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Optimization of Shovel-Truck Productivity in Quarries

Matsimbe J

Abstract— In open pit operations, the loading equipment drives production but the haulage fleet drives costs. Most quarries in Malawi face challenges in shovel-truck productivity due to factors which require optimization of mine operations. The case of Njuli quarry is used to come up with a model that can be applied by quarries in Malawi. Loading and haulage costs account as much as 50 – 60 % of a company's total operation cost hence it is necessary to maintain an efficient shovel-truck system. This research optimized the shovel-truck productivity per day, applied the queuing theory to the haul cycle, and suggested ways to improve the efficiency of materials handling operations. Examining a match between truck body size and shovel bucket size yielded the size of the load, cycle time and number of trips in an hour. The cycle time depended on the weight of the equipment, the horsepower of the engine, haul distance, and condition of the road plus dump area. Quarry companies in Malawi will apply this new knowledge to improve equipment selection and maximize the tonnage of aggregates produced per day to meet production targets.

Index Terms— Equipment selection; linear programming; Malawi; queuing theory; surface mining.

I. INTRODUCTION

The mining sector in Malawi is dominated by artisanal and small-scale rock aggregate and limestone quarrying, coal mining and gemstone exploitation [5]. Figure 1 shows that rock aggregate is commonly exploited in many parts of the country for the construction industry from small to medium scale level [10]. Most of these quarries just operate from experience without reference to any research that might improve their loading-hauling operations. Loading and haulage costs account as much as 50 – 60 % of a company's total operation cost hence it is necessary to maintain an efficient shovel-truck system [2]. Present study seeks to fill that research gap by creating and applying a queuing model to represent truck and shovel behaviour in quarry operations. It is imperative to optimize the shovel-truck combination so as to eliminate idle time of equipment while in operation. Queuing theory was developed to model systems that provide service for randomly arising demands and predict the behavior of such systems. A queuing system is one in which customers arrive for service, wait for service if it is not immediately available, and move on to the next server once they have been serviced [3]. For modeling truck-shovel systems in a mine, haul trucks are the customers in the queuing system, and they might have to wait for service to be loaded and at the dumping locations.

Njuli quarry (Figure 2) located at Latitude -15.706495° and Longitude 35.118275° is among the pioneers in the rock aggregate business in Malawi hence it is used as a case study upon which other quarry mines can emulate. The rock type at Njuli quarry is Basalt which is a common extrusive igneous (volcanic) rock formed from the rapid cooling of basaltic lava exposed at or very near the surface of a planet or moon. Basalt has a mineral density of 3 t/m³. The Njuli quarry mine produces approximately 400,000 tonnes of aggregates per year which is mostly used in construction of roads, buildings and other infrastructures.

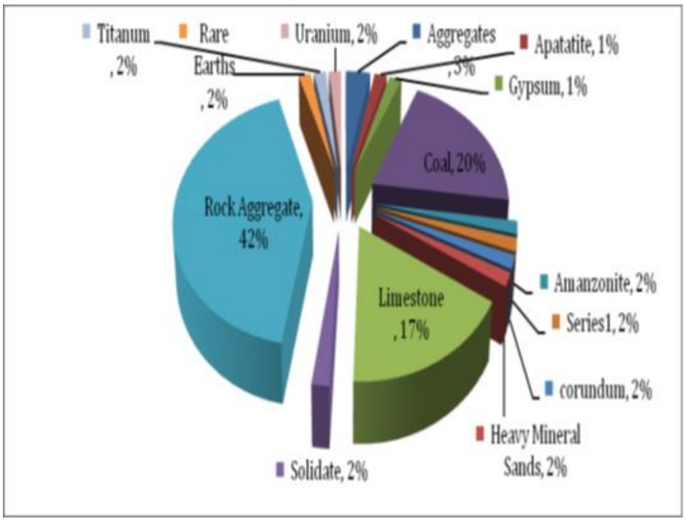

Fig. 1: Mining licenses issued per mineral [6]

It is hoped that the outcomes of this research will help maximize shovel-truck productivity and minimize operational costs by matching shovels to trucks based on their characteristics. The loader selected should also be able to fully load a haul truck in three to six passes without using any partially filled buckets [1], [8]. Present study applies the capacity-constrained queuing theory to a scenario that requires relatively few trucks in order to meet production targets.

