Application of Queuing Theory for Effective Equipment Utilization and Maximization of Productivity in Construction Management

Afshan Sheikh  
PG Scholar(Construction Engineering and Management),  
Department of Civil Engineering,  
SRM University, Kattankulathur, Kancheepuram, Tamil Nadu, India

M. Lakshmipathy  
Professor, Department of Civil Engineering,  
SRM University, Kattankulathur, Kancheepuram, Tamil Nadu, India

Arokiaparakash  
Assistant Professor, Department of Civil Engineering,  
SRM University, Kattankulathur, Kancheepuram, Tamil Nadu, India

Abstract
Each and every process in construction is strictly connected with costs and deadlines which have to be met by the investor/owner and the construction company. Equipment usage will give fast and accurate results at a reduced cost. However, some machine combinations fail to achieve results under the given conditions while other combinations will be optimal in all aspects for the given task. Thus an effective process is required to analyze the conditions carefully and to choose the optimal type, number and combination of equipment. The queuing theory can be used for this purpose of optimization, where the process of queues formation takes place and where customers are served by servers. The construction processes can be examined from the point of view of ‘servicing centers’ that provide service, as well as from the ‘customer’ point of view, which is waiting in the queue for service. In this paper the queuing theory is being applied to the construction activities of concreting and excavation in a multi-storey residential construction project to demonstrate how equipment utilization can be achieved.

Keywords: Equipment utilization, Equipment selection, Optimization, Queuing Theory.

Introduction
Equipment can be used at every phase of construction like excavation, compaction, leveling, hauling, grading etc. A large amount of project cost is accounted to equipment and machinery. Advantage of equipment utilization includes increased rate of output, reduction in overall cost, carrying out activities that cannot be carried out manually, maintaining the planned rate of production when there is labour shortage, maintain high quality standard etc. Thus proper choice and use of the equipment contributes to economy, quality, safety, speed and timely completion of the project. Factors affecting equipment selection include site considerations, economic considerations, equipment specifications, labor consideration, client and project specifications etc. However, delays in project execution may occur due to improper choice of equipment, unavailability of equipment at the required time, increased cycle time and waiting time and also poor technology and wrong mechanization. These problems can be overcome by applying queuing theory for equipment selection in order to minimize the extent of delays by reducing cycle time and idle time and thus reducing the associated cost.

Queuing theory is generally considered as a branch of operations research because the results are often used when making business decisions about the resources needed to provide a service. The study requires the analysis of parameters which govern planning and selection of equipment in order to determine equipment requirement (type and optimum number), waiting time, idle time, cycle time and time spent in system. Thus identify the conditions to apply queuing model can be achieved which provides outputs useful for higher production rates and optimizing the equipment utilization.

Literature Survey
Queuing theory is applied in mining operations for haul routes in multi-channel queuing models by assuming finite customers, closed system that serves customers in FIFO concept. The model developed calculates several outputs like loader utilization, time spent in system, number of trucks/customers in the system etc. which are used to measure the efficiency of haulage operations. However in this model if any changes are made to the mining haul system then new service rate and inter arrival times have to be calculated and also the scope of the project is limited to truck and shovel behavior in open pit mining operations [1].

A construction management process reengineering performance measurement (CMPRPM) model is developed based on queuing theory [2] to calculate process operation time in order to strike an optimal balance between manpower service capacity and process execution demand. This paper proposed a CMPRPM model that integrates efficiency and effectiveness estimators that are applicable to the construction industry needs and employs queuing theory to estimate operation time to evaluate efficiency. Process operation time and customer satisfaction are used as effectiveness and
efficiency evaluation indices. The queuing theory is a highly
suitable and significant tool for process operation time
evaluation since it allows dual conditions, i. e., an idle service
and customer queuing mechanism.

Study [3] uses empirical data collected at an Australian
refinery to verify and check the assumptions for queue
distributions to plan the off-road-truck hauling of titanium
dioxide to a refinery-surface mining operations(earthwork and
haulage) for the two models M/M/1 and M/G/1. Cycle time is
taken as a function of service components, machine
characteristics, machine efficiency; material characteristics
swell factor and system characteristics like number of servers
and waiting time, delays in the queue system. In a queuing
system/model all of these factors should be considered while
forming the underlying distribution. The Poisson distribution
can be considered for estimating the arrival rate, while the
normal distribution is taken for the service rate in a queuing
model. The distribution assumptions were tested by observing
the sand refiner queues and truck arrivals and comparing the
resulting distributions.

