# Performance Evaluation of Surface Mining Equipment with Particular Reference To Shovel-Dumper Mining

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# PERFORMANCE EVALUATION OF SURFACE MINING EQUIPMENT WITH PARTICULAR REFERENCE TO SHOVEL-DUMPER MINING

*A Thesis submitted in partial fulfilment of the requirements for the degree of*

**Master of Technology**

in

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by

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May 31, 2016

# Supervisors' Certificate

This is to certify that the work presented in the dissertation entitled ***Performance Evaluation of Surface Mining Equipment with Particular Reference to Shovel-Dumper Mining*** submitted by *Shailesh Kumar Sone*, Roll Number *214MN1451*, is a record of original research carried out by him under my supervision and guidance in partial fulfilment of the requirements of the degree of *Master of Technology in Mining Engineering*. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Dr. H. K. Naik
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# ABSTRACT

Surface mining is the most well-known mining around the world, and open pit mining accounts for more than 60% of all surface yield. Haulage costs represent as much as 60% of the aggregate working expense for these type of mines, so it is desirable to keep up an effective haulage framework. Equipment availability and estimation of utilization very precisely which is very important since mine manager wants to utilize their equipment as effectively as possible to get an early return of their investment as well as reducing total production cost. In present situation to achieve high production and productivity of HEMMs in opencast mines, it is desired to have high % availability and % utilization of equipment besides ensure overall equipment effectiveness as per CMPDI norms/global bench marks. OEE shows that how an equipment is utilized with its maximum effectiveness. It uses parameters like availability, performance and utilization for the estimation of equipment effectiveness. One method for effectively use of equipment in haul cycle is queuing theory. Queuing theory was developed to model systems that provide service for randomly arising demands and predict the behaviour of such systems. A queuing system is one in which customers arrive for service, wait for service if it is not immediately available, and move on to the next server or exit the system once they have been serviced. Most mining haul routes consist of four main components: loading, loaded hauling, dumping, and unloaded hauling to return to the loader. These components can be modelled together as servers in one cyclic queuing network, or independently as individual service channels. Data from a large open pit mine are analysed and applied to a multichannel queuing model representative of the loading process of the haul cycle. The outputs of the model are compared against the actual dumper data to evaluate the validity of the queuing model developed.

Key Words: Shovel Dumper, Performance, Availability, Utilization, Equipment Effectiveness, Cycle time, Queuing network.

## ACRONYMS

| | |
|---|---|
| HEMM | Heavy Earth moving machine |
| CMPDI | Central Mine Planning & Design Institute Limited |
| OEE | Overall Equipment Effectiveness |
| MPI | Mine Production Index |
| TPM | Total Productive Management |
| A | Availability |
| P | Performance rate |
| U | Utilization |
| TH | Total Hours |
| DT | Downtime Hours |
| ID | Idle Hours |
| WH | Working Hours |
| MTH | Maintenance Hours |
| BDH | Break Down Hours |
| $\lambda$ | Average Arrival rate of new Dumper |
| $\mu$ | Average Service Rate per Loader |
| c | Number of loader Operated |
| r | Expected number of Dumper in Service |
| $\rho$ | Service Rate Factor |
| $P_0$ | Probability of zero Dumper in Queuing System |

| | |
|---|---|
| n | Number of Dumper available in Haulage System |
| Lq | Expected number of Dumper Waiting to be loaded |
| L | Average number of Dumper in Queuing System |
| W | Average time a Customer spend in the System |
| Wq | Average waiting time a Customer spend in Queue |
| ϴ | Output of System |

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# ***CHAPTER 1***

INTRODUCTION

## 1.1 INTRODUCTION

Mining is a very capital-intensive industry, and it is known fact that the equipment utilization and accurate estimation is very important. Presently in India 70-80% production of minerals comes from the surface mines. In a surface mining operation, materials handling system is composed of loading, hauling and dumping. Shovel-Dumper systems are most common in open pit mining. Shovel-Dumper refers to a load-haul-dump mining system, involving any combination of loading units and dumper. The most important factor in every operation is profitability. Overall Equipment Effectiveness (OEE) of equipment used is an important factor of profitability. Further profitability can be increased by optimization of the equipment combination by matching factor used.

Dumper-shovel cycle optimizations are commonly performed to increase productivity, reduce costs and generally improve the profitability of the mobile assets at the mine. Therefor the first goal is to discuss the OEE to maximize productivity and hence increase production, which in turn will result in cost reduction. If a dumper shovel system is optimized, the gap between current production and potential capacity will become narrower, with further improvements only realizable through re-engineering. Better shovel/dumper matching, and optimizing the loading activity are important considerations.

As the size of the haulage fleet being used increases, shovel productivity increases and truck productivity decreases, so an effective fleet size must be chosen that will effectively utilize all pieces of equipment. When selecting earth-moving equipment for a particular mine site, shovels and Dumper must be matched based on their characteristics. The loader needs to be an appropriate size relative to the height and width of the benches being mined, and the dumping height of the loader must be sufficient to clear the side of the haul truck. The loader selected should also be able to fully load a haul dumper in three to six passes without using any partially filled buckets. The number of dumper required to meet production requirements and maximize efficiency is difficult to determine, and the number of trucks necessary will change over time as mining advances and haul routes become longer.

One method of fleet selection involves the application of queuing theory to the haul cycle. Queuing theory was developed to model systems that provide service for randomly arising demands and predict the behaviour of such systems. A queuing system is one in which customers arrive for service, wait for service if it is not immediately available, and move on to the next server once they have been serviced. For modelling Dumper-shovel systems in a mine, haul Dumper are the customers in the queuing system, and they might have to wait for service to be loaded and at the dumping locations.

The scope of this project is to create a queuing model that can represent Dumper and Shovel behaviour in open pit mining operations. An (M/M/c) queuing model was created to characterize vehicle interactions within the pit and provide outputs useful for analyzing efficiency and production rates. Haul Dumper data from a large open pit gold mine were acquired and analyzed to provide inputs to the queuing model to provide a basis of comparison and validation to the queuing model outputs.

## 1.2 OBJECTIVE

The objectives of the study are as follows:

- To study the existing process of operation of the Shovel dumper.
- To study the existing performance of the Shovel dumper.
- To study the mining pattern for the operation of Shovel dumper.
- To analysis various parameters in relation to working efficiency of the Shovel dumper.
- To Improve the effective utilization of Shovel and Dumper in Mines by improving the performance and availability with effective utilization of time.

# *CHAPTER 2*

## LITERATURE REVIEW

## 2.1 INTRODUCTION

Shovel dumper mining is a very popular method used in India and other country through worldwide for excavation of overburden as well as minerals for opencast mines. It is very flexible technology for both internal and external dumps. It's efficiency increases if hauling distance is within 2kms and well maintain haul-road. It is also high cost establishment with a number of machinery as like bulldozer, grader etc. so its initial cost of deployment is high. To compensate its high cost, rate of production should be very high so that cost per tonne of production is low and the mine operates on profit. Therefore, the study on the operation of the shovel dumper mining for its better utilization will be appropriate and beneficial for the mine and company.

## 2.2LITERATURE REVIEW

1. Ercelebi S. G. and Basceti A (2009). Optimization of shovel-truck system for surface mining. The Journal of the Southern African Institute of Mining and Metallurgy 109433-439. This paper describes shovel and truck operation models and optimization approaches for the allocation and dispatching of trucks under various operating conditions. Closed queuing network theory is employed for the allocation of trucks and linear programming for the purpose of truck dispatching to shovels. This approach would provide the capability of estimating system performance measures (mine throughput, mean number of trucks, mean waiting time, etc.) for planning purposes when the truck fleet is composed of identical trucks. A computational study is presented to show how choosing the optimum number of trucks and optimum dispatching policy affect the cost of moving material in a truck shovel system [9].

2. Elevili, S. and Elevli, B., (2010), Performance Measurement of Mining Equipment by Utilizing OEE, Acta Montanistica stovaca racnik 15(2010), cirlo 2, 95-101, have suggested in their study, the organization should introduce a maintenance system to improve and increase both the quality and productivity continuously. OEE is one of the performance evaluation methods that are most common and popular in the production industries. The Overall Equipment Effectiveness was improved with low machine breakdown, less idling and minor stops time, less quality defects, reduced accident in plants, increased the productivity rate, optimized process parameters, worker involvement, improved profits [1].

