Optimization of Truck and Shovel for Haulage System in the Cao Son Mine, Viet Nam using Queuing Theory

Dang Vu Hai

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Author	Mr. Dang Vu Hai
Major Program	Mining Engineering

Major Advisor

....
(Asst. Prof. Dr.Manoon Masniyom)

Examining Committee :

....Chairperson
(Asst. Prof. Dr.Vishnu Rachpech)

....Committee
(Asst. Prof. Dr.Manoon Masniyom)

....Committee
(Assoc. Prof. Dr.Surapon Arrykul)

The Graduate School, Prince of Songkla University, has approved this thesis as partial fulfillment of the requirements for the Master of Engineering Degree in Mining Engineering

....
(Assoc. Prof. Dr. Teerapol Srichana)
Dean of Graduate School

This is to certify that the work here submitted is the result of the candidate's own investigations. Due acknowledgement has been made of any assistance received.

....Signature
(Asst. Prof. Dr.Manoon Masniyom)
Major Advisor

....Signature
(Mr. Dang Vu Hai)
Candidate

I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

....Signature
(Mr. Dang Vu Hai)
Candidate

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ABSTRACT

In surface mining, truck haulage is the largest item in the operating costs, constituting of 50 to 60 percent. The problem of selecting a proper fleet equipment is very important to decision makers in order to transfer all the mining materials with an optimal cost. In an open pit operation the trucks move from the shovels to the dump-crusher and back. Occasionally the trucks have to wait at the shovel, or at the fueling station when there already is a truck being loaded or being fueled. These waiting times reduce the capacity of the operation. The queueing theory 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 Viet Nam. The main objective of this study is to evaluate and to optimize the shovel – truck haulage system for open pit mines by using the queueing theory method. Using the queuing model (M/M/1), the result of the model showed the relationships between the number of truck in the fleet and shovel utilization, production and the queue length. The case also pointed out the optimized number of truck in the fleet by analysing costs in order to find the minimal cost.

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Dang Vu Hai

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LIST OF ABBREVIATIONS AND SYMBOLS

λ	Customer arrival rate
μ	Service rate
L_q	the average number waiting for service
L	the average number in the system
P_0	the probability of zero units in the system
ρ	the system utilization
W_q	the average time customers must wait for service
W_f	the average time customers spend in the system
M	the expected maximum number waiting for service for a given level of confidence
r	System utilization
N	Number of trucks
C_{total}	Total cost for unit production
$C_{loading}$	Cost per unit time of shovel
$C_{hauling}$	Cost per unit time of a truck
Q_n	Production per hour of fleet

CHAPTER 1
INTRODUCTION

As mining companies rapidly exploit deep deposits, the mines of the future will be deeper and more remote in extreme climatic conditions, with more expensive energy costs. This will affect the overall economics of mining with increased costs for material transportation.

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 dump-crusher and back. Occasionally the trucks have to wait at the shovel, at the dump-crusher, 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. It is quite obvious that the waiting times increase when trucks are added to an existing system if no other changes are made to the system. The productivity per truck will thus decrease (while the productivity of the shovels will increase).

The estimation of these waiting times 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. Also important is the estimation of the truck's travel times, full and empty, on the pit roads, for example by a truck performance calculator, and the estimation of the loading, dumping and repairing times.

The estimation of waiting times is the subject of operations research techniques such as simulation by random numbers or the queuing theory. These techniques together with the performance calculators of trucks and shovels are important tools in the design process, in equipment selection, and in the management of the daily operation.

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 by random numbers. Sometimes the queuing approach can completely substitute simulation; sometimes it offers an interesting supplement to simulation in that it can fill in missing points in a simulation study quickly and cheaply. In truck dispatching, where a forward estimate of waiting times is important information for the dispatcher, it offers the only way fast enough to provide that information (Jorgen, 1979).

The main objective with this study is to evaluate and to optimize the shovel – truck haulage system for open pit mines by using the queuing theory method. The scope of this study focuses on using the queuing model of (M/M/1) on analyzing the shovel-truck haulage systems in an open pit mine in Viet Nam. The outcome of this model would be an useful tool for assessment the effects of truck fleet size to equipment utilization, and total operating cost.

CHAPTER 2
LITERATURE REVIEW

2.1. Equipment selection problem

Mining is among very capital intensive industries. Mine construction and development require a large sum of capital, in which loading and hauling operations generally take a huge amount for operating, maintenance and investment costs. In surface mining, truck haulage is the largest item in the operating costs, constituting of 50 to 60 percent (Alarie and Gamache, 2002). Shovel and truck system normally refers to combination of different types of loaders and trucks. This combination has many effects to mining operation in terms of operational efficiency. Truck and shovel optimization process increase the output of the system and reduce the operating costs as a result. According to Carmichael, once a truck-shovel system is optimized, the different between current production and potential capacity will become narrower, with further improvements only realizable through reengineering (Carmichael, 1986).

2.2. Methods of mining equipment selection

The equipment selection problem is very important to mining industry for some reasons. First, this is an industry that requires to transfer a quite large quantity of materials throughout mine age of many years. In addition, to mining decision makers, selecting suitable shovel and truck fleets must ensure either meeting material handling needs or minimum cost.

2.2.1. Shovel – truck productivity

The shovel – truck productivity research area focuses on estimating and optimizing the productivity of a truck and loader fleet. It is believed that improving productivity will lead to cost reductions. The method of productivity optimization is then developed and works as an equipment selection solution. The key factor here is to find the optimized number of trucks needed in the fleet in order to meet the materials handling requires (Schexnayder, et at., 1999). The simplest method for determining fleet size based on productivity is as follows:

$$\text{Number of units required} = \frac{\text{Hourly production requirement}}{\text{Hourly production per unit}} \quad (2\text{-}1)$$

There are three methods taken into account: match factor, bunching theory and queuing theory.

Match factor

For the mining industry, the match factor is an important indicator of productivity performance. The term match factor is usually defined as the ratio of truck arrival rate to loader service time. This ratio relies on the assumption that the truck and loader fleets are homogeneous. That is, all the trucks are of the same type, and all the loaders are of the same type (Burt and Caccetta, 2007).

$$\text{MF} = \frac{\text{No. of trucks x loader cycle time}}{\text{No. of loader x truck cycle time}} \qquad (2\text{-}2)$$

In another research, Burt and Caccetta (2014) also pointed that a system with a low match factor is working under its capacity, while a high match factor means there are more trucks needed in the fleet to maintain the balance of the productivity for the shovel and truck in the system (Burt and Caccetta, 2014).

Bunching theory

In public transport, bunching refers to a group of two or more transit vehicles, which were scheduled to be evenly spaced running along the same route, instead running in the same location at the same time. This occurs when at least one of the vehicles is unable to keep to its schedule and therefore ends up in the same location as one or more other vehicles of the same route at the same time.

In mining transportation, bunching certainly occurs in a system of a loader and its correlating fleet of trucks. The relationship is not as complex as that of buses and passengers; if a truck has a greater cycle time due to some delay this time is absorbed by either the queue or the fleet cycle time. That is, the slowest truck will cause the trucks that follow to wait. In this manner, the cycle times of all of the trucks approaches the cycle time of the slowest truck. Smith et al. (2000) claimed that the effect of bunching is significant to fleet. His study pointed out that actual travel times were 20% longer than the calculated times, although they attributed this difference to overestimation of machine efficiency and poor rolling resistance estimates. He also suggested that these effects can be curbed by providing accurate equipment speeds before selecting the equipment and fleet sizes.

Queuing theory

Queuing theory is the study of the waiting lines, queue lengths and other properties of queues. Using queuing theory in productivity research does not give out a good result in equipment selection, but it provides a detail analysis on truck behavior in the system. This method was first applied to shovel-truck productivity by O'Shea (1964). O'Shea used queuing theory in analyzing the loss of productivity of the fleet when the trucks stayed in the queue at the loader.

2.2.2. Equipment selection

The problem of equipment selection to mining industry aims to select an appropriate a fleet of trucks and loaders in order to meet different requirements of mine. There are five methods: heuristic, statistical, optimization, simulation and artificial intelligence techniques.

Heuristic methods

A heuristic technique is any approach to problem solving, learning or discovery that employs a practical method not guaranteed to be optimal or perfect, but sufficient for the immediate goals. Where finding an optimal solution is impossible or impractical, heuristic methods can be used to speed up the process of finding a satisfactory solution. Heuristics can be mental shortcuts that ease the cognitive load of making a decision.

Statistical methods

Statistics is the study of the collection, analysis, interpretation, presentation and organization of data. In applying statistics, it is conventional to begin with a statistical population or a statistical model process to be studied. Two main statistical methodologies are used in data analysis: descriptive statistics, which summarizes data from a sample using indexes such as the mean or standard deviation, and inferential statistics, which draws conclusions from data that are subject to random variation. A standard statistical procedure involves the test of the relationship between two statistical data sets or a data set and a synthetic data draw from idealized model.

In mining application, this method was applied by Blackwell (1999) in determining the best fleet of trucks and loaders. Blackwell developed a multiple linear regression model analyzing variables of a fleet such as truck cycle time, fuel consumption, tire consumption, operating hours. He also pointed out the relationship of these parameters with truck power and load carried. The appropriate fleet of trucks and loaders was then determined through these parameters with a complimentary of a simple match factor.

Optimization techniques

The use of optimization techniques is well applied in a wide range of the mining operations. There are integer programs were developed in mining schedules (Dagdelen & Ramazan, 2002) and pit optimization (Caccetta & Hill, 2003). In mining equipment selection, this technique also stands out its application in fleet allocation (Ercelebi & Kirmanh, 2000). Besides, it is also used to optimize productivity and equipment matching (Morgan 1994).

Cebesoy et al. (1995) developed an integer program to select different equipment types. The model was created to deal with a single period, single location mine. A single location mine is a mine which has only one mining location with a single route to a dump-site. This model also assumed that fleet is homogeneous, it means all the loaders and trucks operate as one fleet. Therefore, this model is a most useful tool for small mines or for mines where there is no significant difference in the mining locations and route lengths.

Simulation

Simulation is a well-used and notably powerful tool for the mining industry (Hall, 2000). Although simulation is most effectively used in mining equipment selection to analyze the earth-moving system, there are some equipment selections solutions that used simulation models. Shi (1999) used simulation to handle a large set of data in order to predict earth-moving production. Simulation also is a useful tool to observe the interactions of particular equipment. There are Schexnayder, et al., (2005) who used a simulation model for productivity prediction. Besides, this is also be used to estimate a suitable truck cycle time (Frimpong, et al., 2003).

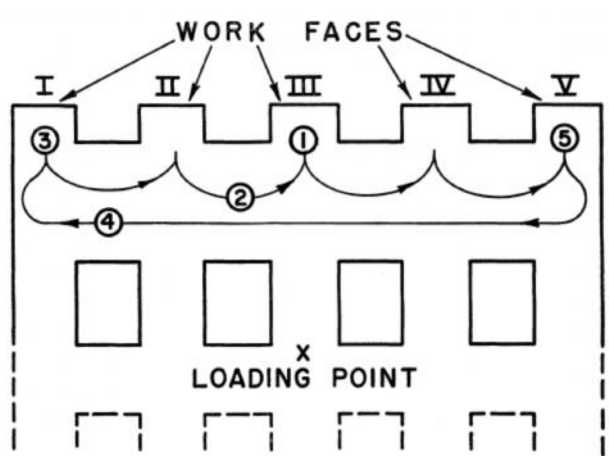
Artificial intelligence

Artificial intelligence techniques are amongst large scale mining applications due to their ability to find feasible solutions within a short time (Clement & Vagenas, 1994). The three common methods are the expert system, decision support system and genetic algorithms.

An example of the expert system for equipment selection is the study of Ganguli and Bandopadhyay (2002). This research mentioned an important factor of modeling equipment selection is the equipment subset to be considered in the model will be dependent on the soil and mining conditions. There are decision support systems such as analytical hierarchy process (Bascetin, 2004) and expert systems (Amirkhanian & Baker, 1992). These methods considered all the parts of equipment selection as a whole, including conditions of geology, environment and equipment matching. The analysis of equipment matching here only concerns with the compatibility of equipment. Naoum and Haidar (2000) developed a genetic algorithm model for the equipment selection problem. This model is dealt with only homogeneous fleets. The type of the loader will be selected before the optimization starts. Additionally, this model assumed that all the equipment will be used from purchase until retirement age.

2.3. Applying queuing theory to mining

Queuing theory was applied to mining practices since 1958 by Ernest Koenigsberg. His research dealt with service standards and output for a closed loop queuing system which services a finite number of customers. In this cyclic system, a customer who has completed service at the M^{th} stage rejoins the queue at the first stage. The service time distribution is assumed exponential. The calculations are conducted for “conventional” mechanized deep mining operations, in which a “section”, consisting of a group of specialized machines and their complement, works on a number of faces in succession (Figure 2.1). A face is worked in sequence by a cutting machine, a drilling machine, a blasting crew, a loading machine group and a timbering or roof bolting machine. Each machine proceeds to the next face after completing its task.



Firgure2.1: A typical mine layout in Ernest’s model. 1 indicates machine location at an arbitrary instant of time (Koenigsberg, 1958)

Ernest's approach for this queue system is to consider machines queuing up to serve faces in fixed sequence and the faces queuing for services in first come – first served order (Figure 2.2). Formulas are applied to determine the probability that the system is in a state, the mean number of units at a given state, the mean number of units awaiting service at a given state, the mean cycle time, the daily output. These equations also can be used to compare with different cases in various numbers of customers and servers. Ernest finds that the output increases when the number of faces worked N increases, and the rate of change of increase decrease with increasing N and is limited by the service rate of the slowest machine (Koenigsberg, 1958).

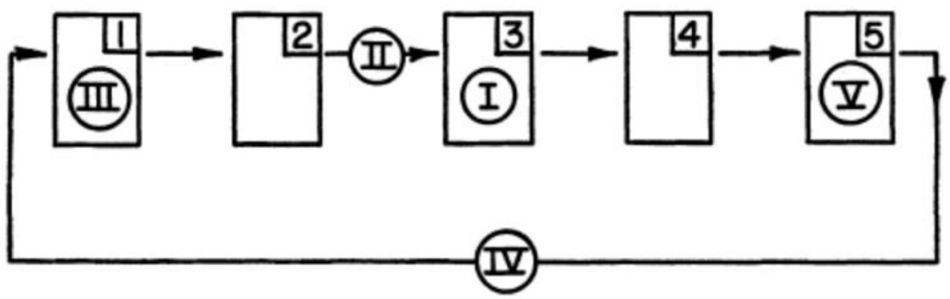


Figure2.2: Model of mining operations (Koenigsberg, 1958)

In 1973, Maher and Cabrera studied a cyclic queuing problem in civil engineering earth moving projects. The queuing system here is quite similar to system in mining, in which there are m excavators and n trucks in queue to be loaded by the excavators. The purpose of using queuing theory in this research is to optimize the size of the haul fleet in order to minimize the cost per unit volume of earth moved. The queuing model is set with an assumption of negative exponentially distributed loading and transit times for the single excavator case. The result of the research gives out graphs which show regions of optimal n in the parameter space. The optimum truck number is chosen based on the two ratios, the average loading time with transit time and the hourly costs of excavator and truck (Maher & Cabrera, 1973).

