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Fleet Size Optimization in Cao Son Coal Mine In Vietnam Using Queuing Theory

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Abstract: In Vietnam surface mining, truck is a popular transportation mode, therefore, the problem of selecting a proper fleet is very important to decision makers. Queuing theory is a method with many industrial applications, it offers an interesting approach to the estimation of waiting times because of its calculation speed and relative simplicity. In this research, there is a case study was taken in Cao Son coal mine in Vietnam. Using the queuing model (M/M/1), the result of the model showed the optimized number of truck in the fleet by comparing costs in order to find the minimal value.

Key words: Haulage system, queuing theory, trucks, shovel, optimization, transportation mode

INTRODUCTION

Cao Son Joint Stock Coal Mine is a big surface mine in Vietnam with high level of mechanization of Vinacomin Group. This is one of surface mines in Vietnam with the highest deposit. Currently, this mine is in the period of enlarging and increasing its capacity from 3.7-4.5 million tons (2012-2015).

The mining operation in mine include: drilling and blasting, loading, hauling, dumping, drainage, coal sorting and other auxiliaries. Loading rock in mine is still being handled by EKG shovels from Russia. These shovels have capacities of 4.6-10 m^3 and the C quality. In recent years, Cao Son mine has invested many modern hydraulic backhoes with bucket capacities from 3.5-12 m^3 in order for loading rock, stripping mine pit and coal exploitation (Table 1).

Mine uses trucks for hauling rock and coal. The capacity of truck has a range from 27-96 tons with many kinds such as CAT 773E, HD465-7 (55-58 tons); CAT 777 (96 tons) and so on. Besides, mine also invested in some modern trucks like Volvo A35D, HM400-2R 37 tons for hauling in extreme conditions. Transferring rock to dumping areas is conducted mainly by CAT 773E (58 tons), Belaz 7555, HD 465 (55 tons) and CAT 777 (96 tons). Average haulage distance is about 3.85 km. However, in recent years as a result of difficult working conditions such as deepening mine pit, lengthening haulage distance, hard rock (f = 10-13), old equipments increasing working hour, haul routes become bad in rainy seasons, these factors cause many effects to equipment's productivity. It is very important to measure and control the performance of haulage system in mine with aim of optimization.

Table 1: Mine geometrical parameters

Parameters	Values
Bench height for rock (m)	12÷15
Bench height for coal (m)	5÷7,5
Ended bench height (m)	15÷30
Working bench width B_{min} (m)	45÷50
Rest bench width (m)	18÷20
Bench number in a group	3÷4
Bench angle (degree)	65÷70
φ_{max} (degree)	28÷32
Current level of mine pit (m)	+70

There are a number of documents devoted to study the application of queuing theory in mining system. Ernest Koenigsberg conducted a research using a queuingmodelon mechanized deep mining operations to observe machines queuing up to serve faces and the faces queuing for services in the first come first served order. His study pointed out that the output depends on the number of faces and the service rate of the machines (Koenigsberg, 1958). Besides, queuing theory used as a method for fleet optimization which was put in FLSELECTOR computer module created by Moslmani (2002). In this program, he compared different production outputs from many fleets achieved on different haul routes from the loading point to the dumping area and selected the best fleet based on least cost and maximum production. Another fleet optimization study was shown by Ereclebi with the queuing theory approach on the allocation and truck dispatching under various operating conditions (Ercelebi and Bascetin, 2009). Recently, queuing models are used in analyzing haulage system's performance. Meredith developed an (M/M/c) queuing model to model truck and shovel interactions. This model

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gave out detail results on the system behavior such as truck waiting time, the queue length and the shovel utilization (Meredith, 2012).

In the present study, the Shovel-truck haulage system in Cao Son Coal Mine in Vietnam will be put in analysis using the (M/M/1) queuing model. The objective of this study is tofind the optimized number of truck in the studied system based on least cost through queuing analysis

MATERIALS AND METHODS

System performance analysis: In mining haulage operations, queues are formed when trucks line up at the loading area or dumping sites and wait for the service. The queuing models in mining system are described as (M/M/c) format with conditions (Stevenson and Orgur, 2008):

- One or more server
- A poisson arrival rate
- A negative exponential service time
- First come, first serve processing order
- A finitive calling population
- No limit on queue length

The time data of the shovel-truck system was recorded during a month in different positions and in a stable working shift.