Queuing theory models based on assumptions applicable to
construction and mining operations have been validated by
reference to field data records by comparing theory with
practice. Models for several different circumstances are
provided, including queues with random arrivals and
exponential service times, cyclic queues, queues with
alternative distributions for arrivals and servicing, serial
queues and storage; earthmoving, open-cut mining operations
and quarrying, and machine maintenance and repair. While
there are many formulae and equations supplied for all of
these topics that can easily be used as tools, in scheduling,
cost analysis, productivity analysis and planning, there is
however very little information known about how closely
these models follow actual operations [4].

Several useful mathematical analyses in queuing theory and
mathematical models of key technologies have been stated in
wireless and wired communication networks such as internet
applications, channel access controls, topology construction,
energy saving schemes, and transmission scheduling [5]. This
work provides novel ideas, new analytical models, and
simulation and experimental results in the field of queuing
theory that can be used in construction management field as
well.

Attention is focused on establishing server utilization i. e. the
server computer must not be idle. The haul segments, the
dump segment and the loading segment of a truck cycle may
all be considered simultaneously rather than having to
consider one segment at a time as is the case in a finite source
analysis. This means that segmentation of the more
convenient and effective for analysis and application of the
theory [6].

The queues theory is used to examine operating channels in
evacuations, where queue formation takes place and then
subsequent servicing of customers by the servers [7]. It
demonstrates the use of a mathematical simulation model
which shows that some machine combinations achieve the
tasks while some others fail to do so. It assumes a closed
system where customer servicing is done according to FIFO.
Input parameters for the model include construction process,
volume of task, working shift, construction task, time
limitations etc. and also random values accounting for the
random effects. This study shows that it is possible to model
mathematically and technically the whole complicated
construction processes, with a number of simplifications and
then to perform various calculations and changes for effective,
efficient and long term planning of construction. The
limitation of this study is that only three variants of excavators
(server) and trucks (customer) are taken into account.

The queuing theory formulae are simplified for practical
applications in construction industry using the queuing rule of
thumb and this is achieved through considering two case
studies of concreting and earth moving, where two main
components of the queue system are stated to be customers
and servers. Also, it is learnt that hiring lower or more number
of servers or customers incurs loss. Cost is minimized only
under optimal conditions for both customers and servers. It
provides a simpler formula that people can memorize easily.
But, the queuing thumb rule only provides very rough
approximations and it is rather conservative when compared to
the standard stochastic queuing formula [8].

Pilot Study: Factors Affecting Equipment Selection
For the efficient selection of equipment the factors affecting
equipment use and efficiency have to be carefully analyzed.
From critical literature review it is found that the following
factors have to be taken into consideration while choosing
equipment:

Suitability for Job Conditions
The equipment must meet the requirement of the work,
climate and working conditions.

Size of the Equipment
Size of equipment should be such that it must be able to be
used with other matching units. If the equipment selected is of
larger size that will remain idle for most of the time or shall
work on part loads, which means production cost will be
more. On other side, if the equipment is of smaller size than
desired, the equipment will not be able to work with the
matching equipment and hence other equipment will have to
remain idle or to be allowed to work on part loads, which shall
again be uneconomical.

Standardization
It is better to have same type and size of equipment in the
project. It means lesser spare parts reserve, more inter
changeability of parts, easy for the operators to understand,
mechanics will be able to maintain and repair better as. They
become expert by handling similar type of equipment.

Availability of Equipment
The equipment which is easily available in the market should
be purchased. It should also be ensured that the equipment is
of repute and is likely to be continued manufactured in future
also. This is necessary for future standardization and ensuring
spare parts supply. It is easy to dispose of equipment after
completion of project.
Availability of Spare Parts
While selecting a particular type or make of equipment, it should be ensured that the spare parts will be available at a reasonable price throughout the working life of the equipment. It should also be ensured that the downtime of the equipment for want of spare parts may not be more. This is all the more necessary in case of imported equipment.

