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To Minimize the Waiting Time and Waiting Time Cost of Dumpers, Waiting in a Queue for Loader at Stone Crusher Plant Mine by Using the Single and Multi-Channel Queuing Theory.

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Abstract
Waiting line problems arise because there is too much demand on the facilities so that we can say that there is an excess of waiting time or inadequate number of service facilities. At the stone crusher plant mine the dumpers come to load from the loader. The crusher plant has 11 dumpers and these 11 dumpers make 88 trips during 8-hour day. The company has one loader to load all the dumpers, which results in a formation of long waiting line or queue. Due to this queue there is a long waiting time in queue of dumpers and cost associated with waiting time of dumpers. Queuing theory can quite effectively analyze such queuing phenomenon. In this research paper I have applied the queuing theory to the stone crusher plant mine, where the queue of dumpers formed at the loading station. By applying the single channel queuing theory I analyzed the current situation of the stone crusher plant mine and find the problems of the current system. To overcome the above problems I have applied the multi-channel queuing theory to minimize the waiting time in queue of dumpers and very high cost associated with waiting time of dumpers. In the new system not only waiting time in queue of dumpers and very high cost associated with waiting time of dumpers is reduced but also there is an efficient utilization of dumpers and loaders along with provide the profitable situation to the crusher plant.
Keywords: Waiting lines, stone crusher plant mines, single& multi-channel queuing theory, waiting time and waiting time cost.

I. Introduction of Stone Crusher Plant

The stone crusher plant is used to cut the bigger stone pieces obtained after the blasting to the required sizes for construction purpose. Generally we get the stone pieces after blasting through the explosives and then these broken stone pieces are collected and loaded by the loader to the dumpers.

I have focused my research on the loader-dumper combination working, where the loader loads the dumpers. I observed that there is a long waiting time in queue of dumpers and high cost associated with waiting time. So my objective is to identify the problems of loader-dumper combination working and provide the appropriate solution in favour of the company.

Specifications and Details of loader, dumper and their working conditions

- Loader cycle time : 4.8minutes
- Dumper cycle time : 47.8minutes
- Loader Production(m^3/hr) : 150m^3/hr
- Dumper Production(m^3/hr) : 15.6m^3/hr
- Number of loaders : 01
- Number of dumpers : 11
- Number of trips by 11 dumpers during 8-hour day : 88
- Loader bucket capacity : 1.5m^3
- Dumper capacity : 12m^3
- Number of buckets used to fill one dumper : 08 buckets
- Loader Price : Rs.64,000,00/-
- Dumper Price : Rs.28,000,00/-
- Distance from mines to crusher plant : 08km
- Working days in a year : 300 days
- Effective working hours per day : 08 hours
- Arrival rate of dumpers (λ) : 11 dumpers/hour
- Service rate of loader (μ) : 12.5 dumpers/hour

- Loader Operating Cost : Rs.2130/- per hour
- Dumper Operating Cost : Rs.1160/- per hour

II. Introduction of Queuing Theory

A. Single-channel Queuing Theory

A single –channel queuing problem results from random interarrival time and random service time at a single service station. The random arrival time can be described mathematically by a probability distribution. The most common distribution found in queuing problem is Poisson distribution. This is used in single-channel queuing problems for random arrivals where the service time is exponentially distributed. Both the arrivals and service rates are independent of the number of customers in the waiting line. Arrivals are handled on first come first serve basis. Also the arrival rate λ is less than the service rate μ.

Let,

λ = mean arrival rate of arrivals,
μ = mean service rate,
n= number of customers in the system.

- **Properties of Single-channel queuing system**
- Expected (Average) number of customers in the system

$$Ls = \frac{\lambda}{(\mu - \lambda)}$$

- Expected (Average) number of customers waiting in the queue

$$Lq = \frac{\lambda^2}{\mu (\mu - \lambda)}$$

- Average time a customer spends in the system

$$Ws = \frac{1}{(\mu - \lambda)}$$

- Average waiting time of a customer in the queue

$$Wq = \frac{\lambda}{\mu (\mu - \lambda)}$$

- Probability of having no customer in the system

$$Po = 1 - (\lambda / \mu)$$

B. Multi-channel Queuing Theory

Multi-channel queuing theory treats the condition in which there are several service stations in parallel and each customer in the waiting line can be served by more than one station. Each service facility is prepared to deliver the same type of service. The new arrival selects one station without any external pressure. When a waiting line is formed, a single line usually breaks down into shorter lines in front of the each service station. The arrival rate λ and service rate μ are mean values from Poisson distribution and exponential distribution respectively. Service discipline is first come, first served and customers are taken from a single queue i.e., any empty channel is filled by the next customer in line.