El-Moslmani in 2002 designed a computer module called FLSELECTOR for equipment fleet selection for earth moving operations using queuing theory models of the form (M/E/c)/K. FLSELECTOR is implemented using Visual Basic for Application (VBA) and Microsoft Excel and allows for an optimum fleet to be selected based on least cost, maximum production. This program allows the users to compare the different production outputs that would be achieved using different haul routes from the loading area to the dumping area. It also provides the users with a list of the best ten fleet alternatives, in which arrival rate, service rate, utilization, production, cost, duration, and cost per unit are calculated for each fleet. (El-Moslmani, 2002). The fleet selection process and data analysis using in this model showed as in the figure 2.3.

Another computational study in optimization of shovel-truck system for surface mining was shown by Ereclebi and Bascetin in 2003. This research describes shovel and truck operation models and optimization approaches for the allocation and dispatching of trucks under various operating conditions. The first stage consisted of determining of the optimal number of trucks working with each shovel in the system using a model based on the closed queuing network theory. At the next stage, it has been determined how the trucks should be dispatched to shovels, using the linear programming model. The methodologies developed and presented here have the potential to be useful for mine operators for loading and haulage planning in open pit mines and/or at the stage of equipment procurement. Since the cost of shovels and trucks is several hundred dollars per hour, the application of the methodologies has potential for substantial savings. (Ercelebi and Bascetin, 2003).

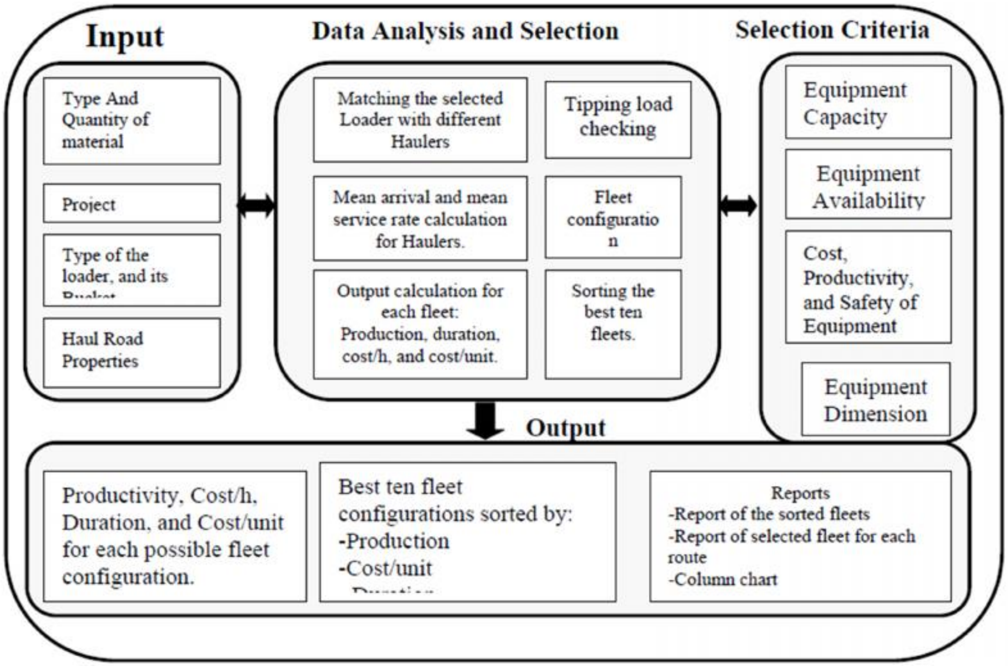


Figure 2.3:Fleet selection and data analysis in FLSELECTOR (El-Moslmani, 2002)

Meredith in 2012 developed an (M/M/c) queuing model to model truck and shovel interactions in open pit mines. This model makes the assumption of exponentially distributed truck inter-arrival times and service times, and can be applied to operations with seven or fewer loaders. To apply this model the user must know the average arrival rate of new trucks to the system, λ, the number of loaders and the average service rate per loader, μ. Based on these values, the model calculates several outputs describing system behavior, e.g. the amount of time trucks spend waiting to be loaded, W_q, and the server utilization, ρ, are both indicators of how efficiently the system is operating. (Meredith, 2012).

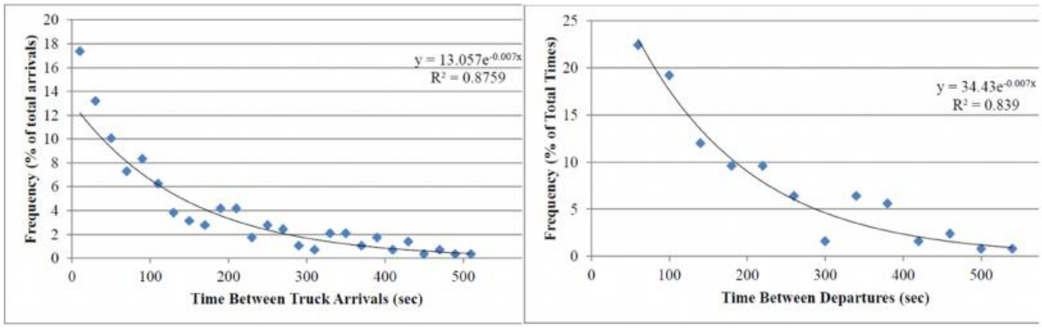


Figure 2.4: The distribution of times between truck arrivals and departures (Meredith, 2012)

	A	B	C	D	E	F	G	H	I	J	K	L
1	M/M/c		Exponential service times									
2			Exponential interarrival times									
3			c servers									
4	Number of Servers, c	3			r =	1.71755		is = λ/μ, traffic intensity, aka service rate factor				
5	Arrival Rate, λ	23.1667	cars/hour		ρ =	0.57252		is = r/c, traffic intensity per server				
6	Service Rate (per server), μ	13.4882	cars/hour		Q =	0.74667						
7												
8												
9			n	n	n	n						
10	r	1.71755	0	1	2	3	4	5	6			
11	ρ	0.57252	2.97542	3.69297	3.45041	2.81987	2.33801	2.09997	2.01107			
12	P_0	0.09883										
13	number waiting, Lq	0.26146	Pn									
14	Time waiting in line, Wq	0.01129	0.00872	0.02371	0.03223	0.02921	0.02647	0.02399	0.02174			
15	Time in system, W	0.08542	0.02616	0.04741	0.03223	0	-0.02647	-0.04799	-0.06523			
16	Number in system, L	1.97901										
17	System Output (trucks/hour), θ	39.0376										

Figure 2.5: The model used for calculating (Meredith, 2012)

2.4. Conclusion

Haulage system in ore and waste material transportation plays an important role in most open pit mines. The mining progresses results in unconstant size of fleet equipment and an increase in the length of the haul road, the problem of determining the proper number and suitable type of trucks in system is extremely difficult for mine-planners.

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

CHAPTER 3
QUEUING THEORY

3.1. Introduction

In our daily lives, we commonly encounter waiting lines at gas stations, stop signs, supermarkets, restaurants and other places. We often experience waiting lines in transportation systems such as planes circling an airport awaiting clearance from the control tower, trucks waiting to load or unload cargo, buses backed up waiting to enter a terminal, passengers queuing up waiting for cabs. Frequently, there are waiting lines at banks and post offices. In factories, jobs queue up awaiting processing, orders need to be filled, machines need repairs or need to be loaded after a job.

Most of these systems are characterized by highly variable arrival and service rates. Waiting-line models are predictive models of the expected behavior of a system in which waiting lines form.

3.2. Elements and characteristics

Queuing theory was developed to provide models capable of predicting the behavior of systems that provide service for randomly arising demands. 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. Queuing theory was originally developed to model telephone traffic. Randomly arising calls would arrive and need to be handled by the switchboard, which had a finite maximum capacity (Taha, 1975).

Waiting-line systems can be differentiated by certain characteristics, such as the number of servers or whether access to the system is unrestricted or limited. The major elements of waiting-line systems are outlined in figure 3.1.

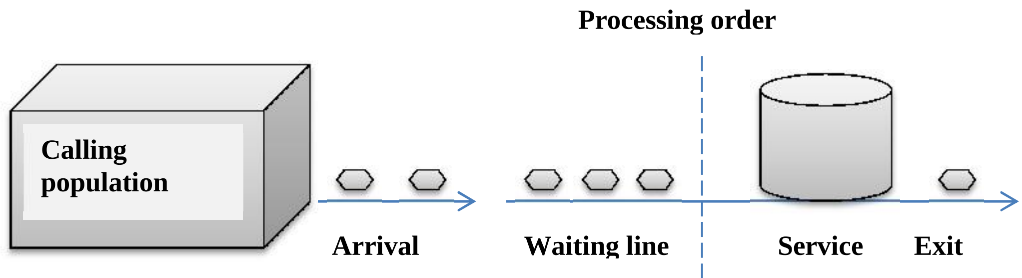


Figure 3.1: Major elements of waiting-line systems (Stevenson, 2008)

Calling population

The calling population refers to the pool of potential arrivals to the system. In queuing terminology, it is often called the customer source. If the source is large enough that the probability of an arrival is not significantly influenced by the fact that some of the customers are waiting in line, we say that the calling population is infinite. On the other hand, there are systems that have limited access for service; therefore, there is a limit to the number of presses waiting to be loaded or unloaded. If the number of jobs that require service or the number of customers waiting for services causes the probability of another arrival to decrease (because the percentage in the population is substantially reduced), the calling population or population source is described as finite or limited.

Customer arrivals

Customers are considered units that request or require service. In some systems the customers are people, and in others they are not. Examples of non-people systems include automobiles arriving at intersections, trucks arriving at a loading dock, machines awaiting repair, orders waiting to be filled, planes waiting to land and so on.

One key question is whether customers arrive at the system in single units (i.e., one at a time) or whether they arrive in batches. For instance, cars usually arrive at a car wash singly, whereas an entire busload of customers may arrive at a fast-food restaurant. A second key question relates to the distribution of customer arrivals. Generally, the models require that the arrival rate variability follow a Poisson distribution. An equivalent distribution that describes the inter-arrival time (i.e., the average time between arrivals) when the arrival rate is Poisson, is the negative exponential distribution. A typical distribution is illustrated in figure 3.2.

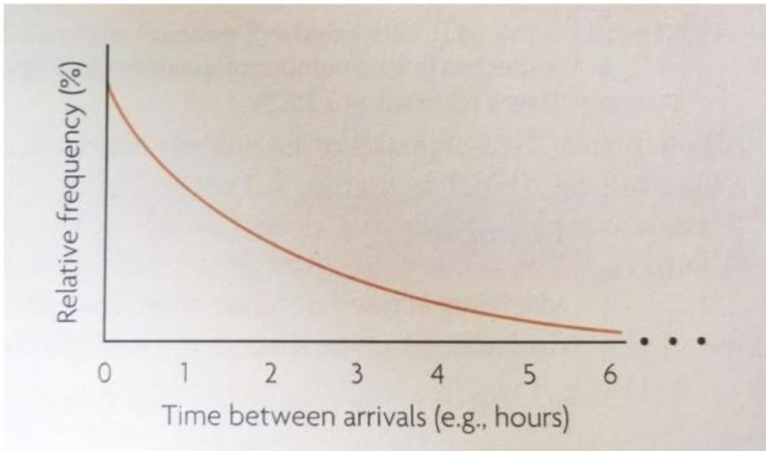


Figure 3.2: inter-arrival time distribution (Stevenson, 2008)

The waiting line

The waiting line consists of customers who have been admitted to the system and are waiting for service. Some key issues are whether arriving customers may refuse to enter the system (balking) because of a long waiting line; whether customers may arrive, wait for a while, but then leave without being served (reneging); or whether customers may switch lines in an attempt to lessen waiting time (jockeying). However, all models here assume that once customers enter the queue, they remain there until they have been served.

Processing order

A commonly encountered queue discipline (processing order) rule is first come, first served.

Service

The key issues for service concern the number of servers, the number of steps in the service process and the distribution of service time.

A service center can have one server (single channel) or more than one server (multiple channel).

Service may consist of one or a few steps that are handled together, this is called single phase. Conversely, some systems involve a series of steps, are called multiple phase.

The third important issue is the distribution of processing or service time. The most common assumption is that service time can be described by a negative exponential distribution (figure 3.3). The implication of this sort of distribution is that most customers require short service times, a small portion requires moderate service times and a few may require relatively long service times.

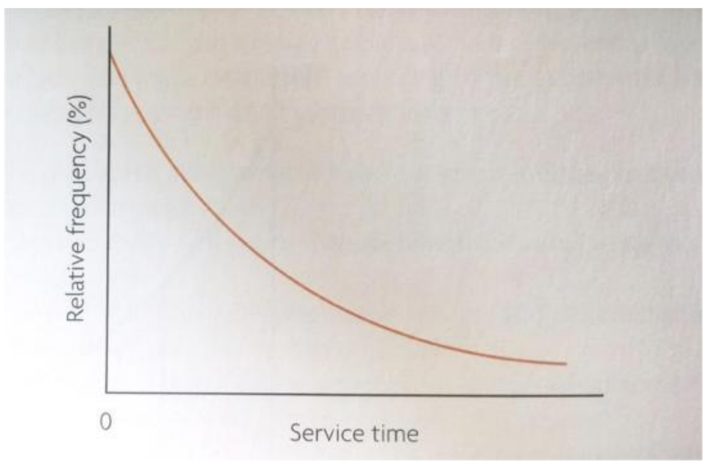


Figure 3.3: Service time distribution (Stevenson, 2008)

Exit

The final consideration is what customers do after leaving the system.