Multipurpose Equipment
There are certain types of equipment which are not utilized fully. Therefore if possible, they should be capable of performing more than one function. For example, take the case of an excavator with wheel loader bucket arrangement or with rock breaker attachment.

Availability of know-how
The equipment selected should be satisfactorily handled by available operators and mechanics. Sophisticated equipment may give excellent performance but it may be difficult to handle and maintain it through available know-how.

The Economic Aspects
While selecting the equipment, it should be considered that the cost of unit production should be a minimum.

Use in Future Projects
When equipment completes only a part of their useful life in a project, it should be kept in view that the equipment can be used in future projects and may not become obsolete.

Reliability of the Equipment
Equipment selected for the project must be reliable one.

Service Support
Service support should be available in the area of project where the equipment shall be used. Service after sales is a major criterion for selection of equipment.

Operating Requirements
The equipment selected should be easy to operate and maintain, acceptable to the operator and should have lesser fuel consumption.

Past Performance
If the equipment being purchased is of new make and model, it is desirable to enquire about its performance from other users, who are using this make and model.

Versatility
Versatility of the equipment should be given due priority. This means a machine which can be used for many jobs. The versatility promises extra profit from two directions; (i) allows one machine to do the job of several machines and thus cutting into ownership and operating costs associated with additional plant and labour, (ii) it increases equipment utilization, which means a machine earns money when it might otherwise be idle. Now-a-days attachments can be fitted or changed quickly with the help of couplers. A balance should be maintained between reliability, operating cost, and investment cost, since selecting the lowest priced equipment can often lead to overall higher costs.

Problem Statement
The following are some of the problems faced during equipment usage:

Element Failure and Accidents
Sudden and unexpected equipment failures, or breakdowns, are will obviously cause loss in time and money, since an equipment failure means that the machine is not producing any output. Failure also leads to defect loss which means that the equipment is producing products that do not fully meet the specified quality characteristics.

Maintenance
Maximizing product output at the optimum quality is the key to profitability. The value of maintenance lies in maintaining peak performance while minimizing equipment downtime in order to keep both throughput and quality at their highest possible levels. Regular maintenance ensures quality and timely project completion.

Unnecessary Costs Due To Poor Technology and Wrong Mechanism
If the wrong type of equipment is chosen then it will lead to increased cost as it results in poor quality work or takes excessive time for completion thus causing delays. Poor quality work will have to be redone. Also in a construction process time means money, so any delay caused will increase the expense. Rework and delays result in increase in the overall cost.

Unnecessary Delays Due To Accidents, Failure, Lack of Operators Etc.
Accidents, failure, lack of operators, strikes, labour union activities, non-timely maintenance etc. are some non-productive activities that cause delays or stoppage of work.

Additional Costs Due To Maintenance, Repair and Accidents
Unexpected accidents, untimely repairs and maintenance activities result in additional cost.

Lack of a systematic method for selection of suitable equipment and combinations
The lack of a systematic process or method which is quick and understandable for equipment selection mostly leads to the choice of wrong equipment (type and number).

Constrain in Placing or Accommodating the Equipment
This may be applicable to only some sites. The lack of a suitable place for placing equipment will result in reduction of its efficiency.

Difficulty to Manage, Supply and Schedule Machinery
If the equipment if not efficiently managed and scheduled then they will not be available at the required time and place. This causes delays and thus subsequently increases cost.
Unavailability of the Right Equipment in Right Number at the Required Time

Equipment unavailability causes delays in the production process.

Solution Approach
Application of queuing theory in construction processes

A queueing system is a system in which customers come for service, wait for the service if it is not free at the moment/readily available, and go on to the next server (which is free to provide service) and leave the system once they have been serviced. This theory was developed in 20\textsuperscript{th} century by AdnerKrarupErlang. Customer can be identified as the person or thing that demands service, and servers are those that provide service. This theory can be applied to equipment to choose the optimum fleet size, reduce the cycle time and idle time and reduce fuel consumption, rate of failures, financial cost and environmental impacts.