3. Newman, Alexandra M., (2010), A Review of Operations Research in Mine Planning. Interfaces 40(3), pp. 222–245. In this paper, we review several decades of such literature with a particular emphasis on more recent work, suggestions for emerging areas, and highlights of successful industry applications [10].

4. Subtil et al. (2011), A Practical Approach to Truck Dispatch for Open Pit Mines. WOLLONGONG, NSW, 24 - 30 SEPTEMBER 2011. This paper proposes a multistage approach for dynamic truck dispatching in real open pit mine environments. The first stage of this approach defines the optimal number of trucks that maximises the tonnage production by means of a robust linear programming model, which considers the operational constraints of a real mining process. The second stage uses a dynamic dispatching heuristic joining computational simulation and multi criterion optimisation techniques for decision making for truck dispatching [11].

5. Relkar, Anand S. And N. Nandurkar, k., (2012), Optimizing & Analysing Overall Equipment Effectiveness (OEE) Through Design of Experiments (DOE), K.K. WAGH Institute of Engineering Education & Research, have stated that an OEE is an important performance measure for effectiveness of any equipment, careful analysis is required to know the effect of various components. An excel sheet can be used as simplest tool to measure and monitor true data collection. An attempt has been done in their study to optimize the OEE by using Genetic Algorithm (GA). Their study indicates that OEE will be significantly improved if focus is given on performance rate improvement. A regression analysis gives classic equation of OEE [2].

6. Lanke et al. (2014), Mine Production index(MPI), New Method of Evaluate Effectiveness of Mining Machinery. International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:8, No:11, 2014. Due to limitations of original OEE, it has been modified by various researchers. OEE for mining application is special version of classic equation, carries these limitations over. In this paper it has been aimed to modify the OEE for mining application by introducing the weights to the elements of it and termed as Mine Production index (MPi). As a special application of new index MPi shovel has been developed

by authors. This can be used for evaluating the shovel effectiveness. Based on analysis, utilization followed by performance and availability were ranked in this order [10].

7. Burt et al. (2014). Equipment Selection for Surface Mining, Interfaces 44(2) 143-162. This paper addresses equipment selection for surface mines. Given a mine plan, the ultimate objective is to select the trucks and loaders such that the overall cost of materials handling is minimised. Such a fleet must be robust enough to cope with the dynamic nature of mining operations where the production schedule can sometimes be dependent on refinery requirements and demand. Due to the scale of operations in mining, even a small improvement in operation efficiency translates to substantial savings over the life of the mine [6].

8. Kalra, V.M., Thakur, Tilak. And Pabla, B.S., (2015), Operational Analysis of Mining Equipment in Opencast Mine using Overall Equipment Effectiveness (OEE), IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X. PP 27-31, The concept of TPM was given by Nakajima in the year 1971 in Japan, which states that it is the joint responsibility of the operators and the maintenance staff to upkeep the machines. The operator of the machinery needs to be trained to perform many small issues of maintenance and fault finding. Small teams of production and maintenance staff should be formed for reducing the downtime for effective utilization of the equipment and hence increase the life cycle of equipment. The main objective of the TPM is to reduce the breakdowns to zero, zero defects in operation and maintenance so that there are almost zero wastage and zero accidents [3].

9. Mohammadi et al. (2015), Performance Measurement of Mining Equipment, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 5, Issue 7, July 2015, In this light, various indicators such as cycle time, bucket-fill factor, material-swell factor, reliability, availability, maintainability, utilization, and production efficiency have been in vogue since long for evaluating the performance of BELT equipment. The present aims at reviewing the available pertinent literature in the subject field and deals with various aspects of performance measurement of BELT equipment in the mining industry. These indicators which are used for evaluating the performance of BELT equipment are described herewith. It is worthy to note that, the term of BELT has been introduced as acronym, in the present work, to cover the entire

variety of equipment that have bucket, which is capable of excavating, loading, hauling and dumping or even for transporting the excavated material [4].

10. Choudhary, Ram Prasad., (2015), Optimization of Load–Haul–Dump Mining System by OEE and Match Factor for Surface Mining. International Journal of Applied Engineering and Technology ISSN: 2277-212X (2015) Vol. 5 (2) April-June, pp. 96-102. It is necessary to use shovel truck combination efficiently for improving economy in the mining sector. Various techniques are available to analyze and optimize the combination. This paper describes and suggests the shovel and truck operation optimization approaches by applying overall equipment effectiveness (OEE) and matching simultaneously [12].

11. Koenigsberg, E. (1958). Cyclic Queues. Operational Research Quarterly, 22-35. Koenigsberg adapts formulas to determine the probability that the system is in a given state, the mean number of units waiting for service at a given stage, the delay at a given stage, mean cycle time, probability that a stage is idle, and daily output. These equations can be recalculated for different numbers of servers and customers so that the results for different machine configurations can be compared. Koenigsberg finds that output increases as $N$, the number of working faces is increased, and the rate of change of increase decreases with increasing $N$. He also finds that the overall output is limited by the service rate of the slowest machine [25].

12. Maher, M. J., & Cabrera, J. G. (1973). The Transient Behaviour of a Cyclic Queue. Operational Research Quarterly, 603-613. They applied cyclic queuing theory to civil engineering earthmoving projects, similar to haulage systems found in open pit mining. Queuing theory is used here to find the optimum number of trucks that should be used to minimize the cost per unit volume of earth moved. The haulage system is analyzed with the option of considering loading and transit times to be constant or variable, fitting a negative exponential distribution. This study also recognizes that with more than one excavator in operation the system can have either two separate queuing systems or one joint queue. The end result of this modelling is a set of charts for choosing the most cost-effective number of trucks based on the ratio of the loading time and haulage time and the ratio of the costs to operate the loader and the trucks. These charts could be applied to any earthmoving or mining operation as long as the data about cost and cycle time is known [26].

13. Elbrond, J. (1977, October). Calculation of an Open Pit Operation's Capacity. St. Louis, Missouri: SME. He developed a straightforward calculation technique based on queuing theory to be used as an alternative to computer simulation for evaluating open pit operation capacity. Elbrond's technique is based on queuing theory's formula for waiting time in a closed circuit with added correction factors which reflect variability in loading, travel, and dumping times. Waiting times at service stations are calculated as a function of the number of trucks in the circuit by averaging the results found through simulations for three different cases: constant travel time and constant service time, exponentially distributed travel time and exponentially distributed service time, and exponentially distributed travel time and constant service time. Correction factors are calculated using an interpolation procedure combining theoretical and simulated cases. Other data relevant to the haul cycle such as dumping time and shift composition is found using time studies. Once formulas had been completely developed, time studies made at Hamersley Iron found a correlation coefficient of 0.865 between observed and calculated wait time at shovels. This suggests that the technique used is a reasonably accurate method of modelling haulage systems [15].

14. Barnes, R. J., King, M. S., & Johnson, T. B. (1979). Probability Techniques for Analyzing Open Pit Production Systems. In 16th Application of Computers and Operations Research inthe Mineral Industry - 1979 (pp. 462-476). SME. They approach queuing theory as an alternative to costly computer simulation and rough-estimate match factor and efficiency factor methods of approximating production capacities of open-pit systems. In their paper Ernest Koenigsberg's approach to mine modelling using cyclic queues and Jorgen Elbrond's work with finite queues are outlined and compared to one another and to the results of stochastic simulation. The goal of this comparison is to observe any systematic relationship between the estimates found using each method [14].

15. Muduli, P. K., & Yegulalp, T. M. (1996, March). Modeling Truck-Shovel Systems as Multiple-Chain Closed Queuing Networks. Phoenix, Arizona: SME. They proposed in queuing theory, a chain consists of a permanent categorization of jobs. As it applies to mining, a job (truck) which is part of one chain cannot switch to another. Different types of trucks can be sorted into

different classes depending on their size and productivity. For this model, it is assumed that there is a single class of trucks per chain. Different classes of trucks can be given different characteristics by assigning different general service-time distributions to each one [27].