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***Jabulani Matsimbe**, Department of Mining Engineering, University of Malawi-The Polytechnic, Blantyre, Malawi.*

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Fig. 2: Map of Njuli quarry (Google Earth, 2020)

II. METHODOLOGY

Cycle time and productivity data was collected on site to provide input to the queuing model thereby providing outputs useful for analyzing efficiency and production rates. Cycle time (Figure 3) was recorded in-situ using a stopwatch. The arrival rate, service rate, utilization, production, duration, and cost per unit time were calculated for each fleet. The operation started from the loading point by an excavator to dumping point (jaw crusher) by articulated dump truck (ADT). The idea was to determine productivity of the shovel-truck matching based on the cycle time. The loading time and number of passes made by a shovel to fill truck were recorded on site in a period of one hour. Also, the hauling time of the ADT was recorded in a period of one hour.

Fig. 3: Illustration of shovel-truck cycle time at Njuli quarry

Figure 4 shows the simulation of the queueing concept to the shovel-truck combination, where a number of trucks (customers) are serviced by a single shovel (server). The fleet of trucks (customers) arrive at the shovel (server) and form a queue waiting for service if the shovel is not immediately available. The trucks then proceed through the system once service has been completed.

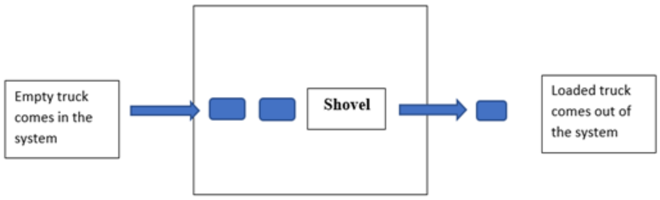

Fig. 4: Proposed queueing system of shovel truck combination

According to [7], if a truck arrival event occurs, then two states are made for the haulage system. In the first case, the shovel is idle and ready for servicing the truck. In the second case, the shovel is busy and the truck goes to queue line (Figure 5).

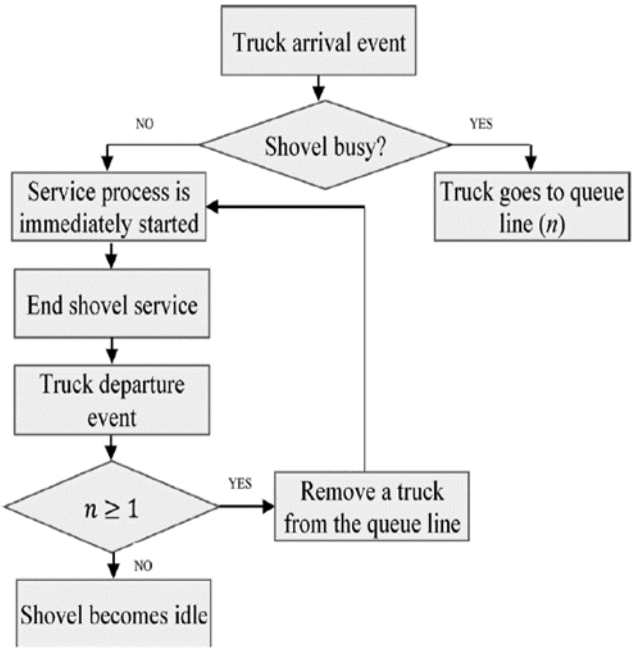

Fig. 5: Occurrence of arrival and departure events flowchart [7]

A. Queueing Model Formulation for Shovel-Truck Combination

The formulation of a queueing model requires stochastic assumptions and variables comprising truck arrival pattern, service pattern, size of truck fleet, service discipline, ultimate queue size and cost of idling to arrival and service units [9]:

i. The arrival of trucks, as it is a random function, is best explained by Poisson's distribution as shown by the probability mass function in Eq. (1) to Eq. (4):

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$$P(x) = [(\lambda t)^{x} e^{-\lambda t}]/X! \quad (1)$$

where X = 1, 2, 3, 4…n
λ = truck arrival rate

The following stochastic assumptions provide a basis to the queuing model:

a) An arrival may occur at random at any time.
b) The occurrence of an arrival in a given time interval is independent of arrivals in other non-overlapping intervals.
c) The probability of an arrival in a small interval (t0, t0+h) is proportional to interval length h and equal to λh.
d) The probability of more than one arrival in this small interval is negligible.