The queuing theory examines systems, where the process of queues formation takes place and the servicing of customers by servicing centers. The construction processes can be examined from the point of view of ‘servicing centers’ or ‘servers’, that provide service, as well as from the ‘customer’ point of view, which is waiting in the queue for service and are concerned with the waiting time. A waiting element decides which queue to wait in or whether to go to another system entirely.

In a construction process for the process of optimization, a closed system is more convenient, where customers, after a certain time of the service return back into the system and form the queue again. The queue length is limited and the processing of customer requirements is done according to the FIFO method. Fig. 1 depicts the closed queuing system that follows FIFO method.

![Figure 1: Closed system following FIFO](image)

Customer Arrivals:
The input describes the way in which the customer’s arrived and joins the system. It is necessary to know the distribution of the times between successive customer arrivals, or the inter-arrival times and to understand the behavior of customers upon entering the system. Customers arrive in a more or less random fashion which is not worth making the prediction. In situations with two or more parallel waiting lines a customer who switches from one line to the other. We deal with those queuing system in which the customers arrive in Poisson distribution.

Service Distributions:
This means the arrangement of service to serve customers. A probability distribution is also necessary to describe customer service times, since it will not always take the same amount of time for each customer to receive service. Single service is where one customer is serviced at a time, or batch service, where multiple customers receive simultaneous service from a single server are both service options. If the number of servers is finite then the customers are served in a specific order with the service time as a constant or a random variable. The mean service rate is denoted by μ.

Queue Discipline:
The manner in which customers in a queue are selected for service is referred to as the queue discipline. The most common queue discipline is First Come First Out(served), FIFO or FCFS, where customers receive service in the order in which they arrived.

System Capacity:
If a queue has a physical limitation to the number of customers that can be waiting in the system at one time, the maximum number of customers who can be receiving service and waiting is referred to as the system capacity. These are called finite queues since there is a finite limit to the maximum system size. If capacity is reached, no additional customers are allowed to enter the system.

Number of Service Stations:
The number of service stations in a queuing system refers to the number of servers operating in parallel that can service customers simultaneously. In a single server station, there is only one path that customers can take through the system. While in multiple servers available operating in parallel, incoming customers can wait for service by forming multiple queues at each server. Normally a finite number of multiple servers are considered.

Symbols and Abbreviations
Po = Probability of system being idle or probability of no customers are being server.
Ws = Expected waiting time for a customer in the system.
Wq = Expected waiting time in queue.
Ls = Expected number of customers in the System or length of the system.
Lq = Expected number of customers in queue.
Uf = Utility factor.
μ = Service Pattern.
C = Number of Servers in the System.
λ = Arrival rate.

Queuing Theory Models and Equations
Two models have been taken into consideration. The first model has a single server with finite customers and the second model has multiple servers with finite customers. The formulae [9] that can be used for both models are as below.

Queuing Model with Single Server (M/M/1)
\[ Po = 1 - \frac{2}{\mu} \] (1)
\[
W_s = \frac{1}{\mu \rho}, \\
W_q = \frac{\lambda}{\mu (\rho - \lambda)}, \\
L_s = \frac{1}{\mu (1 - \lambda / \mu)}, \\
L_q = \frac{\lambda^2}{\mu (\rho - \lambda)}.
\]

**Queueing Model with Multiple Servers (M/M/C)**

\[
Po = \frac{1}{(\Sigma_{n=0}^{\infty} (\frac{\lambda}{\mu})^n)} \left(\frac{1}{1 - \frac{\lambda}{\mu}}\right)^\rho
\]

\[
W_s = \frac{1 + Po}{\rho c \left(1 - \frac{\lambda}{\mu}\right)},
\]

\[
W_q = Po \frac{\rho c \left(1 - \frac{\lambda}{\mu}\right)}{\rho c \left(1 - \frac{\lambda}{\mu}\right)^2}
\]

\[
L_s = Po \frac{\rho c \left(1 - \frac{\lambda}{\mu}\right)}{\rho c \left(1 - \frac{\lambda}{\mu}\right)^2} + \frac{\lambda}{\mu}
\]

\[
L_q = Po \frac{\rho c \left(1 - \frac{\lambda}{\mu}\right)^2}{\rho c \left(1 - \frac{\lambda}{\mu}\right)^2}
\]