16. Alkass et al. (2003). A Computer Model for Selecting Equipment for Earthmoving Operations Using Queuing Theory. Montreal, Canada: Concordia University. They created a computer model based on queuing theory to model multi-loader truck systems assuming trip times have a negative exponential distribution and service times follow an Erlang distribution with three or fewer servers. For cases with multiple types of haulers, unlike Muduli and Yegulalp's method involving multiple chain queuing systems, an approximation based on weighted averages is used to convert the heterogeneous system into a homogeneous one [18].

17. Najor, J., & Hagan, P. (2004). Mine Production Scheduling within Capacity Constraints. Sydney, Australia: The University of New South Wales. They present an approach to mine scheduling that incorporates a heuristic model based on queuing theory. The goal in developing this model is to reduce financial expenditure in the mine production system by efficiently managing the fleet, maximizing the use of equipment while minimizing the resources necessary to support this equipment, and ensuring that fleet size matches targets for material movement. To develop this model, queuing theory is applied to a capacity-constrained model based on truck productivity [28].

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18. Ta, C. H. et al. (2010). Haul Truck Allocation via Queuing Theory. European Journal of Operational Research. They present a paper based on truck and shovel behaviour in oil sands mining. Their goal is to use queuing theory to capture the nonlinear relationship between average mine throughput and the number of trucks in use and then develop this relationship into a manageable optimization model. The model includes options for only a single truck size or multiple truck sizes, and individual trucks are assigned a readiness parameter so that the model can indicate both how many trucks are necessary and which individual trucks ought to be used. Shovel service times and truck back-cycle times are represented with an Erlang distribution. The probability that a shovel is idle is linearized so that shovel throughput can be expressed as a linear function. This model is compared to simulation results and it is shown that the optimization model accurately predicts shovel utilization and idle time. Information

about truck utilization and idle time is not calculated, but the optimization model provides valuable information about how many trucks should be used to meet necessary production targets [21].

# *CHAPTER 3*

**MINES DETAIL**

**MAJOR HEMM OF MINES**

## 3.1 INTRODUCTION

This chapter presents the project profile of the mines and major HEMM equipment used in mine and its detail. There is five major HEMM used for effectively extraction of ore in mines. In that, the main focus is on the shovel and dumper, because they take majority of operational work in mine. And they have high initial and operational cost. For efficient work in mining operation those machineries should gave their maximum performance.

## 3.2 MINES DETAIL

### 3.2.1 OCL INDIA Ltd (LANGIBERNA)

| SL. No. | DISCRIPTION | DETAIL |
|---|---|---|
| **1** | Type of Mine | Open cast |
| **2** | Date of Approval | 28.04.2010 |
| **3** | Capacity of Mines | 2.5MTPA |
| **4** | Total leasehold Area | 893.59 Ha |
| **5** | Surface Area | 333.429 ha |
| **6** | Forest Area | 62.648 |
| **7** | Stripping Ratio | 1:1 |
| **8** | No. of Quarries | 6 |
| **9** | Present area of Working | Quarry no. 2,3 North and 5,6 South |
| **10** | Thickness of the Seam | 11m |
| **11** | Grade of coal | G-13 |
| **12** | Project type | Expansion |
| | | |

### 3.2.1 BELPAHAR OCP

| SL. N0. | DESCRIPTION | DETAIL |
|---|---|---|
| **1** | Type of Mine | Open cast |
| **2** | Date of Approval | 11.02.2011 |
| **3** | Capacity of Mines | 6.0MTPA |
| **4** | Total leasehold Area | 1444.053 Ha |
| **5** | Surface Area | 624.62 Ha |
| **6** | Forest Area | 93.80 Ha |
| **7** | Stripping Ratio | 1:1.43 |
| **8** | No. of Quarries | 4 |
| **9** | Present area of Working | Quarry no. 2,3 North and 3 South |
| **10** | Thickness of the Seam | 9m |
| **11** | Grade of limestone | M-40 |
| **12** | Project type | Expansion |
| | | |

## 3.4 HEMM DETAIL OF BELPAHAR OCP

| S. NO. | EQUIPMENT | MAKE | NUMBER OF EQUIPMENT | CAPACITY or VOLUME |
|---|---|---|---|---|
| **1** | Hydraulic Shovel | HIL | 1 | 6.5 cum |
| **2** | Hydraulic shovel | BEML | 3 | 6.5 cum |

| | | | | |
|---|---|---|---|---|
| **3** | Electrical Shovel | HEC | 2 | 6.5 cum |
| **4** | Dumper | BEML | 16 | 50T |
| **5** | Dumper | BEML | 15 | 60 T |
| **6** | Dozer | BEML | 2 | |
| **7** | Drill Machine | RECP | 4 | 50 l/hrs |
| **8** | Motor Grader | BEML | 2 | |

## 3.5 HEMM DETAIL OF OCL INDIAL (LANGIBERNA)

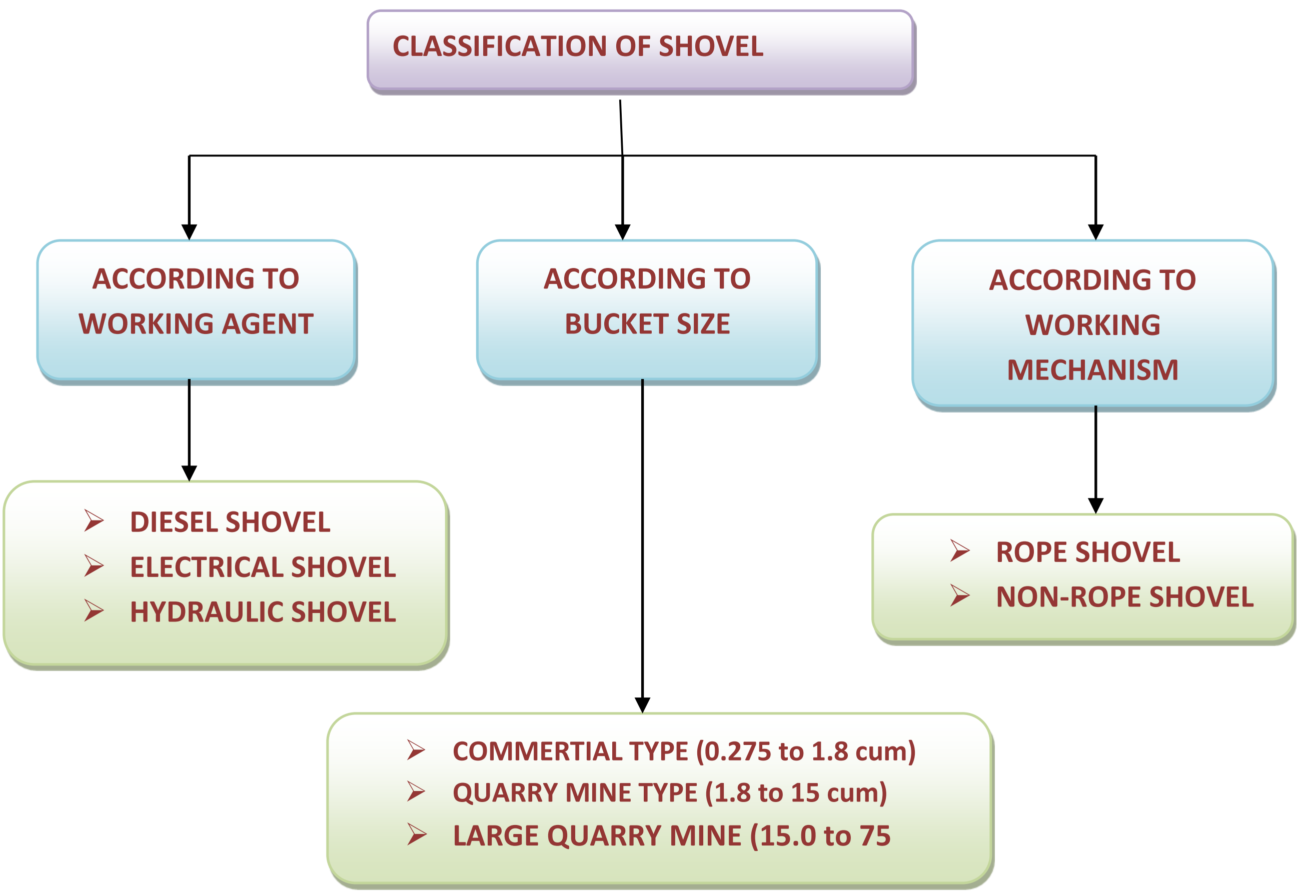
| S. NO. | EQUIPMENT | MAKE | NUMBER OF EQUIPMENT | CAPACITY or VOLUME |
|---|---|---|---|---|
| **1** | Hydraulic Shovel | Tata Hitachi | 6 | 4.0 cum |
| **2** | Hydraulic shovel | Tata Hitachi | 5 | 6.5 cum |
| **3** | Hydraulic Shovel | Komatsu | 1 | 6.5 cum |
| **4** | Dumper | Tata Hitachi | 15 | 50T |
| **5** | Dumper | Tata Hitachi | 18 | 35 T |
| **6** | Dozer | Tata Hitachi | 4 | |
| **7** | Stone Breaker | L&T Komatsu | 2 | PC200 |
| **8** | Drill Machine | Atlas Copco | 3 | 50 l/hrs |
| **9** | Drill Machine | Sandwich | 1 | 50 l/hr |