Measures of system performance

A number of different performance measures can be computed that summarize waiting line behavior given the customer arrival rate, the number of servers, the service rate and certain other information, are the following:

L_q = the average number waiting for service

L = the average number in the system (i.e., waiting for service or being served)

P_0 = the probability of zero units in the system

ρ = the system utilization (percentage of time servers are busy serving customers)

W_q = the average time customers must wait for service

W_f = the average time customers spend in the system (i.e., waiting for service and service time)

M = the expected maximum number waiting for service for a given level of confidence

Two key parameters in any waiting line system are the mean arrival rate, λ, and the mean service rate, μ

Basic relationships

- System utilization (percentage of time server is busy) for a single channel system:

$$r = \frac{\lambda}{\mu} \qquad (3-1)$$

Where: λ = customer arrival rate; μ = service rate

- The average number in the system:

$$L = L_q + r \qquad (3-2)$$

Where: L = average number in the system; L_q = average number in line

- The average time in line:

$$W_q = \frac{L_q}{\lambda} \qquad (3-3)$$

- The average time in the system, including service:

$$W_s = W_q + \frac{1}{\mu} \qquad (3-4)$$

3.3. Queuing models

3.3.1. Queuing models classification

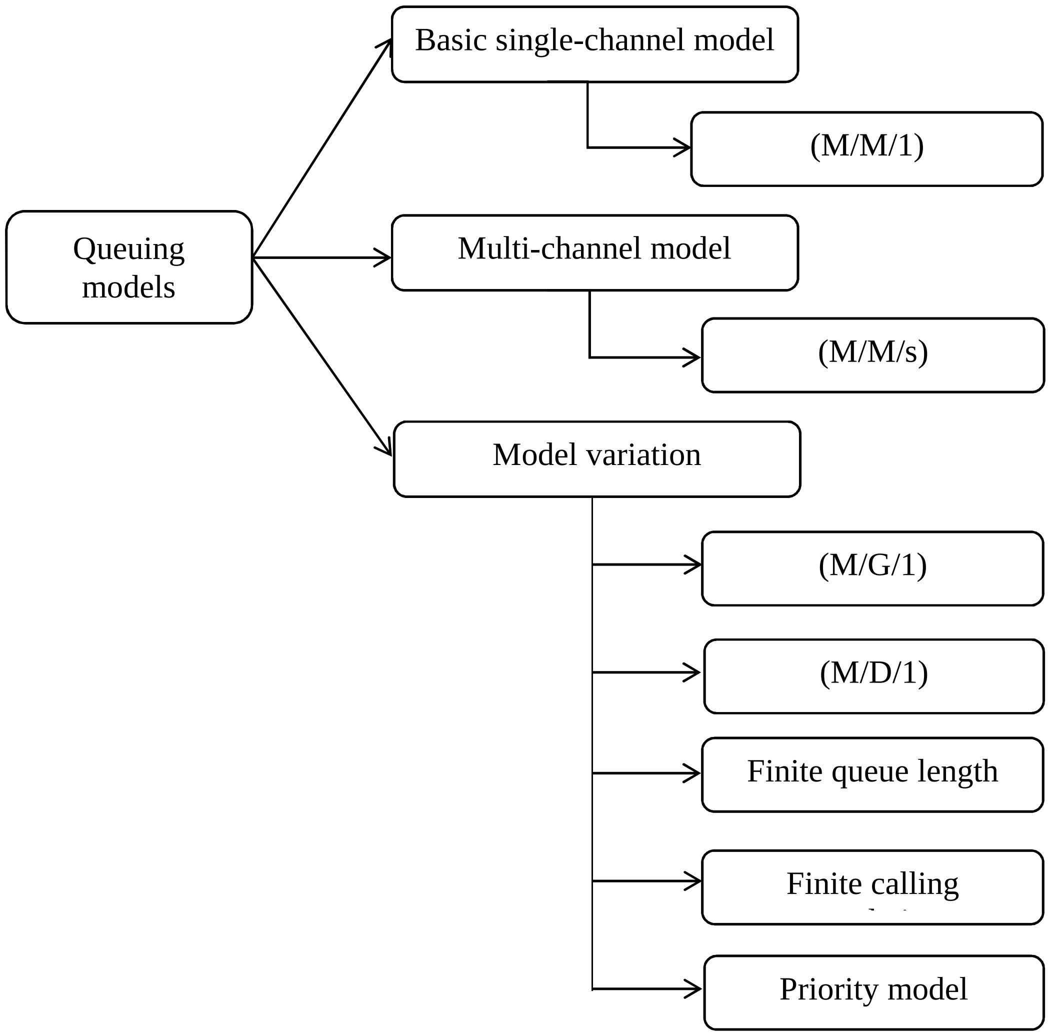


Figure 3.4: Queuing model classification

3.3.2. Basic single-channel (M/M/1) model

This model pertains to situation in which there is one channel or server that processes all customers. A single channel (M/M/1) model is appropriate when these conditions exist:

- One server or channel
- A Poisson arrival rate

- A negative exponential service time
- First-come, first-served processing order
- An infinite calling population
- No limit on queue length

The necessary formulas for the single-server model are presented in table 3.1.

Table 3.1: Basic single-channel (M/M/1) model (Stevenson, 2008)

Performance measure	**Formula**	
System utilization	$\rho = \frac{\lambda}{\mu}$	3-5
Average number in line	$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$	3-6
Average number in system	$L = L_q + \frac{\lambda}{\mu}$	3-7
Average time in line	$W_q = \frac{L_q}{\lambda}$	3-8
Average time in system	$W = W_q + \frac{1}{\mu}$	3-9
Probability of zero units in the system	$P_0 = 1 - \frac{\lambda}{\mu}$	3-10
Probability of n units in the system	$P_n = P_0 \left(\frac{\lambda}{\mu}\right)^n$	3-11
Probability the waiting line won't exceed k units	$P_{n \le k} = 1 - \left(\frac{\lambda}{\mu}\right)^{k+1}$	3-12
Average waiting time for an arrival not served immediately	$W_a = \frac{1}{\mu - \lambda}$	3-13

3.3.3. Multiple-channel model (M/M/s)

The multiple-channel model or multiple-server model is very similar to the single-server model, except that the number of servers is not limited to one. The multiple-channel model is appropriate when these conditions exist:

- A Poisson arrival rate
- A negative exponential service time
- First-come, First-served processing order
- More than one server
- An infinite calling population
- No upper limit on queue length
- The same mean service rate for all servers

The multiple-server formulas are presented in table 3.2.

3.3.4. Model variation I: Poisson arrival rate with any service distribution (M/G/1)

The assumptions of this model are identical to the basic single-server model, except that service time need not be exponential. The service times can be of any distribution. This is indicated by the letter “G” for general in the abbreviated statement of the model. Key formulas are presented in the table 3.3.

3.3.5. Model variation II: Poisson arrival rate, constant service time (M/D/1)

The assumptions of this model are identical to those of the basic single-server model, except that the service time is constant. This waiting line is described by the M/D/1 model, where D indicates that service times are deterministic. Key formulas are presented in the table 3.4.

Table 3.2: Multiple-channel model (M/M/s) (Stevenson, 2008)

Performance measure	**Formula**	
System utilization	$\rho = \frac{\lambda}{s\mu}$	3-14
Average number in line	$L_q = \frac{\lambda\mu(\lambda/\mu)^x}{(s-1)!(s\mu-\lambda)^2}P_0$	3-15
Average number in system	$L = L_q + \frac{\lambda}{\mu}$	3-16
Average time in line	$W_q = \frac{L_q}{\lambda}$	3-17
Average time in system	$W = W_q + \frac{1}{\mu}$	3-18
Probability of zero units in the system	$P_0 = \left[\sum_{n=0}^{s-1}\frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!(1-(\lambda/s\mu))}\right]^{-1}$	3-19
Probability of n units in the system, where $n \leq s$	$P_n = P_0\frac{(\lambda/\mu)^n}{n!}$	3-20
Probability of n units in the system, where $n > s$	$P_n = \frac{P_0(\lambda/\mu)^n}{s!\,s^{n-s}}$	3-21
Average waiting time for an arrival not immediately served	$W_a = \frac{1}{s\mu-\lambda}$	3-22
Probability that an arrival will have to wait for service	$P_w = (\lambda/\mu)^s\frac{P_0}{s!(1-(\lambda/s\mu))}$	3-23
s = number of servers or channels		

Table 3.3: Model variation I: Poisson arrival rate with any service distribution (M/G/1) (Stevenson, 2008)

Performance measure	**Formula**	
Average number waiting in line	$L_q = \frac{(\lambda/\mu)^2 + \lambda^2\sigma^2}{2(1 - \lambda/\mu)}$	3-24
Average number in the system	$L = L_q + \frac{\lambda}{\mu}$	3-25
Average time waiting in line	$W_q = \frac{L_q}{\lambda}$	3-26
Average time in the system	$W = W_q + \frac{1}{\mu}$	3-27
System utilization	$\rho = \frac{\lambda}{s\mu}$	3-28

Table 3.4: Model variation II: Poisson arrival rate, constant service time (M/D/1) (Stevenson, 2008)

Performance measure	**Formula**	
Average number waiting in line	$L_q = \frac{\lambda^2}{2\mu(\mu - \lambda)}$	3-29
Average number in the system	$L = L_q + \frac{\lambda}{\mu}$	3-30
Average time waiting in line	$W_q = \frac{L_q}{\lambda}$	3-31
Average time in the system	$W = W_q + \frac{1}{\mu}$	3-32
System utilization	$\rho = \frac{\lambda}{s\mu}$	3-33

Table 3.5: Model variation III: finite queue length (Stevenson, 2008)

Performance measure	Formula	
System utilization	$\rho = \frac{\lambda}{\mu}$	3-34
Probability of zero units in the system	$P_0 = \frac{1 - \rho}{1 - \rho^{m+1}}$	3-35
Probability of n units in the system	$P_n = P_0 \rho^{\bar{n}}$	3-36
Average number of units in the system	$L = \frac{\rho}{1 - \rho} - \frac{m + 1 \ \rho^{m+1}}{1 - \rho^{m+1}}$	3-37
Average number of units waiting in line	$L_q = L - (1 - P_0)$	3-38
Average time in system	$W = \frac{L_q}{\lambda \ 1 - \rho_m} + \frac{1}{\mu}$	3-39
Average time waiting in line	$W_q = W - \frac{1}{\mu}$	3-40
m = maximum number permitted in the system		

3.3.6. Model variation III: finite queue length

This model incorporates all of the assumptions of the basic single-server model. In addition, it allows for a limit on the maximum length of the line. The implication is that once the line reaches its maximum length, no additional customers will be allowed to join the line. New customers will not be allowed on a space-available basic. The formulas are shown in the table 3.5.

3.3.7. Model variation IV: finite calling population

This model has the same assumption as the basic single-server model except that there is a limited calling population. The formulas are shown in the table 3.6.

3.3.8. Model variation V: multiple-server, priority servicing model

This model incorporates all of the assumption of the basic multiple-server model except that priority serving is used rather than first-come, first-served. Arrivals to the system are assigned a priority as they arrive (e.g., highest priority = 1, next priority class = 2, next priority class = 3 and so on). The formulas are shown in the table 3.7.

Table3.6: Model variation IV: finite calling population (Stevenson, 2008)

Performance measure	**Formula**	
Probability of 0 units in the system	$P_0 = \frac{1}{\sum_{i=0}^{N} (\lambda/\mu)^i \frac{N!}{(N-1)!}}$	3-41
Probability of n units in the system	$P_n = \frac{N!}{(N-n)!}\left(\frac{\lambda}{\mu}\right)^n P_0$	3-42
Average number waiting in line	$L_q = N - \frac{\lambda + \mu}{\lambda}(1 - P_0)$	3-43
Average number in the system	$L = L_q + (1 - P_0)$	3-44
Average waiting time in line	$W_q = \frac{L_q}{\lambda(N - L)}$	3-45
Average time in the system	$W = W_q + \frac{1}{\mu}$	3-46
N = number in calling population λ = mean arrival rate per unit in the population		

3.4. Queuing system in mining

In mining operations, queuing systems normally originate from haulage process when trucks arrive at the loading position, crushing area or dumping sites and wait for their turns in line. In these queuing systems, trucks play a role as the customers of the system and the servers here are the loaders or crushers. A basic mining queuing system included trucks and loader can be illustrated as in figure 3.5.

Table 3.7: Model variation V: multiple-server, priority servicing model (Stevenson, 2008)

Performance measure	**Formula**	
System utilization	$\rho = \frac{\lambda}{\mu}$	3-47
Intermediate values	$A = \frac{\lambda}{(1-\rho)L_q}$	3-48
	$B_k = 1 - \sum_{c=1}^{k} \frac{\lambda C}{s\mu}$ $(B_0 = 1)$	3-49
Average waiting time in line for units in *k*th priority class	$W_k = \frac{1}{A(B_{k-1})(B_k)}$	3-50
Average time in the system for units in the *k*th priority class	$W = W_k + \frac{1}{\mu}$	3-51
Average number waiting in line for units in the *k*th priority class	$L_k = \lambda_k \times W_k$	3-52

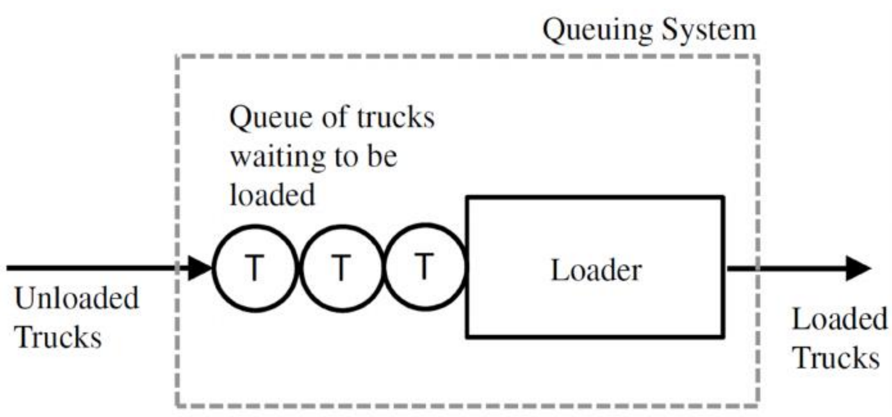


Figure 3.5: Truck and Loader Queuing System (Meredith, 2012)

In cyclic queuing system, the haul route of a truck can be divided into four parts: being loaded at the loader position, loaded travelling route, unloading at the crusher and unloaded travelling route. These four stages are repeated in sequence as shown in the figure 3.6:

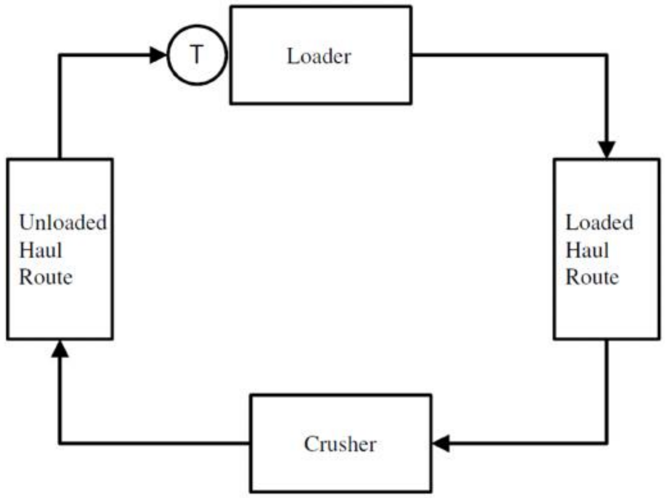


Figure 3.6: Cyclic Queuing System (Meredith, 2012)

In some mining operations, there are multiple loaders working at the same time, the cyclic queuing system for these operations can be adjusted as a system with multiple loaders. The queuing system here is a typical of a queuing system with multiple servers, figure 3.7:

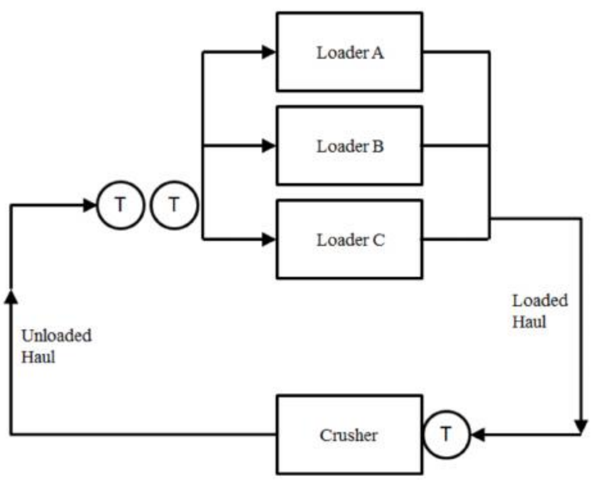


Figure 3.7: Cyclic queuing system with parallel loaders (Meredith, 2012)

The above system also can be adjusted to be more convenient to some mining operations with more complex and the truck haul paths are unstable as in figure 3.8. After being loaded at the loader, trucks have their own routes to which crushers' positions.