There are two kinds of shovel are EKG 5 (5 m^3 bucket capacity) and EKG 10 (10 m^3 bucket capacity), truck includes many types with capacities from 55-96 tons. The daily data of equipment were collected in order to calculate the arrival rate, λ and the service rate, μ. From these values, the haulage system's performance is defined by Stevenson and Orgur (2008). System utilization (percentage of time server is busy) for a single channel system:

$$r = \frac{\lambda}{\mu} \tag{1}$$

The average number in the system:

$$L = L_q + r \tag{2}$$

Where:
L = Average number in the system
L_q = Average number in line

The average time in line:

$$W_q = \frac{L_q}{\lambda} \tag{3}$$

The average time in the system, including service:

$$W_s = W_q + \frac{1}{\mu} \tag{4}$$

The results are summarized in Table 2.

Table 2: Fleet performance analysis using queuing theory

Date	05-Aug	06-Aug	07-Aug	08-Aug	10-Aug	11-Aug	12-Aug	13-Aug	14-Aug
Shovel	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5
Truck	HD 465	CAT 769 D	CAT 769D	HD 465	HD 465	CAT 773E	CAT 769D	CAT 769D	HD 465
Distance (km)	3.5	3.5	3.5	3.5	3.5	3.8	4	4.2	3.6
λ (trucks/h)	9.23	10.97	11.13	10.19	10.48	9.52	8.45	7.84	10.46
λ (trucks/h)	17.06	17.11	17.92	15.71	16.91	17.73	17.52	17.24	16.77
Expected number of truck in system	1.18	1.79	1.64	1.85	1.63	1.16	0.93	0.84	1.66
Expected number of truck in queue	0.64	1.14	1.02	1.20	1.01	0.62	0.45	0.38	1.03
Expected number in system (min)	7.66	9.77	8.83	10.87	9.33	7.31	6.61	6.39	9.50
Expected number in queue (min)	4.15	6.26	5.48	7.05	5.78	3.93	3.19	2.91	5.93
Server utilization (%)	54	64	62	65	62	54	48	46	62
Date	15-Aug	17-Aug	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	23-Aug	24-Aug
Shovel	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-5	EKG-10	EKG-10
Truck	CAT 773E	CAT 773 E	HD 465	HD 465	HD 465	HD 465	HD 465	HD 785	HD 485
Distance (km)	3	3.4	3.5	3.8	3.5	3.5	3.5	4.2	4.2
λ (trucks/h)	10.13	9.47	10.21	8.46	8.39	8.22	8.35	8.58	8.53
μ (trucks/h)	17.15	17.16	16.88	16.96	15.12	15.45	15.40	14.98	14.78
Expected number of truck in system	1.44	1.23	1.53	1.00	1.25	1.14	1.18	1.34	1.36
Expected number	0.85	7.80	8.99	7.06	8.91	8.30	8.51	9.37	9.59
Expected time in queue (min)	5.05	4.30	5.44	3.52	4.95	4.41	4.61	5.36	5.53

Table 2: Continue

Date	05-Aug	06-Aug	07-Aug	08-Aug	10-Aug	11-Aug	12-Aug	13-Aug	14-Aug
Server utilizaton (%) of truck in queue	59	55	60	50	55	53	54	57	58
Date	25-Aug	26-Aug	27-Aug	28-Aug	29-Aug	30-Aug	01-Sep	02-Sep	
Shovel	EKG 10	EKG 10	EKG 10	EKG 10	EKG 10	EKG 10	EKG 10	EKG 10	
Truck	HD 785	HD 785	CAT785	CAT 785	CAT 785	CAT 785	CAT 785	CAT 777D	
Distance (km)	4.2	4.2	3.8	3.8	3.8	3.8	3.8	3.5	
λ (trucks/h)	8.47	8.32	8.55	7.85	8.35	8.58	8.16	8.56	
μ (trucks/h)	15.20	14.88	15.10	14.48	14.72	14.82	14.45	15.02	
Expected number of truck in system	1.26	1.27	1.30	1.18	1.31	1.37	1.30	1.33	
Expected number of truck in queue	0.70	0.71	0.74	0.64	0.74	0.80	0.73	0.76	
Expected time in system (min)	4.97	5.11	5.18	4.91	5.35	5.56	5.40	5.30	
Server utilization (%)	56	56	57	54	57	58	57	57	