Let,

c = number of parallel service channels (c>1),
λ = arrival rate of arrivals,
μ = service rate of individual channel,
n= number of customers in the system.

- **Properties of Multi-channel queuing system**
- Expected (Average) number of customers in the system

$$Ls = \frac{\lambda . \mu \quad (\lambda / \mu)^c \; Po}{(c-1)! \, (c\mu - \lambda)^2} + (\lambda / \mu)$$

- Expected (Average) number of customers waiting in the queue

$$Lq = \frac{\lambda . \mu \quad (\lambda / \mu)^c \; Po}{(c-1)! \, (c\mu - \lambda)^2}$$

- Average time a customer spends in the system

$$Ws = \frac{\mu \quad (\lambda/\mu)^c \; Po}{(c-1)!\,(c\mu-\lambda)^2} + (1/\mu)$$

- Average waiting time of a customer in the queue

$$Wq = \frac{\mu \quad (\lambda/\mu)^c \; Po}{(c-1)!\,(c\mu-\lambda)^2}$$

- Probability of having no customer in the system

$$Po = \frac{1}{\sum_{n=0}^{c-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^c}{c!} \cdot \frac{c\mu}{c\mu-\lambda}}$$

III. Applying Single-channel Queuing Theory to analyze the Current Situation (Number of loaders=01 or c=01)

- Expected (Average) number of customers in the system

$$Ls = \frac{\lambda}{(\mu-\lambda)}$$

$$Ls = \frac{11}{(12.5-11)}$$

$$Ls = 7.34 \text{ dumpers}$$

- Expected (Average) number of customers waiting in the queue

$$Lq = \frac{\lambda^2}{\mu(\mu-\lambda)}$$

$$Lq = \frac{11^2}{12.5(12.5-11)}$$

$$Lq = 6.45 \text{ dumpers}$$

- Average time a customer spends in the system

$$Ws = \frac{1}{(\mu-\lambda)}$$

$$Ws = \frac{1}{(12.5-11)}$$

$$Ws = 0.67 \text{ hours}$$

$$Ws = 40 \text{ minutes}$$

- Average waiting time of a customer in the queue

$$Wq = \frac{\lambda}{\mu(\mu-\lambda)}$$

$$Wq = \frac{11}{12.5(12.5-11)}$$

$$Wq = 0.587 \text{ hours}$$

$$Wq = 35.2 \text{ minutes}$$

- Probability of having no dumper in the system

$$Po = 1-(\lambda/\mu)$$
$$Po = 1-(11/12.5)$$
$$Po = 0.12$$

IV. Applying the Multi-channel Queuing Theory to analyze the New Suggested System

(In the new system, i have taken the number of loaders=02 or c=02)

- Expected (Average) number of customers in the system

$$Ls = \frac{\lambda.\mu \quad (\lambda/\mu)^c \; Po}{(c-1)!\,(c\mu-\lambda)^2} + (\lambda/\mu)$$

$$Ls = \frac{11*12.5\,(11/12.5)^2*0.39}{(2-1)!\,(2*12.5-11)^2} + (11/12.5)$$

Ls= 1.09 dumpers

- Expected (Average) number of customers waiting in the queue

$$Lq = \frac{\lambda.\mu \quad (\lambda/\mu)^c \; Po}{(c-1)!\,(c\mu-\lambda)^2}$$

$$Lq = \frac{11*12.5\,(11/12.5)^2*0.39}{(2-1)!\,(2*12.5-11)^2}$$

Lq= 0.212 dumpers

- Average time a customer spends in the system

$$Ws = \frac{\mu \quad (\lambda/\mu)^c \; Po}{(c-1)!\,(c\mu-\lambda)^2} + (1/\mu)$$

$$Ws = \frac{12.5\,(11/12.5)^2*0.39}{(2-1)!\,(2*12.5-11)^2} + (1/12.5)$$

Ws= 0.09926 hours

Ws= 5.96 minutes

- Average waiting time of a customer in the queue

$$Wq = \frac{\mu \quad (\lambda/\mu)^c \; Po}{(c-1)!\,(c\mu-\lambda)^2}$$

$$Wq = \frac{12.5 \quad (11/12.5)^2 * 0.39}{(2-1)!\,(2*12.5-11)^2}$$

Wq= 0.019261224 hours

Wq= 1.1557 minutes

- Probability of having no customer in the system

$$Po = \frac{1}{\sum_{n=0}^{c-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^c}{c!} \cdot \frac{c\mu}{c\mu-\lambda}}$$

$$Po = \frac{1}{\sum_{n=0}^{2-1} \frac{(11/12.5)^n}{n!} + \frac{(11/12.5)^2}{2!} \cdot \frac{2*(12.5)}{2\,(12.5-11)}}$$