## 3.6 SHOVEL

Shovels made their first appearance as early as 1835 and were mounted on rail tracks and powered by steam engine at that time. Those shovels were slow in action and were very clumsy. As time passed they became stronger, faster and lighter and left the rail to move on crawler tracks and some time on rubber tyres. Shovels can be visualised on the three structural divisions. The top or revolving unit is the head. The mounting unit are legs and other attachment are the arms and hands.

### 3.6.1 Classification of shovel

By considering the following factors- working agent, bucket size and working mechanism.



### 3.6.1.1 Diesel Shovel

Diesel shovel is one of the oldest type of shovel used in open cast mimes project. There is four essential part in that shovel, which are prime mover that is diesel engine, power transmission system including crowd and hoist mechanism, travel mechanism, swing mechanism, third one is undercarriage unit which is also known as crawler travel unit, which is used for supporting the whole machine, helps in the marching of machine and steering the machine. And forth part is front attachment which include a boom, a dipper stick and bucket. Poor utilisation of power in that machine

### 3.6.1.2 Electrical Shovel

Shovel under this category are used widely in Indian mines. It's essential mechanism are motor generator sets, crowd mechanism, hoist mechanism, swinging mechanism, travel mechanism, pneumatic control system and undercarriage unit. That type of shovel is used where large production of ore is required with huge demand. It is difficult to steer and move near the face and high power requirement for digging and loading operations.

### 3.6.1.3 Hydraulic Shovel

Now a day hydraulic shovel is used throughout the world because of its availability. Its essential part are prime mover, superstructure and its attachment, hydraulic mechanism and undercarriage unit. In that time log of power transmission is shortest cycle time. Noise level is low as operation is done mainly through hydraulic system.

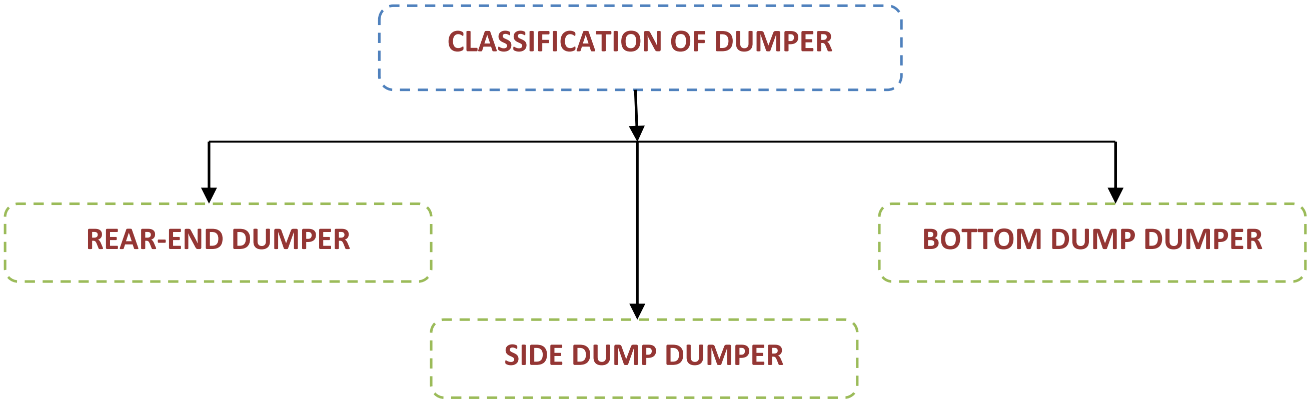

Fig.2.1: Hydraulic shovel used in mine

Operation is very smooth due to presence of hydraulic mechanism shape and size occupies less space and efficient utilization of power because of variable pressure or variable flow hydraulic circuit.

## 3.7 DUMPER:

Dumpers play an important role in carrying material such as coal and ore from the working areas to the dumping ground. This equipment is classified into three main groups.

### 3.7.1 CLASSIFICATION OF DUMPER




#### 3.7.1.1 Rear-end Dumper

Rear-end dumper are very popular and widely used in open cast project and irrigation. In this type, the main body which accepts the material from the shovel, is placed at the rear end of the operator cabin and discharge the material through the rear portion of the equipment. Here the rear-end body is tilted on the rear side by means of hydraulic jacks, upper end of which are fitted to the bottom of the main body, while the lower end s are attached to the chassis.

### 3.7.2 Side Dump Load Dumper

The general feature of the equipment is same as before. They deliver material over the driver tyres. Stability of the dumper is very important during discharge of dump. Side dump bodies are used in quarry stripping and discharge material on the fly whereas the rear dump equipment must stop while discharging material.

### 3.7.3 Bottom Dump Dumper

The bottom dump dumper consists of a diesel powered prime mover fitted with a large trailer at its rear end mounted on the two large wheels, the trailer unit has bottom door type. They are usually four-wheel type, which is suitable for high speed of about 40 to 50 km/hour. They are well suited to free following material such as earth, sand, gravel and crushed stone. Suitable for long haul and high speed operation.


Fig 3.2: Dumper used in mines

# *CHAPTER 4*

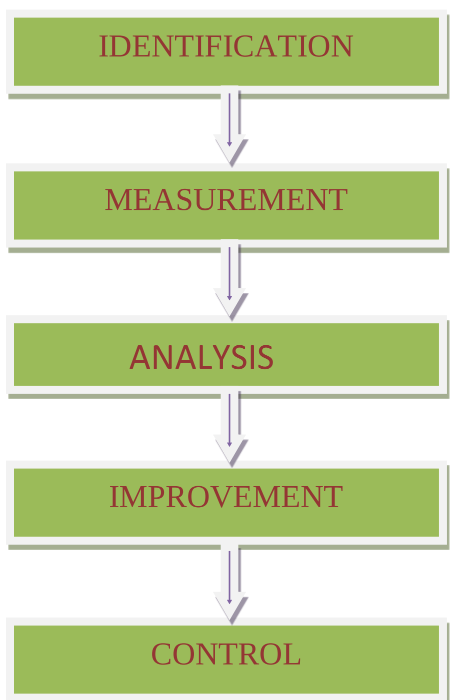
**METHODOLOGY**

**DATA & ITS INTERPRETATION**

## 4.1 INTRODUCTION

Shovel dumper mining is a very popular method used in India and other country through worldwide for excavation of overburden as well as minerals for opencast mines. It is very flexible technology for both internal and external dumps. It's efficiency increases if hauling distance is within 2kms and well maintain haul-road. It is also high cost establishment with a number of machinery as like bulldozer, grader etc. so its initial cost of deployment is high. To compensate its high cost, rate of production should be very high so that cost per tonne of production is low and the mine operates on profit.

## 4.2 FLOW CHART FOR CARRY OUT THE STUDY:




- The first step is the identification of the problem i.e. the identification and defining the problem.
- Second step is measurement which includes collection of data, mine visit, time study, observation & study of the operation of the machineries.

- Third step is analysis of the data and the system & to find out the root cause of the problem.
- Fourth step is improvement i.e. finding out the solution of the problem on the basis of the above analysis and development of alternatives and finally selection of one alternative for implementation.
- Fifth step is control it includes enforcing control in all the above activities and including monitoring & feedback.