Table 3: Record data of fleet

Arrival time (am)	Inter-arrival time (min)	Service time (min)
8:51:08	-	3.00
8:56:10	5.03	3.50
9:05:09	8.98	3.50
9:09:05	3.93	3.10
9:14:06	5.02	3.80
9:24:02	9.93	3.50
9:27:12	3.17	3.20
9:35:21	8.15	4.00
9:46:22	11.02	3.70
9:50:21	3.98	3.10
9:57:07	6.77	3.70
10:03:14	6.12	3.80
10:06:03	2.82	3.30
10:16:20	10.28	3.30
10:23:00	6.67	3.30
10:25:16	2.27	3.20
10:32:22	7.10	4.00
10:39:08	6.77	3.30
10:43:18	4.17	3.50
10:50:02	6.73	3.90
10:58:11	8.15	3.60
11:05:02	6.85	3.70
11:11:06	6.07	3.80
11:19:04	7.97	3.50
11:26:23	7.32	3.40
11:32:00	5.62	3.70
11:40:07	8.12	3.70
Mean	6.50	3.52

Fig. 1: Observed queuing system

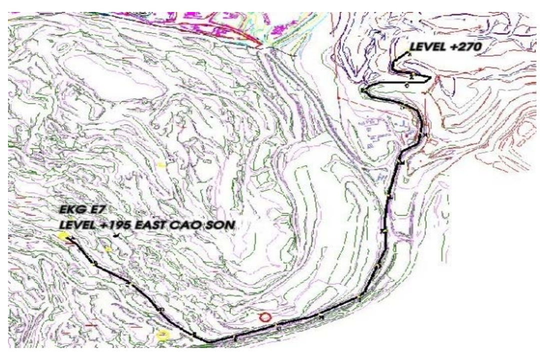

Fig. 2: Contour map of the route from the shovel to the dumping site

RESULTS AND DISCUSSION

Optimization process: The case was observed at the level +195 East Cao Son Mine. At the normal working condition, mine operates within three shifts, 8 h per shift and 1 h break between a shift (Fig. 1).

At the observed time, the morning shift, there was 1 shovel EKG (5 m^3 bucket capacity) loading rocks to dump trucks HD 465 (55 tons). This loading and haulage system creates a form of queuing system, a cyclic queuing system in which dump trucks are customers getting service at the shovel. After being loaded, these trucks follow the same route to the dump site at the level +270 East Cao Son, then back to the loading position and wait for their turns. The haulage distance is estimated about 3.5 km. Bench rock after blasting has a density of 2.63 t/m^3. The estimated hourly unit costs of hauling and loading (owning and operating) for these equipment are $83 and 105, respectively. The transformation route from loading point to the dumping site is given as in Fig. 2. The steps of the optimization process are illustrated as in Fig. 3 (Table 3).

Step 1; Record time data: The time data was recorded for the system as in Table 4. The arrival times of each

Table 4: Result of the model

Variables	Values							
λ	9							
μ	17							
r	0.54							
N		2	3	4	5	6	7	8
P(0)		0.46	0.19	0.08	0.03	0.01	0.00	0.001
P(n)	1	0.50	0.30	0.17	0.08	0.03	0.01	0.00
	2	0.27	0.33	0.28	0.17	0.08	0.03	0.01
	3		0.18	0.30	0.27	0.17	0.08	0.03
	4			0.16	0.29	0.27	0.17	0.08
	5				0.16	0.29	0.27	0.17
	6					0.16	0.29	0.27
	7						0.16	0.29
	8							0.16
Lq		0.27	0.69	1.38	2.23	3.18	4.16	5.15
Ls		1.04	1.50	2.30	3.21	4.17	5.16	6.15
Wq		1.83	2.97	5.27	8.09	11.27	14.66	18.14
W		1.89	3.03	5.33	8.15	11.33	14.72	18.20
ç (s) (%)		54	81.2	92.0	97.1	99.1	99.8	99.9
Qn (tons/h)		460	693	785	829	845.0	851.00	852.00
C (load)		0.23	0.15	0.13	0.13	0.12	0.12	0.12
C (hauling)		0.36	0.36	0.42	0.50	0.59	0.68	0.78
C (total)		0.59	0.51	0.56	0.63	0.71	0.81	0.90