Po= 0.39

V. Comparison between Current system & New suggested system

S.No.	Parameters	Current System	New System	Remarks
1.	Average waiting time of a customer in the queue (Wq)	35.2 minutes	1.1557 minutes	Minimized
2.	Average time a customer spends in the system (Ws)	40 minutes	5.96 minutes	Minimized
3.	Expected (Average) number of customers waiting in the queue(Lq)	6.45 dumpers	0.212 dumpers	Minimized
4.	Expected (Average) number of customers in the system(Ls)	7.34 dumpers	1.09 dumpers	Minimized

VI. Cost Analysis

- **Waiting time cost analysis when number of loaders is one (c=1)(Current System)**

Since one dumper waiting time in queue = 35.2 minutes
Then, waiting time in queue by 11dumpers of 88 trips during 8-hour day = 3097.6 minutes = 51.62 hours
Then, waiting time in queue by 11dumpers of 88 trips during 300 days = 15488 hours
Since the dumper operating cost = Rs.1160/- per hour
The dumper operating cost = dumper operating cost during the waiting time in queue = Rs.1160/- per hour*(the explanation is given below)
Then, the dumper operating cost of 15488 hours waiting time = Rs.1,79,66,080/-
The loss to the crusher plant with respect to waiting time in queue of dumpers in the current system = Rs.1,79,66,080/-
(which is the hidden loss to the company)

- **Waiting time cost analysis when number of loaders is two (c=2)(New System)**

Since one dumper waiting time in queue = 1.557 minutes
Then, waiting time in queue by 11dumpers of 88 trips during 8-hour day = 101.7 minutes = 1.695 hours
Then, waiting time in queue by 11dumpers of 88 trips during 300 days = 508.5 hours
Since the dumper operating cost = Rs.1160/- per hour
Then, the dumper operating cost of 508.5 hours waiting time = Rs.5,89,860/-
The loss to the crusher plant with respect to waiting time in queue of dumpers in the new system = Rs.5,89,860/-

Cost Comparison between Current system & New suggested system

S.No.	Parameter	Current System (c=1)	(New System) (c=2)	Remarks
1.	Waiting time cost	Rs.1,79,66,080/-	Rs.5,89,860/-	Minimized
2.	Extra loader Price	Nil	Rs.64,000,00/-	
3.	Extra Loader Operating Cost	Nil	Rs.51,12,000/-	
4.	Total Cost	Rs.1,79,66,080/-	Rs.1,21,01,860/-	Rs.58,64,220/- Profit in New System

(It means if we continue the current system the loss with respect to waiting time cost is Rs.1,79,66,080/- and if we adopt the new system profit to the company will be Rs.58,64,220/-. So the company should adopt the new system or increase the one extra loader to maintain the profitable condition.)

***[Reason of dumper operating cost is equal in load carrying condition and idling (no load, waiting in a queue for loading) condition.]**

We know that when the dumper runs in a loading condition rich fuel have to supply. And when the dumper runs at an idling (the no load running mode of engine is known as idling) and empty condition lean fuel have to supply.

But in the idling condition, the air supply is restricted by the nearly closed throttle and the suction pressure is very low. This condition of low pressure gives rise to back flow of exhaust gases and air leakage from the various parts of the engine intake system. At idling back flow during the valve overlap period occurs since the exhaust pressure is higher than the intake pressure. This increases the amount of residual gases. During the suction process the residual gases expand, thereby, reducing the fresh air inhaled. Increase dilution cause the combustion to be erratic or even impossible.

This problem can be overcome by providing the rich fuel in the idling condition to maintain the smooth running of an engine so that the combustion process improves. Hence the fuel economy is not occur at idling condition.