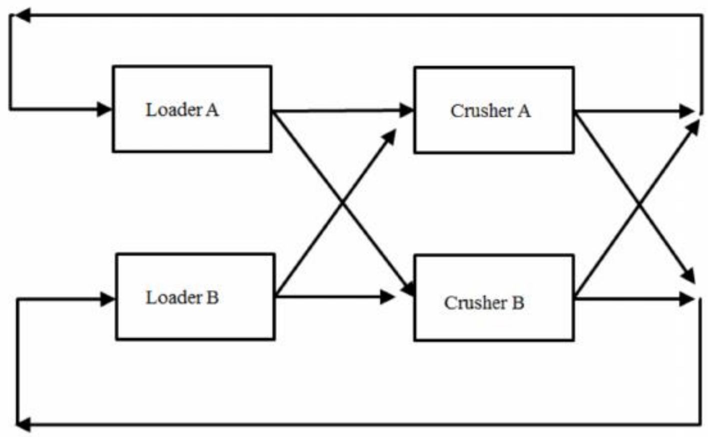


Figure 3.8: Network queuing system (Meredith, 2012)

Besides, with some mines that have more than one pit operating at the same time, each pit's queuing system can be seen as an independent network with or without sharing any resources. For example, in figure 3.9, there are two seperate pits sharing one crusher, each pit here is a sub-queuing system for this operation.

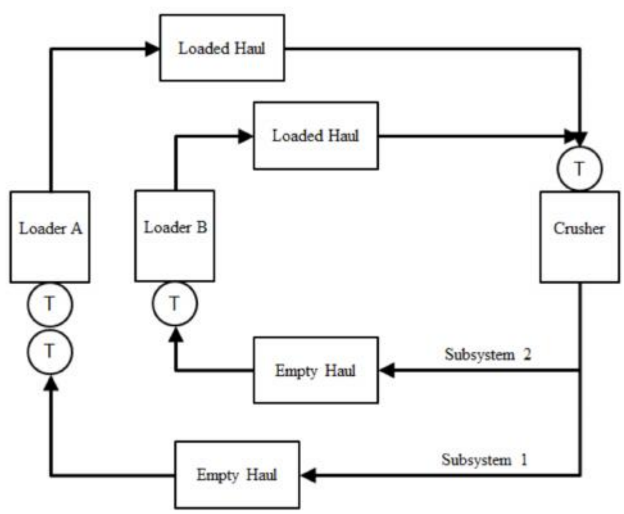


Figure 3.9: Queuing schematic with multiple pits (Meredith, 2012)

3.5. Cost model

Production over a given time period of interest (typically one shift) can be calculated by the number of loads that trucks take to the dump:

$$\text{Production} = \frac{\text{Time period of interest}}{\text{Average cycle time}} \times N \times \text{truck capacity} \qquad (3\text{-}53)$$

Where- N is the number of trucks in the system. Also production may be calculated from:

$$P = \text{time period of interest} \times \eta_{shovel} \times \mu_{shovel} \times \text{truck capacity} \qquad (3\text{-}54)$$

η_{shovel} is shovel utilization and μ_{shovel} is shovel loading rate.

For shovel – truck type operations, the minimum unit cost of moved material is the main concern. When the cost is of prime importance, a trade-off is sought between the cost of idle time of the shovel and the cost of providing extra trucks. The solution yields the optimum number of trucks of any given capacity that can be assigned to a shovel.

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

$$C = \frac{C_1 + C_2N}{\text{unit production} \times \text{truck capacity}} \qquad (3-55)$$

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. (Ercelebi and Bascetin, 2003).

CHAPTER 4
CASE STUDY: APPLYING QUEUING THEORY TO OPTIMIZE SHOVEL TRUCK SYSTEM IN CAO SON COAL MINE - VIETNAM

4.1. Introduction

Vietnam has important untapped mineral reserves across the country: around 8.8 billion tons of coal in the North East basin, approximately 29 billion tons of brown coal in the Northern Delta region, the world-class bauxite reserve amount of around 5.5 billion tons in the Central Highlands and various other minerals such as titanium, iron ore, chromite, copper, limestone, gold, rare earths, tungsten, etc. According to statistics of the first six months of 2015, mining is the third biggest contributor to GDP and has high growth rate of 8.15%.

However, mining industry, specialy coal mining industry is facing many challenges. In the period from 2015-2020, the total amount of annual overburden in open pit mines is predicted of about 28.83 – 189 million cubic meter, and coal production is estimated from 2.3 to 15.6 million tons per year. With that high amount of overburden, difficult working conditions, haulage distance extended, there is a need for technical solutions in mining in order to meet production require, increase mining efficiency, and decrease mining costs to mines. Therefore, mines should focus more on enhancing working of current mining equipment, selecting effective haulage system to meet annual production of mine.

In this part, there is a case example for analyzing and selecting a suitable fleet size in an open pit mine in Viet Nam. The data was taken from the mine based on current shovel and trucks working in normal shifts. Using queuing model in analyzing time data of the system, the model then showed outputs about effects of truck fleet size to haulage system. An optimized system also was pointed out while examining relationship between truck number and operating costs.

4.2. Background information of the mine

4.2.1. Current technology and mining operation

Cao Son joint stock coal mine is a big surface mine with high level of mechanization of Vinacomin Group. This is one of surface mines in Vietnam with the highest deposit as well as annual output. Currently, this mine is in the period of enlarging and increasing its capacity from 3.7 million tons to 4.5 million tons (2012-2016), the amount of overburden rose from 15 million cubic meter in 2005 to 27 million cubic meter in 2009, and is predicted to increase to 55 million cubic meter.

Table 4.1: Geometrical parameters in mine (Cao Son's report, 2014)

No	Parameters	Unit	Values
1	Bench height for rock	m	12-15
2	Bench height for coal	m	5-7.5
3	Ended bench height	m	15-30
4	Working bench width B_{min}	m	45-50
5	Rest bench width	m	18-20
6	Bench number in a group	-	3-4
7	Bench angle	degree	65-70
8	φ_{max}	degree	28-32
9	Current level of mine pit	m	+70

The mining operation in mine includes: drilling and blasting – loading – hauling – dumping – drainage – coal sorting and other auxiliaries.

Mine's geometrical parameters were designed with the working bench width of 50 – 55 m, overall slope angle of 25 – 28^0, the working bench is divided into groups in which there is one working bench with 45 – 50 m width. The geometrical parameters are summarized in the table 4.1.

4.2.2. Loading

Currently, loading rock in mine is still being handled by EKG shovels from Russia. These shovels have capacities of 4.6 – 10 cubic meter, and the C quality. In recent years, Cao Son mine has invested many modern hydraulic backhoes with bucket capacities from 3.5 to 12 cubic meter in order for loading rock, stripping mine pit and coal exploitation.

Table 4.2: Working time and output of loaders(Cao Son's report, 2014)

No	Loaders	Number	Working time (hour)	Output, 10^3 m^3
1	PC 1250	3	9,753	2,549
2	PC 750-7	2	5,625	1,066
3	CAT-365B	2	4,115	727
4	Hitachi 670	2	5,791	963.2
5	EKG-4,6+5A	11	26,588	4,340.5
6	EKG-8U	8	14,690	3,075.6
7	EKG 10Y	1	2,855	825.7

There are 10 hydraulic backhoes using in mine (3.5 – 12 cubic meter of bucket capacity), in which 1 PC1800-6 (12 cubic meter) and 3 PC 1250 (6.7 cubic meter) are using for rock loading and coal exploitation. The consolidated working time and output of loaders are presented in the table 4.2 and 4.3.

4.2.3. Hauling

Mine uses trucks for hauling rock and coal. The capacity of truck has a range from 27 to 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.

Table 4.3: Loader’s capacities (Cao Son’s report, 2014)

No	Loaders	Unit	Capacity norm 2034/QĐ-HĐQT	Actual capacity 2011-2014
1	Hydraulic backhoe CAT-1800-6; E = 12m^3	10^3m^3	1,637	1,525-1,624
2	Hydraulic backhoe HT2, CAT-365BL; E = 3,5m^3	10^3m^3	624	572- 904
3	Hydraulic backhoe PC1250; E = 6,7m^3	10^3m^3	987	1,224
4	EKG 4,6b-(5A); E=4,6 ÷ 5m^3	10^3m^3	835-907	713-893
5	EKG 8U; E = 8m^3	10^3m^3	1,026	727-866
6	EKG - 10Y; E = 10m^3	10^3m^3	1,283	1,340-1,512

Haul route

At present, in mine area, there are stable and unstable haul routes for transferring rock, coal and communication to outside as below:

- From main office to mining areas
- Routes to West Cao Son and Khe Cham III dumping sites
- Routes to crushing plants
- Coal conveyor routes
- Route from mine pit to North Bang Nau dumping site

All the stable and unstable routes are built properly to connect transportation networks in mine and the outside. The current main road is used for transfering rock from working benches to dumping areas, the length of steep parts accounts for 60% that of total route. Cross slope is of 1 – 3%, road grade is of 1 – 10%, minimum curve radius is 20 – 25m.

Haulage productivity

Table 4.4: Trucks‘ capacitites (Cao Son’s report, 2014)

No	**Trucks**	**Average working hour, hour**		**Average productivty , m^3/year**	
		2014	***2015***	***2014***	***2015***
1	CAT773E	3,582	3,262	145,941	97,725
2	CAT777D	3,572	2,133	210,544	154,725
3	HD 465-5; 7	4,054	1,323	163,698	77,600
4	HD 785-5; 7	4,084	985	251,398	137,879
5	A35D	2,900	2,324	12,986	10,191
6	HM 400-2R	4,108	2,430	107,996	61,744

Trucks capacities are summarized as in the table 4.4. Total working hour of these equipments follows a downward trend through the year and the haulage productivity gradually decreases as a result of downgrading equipment’s availability.

However, in recent years, as a result of difficult working conditions such as deepening mine pit, lengthening haulage distance, hard rock (hardness f = 10 – 13), old equipments, increasing working hour, haul routes become bad in rainy seasons, these factors cause many effects to equipment’s productivity. Trucks in mine are classified as in table 4.5.

4.3. System performance analysis using queuing theory

The shovel-truck haulage system analyzed here using queuing model. The time data of the shovel-truck was recorded during a month in different positions and in a stable working shift, the detail of these values can be found in the appendix.

The first two needed inputs for the model are the arrival rate, λ and the service rate, μ. From these values, the haulage system’s performance is defined by:

Table 4.5: Mine truck classification (Cao Son's report, 2014)

No	**Trucks**	**Origin**	**Amount**	**Classification**		
				A	B	C
1	Cat 773E 58 Tons	USA	25	10		15
2	HD 465 -7 55 Tons	Japan	50	5	45	
3	CAT 777E 96 Tons	USA	4		4	
4	VOLVO 32 Tons	Swiss	10			10
5	VOLVO 40E 32 Tons	Swiss	8	8		
6	KOMATSU HM - 2R 36Tons	Japan	5		5	
7	KOMATSU HM - 2R 36Tons	Japan	10		10	

- System utilization
- The average number of truck in the system
- The average number of truck in line
- The average time in the system, including service
- The average time in line

Using the formulas from (3-1) to (3-4), the results are summarized in the table 4.6:

Table 4.6: 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	15-Aug
Distance, km	3.5	3.5	3.5	3.5	3.5	3.8	4	4.2	3.6	3
λ, trucks/h	9.23	10.97	11.13	10.19	10.48	9.52	8.45	7.84	10.46	10.13
μ, trucks/h	17.06	17.11	17.92	15.71	16.91	17.73	17.52	17.24	16.77	17.15
Expected number of truck in system	1.18	1.79	1.64	1.85	1.63	1.16	0.93	0.84	1.66	1.44
Expected number of truck in queue	0.64	1.14	1.02	1.20	1.01	0.62	0.45	0.38	1.03	0.85
Expected time in system, mins	7.66	9.77	8.83	10.87	9.33	7.31	6.61	6.39	9.50	8.55
Expected time in queue, mins	4.15	6.26	5.48	7.05	5.78	3.93	3.19	2.91	5.93	5.05
Server utilization, %	54%	64%	62%	65%	62%	54%	48%	46%	62%	59%

Date	17-Aug	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	23-Aug	24-Aug	25-Aug	26-Aug
Distance, km	3.4	3.5	3.8	3.5	3.5	3.5	4.2	4.2	4.2	4.2
λ, trucks/h	9.47	10.21	8.46	8.39	8.22	8.35	8.58	8.53	8.47	8.32
μ, trucks/h	17.16	16.88	16.96	15.12	15.45	15.40	14.98	14.78	15.20	14.88
Expected number of truck in system	1.23	1.53	1.00	1.25	1.14	1.18	1.34	1.36	1.26	1.27
Expected number of truck in queue	0.68	0.92	0.50	0.69	0.60	0.64	0.77	0.79	0.70	0.71
Expected time in system, mins	7.80	8.99	7.06	8.91	8.30	8.51	9.37	9.59	8.92	9.15
Expected time in queue, mins	4.30	5.44	3.52	4.95	4.41	4.61	5.36	5.53	4.97	5.11
Server utilization, %	55%	60%	50%	55%	53%	54%	57%	58%	56%	56%