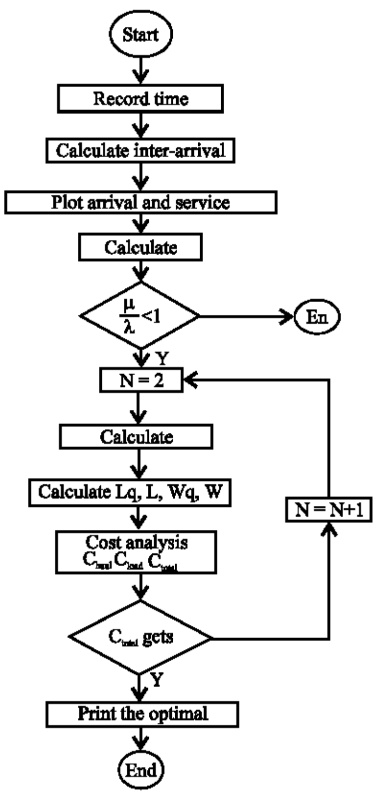

Fig. 3: Optimization flow chart

truck were saved with its loading time. The value of inter-arrival times are calculated by subtracting times between arrivals.

Step 2; Check arrival and service time distribution: The inter-arrival times were sorted out in order to create the graph of time between truck arrivals with frequency. The value of frequency here is set as a percentage of the total number of arrivals during the observed time. This relationship is displayed as in Fig. 4 and can notice that the exponential distribution is fit for the inter-arrival times of trucks. Similarly, the service time distribution is illustrated as in Fig. 5.

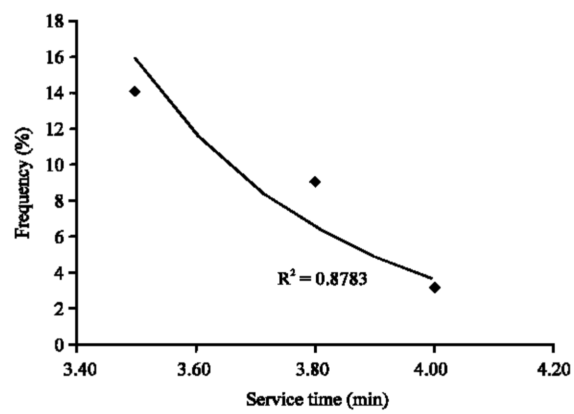

Fig. 4: Inter-arrival time distribution

Step 3; Calculate arrival rate and service rate of the system:

$$\text{Arrival rate } \lambda = \frac{1}{\text{Average interarrival rate}},\ \lambda = \frac{1}{\frac{6.5}{6.0}} = \frac{\text{trucks}}{\text{h}} \quad (5)$$

$$\text{Service rate } \mu = \frac{1}{\text{Average service rate}},\ \mu = \frac{1}{\frac{3.52}{60}} = 17\frac{\text{trucks}}{\text{h}} \quad (6)$$

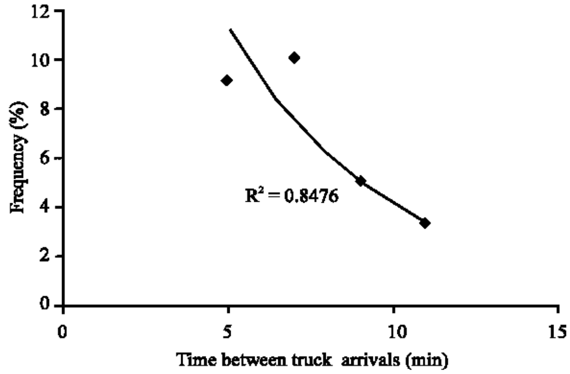

Fig. 5: Service time distribution

Here, we have $\Lambda/\mu = 9/17 = 0.54<1$ .This ratio satisfies the condition of the (M/M/1) queuing model. The optimization process starts with setting the number of truck in the fleet N = 2.