## 4.3 SELECTION OF SHOVEL

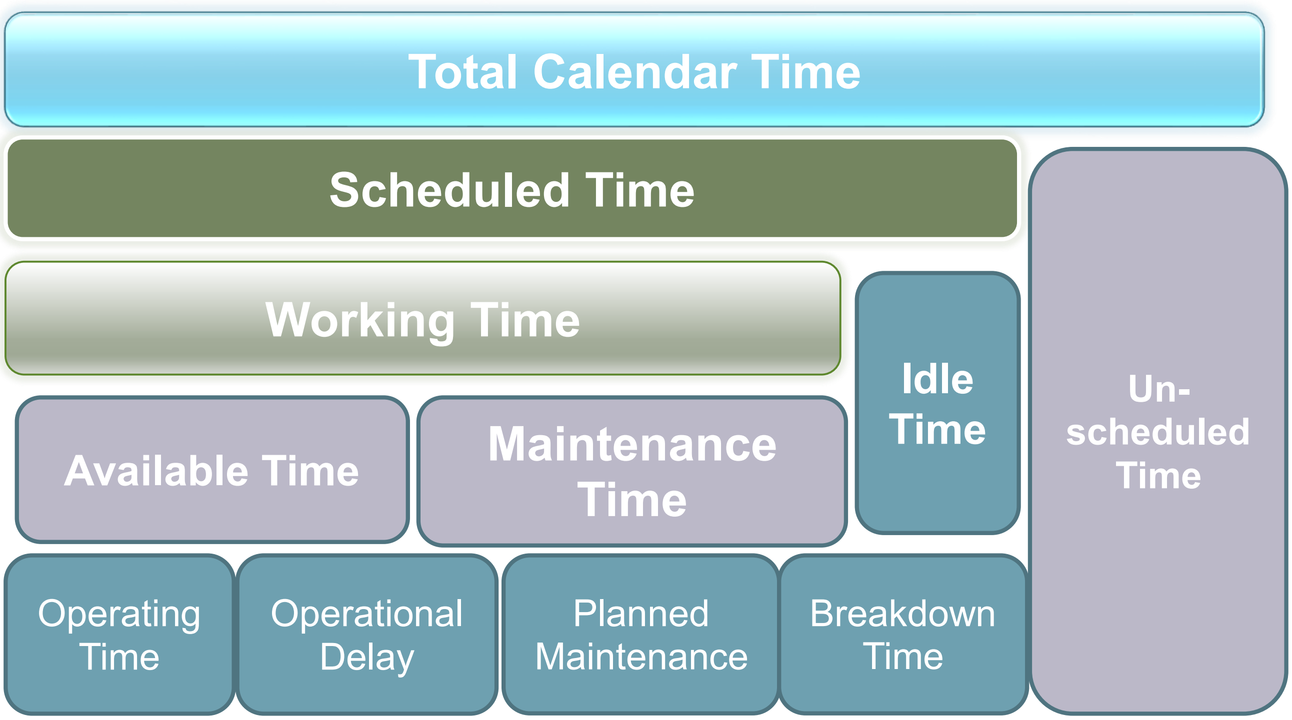
The following factors are to be considered during selection of shovel:

- The power shovel is somewhat flexible in its operation. Since cost of shovel is very high, it must be selected for a fairly long life project.
- Due to its poor mobility a power shovel is confined to operating near to similar area of coverage. So the selection of a single shovel for widely spread area of the mine is to be ruled out.
- Consideration must be given during planning of an adequate electric distribution system during selection of electrical shovel.
- Due to ease of operation of a shovel, shovel output does not hamper due to operator fatigue.
- The power shovel has excellent digging capability due to its own weight, traction and high powered crowd and hoist motion. Due to crawler mounting the power shovel has a distinct advantage over the tire mounted loading equipment.
- Construction of shovel is rugged with the use of electric motors and sophisticated electric and hydraulic controls the reliability and the efficiency of the shovel is exceptionally high.
- It can give high production.
- It can handle all types of materials, including large blocky materials.
- Operating conditions are fairly rigid.
- It may require supporting equipment for waste disposal.

## 4.4 PARAMETERS TO BE CONSIDERED DURING MEASUREMENT

- Daily Production required.
- Total tonnage to be removed.
- Size of area where shovel will operate.
- Number of faces is to be worked.
- Capacity of haulage machinery.
- Type of material to be loaded.
- Technological parameters.
- Availability.
- Reliability.
- Cost-economic parameters.

## 4.5 STANDARD TIME DURING OPERATION



## 4.6 OEE IN MINING INDUSTRY

Mining industry is characterized by high volume of output and high capacity of equipment. Mining industry is deeply dependent upon use of equipment for achieving targets of profitability. High amount of production time is lost due to unplanned maintenance in mining industry [16] i.e. lack of availability. For early return on investment and reduction of production cost equipment utilization is very important [17]. This indicate crucial need for higher utilization in mining industry. Standby machine increases cost of operation, whereas machinery subjected to downtime causes less output during operation. This directly affects the delivery assurance for mining industry. Hence performance of mining equipment is an important factor. Therefore, OEE in mining application should involve elements of availability, utilization and performance. According to [19] OEE can be used along with other parameters for improvement of mining performance. OEE has been used to determine the loaders and dumper performance in mines with results of suggestions to improve the availability of the equipment [18]. Referring to [19] OEE through TPM is applicable for improvement dragline performance in terms of reliability, cost of operation and productivity. As evident by the literature analysis and application, OEE can be used to determine the performance in mining industry as well. Elevli and Elevli in application of OEE to mining industry have shown benchmark formation for improvement for shovel and dumper performance [17]. They applied quality parameter with respect to defect loss with net operating time. Where the case study in Namibian is mines quality loss as was used as ratio of loaded capacity to full capacity [19]. Since quality parameter is not used as it is defined in original OEE equation, quality rate cannot be used for mining industry in its original definition [19]. The original definition of quality rating includes processed and defect amount. In mining, it is quite difficult to define such a distinction for extracted ore. Considering these limitations, a new OEE was developed which shown in (1) [16].

The original definition for OEE made use of Availability, Performance and Quality factor. Since it is difficult to note the Processed and Defect amount for calculation of Quality factor, therefore OEE for mining applications make use of utilization factor instead of quality factor.

Therefore, the OEE of mining shovel can be measured by Calculating the Availability (A), Performance efficiency (P) and Utilization (U) as per equation (1).

Overall Equipment Effectiveness (OEE) = Availability * Performance Rate* Utilization. …. (1)

### 4.6.1 AVAILABILITY

The operational Availability (A) of the equipment is dependent on the equipment downtime (comprising of Maintenance and breakdown Hours).

$$A = [(TH-DT)/TH]*100 \qquad \text{……… (2)}$$

Where TH is Total Hours, DT is Down Time Hours.

### 4.6.2 PERFORMANCE

The performance of the equipment is dependent on propel time, Idling and Minor stoppages due to Job Conditions such as dusty, snow, fog and speed loss due to reduced speed of working on account of aging of the Equipment and operator inefficiency.

$$P = (\text{Net production time}/\text{Actual available time}) \qquad \text{……… (3)}$$

### 4.6.3 UTILIZATION

Utilization of an Equipment is affected by the Down time and standby Hours due to wrong reassembly and rework.

$$U = [(TH-DT-IT)/TH]*100 \qquad \text{………… (4)}$$

This modified OEE can be used to determine the performance of mining production. However, mining operation is characterized by high degree of uncertainty. Depending upon the delivery schedule, number of available machine and types, age of machinery, production performance can change [20]. Each equipment is selected during mine design process for a specific purpose. Studies on dumper optimization for mining have shown that cycle time for dumper is important [21]. The cycle time for dumper involves time spent in loading, hauling, dumping, standby time. Since main purpose of shovel excavation is to move material, the payload and digging rate are key performance measures [22]. In total above mentioned parameters and restrictions affect the production performance. To take account for these considerations it is necessary to modify the OEE equation for mining applications. For example, the payload or capacity factor for shovel can directly relate to performance efficiency in equation rather than availability of shovel. Cycle time requirement for dumper can be directly attributed to need of higher utilization. Equipment with high criticality for performance index may be hampered in performance due to less availability during the operation. Taking these operational constraints into consideration the OEE for mining application can be modified with introduction of weight for each factor. Since assigned weights can be applied to all equipment and can give impact of each factor on entire mine production. The New OEE equation can be given as;

$$OEE = A^a \times P^b \times U^c \qquad \ldots\ldots\ldots\ldots.. (5)$$

where A is Availability, P is Performance and U is Utilization

and

$0 < a, b, c <= 1$ and $\Sigma$ a, b, c = 1.