Date	27-Aug	28-Aug	29-Aug	31-Aug	01-Sep	02-Sep
Distance, km	3.8	3.8	3.8	3.8	3.8	3.5
λ, trucks/h	8.55	7.85	8.35	8.58	8.16	8.56
μ, trucks/h	15.10	14.48	14.72	14.82	14.45	15.02
Expected number of truck in system	1.30	1.18	1.31	1.37	1.30	1.33
Expected number of truck in queue	0.74	0.64	0.74	0.80	0.73	0.76
Expected time in system, mins	9.15	9.05	9.43	9.61	9.55	9.30
Expected time in queue, mins	5.18	4.91	5.35	5.56	5.40	5.30
Server utilization, %	57%	54%	57%	58%	57%	57%

4.4. Optimization process

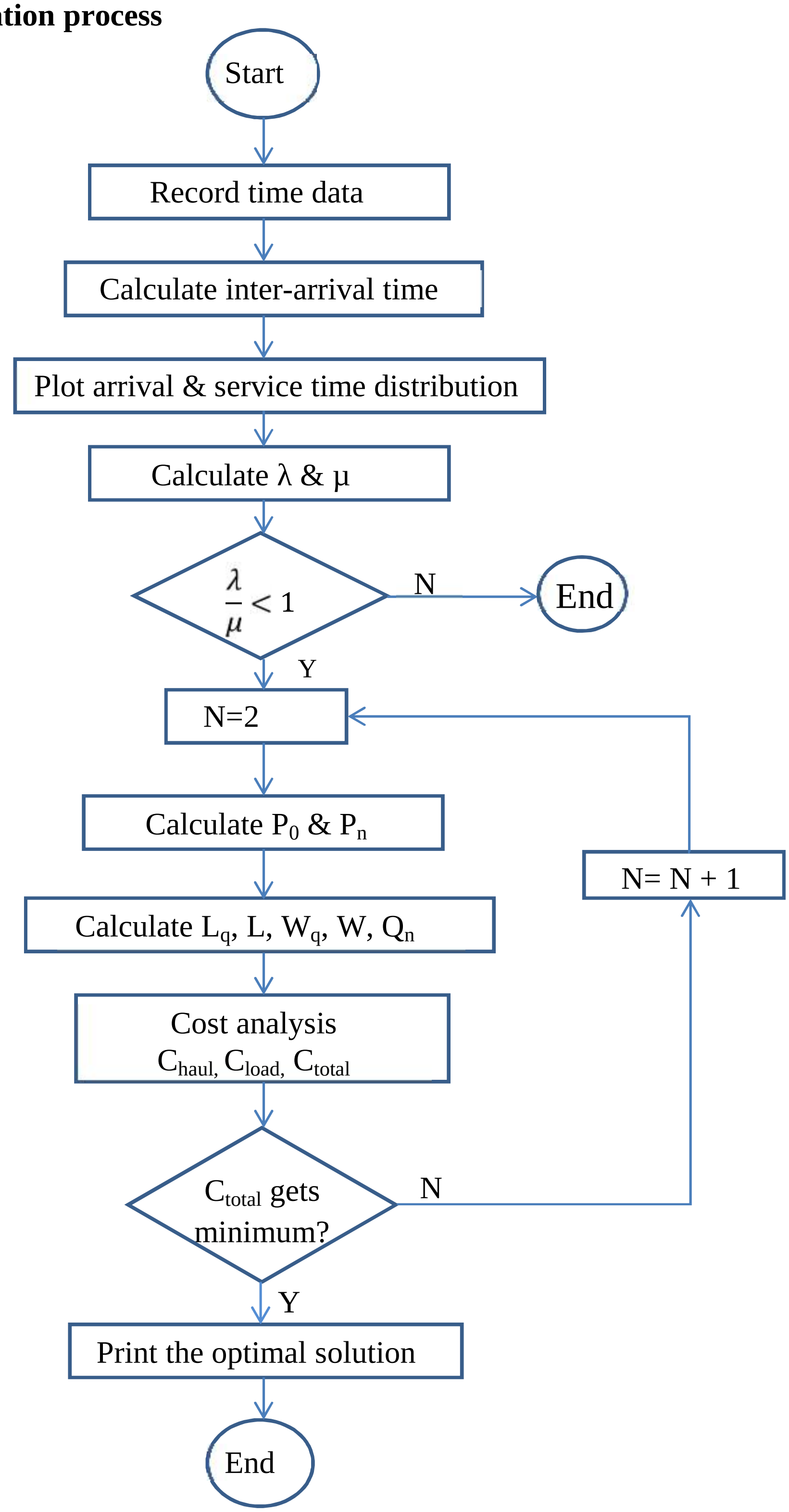


Figure 4.1: Optimization flow chart

4.4.1. Setting up the queuing model

The case was observed on 5th August, at the level +195 East Cao Son mine. At the normal working condition, mine operates within three shifts, 8 hours per ship and 1 hour break between a shift.

Figure 4.2: Observed queuing system

As in figure 4.2, at the observed time, the morning shift, there was 1 shovel EKG –07 (5 m^3 bucket capacity) loading rocks to dump trucks HD 465 (55 tons). This loading and haulage system created 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 (Figure 4.3, 4.4). Bench rock after blasting has a density of 2.63 t/m^3. The estimated hourly unit costs of hauling and loading for these equipments are VND 1,854,360 ($83) and VND 2,354,566 ($105), respectively.

Figure 4.3: Haulage route to dumping site

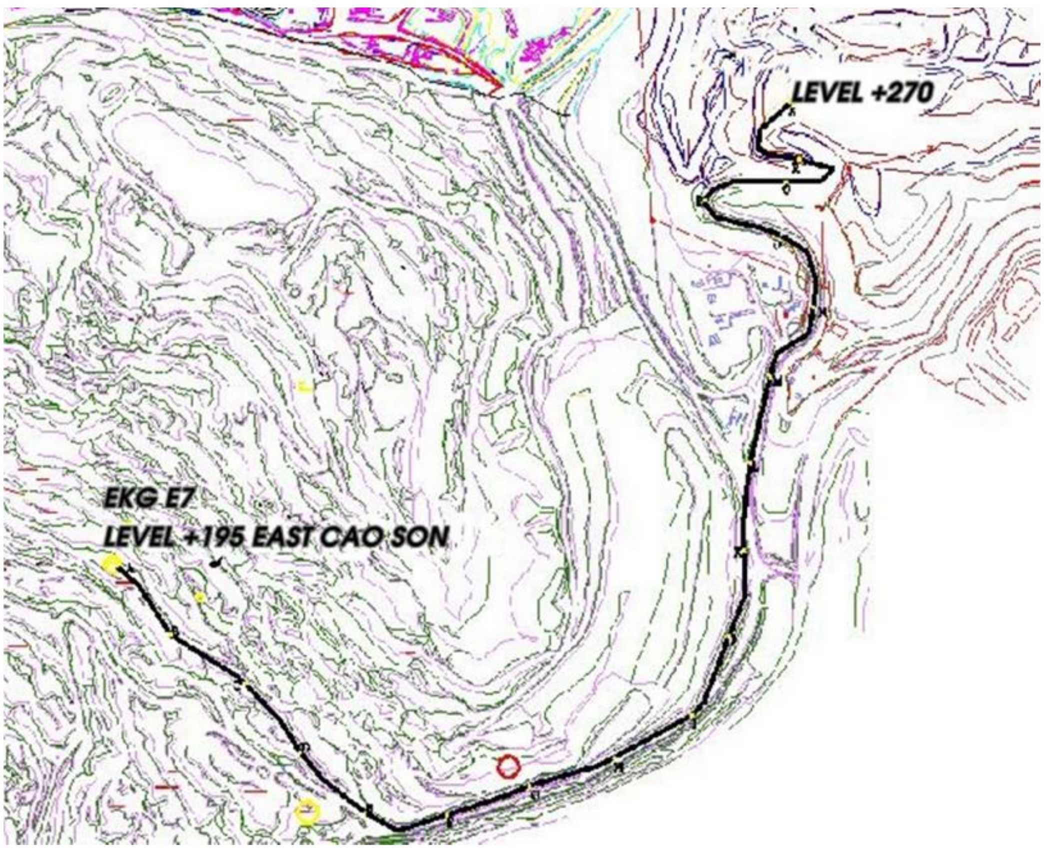


Figure 4.4: Contour map of the route from the shovel to the dumping site

The time data was recorded for the system as in the table 4.7. The arrival times of each truck were saved with its loading time.

Table 4.7: Recorded data of fleet

No	Arrival time	Inter-arrival time (min)	Service time (min)
1	8:51:08 AM	-	3.0
2	8:56:10 AM	5.03	3.5
3	9:05:09 AM	8.98	3.5
4	9:09:05 AM	3.93	3.1
5	9:14:06 AM	5.02	3.8
6	9:24:02 AM	9.93	3.5
7	9:27:12 AM	3.17	3.2
8	9:35:21 AM	8.15	4.0
9	9:46:22 AM	11.02	3.7
10	9:50:21 AM	3.98	3.1
11	9:57:07 AM	6.77	3.7
12	10:03:14 AM	6.12	3.8
13	10:06:03 AM	2.82	3.3
14	10:16:20 AM	10.28	3.3
15	10:23:00 AM	6.67	3.3
16	10:25:16 AM	2.27	3.2
17	10:32:22 AM	7.10	4.0
18	10:39:08 AM	6.77	3.3
19	10:43:18 AM	4.17	3.5
20	10:50:02 AM	6.73	3.9
21	10:58:11 AM	8.15	3.6
22	11:05:02 AM	6.85	3.7
23	11:11:06 AM	6.07	3.8
24	11:19:04 AM	7.97	3.5
25	11:26:23 AM	7.32	3.4
26	11:32:00 AM	5.62	3.7
27	11:40:07 AM	8.12	3.7
Mean		6.50	3.52

4.4.2. Inputs

Two important input data for the queuing model is the arrival rate, λ and the service rate, μ. The arrival rate λ is the average rate at which new trucks arrive at the shovel. The service rate μ is the average service rate of an individual shovel. Both of the arrival rate and service rate are independent of queue length.

From the table 4.7, the inter-arrival time or the time between each new arrival is the difference between times of each successive arrival truck. These 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 the figure 4.5, and can notice that the exponential distribution is fit for the inter-arrival times of trucks.

The service time is determined as the time when the shovel starts loading until finishes. Once the data of service time for arrivals are recorded, they are used for determining the distribution of service time of each arrival and its frequency in total. As in figure 4.6, service time follows an exponential distribution.

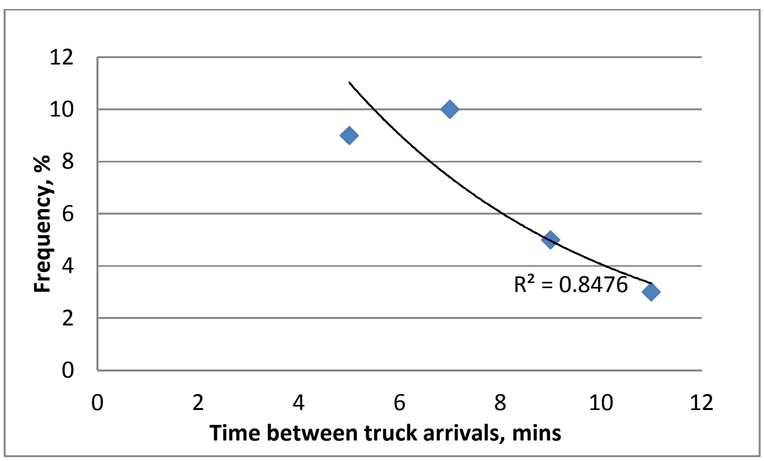


Figure 4.5: Inter-arrival time distribution

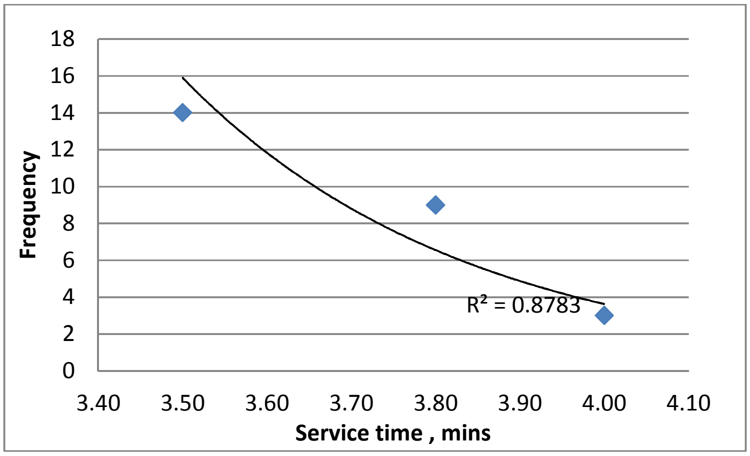


Figure 4.6: Service time distribution

From this point, the suitable queuing model can be applied for this case is (M/M/1), with 1 server in the system and there is exponential distribution for inter-arrival time and service time.