For similar assumptions on the arrivals, the exponential distribution gives information on the time till the first arrivals [9]. Hence

$$P\text{ (arrivals occur at time t)} = P\ [x = 0, \text{time period } t] = e^{-\lambda t} \quad (2)$$

where t is inter arrival time since arrivals are independent of each other

ii. Shovel service time is explained similar to interarrival times. For a service rate μ, the density function for the time t required to serve a unit is often exponentially distributed as:

$$P(t) = \mu e^{-\mu t} \quad (3)$$

iii. The service discipline is first in first out (FIFO).
iv. The availability of all trucks and shovels is assumed to be homogeneous.
v. Similar truck type and capacity is used.
vi. The service mechanism is assumed to be single channel plus single phase, and the queueing time at the dumping station is ignored.
vii. The number of trucks being serviced by one shovel is finite and the size of this fleet of trucks equals k. In addition, the queueing capacity is equal to or greater than k. Therefore, this parameter does not affect the calculation unless it is less than k. Hence, the whole system is illustrated by the following queueing model:

$$(M/M/C) :(FIFO/K/K) \quad (4)$$

where M/M represents the Poisson arrivals and Exponential service distributions respectively. C represents the number of server. FIFO (First in First out) is the service discipline. K/K represents the size of population of trucks and ultimate queueing capacity respectively.

For this finite source queueing model, performance parameters were evaluated as shown in Eq. (5) to Eq. (15):

- Traffic Intensity (e)

$e = \lambda/\mu$ where $e < 1$ otherwise the queue will continue increasing *(5)*

- Probability of 'zero' trucks in the system (P0)

$$P0=1-e/ (1-e^{\wedge 5+1}) \quad (6)$$

- Probability of 'n' trucks in the system (Pn)

$$Pn=e^{5}P0 \quad (7)$$

- Expected number of trucks in the queue/ Length of queue (Lq)

$$Lq=\lambda Wq \quad (8)$$

- Expected number of trucks in the system (Ls)

$$Ls=e[1+ne^{\wedge\eta+1}-(n+1)e^{\wedge\eta}]/(1-e)(1-e^{\wedge\eta+1}) \quad (9)$$

- Expected time that a truck spends in the queue (Wq)

$$Wq=Ws-(1/\mu) \quad (10)$$

- Expected time that a truck spends in the system (Ws)

$$Ws=Ls/\lambda e \quad (11)$$

- Shovel utilization (ƞs)

$$\eta s=1-P0 \quad (12)$$

- Truck utilization (ƞt)

$$\eta t=1-(Wq/(Wq+t1+tt+td) \quad (13)$$

where t1 = loading time, tt is the total travelling time (loaded truck travel time + empty truck travel time), td is the dumping time

- Hourly production of the shovel (Qn)

$$Qn=\eta s*\mu*qn \quad (14)$$

where qn represents the capacity of the truck in tonnes

- Total cost of the operation per ton of material moved CT, (*$/ton*)

$$CT=[(Cops+KCopt)/Qn] \quad (15)$$

where Cops is the owning and operating cost of the shovel per hour, *$/hr* and Copt is the owning and operating cost of each truck per hour, *$/hr*

III. RESULTS AND DISCUSSION

An excavator/shovel, CAT 320D, with 0.6 m^3 bucket capacity is used to load a 730B (30 ton) ADT. The following observations were made in January 2020 for CAT 320D shovel – CAT 730B truck matching in an hour period:

A. Actual In-situ Cycle Time

A stopwatch was used to record the timeline of unit operations in an hour (Table 1). In addition, the number of passes made by a shovel to fully load a truck was recorded. Loading time is the time taken by a shovel to fully load a truck. This is affected by the matching of a shovel to truck. Besides queuing, the loading time as shown in Table 1 varies because the shovel in some cases did a longer reach and swing angle to pull the blasted material towards itself (crowd force) before loading into its bucket. In hydraulic backhoes, the bucket faces the unit rather than the muck pile (Figure 3). Loading is therefore by a pulling towards rather than push

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away action. The variation in the number of passes was affected by the size of fragmentation from the previous blast. Bigger boulders took less time to fill the truck as compared to smaller ones. This shows the need for a well-planned blast to create better fragmentation. Hauling time varies due to queuing at the crusher.

Table 1. Actual cycle time for CAT 320D and CAT 730B ADT

	One hour timeline as observed on site				
Variable	**10:55am to 11:08am**	**11:08am to 11:21am**	**11:21am to 11:35am**	**11:35am to 11:47am**	**11:47am to 12:00**
Loading time	6 min	5 min	5 min	5 min	5 min
Number of passes	15 (more boulders)	16	17 (less boulders)	14	14
Hauling + Return time (Included is 10 seconds Turning and 20 seconds Dumping)	7 min	8 min	9 min	7 min	6 min
One cycle time	6+7 = 13 min	5+8 = 13 min	5+9 = 14 min	5+7 = 12 min	5+6 = 11 min
Mean Loading time	**(6+5+5+5+5)/5 = 5.2 *minutes***				
Mean Hauling time [return trip]	**(7+8+9+7+6)/5 = 7.4 *minutes***				
Mean number of passes	**(15+16+17+14+14)/5 = 15**				
Number of trips per hour	**5**				
Total Cycle time	**13+13+14+12+11= 60 *minutes***				