So we can say that in the in the load carrying condition and in the idling condition, we will have to supply the rich fuel. Hence the dumper operating cost is same in load carrying condition and in idling condition as waiting in the queue.

Usually the dumper operator do not stop the engine because in every 4.8minutes the loader fills one dumper and the dumpers are loaded at the first come first serve basis. So to maintain the proper position in the queue without losing the chance, the dumper operators do not stop the engine and the engine remains in the idling condition.

VII. Observation and Discussion

Problem identified in the Current System

After analyze the current system through the single-channel queuing theory, I observed that there is a long waiting time (35.2 minutes) in queue of dumpers and a very high waiting time cost (Rs.1,79,66,080/-) of dumpers, which is the hidden loss to the company.

Suggested appropriate solution through the New System

In the current system the number of loader is one, due to which there is a long waiting time in a queue of dumpers and associated waiting time cost is very high.

And if we use the two loaders in place of one loader in the current system, the waiting time in a queue of dumpers and associated waiting time cost will become very low.

But the company opinion is that if we increase one extra loader, this will be the costly affair to the company.

But in the cost analysis I have cleared that, by the use of two loaders not only waiting time in a queue of dumpers and associated waiting time cost will become low but also it makes the company in a profitable situation.

VIII. Evaluation

After applying the multi-channel queuing theory, the waiting time in queue of dumper has reduced from 35.2 minutes to 1.56 minutes and cost associated with waiting time has reduced from Rs.1,79,66,080/- to Rs.5,89,860/-.

And if we compare both the current and new suggested systems, the cost analysis reflects the profitable situation to the crusher plant under the new system. So the crusher plant should adopt the new system.

IX. Benefits

- The main gain of this research is minimization of the waiting time in queue of dumpers and very high cost associated with waiting time of dumpers.
- This research can help the crusher plant to increase the quality of service.
- The result of this paper may become the reference to analyze the current system and improve the next system.
- The crusher plant can set the target profit.
- The crusher plant can easily predict and forecast the raw materials processing.
- The formulas that were used during the completion of research are applicable for future research and also could be used to develop more complex theories.
- No any dumper driver will become impatient to wait in the new system because there is less waiting time in queue.

- This research can help the crusher plant to remove the overburden from the loader, which results is an efficient utilization of loader.
- Break down of one loader does not interrupt the entire system.
- Efficient utilization of dumpers.

X. Conclusion

This paper contains the application of single and multi-channel queuing theory to the stone crusher plant mine. Here I have focused on minimize the waiting time in queue of dumpers and very high cost associated with waiting time of dumpers. And I have minimized the waiting time in queue of dumpers and very high cost associated with waiting time of dumpers up to certain extent and provides a profitable situation to the crusher plant. The constraints that were faced for the completion of this research were the inaccuracy of result since some of the data that I used was just based on assumption or approximation. I hope that this research can contribute to the betterment of crusher plant in terms of loader- dumper combination working.

As far as my future work is concerned, I will develop a model for the crusher plant that will contain the whole processing of crusher plant (i.e., from the raw materials processing to finished goods delivery) using the operations research tools for identification of bottlenecks & their remedies.

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References

[1.] Hamdy A. Taha, *Operations Research,* Seventh Edition, ISBN 81-203-2235-5, Printice Hall of India Private Limited, New Delhi, 2013.
[2.] J.K.Sharma, *Operations Research,* Third Edition, ISBN 1403-93151-8, Macmillan India Limited, New Delhi, 2009.
[3.] V.K.Kapoor, *Operations Research,* Seventh Edition, ISBN 81-7014-828-6, Sultan Chand & Sons, New Delhi, 2010.
[4.] Kanti Swarup, *Operations Research,* Fifteenth Edition, ISBN 978-81-8054-771-3, Sultan Chand & Sons, New Delhi, 2010.
[5.] A.P.Verma, *Operations Research,* Fourth Edition, ISBN 81-85749-24-8, S.K.Kataria & Sons,Delhi, 2013.
[6.] Prem Kumar Gupta & D.S.Hira, *Operations Research,* Seventh Edition, ISBN 81-219-0281-9, S.Chand & Company Private Limited, New Delhi, 2014.
[7.] Manohar Mahajan, *Operations Research,* Second Edition, Dhanpat Rai & Company Private Limited, Delhi, 2012.
[8.] S.D.Sharma, *Operations Research,* Fifteenth Edition, Kedar Nath Ram Nath Publishers, New Delhi, 2014