4.4.3. Calculation process and outputs

The two main parameters need to determine first are arrival rate and service rate of the system:

$$\text{Arrival rate } \lambda = \frac{1}{\text{average interarrival rate}} = \frac{1}{6.5/60} = 9 \text{ trucks/h}$$

$$\text{Service rate } \mu = \frac{1}{\text{average service rate}} = \frac{1}{3.52/60} = 17 \text{ trucks/h}$$

The calculation process will be handled to different cases with the number of trucks verify from 2 to 8 trucks. Let N = 2, using formulas from 3.41 – 3.46 we have:

- Probability of zero units in the system:

$$P_0 = \frac{1}{\sum_{i=0}^{2} 9/17^{\ i} \ \frac{2!}{2-1\ !}} = 0.46$$

- Probability of 2 units in the system:

$$P_2 = P_{(1)} + P_{(2)} = \frac{1!}{1-1\ !}\ \frac{9}{17}^{1}\ 0.46 + \frac{2!}{2-1\ !}\ \frac{9}{17}^{2}\ 0.46 = 0.50 + 0.27$$

$$= 0.77$$

- Average number waiting in line:

$$L_q = N - \frac{\lambda + \mu}{\lambda} \; 1 - P_0 \; = 2 - \frac{9 + 17}{9} \; 1 - 0.46 \; = 0.27$$

- Average number in the system:

$$L = \sum_{n=0}^{N} nP_n = \sum_{n=0}^{2} nP_n = 1.04$$

- Average waiting time in line (minute):

$$W_q = \frac{L_q}{\lambda \; N - L} = \frac{0.27 * 60}{9(2 - 1.04)} = 1.83$$

- Average time in the system (minute):

$$W = W_q + \frac{1}{\mu} = 1.83 + \frac{1}{17/60} = 5.35$$

- Shovel utilization:

$$\eta_s = 1 - P_0 = 1 - 0.46 = 0.54$$

- Production:

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

The calculation process then will be handled for the values of truck from 3 to 8. The final results summarized as the table 4.8:

Table 4.8: Results of the model

λ	9							
μ	17							
r	0.54							
N		2	3	4	5	6	7	8
	1	1.08	1.62	2.16	2.71	3.25	3.79	4.33
	2	0.59	1.76	3.51	5.86	8.79	12.30	16.40
	3		0.95	3.80	9.51	19.02	33.28	53.25
	4			2.06	10.29	30.88	72.05	144.10
	5				5.57	33.42	116.97	311.93
	6					18.09	126.61	506.42
	7						68.52	548.12
	8							296.63
P(0)		0.46	0.19	0.08	0.03	0.01	0.00	0.001
P(n)	0							
	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
λ’		8.87	13.86	15.70	16.57	16.91	17.02	17.05
Wq		1.83	2.97	5.27	8.09	11.27	14.66	18.14
W		5.35	6.49	8.79	11.61	14.79	18.18	21.65
η(s)		54%	81.2%	92.0%	97.1%	99.1%	99.8%	99.9%
Qn (tons/h)		460	693	785	829	845	851	852
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

4.4.4. Analysis

System efficiency

This queuing model is useful for analyzing the efficiency of mining haulage and loading operations in which they are currently operating. The efficiency of the system is determined by two indicators are W_q, the amount of time trucks spend waiting to be loaded at the shovel, and r, the server utilization. The larger the values of W_q, the more time trucks have to spend to be loaded, causing waste of fuel. Server utilization indicates the percentage of operational time of shovel.

Effects of fleet size to model outputs

From the table 4.8, 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 as in figure 4.7.

The figures 4.7 and 4.8 present a linear relationship between the number of truck in fleet with the expected number of trucks in queue and the expected time in queue correspondingly. When the number of trucks in the system increase, this will extend the queue length with more trucks have to wait for the shovel; therefore, the time that a truck spend waiting in queue will rise significantly.

Figure 4.9 shows the change of shovel utilization in the system with different number of trucks. As the number of truck increase, server will become more busy, shovel utilization increases gradually to a certain point. After this point, the curve becomes steady, if adding more trucks to the system, it leads to increase the queue length and the waiting time of truck in the queue.

System production also follows the same trend with this as in the figure 4.10. The production value only increases to a value at which more trucks in the system will result in long queue and excessive idling time of the trucks.

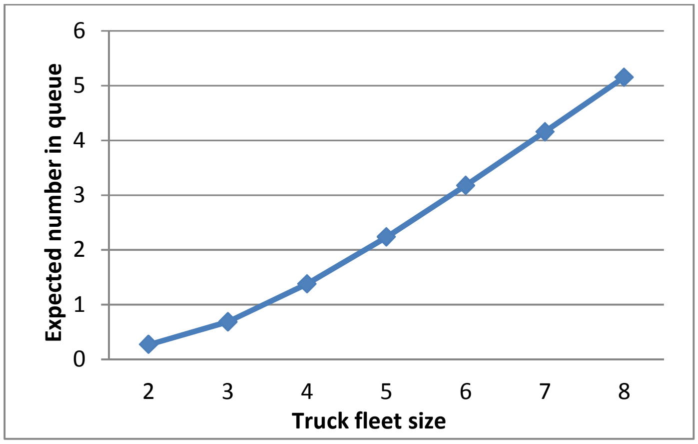


Figure 4.7: Truck fleet size vs. expected number of trucks in queue

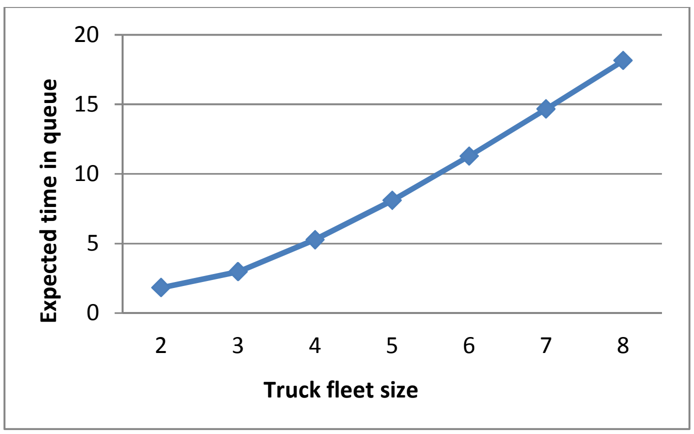


Figure 4.8: Truck fleet size vs. expected time of trucks in queue

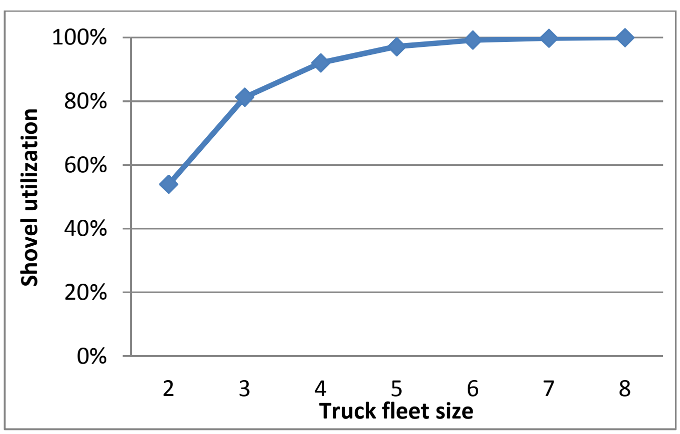


Figure 4.9: Truck fleet size vs. shovel utilization

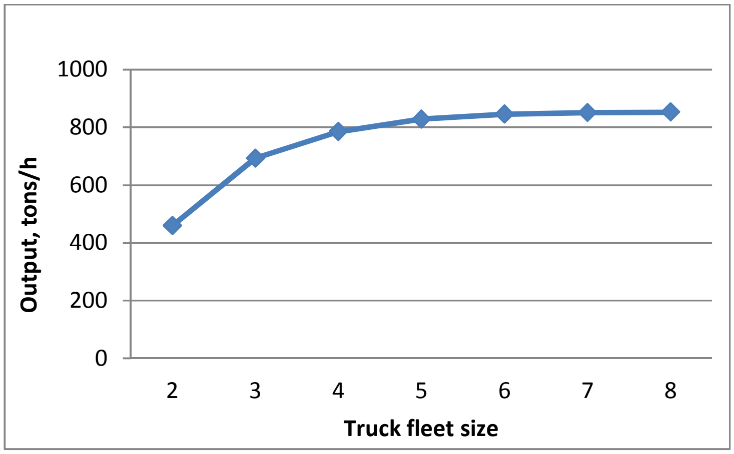


Figure 4.10: Truck fleet size vs. production

Fleet optimization

Regarding the relationship between truck number and operation costs as being given in the Figure 4.11, 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 down and lifting the hauling cost up. The total cost is obtained by summing up the hauling and loading cost curves.

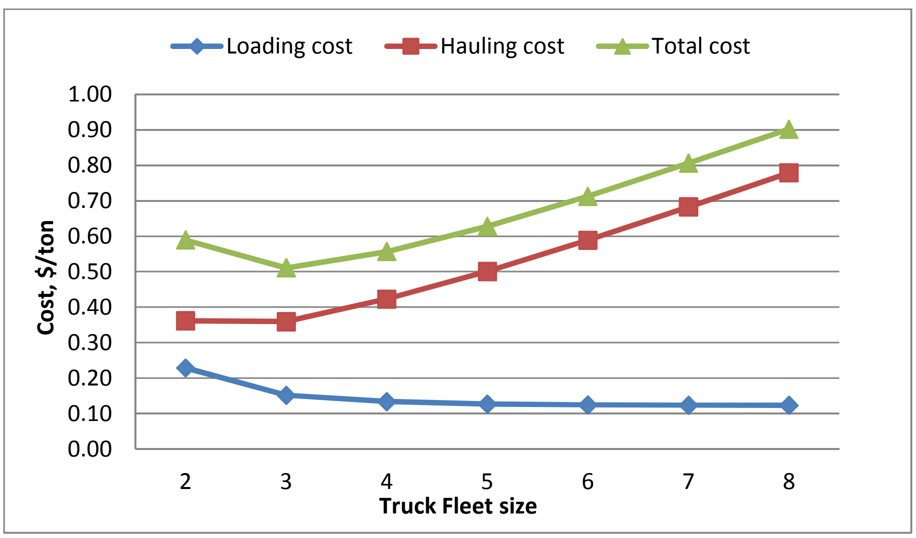


Figure 4.11: Truck fleet size vs. operating costs

From table 4.8, the comparison can be made easier by plotting all the cost values onto curves as in figure 4.11. The minimal value here is determined at the N = 3 or the optimized number of trucks for this fleet are 3.

4.5. Discussion

This study introduces an approach in analyzing shovel-truck haulage system in surface mine using queuing theory. The model was selected has a form of (M/M/1) with the conditions of finite customer resource queuing model. A analyzed model with detail steps was constructed and data were observed during a month on different shovel-truck systems. The two important parameters in the model, inter-arrival time and service time, were determined as the prerequisites of the whole analysis process. The results showed that, as the number of trucks increase, there are more trucks have to line up at the loading point. Meanwhile, this leads to shovel works more effectively and enhances productivity. However, there is a limit point for the number of trucks in the fleet, at which shovel utilization reaches limitation and if adding more trucks, queue will be going on increasing. 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 determined as the point that makes the operating costs minimal.

The (M/M/1) model is capable of analyzing and evaluating the efficiency of operations based on current fleet sizes. It can be applied for any haulage systems with the time data is collected, the arrival times of trucks and service times of shovel fit to the exponential distribuion. This model also can be used to define the optimized number of truck in the fleet at which the total operating cost gets minimum.

CHAPTER 5
CONCLUSION

In surface mining, truck haulage is the largest item in the operating costs, constituting of 50 to 60 percent. The problem of selecting a proper fleet equipment is very important to decision makers in order to transfer all the mining materials with an optimal cost.

Queuing theory is the study of the waiting lines, queue lengths and other properties of queues. Queuing models have been studied and applied in mining industry since long time ago with many successes in mining fleet selection and haul cycle analysis.

The queuing model (M/M/1) with finite calling population was applied for a case in Cao Son coal mine in Viet Nam with aim of analyzing the system's performance and selecting a suitable fleet size. The time data of the shovel-truck system was recorded and put into the model. The results showed the relationships between fleet size and queuing model's outputs such as expected number of truck in queue, time in queue and shovel utilization. In order to find the optimized fleet size, the model showed out the change of the operating costs with the different number of trucks in the system; therefore, the optimal number of truck is defined at the point that makes the operating costs minimal.

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APPENDIX: SHOVEL – TRUCK DATA

Shovel type: EKG-07 (5 m^3)

Truck type: HD465 (55 tons)

Position: level +195 East Cao Son

Table A1: Shovel-truck data, day 5th August 2015

No	Arrival time	Inter-arrival time (mins)	Service time (mins)
1	8:51:08 AM	-	3.0
2	8:56:10 AM	5.03	3.5
3	9:05:09 AM	8.98	3.5
4	9:09:05 AM	3.93	3.1
5	9:14:06 AM	5.02	3.8
6	9:24:02 AM	9.93	3.5
7	9:27:12 AM	3.17	3.2
8	9:35:21 AM	8.15	4.0
9	9:46:22 AM	11.02	3.7
10	9:50:21 AM	3.98	3.1
11	9:57:07 AM	6.77	3.7
12	10:03:14 AM	6.12	3.8
13	10:06:03 AM	2.82	3.3
14	10:16:20 AM	10.28	3.3
15	10:23:00 AM	6.67	3.3
16	10:25:16 AM	2.27	3.2
17	10:32:22 AM	7.10	4.0
18	10:39:08 AM	6.77	3.3
19	10:43:18 AM	4.17	3.5
20	10:50:02 AM	6.73	3.9
21	10:58:11 AM	8.15	3.6
22	11:05:02 AM	6.85	3.7
23	11:11:06 AM	6.07	3.8
24	11:19:04 AM	7.97	3.5
25	11:26:23 AM	7.32	3.4
26	11:32:00 AM	5.62	3.7
27	11:40:07 AM	8.12	3.7
Mean		6.50	3.52

Shovel type: EKG – $5m^3$

Truck type: CAT 769D – 58 tons

Position: +200 East Cao Son

Table A2: Shovel-truck data, day 6th August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:03:20	3.53	
2	13:08:23	3.43	5.05
3	13:13:55	3.50	5.53
4	13:19:03	3.67	5.13
5	13:24:36	3.47	5.55
6	13:30:33	3.47	5.95
7	13:36:43	3.50	6.17
8	13:42:11	3.48	5.47
9	13:47:37	3.57	5.43
10	13:53:27	3.53	5.83
11	13:58:58	3.52	5.52
12	14:04:09	3.42	5.18
13	14:09:30	3.58	5.35
14	14:15:28	3.43	5.97
15	14:20:39	3.37	5.18
16	14:26:19	3.48	5.67
17	14:31:28	3.45	5.15
18	14:37:02	3.52	5.57
19	14:42:25	3.55	5.38
20	14:47:32	3.50	5.12
21	14:53:20	3.47	5.80
22	14:58:21	3.60	5.02
23	15:03:49	3.57	5.47
24	15:09:11	3.52	5.37
Mean			5.47
(h)			0.09

Shovel type: EKG – 5m^3

Truck type: CAT 769D – 58 tons

Position: +200 East Cao Son

Table A3: Shovel-truck data, day 7th August 2015

No	Arrival time	Service time	Inter-arrival time
1	9:05:00	3.60	5.00
2	9:07:10	3.20	2.17
3	9:10:18	3.33	3.13
4	9:17:08	3.30	6.83
5	9:25:14	3.25	8.10
6	9:31:30	3.12	6.27
7	9:34:10	3.33	2.67
8	9:37:18	3.32	3.13
9	9:44:08	3.50	6.83
10	9:51:44	3.13	7.60
11	9:57:30	3.38	5.77
12	10:01:35	3.27	4.08
13	10:03:48	3.08	2.22
14	10:11:33	3.57	9.97
15	10:18:14	3.45	6.68
16	10:24:30	3.20	6.27
17	10:28:35	3.37	4.08
18	10:30:18	3.28	1.72
19	10:38:03	3.25	7.75
20	10:45:14	2.95	7.18
21	10:51:00	3.25	5.77
22	10:55:05	3.80	4.08
23	10:57:18	3.33	2.22
24	11:05:28	3.55	8.17
25	11:11:44	3.77	6.27
26	11:18:00	2.80	6.27
27	11:22:05	3.58	4.08
28	11:24:43	3.50	2.63
29	11:32:28	3.30	7.75
30	11:38:14	3.40	5.77
31	11:44:30	3.60	6.27
Mean		3.35	5.39
(h)		0.06	0.09