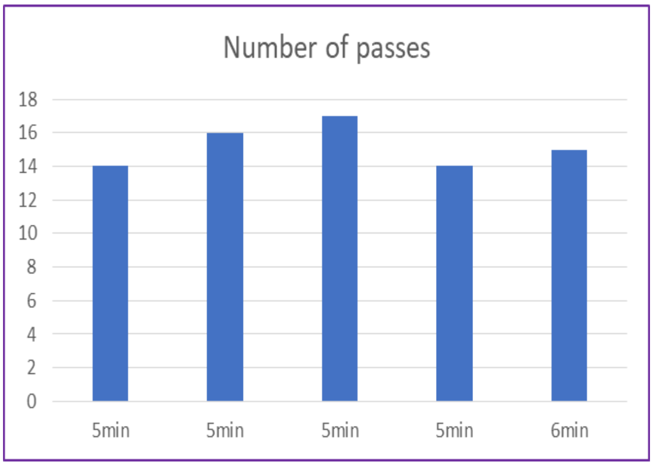

Fig. 6: Graph showing loading time vs number of passes

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B. Actual In-situ Productivity

Bucket load = capacity * density * fill factor (16)
= 0.6 * 3 * 0.9
= 1.62 *tonnes*

NB: Basalt bank density is 3 t/m^3

ADT capacity is 30 *tonnes*; travels a constant speed of 13.6 *km/hour* (3.7 *m/s*) and 7.4 *minute* hauling time (return trip).

Return trip distance (3.7*m/s**7.4*minute* *60) =1642.8 *m* (17)

One way distance = 1642.8 /2 = 821.4 *m*
30 *t*/trip * 5 trips/hour= 150 *t/hour* (18)

Including fill factor: 150*0.9= 135 *t/hour* (19)

135*8= 1, 080 *t/day* (20)

1080*30= 32, 400 *t/month* (21)

32, 400*12=388,800 *t/year* (22)

Hence, the determination of productivity of a 730B ADT loading from an open pit quarry and operating on a 20% grade under average haul conditions makes 5 *trips/hour* or 40 *trips/day* hauling 150 *t/hour* or 1080 *t/day*. These findings are less than the quarry manager's projection of 8 trips per hour (240 *t/hour*) and 64 trips per day (1920 *t/hour*) in 8 working *hours* hence the need for optimization of shovel – truck combination at the quarry.

C. Optimized Productivity Data

According to [1], the loader selected should also be able to fully load a haul truck in 3 to 6 passes without using any partially filled buckets. The loader in this study makes 14 to 17 passes hence being inefficient thereby affecting the cost/hour. Loading in more passes causes the truck to wait excessively in the loading area which reduces efficiency and can lead to truck queuing. The calculations below aim at deriving the right loader match for the ADT and thus in return reduce the loading time:
Number of passes = Haulage unit rated payload/Actual load per bucket (23)

Haulage unit rated payload/Number of passes = Actual load per bucket

- For 3 passes to load 30 *tonnes* ADT:

30 tonnes / 3 passes = 10 *tonnes* (24)

Therefore, a 10 tonnes shovel (equivalent to 10 *t* / (3 t/m^3) = 3.3 m^3 bucket size) makes 3 passes to load a 30 *tonnes* ADT.

Thus, the loading time becomes:

15 passes = 5.2 *minutes*
3 passes = X *minutes*
X = (3 * 5.2) / 15 = 1 *minute*

- For 4 passes to load 30 *tonnes* ADT:

30 tonnes / 4 passes = 7.5 *tonnes* (25)

Therefore, a 10 tonnes shovel (equivalent to 7.5 *t* / (3 t/m^3) = 2.5 m^3 bucket size) makes 4 passes to load a 30 *tonnes* ADT.

Thus, the loading time becomes:

15 passes = 5.2 *minutes*
4 passes = X *minutes*
X = (4 * 5.2) / 15 = 1 *minute* 20 *seconds*

- For 5 passes to load 30 *tonnes* ADT:

30 tonnes / 5 passes = 6 *tonnes* (26)

Therefore, a 10 tonnes shovel (equivalent to 6 *t* / (3 t/m^3) = 2 m^3 bucket size) makes 5 passes to load a 30 *tonnes* ADT.