In order to calculate and assigned the weights (a, b, c) a reliable and quantitative analytical method is needed. One the applicable approach is to use the multifactorial decision making techniques. Based on the past experiences of the authors, the analytical hierarchy process (AHP) method can be used for assigning the weights to the main parameters used in the OEE formula. AHP method was developed [23] that provides a visual structure of complex problems in form of two or more levels of hierarchy [24] and facilitates evaluation of active parameters in decision making process. It can be used for solving the problems with qualitative and quantitative parameters.

In production process of mines, shovels play a critical role and have significant impact on whole operation productivity. In order to evaluate its productivity; OEE is applicable as a practical indicator. For calculating OEE, A, U and P have been given the equal weights but when it comes to actual practice in the field this may not be case. So we assume weights as follows: availability: 0.3, utilisation: 0.5 and performance rate: 0.2 for monthly basis. These weights have been taken after considering the relative importance of the above using Analytic Hierarchy process.

So using the above we have

$$\text{New OEE} = A^{0.3} \times P^{0.2} \times U^{0.5} \quad \ldots\ldots\ldots (6)$$

Table 4.5.1: Weights Obtained for OEE factors for Shovels

| Parameters | Weights obtained |
|---|---|
| Availability | 0.3 |
| Production performance | 0.2 |
| Utilization | 0.5 |

## 4.7 MONTHLY PERFORMANCE OF SHOVEL AND DUMPER IN BELPAHAR OCP.

Table 4.7.1: Performance of Shovel (G-5A) at Belpahar OCP.

| Month | WH | BD H | IDH | MT H | TH | %AV | %PR | %UT | OEE |
|---|---|---|---|---|---|---|---|---|---|
| **Jul14** | 166 | 134 | 389 | 31 | 720 | 77 | 29 | 23 | 0.35 |
| **Aug14** | 141 | 124 | 452 | 27 | 744 | 80 | 24 | 19 | 0.3 |
| **Sep14** | 254 | 98 | 357 | 35 | 744 | 82 | 42 | 34 | 0.46 |
| **Oct14** | 222 | 22 | 442 | 34 | 720 | 92 | 33 | 31 | 0.43 |
| **Nov14** | 269 | 39 | 396 | 40 | 744 | 89 | 40 | 36 | 0.48 |
| **Dec14** | 281 | 130 | 270 | 39 | 720 | 77 | 51 | 39 | 0.5 |
| **Jan15** | 344 | 24 | 324 | 52 | 744 | 90 | 52 | 46 | 0.57 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Feb15** | 382 | 71 | 242 | 49 | 744 | 84 | 61 | 51 | 0.69 |
| **Mar15** | 327 | 78 | 224 | 43 | 672 | 82 | 59 | 49 | 0.59 |
| **Apr15** | 302 | 45 | 351 | 46 | 744 | 88 | 46 | 44 | 0.55 |
| **May15** | 318 | 74 | 281 | 47 | 720 | 83 | 53 | 44 | 0.55 |
| **Jun15** | 274 | 207 | 219 | 44 | 744 | 66 | 55 | 37 | 0.45 |
| **AVG** | 273.3 | 87.16 | 328.91 | 40.583 | 730 | 82.5 | 45.416 | 37.75 | 0.4933 |

Table4.7.2: Performance of Dumper (BH-50) at Belpahar OCP

| Month | WH | BD H | IDH | MH | TH | %AV | %PR | %UT | OEE |
|---|---|---|---|---|---|---|---|---|---|
| **Jul14** | 204 | 227 | 245 | 44 | 720 | 62 | 45 | 28 | 0.39 |
| **Aug14** | 241 | 160 | 299 | 44 | 744 | 73 | 45 | 32 | 0.44 |
| **Sep14** | 307 | 53 | 323 | 61 | 744 | 85 | 49 | 41 | 0.53 |
| **Oct14** | 341 | 0 | 322 | 57 | 720 | 92 | 51 | 47 | 0.68 |
| **Nov14** | 324 | 22 | 347 | 51 | 744 | 90 | 48 | 40 | 0.53 |
| **Dec14** | 322 | 24 | 317 | 57 | 720 | 89 | 50 | 45 | 0.56 |
| **Jan15** | 216 | 111 | 376 | 41 | 744 | 80 | 36 | 29 | 0.41 |
| **Feb15** | 103 | 526 | 99 | 16 | 744 | 27 | 51 | 14 | 0.22 |
| **Mar15** | 72 | 498 | 90 | 12 | 672 | 24 | 44 | 11 | 0.18 |
| **Apr15** | 351 | 36 | 303 | 54 | 744 | 88 | 53 | 47 | 0.58 |
| **May15** | 315 | 102 | 248 | 55 | 720 | 78 | 56 | 44 | 0.55 |
| **Jun15** | 314 | 10 | 356 | 64 | 744 | 90 | 47 | 42 | 0.53 |
| **AVG** | 259.16 | 147.41 | 277.083 | 46.33 | 730 | 73.166 | 47.916 | 35 | 0.467 |