Shovel type: EKG – $5m^3$

Truck type: CAT 769D – 58 tons

Position: +200 East Cao Son

Table A4: Shovel-truck data, day 8th August 2015

No	Arrival time	Service time	Inter-arrival time
1	9:06:00	3.77	6.00
2	9:11:24	3.75	5.40
3	9:17:47	3.67	6.38
4	9:23:40	3.80	5.88
5	9:29:36	3.75	5.93
6	9:35:18	4.45	5.70
7	9:41:20	3.67	6.03
8	9:47:36	3.82	6.27
9	9:53:10	3.50	5.57
10	9:59:48	4.13	6.63
11	10:05:36	3.88	5.80
12	10:11:33	3.60	5.95
13	10:17:28	3.75	5.92
14	10:23:05	3.57	5.62
15	10:28:47	3.97	5.70
16	10:34:45	3.70	5.97
17	10:40:56	3.87	6.18
18	10:46:32	3.95	5.60
19	10:52:09	3.92	5.62
20	10:58:05	3.95	5.93
21	11:03:48	3.75	5.72
22	11:09:37	3.80	5.82
Mean		3.82	5.89
(h)		0.06	0.10

Shovel type: EKG – 5 m^3

Truck type: HD 456 – 56tons

Position: level +215 East Cao Son

Table A5: Shovel-truck data, day 10^{th} August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:00:00	4.13	0.00
2	13:15:10	3.70	15.17
3	13:19:18	3.42	4.13
4	13:23:08	3.22	3.83
5	13:27:20	3.45	4.20
6	13:32:30	3.37	5.17
7	13:37:10	3.32	4.67
8	13:42:22	3.42	5.20
9	13:47:34	4.13	5.20
10	13:53:06	3.38	5.53
11	13:59:18	3.27	6.20
12	14:05:30	3.92	6.20
13	14:10:42	4.23	5.20
14	14:15:54	3.45	5.20
15	14:20:06	3.20	4.20
16	14:26:18	3.37	6.20
17	14:31:30	3.28	5.20
18	14:37:42	3.25	6.20
19	14:42:54	2.95	5.20
20	14:48:06	3.25	5.20
21	14:54:18	3.80	6.20
22	15:01:11	3.47	6.88
23	15:07:23	3.55	6.20
24	15:12:35	3.77	5.20
25	15:16:47	3.80	4.20
26	15:23:44	3.75	6.95
27	15:29:54	3.50	6.17
28	15:35:06	3.30	5.20
29	15:40:18	4.25	5.20
Mean		3.55	5.73
(h)		0.06	0.10

Shovel type: EKG – $5m^3$

Truck type: CAT 773E – 58tons

Position: +190 East Cao Son

Table A6: Shovel-truck data, day 11st- August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:52:00	3.27	52.00
2	8:57:10	3.37	5.17
3	9:03:12	3.80	6.03
4	9:10:04	3.35	6.87
6	9:16:20	3.28	6.27
7	9:21:45	3.55	5.42
8	9:28:00	3.70	6.25
9	9:35:12	3.52	7.20
10	9:42:06	3.32	6.90
11	9:48:50	3.72	6.73
12	9:55:23	3.10	6.55
13	10:03:06	3.42	7.72
14	10:08:23	3.62	5.28
15	10:14:54	3.37	6.52
16	10:20:36	3.53	5.70
17	10:27:29	3.47	6.88
18	10:32:57	3.20	5.47
19	10:39:47	3.25	6.83
20	10:45:39	3.45	5.87
21	10:51:50	3.25	6.18
22	10:58:09	3.47	6.32
23	11:04:21	3.18	6.20
24	11:10:42	3.05	6.35
25	11:16:26	3.43	5.73
26	11:23:46	2.88	7.33
27	11:29:48	3.25	6.03
28	11:35:54	3.50	6.10
29	11:42:07	3.47	6.22
Mean		3.38	6.30
(h)		0.06	0.11

Shovel type: EKG – $5m^3$

Truck type: CAT 769D – 58 tons

Position: level +175 East Cao Son

Table A7: Shovel-truck data, day 12nd August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:48:36	2.93	48.60
2	8:56:20	3.70	7.73
3	9:04:16	3.37	7.93
4	9:11:45	3.63	7.48
5	9:19:23	2.92	7.63
6	9:24:40	3.45	5.28
7	9:31:28	3.67	6.80
8	9:38:33	4.08	7.08
9	9:47:06	3.63	8.55
10	9:53:55	3.13	6.82
11	9:59:46	3.38	5.85
12	10:06:51	3.27	7.08
13	10:15:03	3.08	8.20
14	10:20:47	3.57	5.73
15	10:27:52	3.62	7.08
16	10:34:38	3.20	6.77
17	10:41:52	3.37	7.23
18	10:48:36	3.62	6.73
19	10:55:11	3.25	6.58
20	11:02:06	2.95	6.92
21	11:10:04	3.25	7.97
22	11:17:06	4.30	7.03
23	11:24:14	3.33	7.13
24	11:31:46	3.55	7.53
25	11:38:54	3.80	7.13
26	11:46:03	2.97	7.15
Mean		3.42	7.10
(h)		0.06	0.12

Shovel type: EKG – $5m^3$

Truck type: CAT 769D – 58 tons

Position: level +175 East Cao Son

Table A8: Shovel-truck data, day 13rd August 2015

No	Arrival time	Service time	Inter-arrival time
1	12:48:36	3.33	48.60
2	12:56:20	3.40	7.73
3	13:04:25	3.70	8.08
4	13:12:05	3.63	7.67
5	13:20:24	3.58	8.32
6	13:28:38	3.78	8.23
7	13:36:47	3.50	8.15
8	13:44:50	4.05	8.05
9	13:52:08	3.80	7.30
10	14:00:20	3.27	8.20
11	14:08:17	3.05	7.95
12	14:16:22	3.10	8.08
13	14:24:45	3.08	8.38
14	14:32:36	3.23	7.85
15	14:40:28	3.62	7.87
16	14:48:36	3.30	8.13
17	14:56:41	3.35	8.08
18	15:04:29	3.40	7.80
19	15:12:45	3.27	8.27
20	15:20:51	3.62	8.10
21	15:28:34	3.30	7.72
22	15:36:53	3.80	8.32
23	15:36:53	3.90	0.00
Mean		3.48	7.65
(h)		0.06	0.13

Shovel type: EKG – 5 m^3

Truck type: HD 456 – 56tons

Position: level +215 East Cao Son

Table A9: Shovel-truck data, day 14th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:43:24	3.30	43.40
2	8:49:03	3.37	5.65
3	8:54:22	3.58	5.32
4	9:00:12	3.32	5.83
5	9:05:32	3.47	5.33
6	9:11:23	3.40	5.85
7	9:17:08	3.65	5.75
8	9:22:36	3.27	5.47
9	9:28:44	3.63	6.13
10	9:34:06	3.55	5.37
11	9:39:32	3.43	5.43
12	9:45:14	3.80	5.70
13	9:50:28	3.90	5.23
14	9:56:21	3.85	5.88
15	10:02:30	3.53	6.15
16	10:08:44	3.70	6.23
17	10:14:36	3.95	5.87
18	10:20:04	3.25	5.47
19	10:25:29	2.95	5.42
20	10:31:36	3.25	6.12
21	10:37:21	3.80	5.75
22	10:43:47	3.47	6.43
23	10:49:22	3.55	5.58
24	10:55:03	3.77	5.68
25	11:00:38	3.58	5.58
26	11:06:35	3.75	5.95
27	11:12:04	3.45	5.48
28	11:17:48	3.80	5.73
29	11:23:54	3.92	6.10
30	11:29:45	4.08	5.85
Mean		3.58	5.74
(h)		0.06	0.10

Shovel type: EKG – $5m^3$

Truck type: CAT 773E – 58tons

Position: level +185 East Cao Son

Table A10: Shovel-truck data, day 15th August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:00:36	3.33	0.60
2	13:06:22	3.40	5.77
3	13:12:27	3.70	6.08
4	13:18:36	3.63	6.15
5	13:24:33	3.58	5.95
6	13:30:46	3.78	6.22
7	13:36:17	3.50	5.52
8	13:42:18	4.05	6.02
9	13:48:37	3.80	6.32
10	13:54:28	3.27	5.85
11	14:00:06	3.05	5.63
12	14:05:29	3.10	5.38
13	14:11:54	3.08	6.42
14	14:17:48	3.23	5.90
15	14:23:40	3.62	5.87
16	14:29:57	3.30	6.28
17	14:35:32	3.35	5.58
18	14:41:27	3.40	5.92
19	14:47:22	3.27	5.92
20	14:53:37	3.62	6.25
21	14:59:19	3.30	5.70
22	15:05:48	3.80	6.48
23	15:11:46	3.90	5.97
24	15:17:38	3.33	5.87
25	15:23:08	4.03	5.50
26	15:28:38	3.53	5.50
Mean		3.50	5.92
(h)		0.06	0.10

Shovel type: EKG – $5m^3$

Truck type: CAT 773E – 58tons

Position: level +185 East Cao Son

Table A11: Shovel-truck data, day 17th August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:05:28	3.30	5.47
2	13:11:42	3.10	6.23
3	13:19:20	3.88	7.63
4	13:26:08	3.47	6.80
5	13:32:35	3.75	6.45
6	13:38:02	3.62	5.45
7	13:44:21	3.67	6.32
8	13:49:55	3.95	5.57
9	13:55:06	3.63	5.18
10	14:02:18	3.53	7.20
11	14:08:36	3.47	6.30
12	14:15:24	3.43	6.80
13	14:22:18	3.22	6.90
14	14:29:05	3.40	6.78
15	14:36:02	3.70	6.95
16	14:42:23	3.47	6.35
17	14:48:36	3.37	6.22
18	14:55:04	4.07	6.47
19	15:01:21	3.30	6.28
20	15:06:57	3.45	5.60
21	15:12:45	3.63	5.80
22	15:18:50	3.22	6.08
23	15:25:02	2.95	6.20
24	15:31:14	3.33	6.20
Mean		3.50	6.34
(h)		0.06	0.11

Shovel type: EKG – 5 m^3

Truck type: HD 456 – 56tons

Position: level +215 East Cao Son

Table A12: Shovel-truck data, day 18th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:15:22	3.33	15.37
2	8:21:03	3.20	5.68
3	8:28:01	3.42	6.97
4	8:34:12	3.15	6.18
5	8:39:57	3.28	5.75
6	8:45:40	3.40	5.72
7	8:52:05	3.77	6.42
8	8:58:26	3.37	6.35
9	9:04:12	3.67	5.77
10	9:10:22	3.55	6.17
11	9:16:34	3.43	6.20
12	9:21:55	3.43	5.35
13	9:27:16	3.72	5.35
14	9:33:40	3.52	6.40
15	9:38:50	3.70	5.17
16	9:44:20	3.85	5.50
17	9:50:18	3.45	5.97
18	9:57:02	3.25	6.73
19	10:03:04	3.43	6.03
20	10:08:40	3.30	5.60
21	10:14:34	3.63	5.90
22	10:20:15	3.57	5.68
23	10:25:48	3.75	5.55
24	10:31:07	3.40	5.32
25	10:36:48	3.35	5.68
26	10:42:36	3.75	5.80
27	10:47:56	3.78	5.33
28	10:54:03	3.45	6.12
29	11:00:08	3.92	6.08
30	11:05:36	3.75	5.47
31	11:11:25	4.32	5.82
32	11:17:18	3.82	5.88
33	11:23:30	3.60	6.20
Mean		3.55	5.88
(h)		0.06	0.10

Shovel type: EKG – 5m^3

Truck type: HD465-7R – 55 tons

Position: level + 190 East Cao Son

Table A13: Shovel-truck data, day 19th August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:04:16	3.80	4.27
2	13:11:24	2.90	7.13
3	13:19:32	3.77	8.13
4	13:26:17	4.30	6.75
5	13:33:20	3.75	7.05
6	13:40:44	3.78	7.40
7	13:47:36	3.93	6.87
8	13:54:16	2.92	6.67
9	14:02:04	2.78	7.80
10	14:09:12	3.33	7.13
11	14:16:26	3.80	7.23
12	14:23:30	3.50	7.07
13	14:30:22	3.42	6.87
14	14:37:24	3.57	7.03
15	14:43:46	3.75	6.37
16	14:50:33	4.30	6.78
17	14:57:45	3.60	7.20
18	15:04:26	3.40	6.68
19	15:11:23	3.53	6.95
20	15:18:39	3.58	7.27
21	15:26:04	2.80	7.42
22	15:33:12	3.33	7.13
Mean		3.54	7.09
(h)		0.06	0.12

Shovel type: EKG – $5m^3$

Truck type: HD465-7R – 55 tons

Position: level + 190 East Cao Son

Table A14: Shovel-truck data, day 20th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:23:14	4.33	23.23
2	8:30:13	3.90	6.98
3	8:37:24	3.78	7.18
4	8:44:36	4.15	7.20
5	8:51:47	4.22	7.18
6	8:58:50	3.93	7.05
7	9:05:22	3.83	6.53
8	9:12:06	4.37	6.73
9	9:19:44	3.72	7.63
10	9:27:20	3.55	7.60
11	9:35:12	4.08	7.87
12	9:42:36	3.80	7.40
13	9:49:54	3.72	7.30
14	9:55:57	4.35	6.05
15	10:02:35	3.78	6.63
16	10:10:21	4.23	7.77
17	10:18:05	3.95	7.73
18	10:25:34	3.67	7.48
19	10:32:32	3.70	6.97
20	10:39:24	4.00	6.87
21	10:46:33	4.17	7.15
22	10:53:02	3.73	6.48
23	11:01:03	3.92	8.02
24	11:08:24	3.83	7.35
25	11:15:30	4.35	7.10
26	11:22:36	4.08	7.10
27	11:29:40	3.62	7.07
28	11:36:22	4.35	6.70
Mean		3.97	7.15
(h)		0.07	0.12