For both models the:

\[
U_f = \frac{1}{\mu}
\]

**Illustration**

**Concreting:**

In the case of concreting activities, the elements taken into consideration are the concrete truck, the concrete pump/crane and the placement crew. Firstly the servers and the customers have to be identified. For doing so, the two stakeholders are identified which are the contractor (carrying out the on-site project execution) and the concrete company (providing the concrete). From the contractor point of view, the concrete trucks are the customers while the crew and the crane with bucket/the concrete pumps are the servers. From the concrete company’s point of view, the concrete trucks are the servers while all the concrete pumps and placement crew are the customers. For the sake of uniformity, the contractor point of view is considered.

The flow of the concreting activities are looked, the crane and bucket (or the concrete pump) is the server for the concrete trucks. The placement and vibrating crew are the servers for the crane and bucket. Next, the most expensive agent is identified, which is the concrete pump, is optimized first: the number of concrete pumps (or cranes or hoists). Their number must be such that the concreting activities can be accomplished at minimum time and cost.

If too many concrete pumps are provided, the concreting activities will be accomplished faster, but it will be at higher cost of renting the concrete pumps and hiring the crew. If too few concrete pumps are provided, it is thought that the total cost of the system will be lower due to lower cost. However, when less number of servers is provided, the delay of the concrete trucks will be more than necessary. If the concrete trucks are made to wait for long durations, then the concrete will harden and the overall concreting activities will be delayed and the overall cost will be higher. Thus, even at less number of servers, the system incurs higher cost.

In concreting activities, the placement and vibrating crew are servers to the concrete pumps or cranes. They are usually the ordinary workers that are always available on the construction site. The concrete pump and placement crew must operate together to serve single customer which is the concrete truck.

If one of the servers (pump or crew) is not available, the service of concreting cannot be done. The number of placement crew is directly related to the number of concrete pumps or the hoists or the cranes. Thus, optimizing the number of concrete pumps will indirectly optimize the vibrating crew, at minimum cost and time. Optimal situation happens when both concrete trucks and concrete pumps would be minimal.

**Excavation**

In this second case study, earth moving activity is taken as a queueing system. Earth moving activities have the agents: excavators and the dump trucks. The excavators cut the soil and fill into the dump truck, which pump the soil to the dumping site. Let’s consider the excavators as the servers and the dump trucks waiting in line for the excavators to fill them up.

From this point of view, the most expensive agents is identified as the servers (in term of rental fee per hour). If too many excavators are provided, the earth moving activity can be finished faster but at a higher cost of renting the excavators. Clearly, providing higher number of servers incurs higher server cost. But on the other hand, if very few excavators are provided it will create long queue for the trucks to wait and there will be an overall delay in the earth moving activities. Thus, providing lower number of servers incurs higher customers cost as well.

Another factor affecting optimization is the distance between the dumping and the excavation site. Id the distance is small, that is when the service time is less than the hauling plus back hauling time, then lesser number of dump trucks is employed. Since the total time for haul and back haul will be small, providing too many dump trucks will result in them waiting in queue for service (increasing idle time). But on the other hand if the haul distance is large, that is service time is less than the hauling time, then more number of dump trucks have to be employed. Else the excavator will remain idle until the dump trucks return for the next service. However, optimization must be such that both excavator and dump truck need not wait for service.

**Application of the formulae**

Taken into consideration is the first case study of concreting activity, with the concrete mixing plant and the transit mixers which follow the finite capacity single server model (M/M/1). The arrival pattern follows poisons distribution with the arrival rate being 7 loads per day. The concrete plant has a discharge rate of 1.5 cubic meters per minute. The average load per truck is 7 cubic meter per load and the plant works for 8 hours per day. The total ownership and operating cost for the plant is 15000 Rupees per hour and for the concrete trucks is 2000 rupees/hour.

\[
\lambda = 7 \text{ loads/day}
\]
\[
m = \frac{1.5 \times 60}{7} = 12.85 \text{ load/hour}
\]