Thus, the loading time becomes:
15 passes = 5.2 *minutes*
5 passes = X *minutes*
X = (5 * 5.2) / 15 = 1 *minute* 40 *seconds*

- For 6 passes to load 30 *tonnes* ADT:

30 tonnes / 6 passes = 5 *tonnes* (27)

Therefore, a 10 *tonnes* shovel (equivalent to 5 *t* / (3 t/m^3) = 1.7 m^3 bucket size) makes 6 passes to load a 30 *tonnes* ADT.
Thus, the loading time becomes:
15 passes = 5.2 *minutes*
6 passes = X *minutes*
X = (6 * 5.2) / 15 = 2 *minutes*

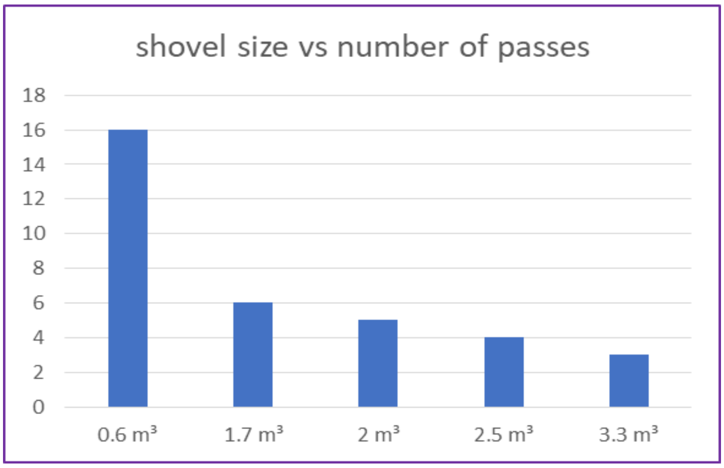

Fig. 7: Graph showing shovel size versus number of passes

As shown in Figure 7, the existing shovel size of 0.6 m^3 is inefficient as it exceeds the optimal number of 3 to 6 passes to fully load a truck. Therefore, a shovel size of 1.7 m^3, 2 m^3, 2.5 m^3, and 3.3 m^3 would be an ideal match as it makes a few number of passes to load the 30 *tonnes* ADT. Figure 7 shows that an increase in shovel size leads to a decrease in the number of passes which in turn will lead to a decrease in the loading time and an increase in the number of trips per hour thereby increasing productivity per day using the same 30 *tonnes* ADT.
The optimized number of passes has a mean ± standard deviation of 4.5 ± 1.2 as compared to the actual number of

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passes with 15.2 ± 1.3. The actual number of passes has a higher mean as compared to the optimized number of passes hence the need to change the shovel size to improve productivity. The lower values in standard deviation in both scenarios implies that the data does not vary a lot hence minimal distortions.

D. Application of Queueing Model to Njuli Quarry

The formulated model (M/M/C:FIFO/K/K) was applied at Njuli quarry mine utilizing 0.6 *m³* shovel size and 30 *tonnes* articulated dump trucks. The queueing theory aims at minimizing idle and wait time of each equipment. The field observations and probability calculations of shovel-truck operation are summarized in Table 2 and illustrated in Figure 8.

Table 2. Inputs and outputs of queueing model

Variables and notations	Values
Arrival rate (λ)	3 trucks/hr
Service rate (μ)	4 trucks/hr
Finite number of trucks n	5
Traffic Intensity (e=λ/μ)	0.75
Probability of zero trucks in system [P0=1-e/(1- e^5+1)]	0.3041
Probability of one truck in system (P1=eP0)	0.2281
Probability of no queue in system (Pno queue= P0+P1)	0.5322
Probability of 5 trucks in the system ($P5=e^5$ P0)	0.0722
Probability that a truck coming in joins the system =(1- P5)	0.9278
Effective arrival rate λe = λ*(1- P5)	2.7834
Probability of 2 or more trucks in system (P[n≥2])=1-P0-P1=1- Pno queue	0.4678
Number of shovels (c)	1
Owning and operating cost of shovel, Cops	120 *$/h*
Owning and operating cost of truck, Copt	80 *$/h*

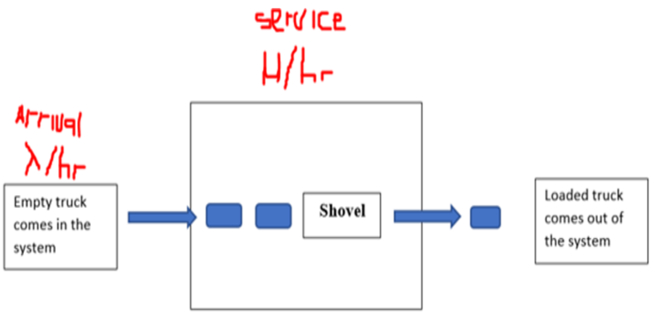

Fig. 8: Queueing model illustration of arrival rate and service rate

The impact of truck fleet size variation on the queue length, waiting time, shovel utilization, approximate production, and total operating cost are calculated in Table 3.

i. Lq vs K and Wq vs K relationship

Figure 9 and 10 shows that an increase in the population of trucks leads to an increase in the length of queue and the waiting time in queue.