Shovel type: EKG – 5m^3

Truck type: HD465-7R – 55 tons

Position: level + 190 East Cao Son

Table A15: Shovel-truck data, day 21st August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:10:45	3.67	10.75
2	8:15:23	3.73	4.63
3	8:25:07	3.62	9.73
4	8:32:12	3.48	7.08
5	8:40:04	4.03	7.87
6	8:47:03	4.27	6.98
7	8:54:36	3.92	7.55
8	9:02:14	3.83	7.63
9	9:09:32	3.78	7.30
10	9:17:30	3.88	7.97
11	9:24:42	3.70	7.20
12	9:32:28	3.80	7.77
13	9:40:02	3.93	7.57
14	9:46:38	3.62	6.60
15	9:54:25	4.00	7.78
16	10:02:00	3.97	7.58
17	10:09:22	3.95	7.37
18	10:15:40	4.17	6.30
19	10:23:14	4.08	7.57
20	10:29:40	3.83	6.43
21	10:37:05	3.90	7.42
22	10:44:02	3.77	6.95
23	10:51:22	3.92	7.33
24	10:57:50	3.80	6.47
25	11:05:26	3.87	7.60
26	11:13:08	4.18	7.70
27	11:20:32	4.13	7.40
Mean		3.88	7.30
(h)		0.06	0.12

Shovel type: EKG – 5m^3

Truck type: HD465-7R – 55 tons

Position: level + 190 East Cao Son

Table A16: Shovel-truck data, day 22nd August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:08:24	3.77	8.40
2	13:15:23	4.07	6.98
3	13:23:02	4.27	7.65
4	13:29:46	3.87	6.73
5	13:37:54	3.80	8.13
6	13:45:21	4.00	7.45
7	13:52:08	3.58	6.78
8	13:59:15	3.92	7.12
9	14:06:39	3.78	7.40
10	14:13:24	3.67	6.75
11	14:20:18	4.30	6.90
12	14:27:45	3.75	7.45
13	14:35:00	3.80	7.25
14	14:42:11	3.67	7.18
15	14:49:04	3.92	6.88
16	14:56:13	3.60	7.15
17	15:03:40	4.10	7.45
18	15:11:32	3.40	7.87
19	15:18:00	4.20	6.47
20	15:25:06	4.42	7.10
21	15:32:11	3.97	7.08
Mean		3.90	7.19
(h)		0.06	0.12

Shovel type: EKG 10 – 10m^3

Truck type: HD 785 – 91 tons

Position: +175 East Cao Son

Table A17: Shovel-truck data, day 23rd August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:25:18	4.13	25.30
2	8:32:24	4.20	7.10
3	8:39:33	4.25	7.15
4	8:46:17	3.83	6.73
5	8:53:32	4.17	7.25
6	9:00:04	3.90	6.53
7	9:07:15	4.43	7.18
8	9:14:40	4.18	7.42
9	9:21:14	3.93	6.57
10	9:28:14	4.05	7.00
11	9:35:26	4.10	7.20
12	9:42:10	3.75	6.73
13	9:49:05	3.87	6.92
14	9:56:27	4.00	7.37
15	10:03:32	4.17	7.08
16	10:10:46	4.10	7.23
17	10:17:23	3.95	6.62
18	10:24:42	3.95	7.32
19	10:31:28	4.02	6.77
20	10:38:40	3.97	7.20
21	10:45:12	3.63	6.53
22	10:52:34	4.07	7.37
23	10:59:03	3.80	6.48
24	11:06:18	3.93	7.25
25	11:13:27	3.83	7.15
26	11:20:32	4.03	7.08
27	11:27:08	3.87	6.60
Mean		4.00	6.99
(h)		0.07	0.12

Shovel type: EKG 10 – 10m^3

Truck type: HD 785 – 91 tons

Position: +175 East Cao Son

Table A18: Shovel-truck data, day 24th August 2015

No	Arrival time	Service time	Inter-arrival time
1	13:02:26	4.08	2.43
2	13:09:12	4.25	6.77
3	13:16:24	3.93	7.20
4	13:24:32	4.03	8.13
5	13:31:16	4.23	6.73
6	13:38:10	4.18	6.90
7	13:45:22	4.27	7.20
8	13:52:08	3.92	6.77
9	13:59:05	4.10	6.95
10	14:06:24	3.87	7.32
11	14:13:05	4.03	6.68
12	14:20:07	4.17	7.03
13	14:27:14	3.80	7.12
14	14:34:36	3.93	7.37
15	14:41:46	4.07	7.17
16	14:48:21	3.97	6.58
17	14:55:34	4.28	7.22
18	15:02:27	4.02	6.88
19	15:09:08	3.87	6.68
20	15:16:33	3.97	7.42
21	15:23:34	4.27	7.02
22	15:30:21	4.23	6.78
23	15:37:21	4.10	7.00
24	15:44:21	3.80	7.00
25	15:51:21	3.95	7.00
26	15:58:21	4.07	7.00
27	16:05:21	4.20	7.00
Mean		4.06	7.04
(h)		0.07	0.12

Shovel type: EKG 10 – 10m^3

Truck type: HD 785 – 91 tons

Position: +175 East Cao Son

Table A19: Shovel-truck data, day 25th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:33:14	3.75	33.23
2	8:40:13	3.87	6.98
3	8:47:33	4.03	7.33
4	8:55:12	3.97	7.65
5	9:02:11	4.07	6.98
6	9:09:26	4.00	7.25
7	9:16:28	4.10	7.03
8	9:23:35	3.93	7.12
9	9:30:24	4.08	6.82
10	9:37:18	4.05	6.90
11	9:44:41	4.17	7.38
12	9:51:02	3.77	6.35
13	9:58:11	3.85	7.15
14	10:05:02	3.80	6.85
15	10:12:03	3.60	7.02
16	10:19:32	4.03	7.48
17	10:26:24	3.95	6.87
18	10:33:08	4.00	6.73
19	10:40:52	3.70	7.73
20	10:47:17	3.97	6.42
21	10:54:33	4.18	7.27
22	11:02:08	4.03	7.58
23	11:09:14	4.05	7.10
24	11:16:20	3.97	7.10
25	11:23:48	4.00	7.47
26	11:30:15	3.70	6.45
Mean		3.95	7.08
(h)		0.07	0.12

Shovel type: EKG 10 – 10m^3

Truck type: HD 785 – 91 tons

Position: +175 East Cao Son

Table A20: Shovel-truck data, day 26th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:35:26	4.20	35.43
2	8:42:34	4.07	7.13
3	8:49:15	4.02	6.68
4	8:56:22	4.17	7.12
5	9:03:18	4.13	6.93
6	9:11:02	4.03	7.73
7	9:18:26	4.10	7.40
8	9:25:03	4.03	6.62
9	9:32:45	3.90	7.70
10	9:40:13	3.80	7.47
11	9:47:56	4.03	7.72
12	9:55:20	4.20	7.40
13	10:02:36	4.25	7.27
14	10:10:09	3.90	7.55
15	10:17:22	3.95	7.22
16	10:24:11	4.00	6.82
17	10:31:34	4.25	7.38
18	10:38:25	4.13	6.85
19	10:45:26	4.10	7.02
20	10:52:18	3.80	6.87
21	10:59:23	3.67	7.08
22	11:06:12	3.93	6.82
23	11:13:22	4.15	7.17
24	11:20:38	3.83	7.27
25	11:28:32	4.17	7.90
Mean		4.03	7.21
(h)		0.07	0.12

Shovel type: EKG 10m^3

Truck type: CAT 785 – 91 tons

Position: +115 East Cao Son

Table A21: Shovel-truck data, day 27th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:40:14	4.30	40.23
2	8:47:21	4.08	7.12
3	8:54:12	4.20	6.85
4	9:01:02	4.13	6.83
5	9:08:24	3.92	7.37
6	9:15:32	4.05	7.13
7	9:22:45	3.97	7.22
8	9:29:36	3.90	6.85
9	9:36:44	3.83	7.13
10	9:43:16	4.02	6.53
11	9:50:11	4.05	6.92
12	9:57:30	3.82	7.32
13	10:04:54	3.93	7.40
14	10:11:32	3.95	6.63
15	10:18:22	3.77	6.83
16	10:25:04	4.02	6.70
17	10:32:07	4.20	7.05
18	10:39:46	4.00	7.65
19	10:46:22	3.93	6.60
20	10:53:10	3.73	6.80
21	11:00:40	4.18	7.50
22	11:07:33	4.00	6.88
23	11:14:21	3.05	6.80
24	11:21:08	4.20	6.78
25	11:28:43	4.08	7.58
Mean		3.97	7.02
(h)		0.07	0.12

Shovel type: EKG 10m^3

Truck type: CAT 785 – 91 tons

Position: +115 East Cao Son

Table A22: Shovel-truck data, day 28th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:25:08	4.13	25.13
2	8:32:17	4.03	7.15
3	8:40:05	4.17	7.80
4	8:47:02	4.18	6.95
5	8:55:01	4.08	7.98
6	9:02:34	4.03	7.55
7	9:10:22	4.23	7.80
8	9:17:40	4.43	7.30
9	9:25:34	4.20	7.90
10	9:33:29	4.10	7.92
11	9:41:56	4.17	8.45
12	9:49:11	4.15	7.25
13	9:56:24	3.93	7.22
14	10:03:38	4.08	7.23
15	10:11:46	4.27	8.13
16	10:20:00	4.08	8.23
17	10:27:33	4.17	7.55
18	10:35:26	4.03	7.88
19	10:42:38	4.12	7.20
20	10:50:11	4.23	7.55
21	10:57:56	4.18	7.75
22	11:05:38	3.97	7.70
23	11:13:22	4.12	7.73
24	11:20:45	4.20	7.38
25	11:28:36	4.30	7.85
Mean		4.14	7.64
(h)		0.07	0.13

Shovel type: EKG 10m^3

Truck type: CAT 785 – 91 tons

Position: +115 East Cao Son

Table A23: Shovel-truck data, day 29th August 2015

No	Arrival time	Service time	Inter-arrival time
1	1:24:10	3.83	24.17
2	1:31:21	3.80	7.18
3	1:38:32	4.08	7.18
4	1:45:43	4.18	7.18
5	1:52:54	3.95	7.18
6	2:00:05	3.55	7.18
7	2:07:16	4.33	7.18
8	2:14:27	4.18	7.18
9	2:21:38	4.10	7.18
10	2:28:49	4.25	7.18
11	2:36:00	4.13	7.18
12	2:43:11	4.13	7.18
13	2:50:22	4.12	7.18
14	2:57:33	4.20	7.18
15	3:04:44	4.27	7.18
16	3:11:55	4.02	7.18
17	3:19:06	4.08	7.18
18	3:26:17	4.17	7.18
Mean		4.08	7.18
(h)		0.07	0.12

Shovel type: EKG 10m^3

Truck type: CAT 785 – 91 tons

Position: +115 East Cao Son

Table A24: Shovel-truck data, day 31th August 2015

No	Arrival time	Service time	Inter-arrival time
1	8:16:14	3.97	16.23
2	8:23:23	4.05	7.15
3	8:30:46	4.08	7.38
4	8:37:18	4.05	6.53
5	8:44:01	4.13	6.72
6	8:51:28	4.07	7.45
7	8:58:02	4.17	6.57
8	9:05:09	4.10	7.12
9	9:12:22	4.18	7.22
10	9:19:33	4.13	7.18
11	9:26:18	3.98	6.75
12	9:33:45	3.92	7.45
13	9:40:11	4.27	6.43
14	9:47:38	4.08	7.45
15	9:54:06	4.10	6.47
16	10:01:32	4.02	7.43
17	10:08:39	3.50	7.12
18	10:15:44	4.00	7.08
19	10:22:04	4.22	6.33
20	10:29:18	4.13	7.23
21	10:36:48	4.08	7.50
22	10:43:07	4.17	6.32
23	10:50:20	4.03	7.22
24	10:57:09	4.10	6.82
25	11:04:05	3.83	6.93
26	11:11:08	3.92	7.05
27	11:18:30	3.92	7.37
28	11:25:04	4.13	6.57
Mean		4.05	6.99
(h)		0.07	0.12

Shovel type: EKG 10m^3

Truck type: CAT 785 – 91 tons

Position: +115 East Cao Son

Table A25: Shovel-truck data, day 1st September 2015

No	Arrival time	Service time	Inter-arrival time
1	8:18:25	4.08	18.42
2	8:25:46	4.18	7.35
3	8:33:17	4.13	7.52
4	8:40:25	4.25	7.13
5	8:47:18	4.17	6.88
6	8:54:26	4.20	7.13
7	9:02:05	4.40	7.65
8	9:09:17	4.27	7.20
9	9:16:09	4.20	6.87
10	9:23:46	4.03	7.62
11	9:31:25	4.22	7.65
12	9:38:15	3.92	6.83
13	9:45:22	3.97	7.12
14	9:52:02	4.03	6.67
15	9:59:11	4.20	7.15
16	10:06:35	4.13	7.40
17	10:14:29	4.17	7.90
18	10:21:37	4.15	7.13
19	10:29:05	4.12	7.47
20	10:36:36	4.27	7.52
21	10:44:52	4.30	8.27
22	10:52:41	4.07	7.82
23	11:00:24	4.12	7.72
24	11:07:30	4.07	7.10
25	11:14:47	4.20	7.28
Mean		4.15	7.35
(h)		0.07	0.12

Shovel type: EKG 10 m^3

Truck type: CAT 777D – 96 tons

Position: level +135 East Cao Son

Table A26: Shovel-truck data, day 2nd September 2015

No	Arrival time	Service time	Inter-arrival time
1	13:14:26	4.17	14.43
2	13:21:17	4.08	6.85
3	13:28:09	4.00	6.87
4	13:35:22	4.03	7.22
5	13:42:06	3.90	6.73
6	13:49:08	4.08	7.03
7	13:56:38	4.13	7.50
8	14:03:27	4.02	6.82
9	14:10:36	4.05	7.15
10	14:17:46	4.15	7.17
11	14:24:44	4.08	6.97
12	14:31:06	4.05	6.37
13	14:38:21	4.07	7.25
14	14:45:56	3.83	7.58
15	14:52:37	3.87	6.68
16	14:59:44	3.93	7.12
17	15:06:02	3.80	6.30
18	15:13:03	3.83	7.02
19	15:20:05	3.90	7.03
20	15:27:33	3.92	7.47
Mean		4.00	7.01
(h)		0.07	0.12

VITAE

Name Dang Vu Hai

Student ID 5710120002

Educational Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Engineering	Hanoi University of Mining and Geology	2011

Scholarship Awards during Enrolment

The Thailand's Education Hub for Southern Region of ASEAN Countries (TEH-AC) 2014

List of Publication and Proceeding (If Possible)

Dang Vu Hai and Manoon Masniyom, (2016). Application of queuing theory in analysing shovel-truck haulage system in Viet Nam surface mine, Proceedings of the IRES International Conference, p43-46.