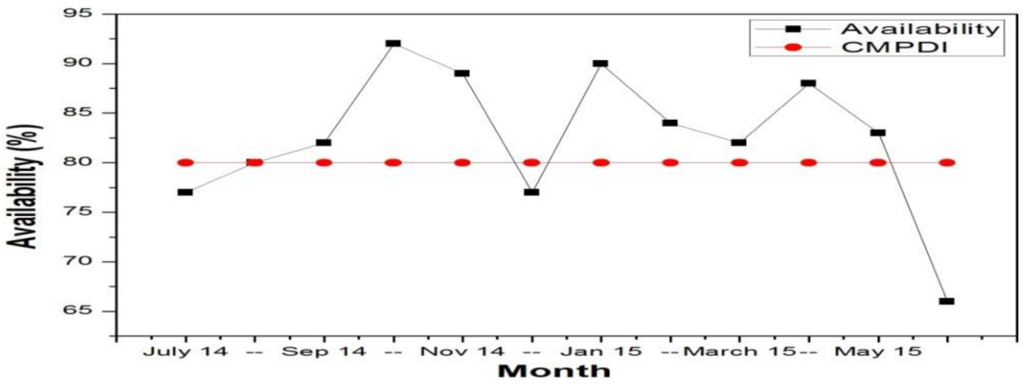



Fig 4.1: Graph shows percentage availability of shovel at Belpahar OCP

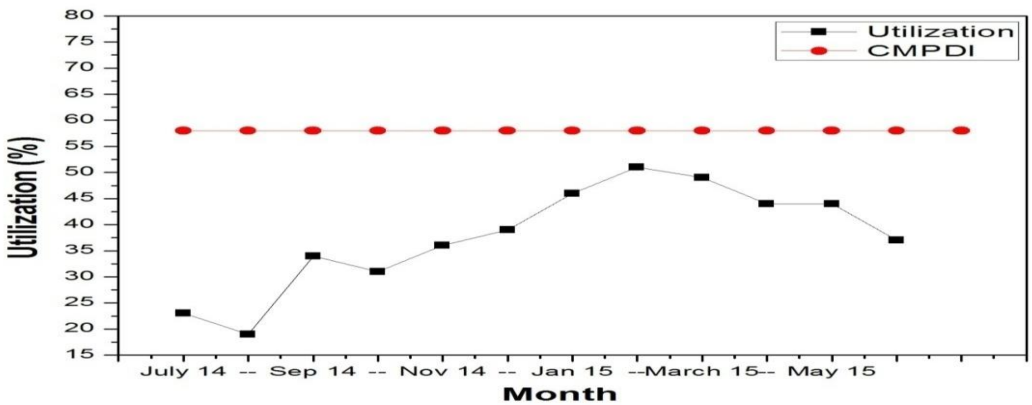



Fig 4.2: Graph Shows percentage utilization of shovel at Belpahar OCP

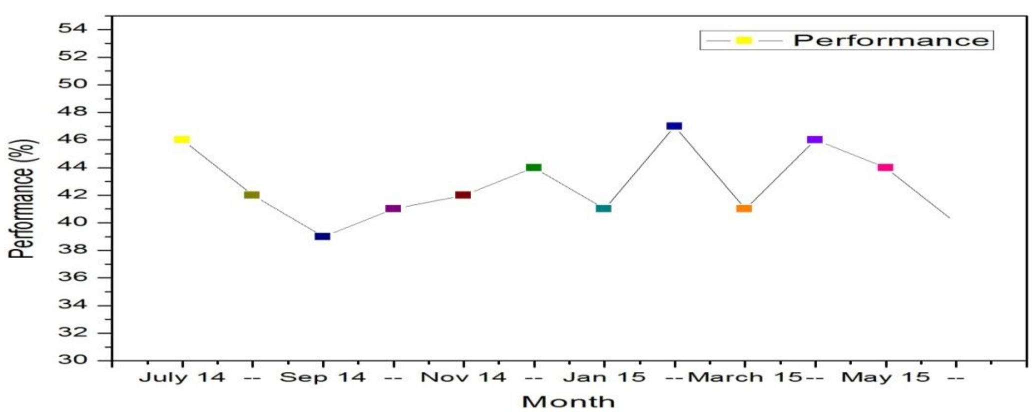



Fig 4.3: Graph shows percentage shovel performance rate at Belpahar OCP

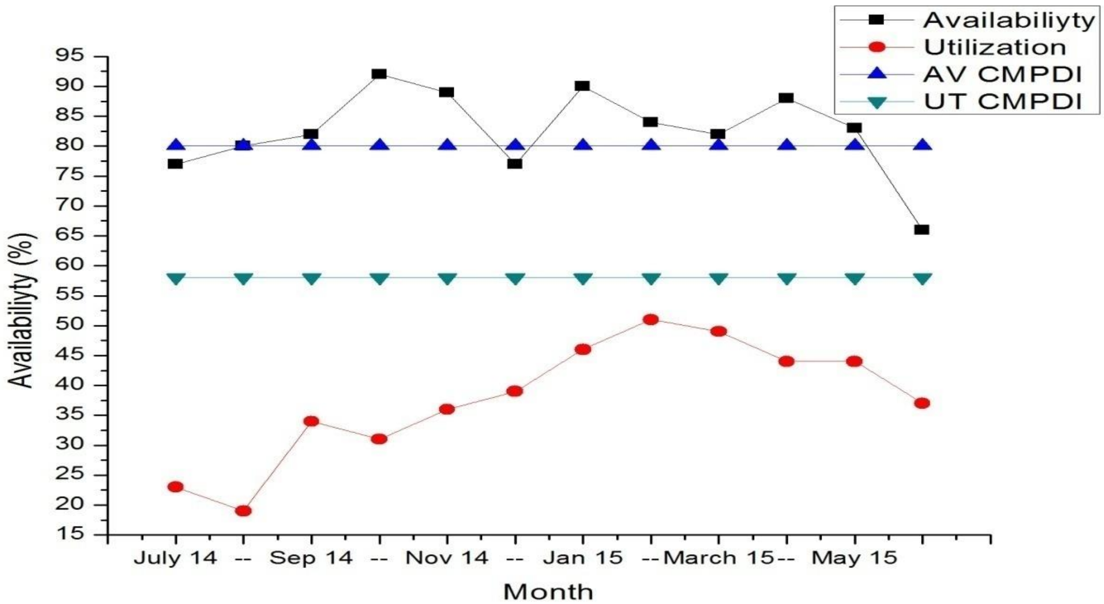



Fig 4.4: Graph shows percentage Availability & Utilization of shovel at MCL

As per the figure 4.4, Availability (66%) was poor in Jan-15 as compare to other months because breakdown and maintenance hours were much more than other month. And the utilization in all the month are much less. Which is because of more idle hours that means not no proper dozing operation was not done and also no power supply availability all time.

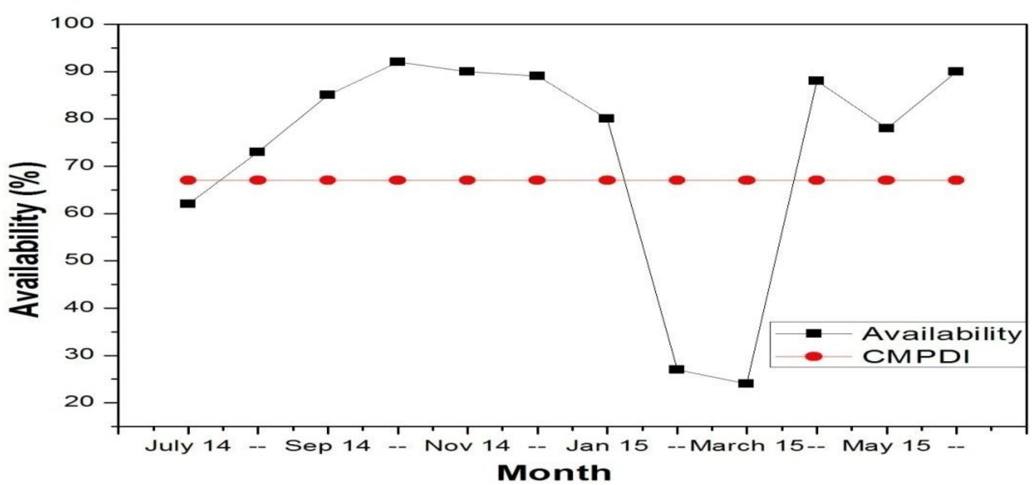



Fig 4.5**:** Graph shows percentage availability of dumper at Belpahar OCP

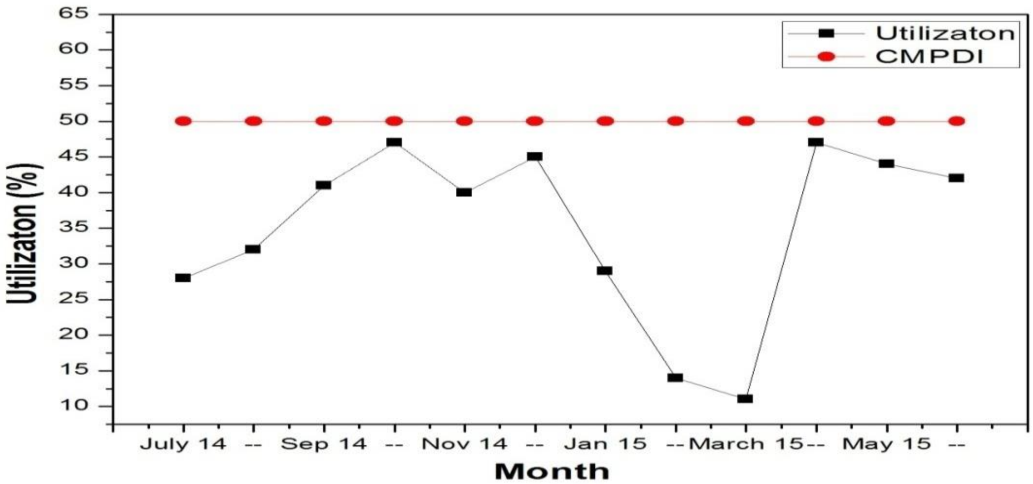



Fig 4.6: Graph shows percentage utilization of dumper at Belpahar OCP

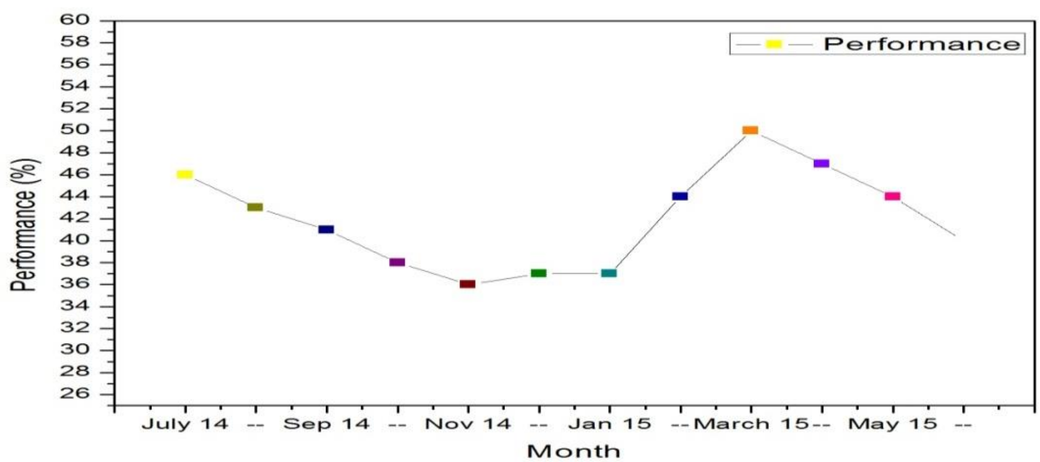



Fig 4.7: Graph shows percentage performance rate of dumper at MCL

As per fig 4.8, Availability 24% and 27% were poor in March-15 and Feb-15 as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in month Jan-15 is 36% also are much less. Which is because of not sufficient loose blasted material and no proper dozing operation and also due to more breakdown hours, which is caused by machine repair work.

