationship in mines from which calculates outputs that describing haulage system behavior [4].

The main objective of this research is to evaluate the usefulness of queuing theory in analysing shovel-truck system operating characteristics with the purpose of supporting the decision-making process. The research aims to fulfill the following specific objectives:
- Analyse shovel-truck system performance.
- Evaluate the effects of variation in truck fleet size on the queue length, waiting time, shovel utilization, approximate production and operating costs.

II. QUEUING THEORY

A queuing system is defined as one in which customers arrive for service, wait for service if it is not immediately available, and move on to the next server or exit the system once service is complete [5].

2.1. Queuing model in mining

In mining operations, queuing models are normally observed during the hauling cycle of trucks from the loading position, in which trucks arrive at the shovels, wait for their turn in queue if there is any truck being loaded, to the dumping sites and then start a new circle. The Fig.1 below depicts a basic mining queuing system with the haul trucks are the customers queuing at line and being loaded by the server is the shovel.

2.2. Elements and characteristics of queuing system

The major elements of queuing systems are calling population, customer arrivals, the waiting line, processing order, service and exit. The calling population or the customer source is the pool of potential arrivals to the system, this population may be finite or infinite. Customer arrivals is normally specified by the distribution of interarrival time – the average time between arrivals. The waiting line consists of customers who have been admitted to the system and are waiting service. A commonly processing order or queue discipline rule is first come
first serve. Service is the key issue in system with the number of servers, steps in the service process and the distribution of service time. The final element in system is exit or what customers do after leaving the system [8].

![Fig.1. Truck and loader queuing system [4]](image)

A convenient notation for summarizing the characteristics of the queueing situation is given by the following format [5]:

\[(a/b/c) : (d/e/f)\]

Here, \(a\) - arrivals distribution, \(b\) - departures (service time) distribution, \(c\) - number of parallel servers (\(= 1, 2, \ldots, \infty\)), \(d\) - queue discipline, \(e\) - maximum number (finite or infinite) allowed in the system (in-queue plus in-service), \(f\) - size of the calling source (finite or infinite).

### 2.3. Measures of system performance

The queuing models in mining system are described as (M/M/c) format with these conditions:
- One or more server
- A Poisson arrival rate
- A negative exponential service time
- First come, first serve processing order
- A finiteive calling population
- No limit on queue length

A number of system performance measures can be computed and referred as the operating characteristics of a queuing model [8]. These parameters are given in table 1.

### 2.4. Production forecasting model

For an operation involving single shovel and \(N\) trucks, the total hourly cost is \(C_1 + C_2N\), where \(C_1\) is the cost per unit time of shovel and \(C_2\) is the cost per unit time of a truck.

### Table 1: Performance measure for the (M/M/1) queuing system

<table>
<thead>
<tr>
<th>Performance measure</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>System utilization</td>
<td>(r = \frac{\lambda}{\mu} (1))</td>
</tr>
<tr>
<td>Probability of no units in the system</td>
<td>(P_0 = \frac{\left(\begin{array}{c} \lambda T \ \mu T \end{array}\right)}{\sum_{n=0}^{\infty} \left(\begin{array}{c} n \ \lambda T\end{array}\right) \left(\begin{array}{c} n \ \mu T\end{array}\right)} (2))</td>
</tr>
</tbody>
</table>

Both costs include ownership and operating costs. So the total cost for unit production can be found from:

\[C = \frac{C_1 + C_2N}{\text{unit production} \times \text{truck capacity}} (8)\]

Where \(N\) is the number of trucks in the system. Production may be calculated from:

\[\text{Production} = \text{time period of interest} \times \eta_{\text{shovel}} \times \mu_{\text{shovel}} \times \text{truck capacity} (9)\]

\(\eta_{\text{shovel}}\) is shovel utilization and \(\mu_{\text{shovel}}\) is shovel loading rate.

Once the unit production cost is found for a different number of trucks, the cost can be plotted vs. the number of trucks, and the optimum truck number, which minimizes the cost, can easily be determined.

[2].

### III. RESULTS AND DISCUSSION

#### 3.1. Mine information

The study was carried out in Cao Son open pit coal mine in Vietnam. The coal mine is situated in Quang Ninh province and has been continuous operation since 1974. Currently, the mine supplies coal to domestic users and apart to export to international customers such as China, India. At present, the extent of the open pit is 2,120m of width and 2,260 of length with the current pit at the level of -70 m. The working parameters of mine: 15 m high bench, 45 m minimal wide working bench, 28°-33° working bench angle while the face inclination on individual bench is 45°-65°. The mine works three shifts per day, seven days per week and 330 days per year and is anticipated to be in operation until 2039.

The queuing system was observed in this mine included an EKG shovel with 10 m³ of bucket capacity loading on the 50 ton- haul trucks. The data of truck arrival and service times were recorded. The result of field observation of system for calculation was given in the table 2.