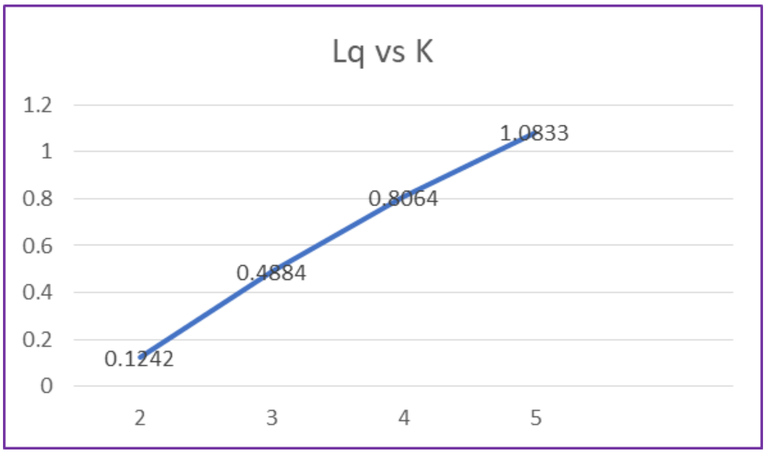

Fig. 9: Relationship between length of queue and number of trucks

Fig. 10: Relationship between waiting time in queue and number of trucks

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Table 3. Queueing model results

Truck fleet size K	Queue Length (trucks)		Waiting Time (*hr*)		Shovel Utilization (%)	Truck Utilization (%)	Approx. Production (*ton/hr*)	Cost of Loading	Cost of Hauling	Total Cost (*$/ton*)
	Lq	Ls	Wq	Ws	η_s	η_t	Qn	Cops/ Qn	KCopt/ Qn	C=(Cops+ KCopt)/Qn
2	0.1242	0.811	0.0414 (2.5*min*)	0.2914 (17.5*min*)	63.46	83.80	57.114	2.10	2.80	4.90
3	0.4884	1.149	0.1628 (9.8*min*)	0.4128 (24.8*min*)	69.59	56.89	83.508	1.44	2.87	4.31
4	0.8064	1.444	0.2688 (16.1*min*)	0.5188 (31.1*min*)	72.89	44.55	109.335	1.10	2.93	4.03
5	1.0833	1.701	0.3611 (21.7*min*)	0.6111 (36.7*min*)	74.94	37.34	134.892	0.89	2.97	3.86

ii. η_s vs K relationship

Figure 11 shows that an increase in the population of trucks leads to an increase in shovel utilization. In addition, Table 2 shows that there is 30.4% probability of zero trucks in the system leading to shovel idle time. This can be solved by increasing the population of trucks thereby increasing the shovel utilization as seen in Figure 11.

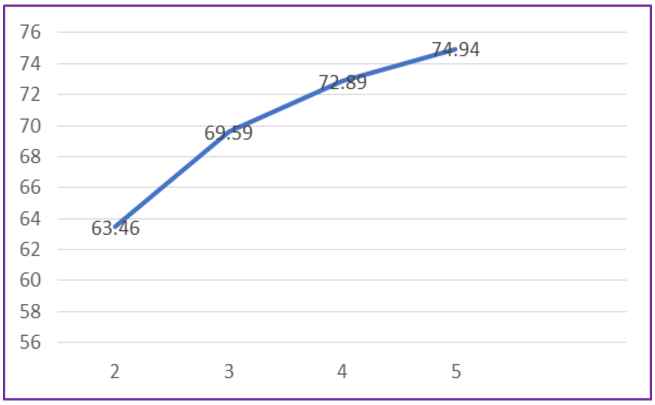

Fig. 11: Relationship between shovel utilization and number of trucks

iii. η_t vs K relationship

Figure 12 shows that an increase in the population of trucks leads to a decrease in truck utilization mostly due to an increase in queue length leading to an increase in waiting time in queue.