Using (1), \(Po = 0.45\)
Using (2), \(Ws = 0.17 \text{ hours/load}\)
Using (3), \(Wq = 0.093 \text{ hours/load}\)
Using (4), \(Ls = 1.9 \text{ trucks = 2 trucks}\)
Using (5), \(Lq = 0.65 \text{ trucks = 1 truck}\)

Amount of money lost due to idleness of the Concrete Plant
\[= 15000 \times Po \times \text{plant working hours per day} (12)\]
\[
= \text{Rupees 54000}
\]

Amount of money spent due to idleness of trucks
\[= 2000 \times Wq \times \lambda \times x \text{ working hours per day}\]
\[
= \text{Rupees 10416 N}
\]

Let ‘N’ denote the ideal number of trucks which can be determined by equating (11) and (12) to each other.

That is, \(10416 \times N = 54000\)

\(N = 5.18\)

Thus the ideal number of trucks for this case can be taken as 6 and the loss in money due to idle trucks as Rupees 62496.

However, it is seen that the concrete plant is idle for 45\% of the time, which means it’s utilization percentage is only 55\%.

In an attempt to improve the utilization and reduce the idle time and overall cost the same case is considered with varying arrival rates as shown in Table 1 below. For a constant service rate, by increasing the arrival rates, the various queue characteristics will vary which is shown in Table 1. It is clear that the number of customers waiting in queue and in the system increases as well as the waiting time in queue and system also increases.

For a constant service rate, by increasing the arrival rates the various queue characteristics will vary which is shown in Table 1. It is clear that the number of customers waiting in queue and in the system increases as well as the waiting time in queue and system also increases.

<table>
<thead>
<tr>
<th>Table 1: Variation of Various Queue Characteristics with Change in Arrival Rate</th>
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<tbody>
<tr>
<td>(\lambda)</td>
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<tr>
<td>12.85</td>
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On plotting a graph as in Fig. 2 which shows the variation of percentage utilization, number of customers and total waiting time, it has been seen that with the increase in arrival rate, the production rate can be maximized. However, the number of customers and the overall waiting time (waiting time of customer and server taken together) also increases. As the servers and customers waiting in line, both time and money are lost. Table 2 shows how the cost varies with the arrival rate and for better getting a better understanding about cost variations, graphs are plotted.

<table>
<thead>
<tr>
<th>Table 2: Loss Incurred due to Change in Arrival Rates</th>
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<tbody>
<tr>
<td>(\lambda)</td>
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<tr>
<td>12.85</td>
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</table>

Fig. 3 clearly shows that with increase in arrival rate the amount lost due to the server remaining idle decreases but at the same time the amount lost due to customer remaining idle drastically increases as shown in Fig. 4. Hence the overall loss, which is the summation of loss due to server idleness as well as loss due to customer idleness increases with increase in arrival rate as in Fig. 5.
To analyze the variation of the queue characteristics with respect to change in service rate table 3 is made. To be on the safer side the arrival rate of 8 loads per day is taken into consideration which has a higher productivity as well as an intermediate waiting time and cost.

**Table 3: Variation of Various Queue Characteristics with Change in Service Rate**

<table>
<thead>
<tr>
<th>µ</th>
<th>Po</th>
<th>Percentage Utilization</th>
<th>Ls (trucks)</th>
<th>Lq (trucks)</th>
<th>N (trucks)</th>
<th>Ws (hours/load)</th>
<th>Wq (hours/load)</th>
<th>Total Waiting Time (minutes/load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.11</td>
<td>89</td>
<td>8.00</td>
<td>7.11</td>
<td>15.1</td>
<td>1.00</td>
<td>0.89</td>
<td>113.3</td>
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<td>11</td>
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<td>73</td>
<td>2.67</td>
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<td>0.20</td>
<td>0.12</td>
<td>19.4</td>
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<td>0.53</td>
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<td>0.07</td>
<td>0.02</td>
<td>5.4</td>
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From the table 3 for a constant arrival rate (λ=8) it is clear that by increasing the service rate, the idle time of server increases while the waiting time, number of trucks required and percentage utilization decreases. To understand this a graph is plotted as in Fig. 6 which shows variation of percentage utilization, number of customers and total waiting time with change in service rates for constant arrival rates. It is thus clear that with the increase in service rate, the production rate and the truck requirement keeps decreasing. Even though the waiting time also reduces, there is drastic reduction in server utilization which cannot be accepted.