#### 3.2. Analysis and results

The queuing model was applied for this haulage system with the number of service is 1 has a format of (M/M/1). After the calculation process, the output of the model were given out are the amount of time trucks spent waiting to be loaded, \(W_q\), the server
utilization, shovel production and costs respectively. These values are summarized as in table 3.

<table>
<thead>
<tr>
<th>Data</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival rate (λ)</td>
<td>7 trucks/h</td>
</tr>
<tr>
<td>Service rate (μ)</td>
<td>16 trucks/h</td>
</tr>
<tr>
<td>Owning and operating cost of shovel</td>
<td>$739</td>
</tr>
<tr>
<td>Owning and operating cost of truck</td>
<td>$179</td>
</tr>
</tbody>
</table>

Table 3 - Queuing model outputs

<table>
<thead>
<tr>
<th>Truck fleet size</th>
<th>N</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of truck waiting in line, trucks</td>
<td>( L_q )</td>
<td>0.18</td>
<td>0.58</td>
<td>1.19</td>
<td>1.98</td>
<td>2.88</td>
</tr>
<tr>
<td>Number of truck in system, trucks</td>
<td>( L_\lambda )</td>
<td>0.76</td>
<td>1.34</td>
<td>2.08</td>
<td>2.93</td>
<td>3.87</td>
</tr>
<tr>
<td>Average time truck waiting in line, min</td>
<td>( W_q )</td>
<td>1.21</td>
<td>2.89</td>
<td>5.13</td>
<td>7.95</td>
<td>11.22</td>
</tr>
<tr>
<td>Average time truck in system, min</td>
<td>( W_\lambda )</td>
<td>5.03</td>
<td>6.72</td>
<td>8.96</td>
<td>11.7</td>
<td>15.05</td>
</tr>
<tr>
<td>Shovel utilization, %</td>
<td>η</td>
<td>57</td>
<td>76</td>
<td>89</td>
<td>95</td>
<td>98</td>
</tr>
<tr>
<td>Product on, torch</td>
<td>( Q_\lambda )</td>
<td>819</td>
<td>1090</td>
<td>1262</td>
<td>1360</td>
<td>1465</td>
</tr>
<tr>
<td>Cost of loading</td>
<td>( C_1 )</td>
<td>0.90</td>
<td>0.97</td>
<td>1.05</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>Cost of hauling</td>
<td>( C_3 )</td>
<td>0.44</td>
<td>0.49</td>
<td>0.57</td>
<td>0.66</td>
<td>0.77</td>
</tr>
<tr>
<td>Total cost</td>
<td>C</td>
<td>0.73</td>
<td>0.71</td>
<td>0.75</td>
<td>0.83</td>
<td>0.94</td>
</tr>
</tbody>
</table>

The effects of changes of fleet size to the values of queue length, the truck waiting time in queue, shovel utilization and costs can be plotted into graphs (Fig.2 to Fig.5).

As can be seen from these graphs, there is an upward trend in the relationships between the number of truck and queuing model’s outputs (queue length, waiting time in queue, shovel utilization and production). When the fleet size increases, it leads to more trucks have to wait in queue for the service at the shovel; therefore, the amount of time in queue will rise respectively. Interestingly, the more number of trucks are dispatched to the system, the much effectively the shovel performs. For example as in Fig.4, the shovel utilization rised by nearly 40% when adding 2 more trucks into the system, also the value of production increased correspondingly as a result.
Taking on the relationship between truck number and operation costs as being given in the Fig.6, we can easily notice that the loading cost and hauling cost are in direct conflict: an increase in the number of truck results in lowering the loading cost and lifting the hauling cost. The total cost is obtained by summing up the hauling and loading cost lines. It is minimized at the lowest point of this curve, finding this point will show the optimum number of truck in the queuing system. For instance from the Fig.6, the optimized point is at 3 or in the other words, dispatching 3 trucks for 1 shovel in this case, the system will work at the optimum cost.

CONCLUSIONS

Using the queuing model (M/M/1) proved its advantages in analyzing haulage system performance. The needed input for the model is the information about arrival rate and service rate. Not only did the result show parameters of this system such as queue length, the waiting time in queue, shovel utilization and system production, it also pointed out the relationships between these values and truck fleet size. When the fleet size increased, the number of trucks had to wait for the shovel and time spending in the system rised respectively, also shovel utilization and production went up significantly.

The optimal number of trucks dispatched to the system in queuing model is described as the point at which the total operating cost is at the lowest. This cost value is found by summing up the loading and hauling cost onto a graph, from which the lowest point in the total cost curve is the number of truck optimized for this queuing system.

Queuing theory presents a promising method to account for idle time caused by trucks waiting to be served at the loading. When trucks and shovels are represented as servers and customers in a queuing network, the proper number of equipment that should be implemented in a mine can be determined, ensuring that production needs can be met while still maintaining efficient use of equipment.

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