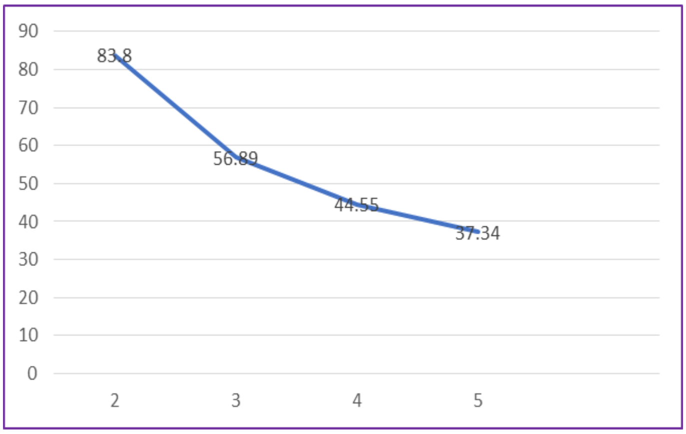

Fig. 12: Relationship between truck utilization and number of trucks

iv. Qn vs K relationship

Figure 13 shows that an increase in the population of trucks leads to an increase in the shovel productivity mostly due to an increase in shovel utilization. But an excess number of trucks with the shovel will lead to formation of long queue and excessive idling of trucks.

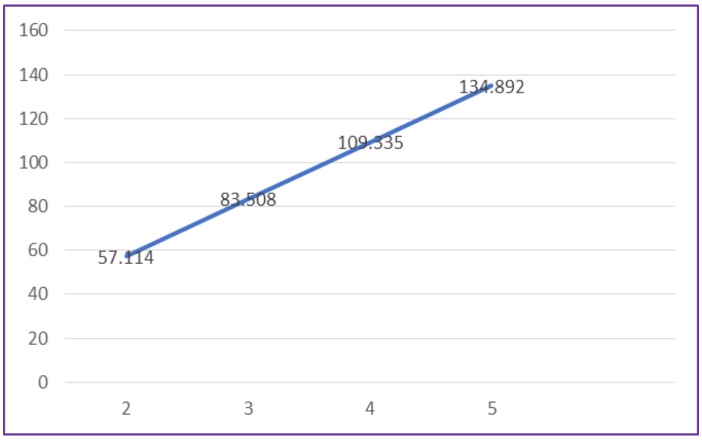

Fig. 13: Relationship between shovel output and number of trucks

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v. Cost vs K relationship

Figure 14 shows that an increase in the population of trucks leads to a decrease in the cost of loading but an increase in the cost of hauling. In open pit operations, the loading equipment drives production but the haulage fleet drives costs. The increase in hauling cost is mostly due to fuel consumption, tyre replacement/maintenance and operator allowance.

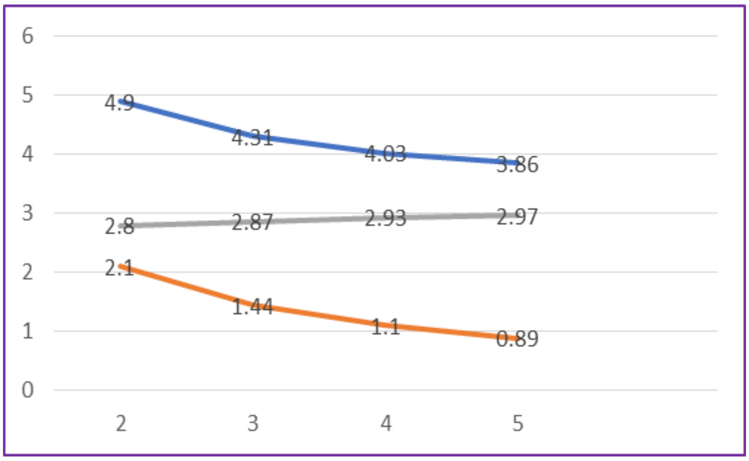

Fig. 14: Relationship between cost element and number of trucks

IV. Conclusion

Truck and shovel system is commonly used in quarries to transport aggregates. It can be challenging to predict equipment performance and determine the appropriate number of trucks to be used in these systems because of the dynamic nature of fleets of equipment and haul road. Different methods of modeling and simulating truck and shovel behaviour are available [4] but the queuing theory is a viable promising option for fleet selection and modeling quarry mine behavior for truck-shovel systems because it accounts for the idle time caused by trucks waiting to be serviced at the loading and dumping section. This study has shown that the queueing model (M/M/1:FIFO/K/K) is an important tool to use when solving optimization problems involving one shovel to varying number of trucks in open pit quarries. The stochastic assumptions when formulating the queueing model must be distinct and logical so as to create a better shovel – truck match. Quarry companies in Malawi will apply this new knowledge to improve equipment selection and maximize the tonnage of aggregates produced per day to meet production targets.