The next criterion to be considered is the amount of money that is wasted due to the use and idleness of the server as well as the customer. For this table 4 are made and the corresponding graphs are plotted. From table 4 it is observed...
that server idleness increases expenses while customer idleness decreases with increase in service capacity. This variation is plotted in the form of graph shown in Fig. 7 and Fig. 8 shows the total amount lost due to idleness of both customer and server its variation with changing service rates.

**Table 4: Loss Incurred due to Change in Service Rates**

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>Amount Lost due to Customer Idleness (Rupees)</th>
<th>Amount lost due to idle server (Rupees)</th>
<th>Total amount lost due idleness (Rupees)</th>
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<td>94374</td>
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</table>

From Fig. 8 it is understood that the overall amount lost due to idleness decreases drastically with increase in service rate. However a higher service rate cannot be chosen since the productivity is gravely affected by the variation. Thus while fixing the arrival rate, servicing rate and the number of customers, they should be such that the equipment utilization percentage is kept high, while at the same time the idle time of both server, waiting time of customer and the total cost must be maintained low. Similarly the various parameters can be calculated for Model 2 (M/M/C) using formulae (6) to (11) and the ideal service and arrival rate and numbers can be determined. The same method can be adopted for the second case study of excavation.

**Discussion**

Information has been obtained the problems associated with equipment usage and their productivity and how they adversely affect the cost is realized. Major problems relating to equipment usage are found to be: difficulty in management, scheduling and maintenance of the machines, the occurrence of unwanted cost due to accidents, failure and wrong choice of technology (machines and their combinations). Hence methods, techniques and measures to ensure equipment utility, lower overall cost and improved productivity is formulated and adopted by means of queuing theory. Two case studies have been taken in account to show the potential use of the queuing theory and application of its formulae. For both cases either single server system or multiple server system can be assumed and the appropriate formulae from (1) to (11) can be applied to calculate the idle time, waiting time, length of queue etc. It is seen clearly from the table that, for a constant service rate, with the increase in arrival rates the utilization of the equipment increases while the idle time of the server and the loss in cost of both the server as well as that of the servers reduces. But, for a constant arrival rate, as the service rate increases the productivity and waiting time reduces while the overall cost initially reduces and then increases. It is not possible to completely eliminate idle time of server and waiting time of customer equipment without incurring heavy costs. Thus in order to strike a balance between the various parameters, various combinations of arrival rate, service rate and number of equipment must be analyzed and the most suitable combination which ensures that the cost is minimum without compromising with the productivity of the equipment must be chosen. A model can be developed for this purpose. In order to reduce the idle time of the server, the arrival rates have to be increased. This can be achieved by improving the efficiency and capacity of the servers. On the other hand, to reduce the waiting time of customers, the service time is reduced (by using more efficient server or with a server of higher capacity). Any changes in capacity of the server or customer will result in a change in their number. Care must be taken to ensure that the arrival rate does not exceed the servicing rate. If this happens it means that the system is overload and that more number of servers will have to be employed. The aim is to reduce the cost of construction, to avoid unnecessary delays in
construction as well as to eliminate unnecessary cost due to wrong choice of technology, mechanism or combination.

Conclusion
Advantages of equipment utilization includes increased rate of output, reduction in overall cost, carrying out activities that cannot be carried out manually, maintaining the planned rate of production when there is labor shortage, maintain high quality standard etc. Thus proper choice and use of the equipment contributes to economy, quality, safety, speed and timely completion of the project. However, delays in project execution may occur due to improper choice of equipment, unavailability of equipment at the required time, increased cycle time and waiting time and also poor technology and wrong mechanization. These problems can be overcome by the applying queuing theory for equipment selection in order to minimize the extent of delays by reducing cycle time and idle time and thus reducing the associated cost. The key to solve queuing problem is on the modeling of customers and servers. This method when formulated appropriately can be used in managing a wide variety of equipment combinations.

References