Step 4; Determine system performance with N = 2 Probability of zero units in the system:

$$P_0 = \frac{1}{\sum_{1=0}^{N}(\lambda/\mu)1\left[\frac{N}{(N-1)}\right]}$$
$$P_0 = \frac{1}{\sum_{1=0}^{2}(9/17)^1\left[\frac{2}{(2-1)}\right]} = 0.46 \tag{7}$$

Probability of 2 units in the system:

$$P_n = \frac{N}{(N-n)}(\frac{\lambda}{\mu})^n P_0$$
$$P_2 = P_{(1)}+P_{(2)} = \frac{1}{(1-1)}(\frac{9}{17})^1 0.46+\frac{2}{(2-1)}(\frac{9}{17})^2 \tag{8}$$
$$0.46 = 0.50+0.27 = 0.77$$

Average number waiting in line:

$$L_q = N-\frac{\lambda+\mu}{\lambda}(1-p_0)$$
$$L_q = 2-\frac{9+17}{9}(1-0.46) = 0.27 \tag{9}$$

Average number in the system:

$$L = L_q+(1-P_0)$$
$$L = 0.27+(1-0.46) = 0.81 \tag{10}$$

Average waiting time in line:

$$W_q = \frac{L_q}{\lambda(N-L)}$$
$$W_q = u.\frac{27}{6(2-0.81)} = 1.83 \tag{11}$$

Average time in the system:

$$W = W_q+\frac{1}{\mu}$$
$$W = 1.83+\frac{1}{17} = 1.89 \tag{12}$$

Shovel utilization:

$$\eta_s = 1-P_0$$
$$\eta_s = 1-u0.46 = 0.54 \tag{13}$$

Production:

$$Q_n = \eta_s \times \mu \times \text{truck capacity}$$
$$Q_2 = 0.54\times 17\times 55 = 460(\frac{\text{tons}}{\text{h}}) \tag{14}$$

Costs: The total cost of the operation C per ton of material moved (Panagiotou, 1993):

$$C = \frac{C_{shovel}+NC_{truck}}{Q_n} \tag{15}$$

Where:

C_{shovel} = Owning and operating cost of shovel per hour money units/ton

C_{truck} = Owning and operating cost of truck per hour, money units/ton

For this system, C_{shovel} = \$ 105 and C_{truck} = \$ 83, we can find.

Cost of loading:

$$C_{load} = \frac{C_{shovel}}{Q_n} = \frac{105}{460} = 0.23, \frac{\$}{ton}$$

Cost of hauling

$$C_{haul} = \frac{NC_{truck}}{Q_n} = \frac{2\times 83}{460} = 0.36, \frac{\$}{ton}$$

$$\Rightarrow C_{total} = C_{load}+C_{haul} = 0.23+0.36 = 0.59\frac{\$}{ton}$$

Step 5; Cost analysis: The purpose of this step is to find out at which value of N, the total cost gets minimum. With N = 2, the comparison can't be made, so, do the calculations again with increased N = 3, 4, 5 and so on. This process can be handled using excel, the result is summarized in Table 4.

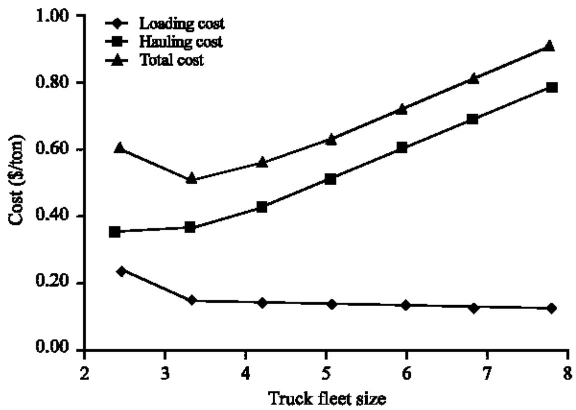

Fig. 6: Cost analysis curves

From Table 4, the comparison can be made easier by plotting all the cost values onto curves as in Fig. 6. The minimal value, here is determined at the N = 3 or the optimized number of trucks for this fleet are 3.

CONCLUSION

In this research, the queuing model (M/M/1) with finite customer resource was applied for a case in Cao Son Coal Mine in Vietnam with an aim of selecting a suitable fleet size. The time data of the shovel-truck system was recorded and put into the model. In order to find the optimized fleet size, the model compared the operating costs with the different number of trucks in the system; therefore, the value of N = 3 is determinedas the point that makes the operating costs minimal.

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