It is recommended that future research work should consider the heterogeneity of trucks and shovels found in quarries so as to create a queuing model that suits both homogeneous and heterogeneous environments.

Conflict of Interest

The author declares no conflict of interest.

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References

[1] Alkass S, Elmoslmani K, Alhussein M. A Computer Model for Selecting Equipment for Earthmoving Operations Using Queuing Theory. Montreal, Canada: Concordia University. 2003.J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," *IEEE Trans. Electron Devices*, vol. ED-11, pp. 34-39, Jan. 1959.

[2] Ercelebi SG, Bascetin A. Optimization of Shovel-Truck System for Surface Mining. The Journal of Southern African Institute of Mining and Metallurgy. 2009. 433-439.

[3] Gross D., & Harris CM. 1998. Fundamentals of Queueing Theory. New York: John Wiley & Sons, Inc.

[4] Krause A, Musingwini C. Modelling Open Pit Shovel-Truck Systems Using the Machine Repair Model. The Journal of Southern African Institute of Mining and Metallurgy. 2007. pp. 469-476.

[5] Catholic Commission for Justice and Peace. Mapping of extractive companies in Malawi. Mining in Malawi publisher. 2012.R. A. Scholtz, "The Spread Spectrum Concept," in *Multiple Access*, N. Abramson, Ed. Piscataway, NJ: IEEE Press, 1993, ch. 3, pp. 121-123.

[6] Mines and Minerals Department. Mining Licences Issued. Lilongwe. 2012.

[7] Moniri AM, Pourgol MM, Aghababaei H, Sattarvand J. A methodology for truck allocation problems considering dynamic circumstances in open pit mines, case study of the Sungun copper mine. The Mining-Geology-Petroleum Engineering Bulletin, UDC: 622.6; 519.85, DOI: 10.17794/rgn.2019.4.6

[8] Najor J, Hagan P. Mine Production Scheduling within Capacity Constraints. Sydney, Australia: The University of New South Wales. 2004.

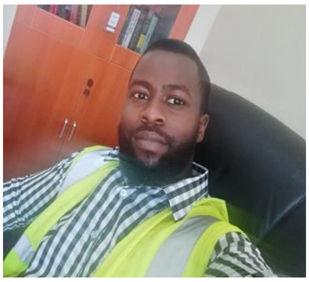
[9] Trivedi R, Rai P, Nath R. Shovel-truck optimization study in an opencast mine - A queueing approach. Indian

doi: 10.32622/ijrat.810202008

Journal of Engineering & Materials Sciences. 1999. Volume 6, pp. 153-157.

[10] World Bank. Mineral Sector Review: Source of Economic Growth and Development, Report No. 50160-MW. 2009. The World Bank: Washington D.C.

AUTHORS PROFILE



Mr. Jabulani Matsimbe (Bsc Civil Eng; Msc Mining Eng) is a Lecturer in Mining & Geotechnical Engineering at University of Malawi-The Polytechnic. In this role, he is involved in the development of teaching materials and teaching of a variety of modules applied to Mining/Geotechnics to undergraduate students. He is a Registered Graduate Engineer with the Malawi Board of Engineers.

Prior to joining The Polytechnic, Jabulani obtained Quarrying, Mining, Industrial Rock Mechanics, Earthworks, Safety and Construction experience at the Nacala Corridor Project in Malawi; and Holman's Test Mine Facility at University of Exeter in UK.

His research interests include mainly, but not limited to; geomechanics and excavation design; photogrammetry and smartphone technologies in geotechnics; mine planning & design; novel mining technologies; blast vibration analysis; safety in the extractive industry; constitutive modelling for geomaterials; soil and rock slope stability; beneficial reuse/recycling of waste materials for sustainable geo-constructions; ground improvement techniques for granular soils.

His recent publications include:

[1] Matsimbe J. (2020), Assessment of Mining Students' Perception of Industrial Attachment Programme at Malawi Polytechnic. In: Education Quarterly Reviews, Vol.3, No.3, 351-374. DOI: 10.31014/aior.1993.03.03.145

[2] Matsimbe J. (2020), Comparative Study of Water Quality from Boreholes and Hand-Dug Wells: Case of Namatapa in Bangwe Township. In: Engineering and Technology Quarterly Reviews, Vol.3, No.2, 67-73.

doi: 10.32622/ijrat.810202008