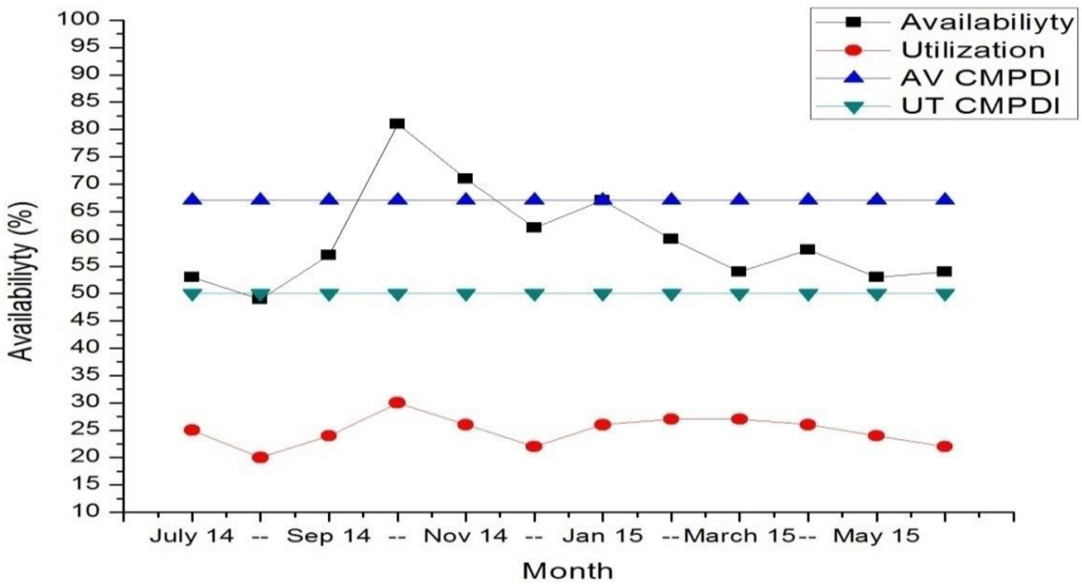



Fig 4.8: Graph shows percentage availability and utilization of dumper at Belpahar OCP

Table 4.7.3: OEE Calculation of Shovel used in Belpahar OCP

| SL. NO. | ITEMS | TIME (Hours/Month) |
|---|---|---|
| 1 | Total Time | 744 |
| 2 | Working Hours | 274 |
| 3 | Breakdown hours | 207 |
| 4 | Maintenance Hours | 44 |
| 5 | Idle Hours | 219 |
| 6 | Availability | (744-207-44)/744<br>= 0.66 |
| 7 | Performance | (493-219)/493<br>=0.556 |
| 8 | Utilization | (744-207-44-219)/744<br>= 0.37 |
| 9 | OEE | (0.66^0.3) x (0.556^0.2) x (0.37^0.5)<br>=0.477 |

Table 4.7.4: OEE Calculation of Dumper at Belpahar OCP

| SL. NO. | ITEMS | TIME(Hours/Month) |
|---|---|---|
| 1 | Total Time | 744(24x31) |
| 2 | Working Hours | 314 |
| 3 | Breakdown hours | 10 |
| 4 | Maintenance Hours | 64 |
| 5 | Idle Hours | 356 |
| 6 | Availability | (744-10-64)/744<br>= 0.90 |
| 7 | Performance | (670-356)/670<br>=0.47 |
| 8 | Utilization | (744-10-64-356)/744<br>= 0.42 |
| 9 | OEE | (0.90^0.3) x (0.47^0.2) x (0.42^0.5)<br>=0.5399 |

## 4.8MONTHLY PERFORMANCE OF SHOVEL IN OCL LANGIBERNA

Table 4.8.1: Performance of Shovel at OCL.

| Month | WH | BD H | IDH | MTH | TH | %AV | %PR | %UT | OEE |
|---|---|---|---|---|---|---|---|---|---|
| **Apr15** | 242 | 35 | 110 | 38 | 482 | 85 | 73 | 62 | 0.7 |
| **May15** | 246 | 88 | 107 | 41 | 482 | 73 | 71 | 51 | 0.61 |
| **Jun15** | 278 | 13 | 153 | 38 | 482 | 89 | 65 | 57 | 0.67 |
| **Jul15** | 284 | 34 | 119 | 31 | 482 | 86 | 71 | 59 | 0.68 |
| **Aug15** | 247 | 28 | 105 | 47 | 482 | 84 | 74 | 51 | 0.64 |
| **Sep15** | 314 | 3 | 114 | 51 | 482 | 89 | 69 | 65 | 0.72 |
| **Oct15** | 303 | 15 | 122 | 42 | 482 | 88 | 71 | 62 | 0.71 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Nov15** | 335 | 23 | 97 | 27 | 482 | 89 | 77 | 69 | 0.76 |
| **Dec15** | 258 | 74 | 112 | 38 | 482 | 76 | 69 | 53 | 0.62 |
| **Jan16** | 281 | 11 | 156 | 34 | 482 | 90 | 64 | 58 | 0.67 |
| **Feb16** | 297 | 34 | 117 | 27 | 482 | 87 | 72 | 61 | 0.7 |
| **Mar16** | 328 | 7 | 93 | 44 | 482 | 89 | 78 | 68 | 0.76 |
| **AVG** | 284.4 | 30.41 | 117.0 | 38.16 | 482 | 85.416 | 71.166 | 59.66 | 0.686 |

Table 4.8.2: Performance of Dumper in OCL

| **Month** | **WH** | **BD H** | **IDH** | **MTH** | **TH** | **%AV** | **%PR** | **%UT** | **OEE** |
|---|---|---|---|---|---|---|---|---|---|
| **Apr15** | 234 | 62 | 152 | 34 | 482 | 80 | 60 | 48 | 0.58 |
| **May15** | 11 | 21 | 163 | 59 | 482 | 83 | 59 | 49 | 0.57 |
| **Jun15** | 251 | 17 | 179 | 35 | 482 | 89 | 58 | 51 | 0.62 |
| **Jul15** | 198 | 53 | 189 | 42 | 482 | 80 | 51 | 41 | 0.52 |
| **Aug15** | 221 | 51 | 163 | 47 | 482 | 79 | 57 | 46 | 0.56 |
| **Sep15** | 256 | 22 | 178 | 26 | 482 | 90 | 60 | 53 | 0.64 |
| **Oct15** | 246 | 7 | 195 | 42 | 482 | 89 | 59 | 51 | 0.62 |
| **Nov15** | 185 | 52 | 218 | 27 | 482 | 83 | 46 | 38 | 0.50 |
| **Dec15** | 231 | 46 | 137 | 38 | 482 | 82 | 66 | 48 | 0.60 |
| **Jan16** | 227 | 18 | 198 | 39 | 482 | 88 | 53 | 47 | 0.58 |
| **Feb16** | 243 | 37 | 138 | 29 | 482 | 86 | 66 | 50 | 0.62 |
| **Mar16** | 257 | 11 | 176 | 41 | 482 | 89 | 59 | 53 | 0.63 |
| **AVG** | 232.33 | 33.08 | 173.83 | 38.25 | 482 | 84.83 | 57.83 | 47.916 | 0.586 |

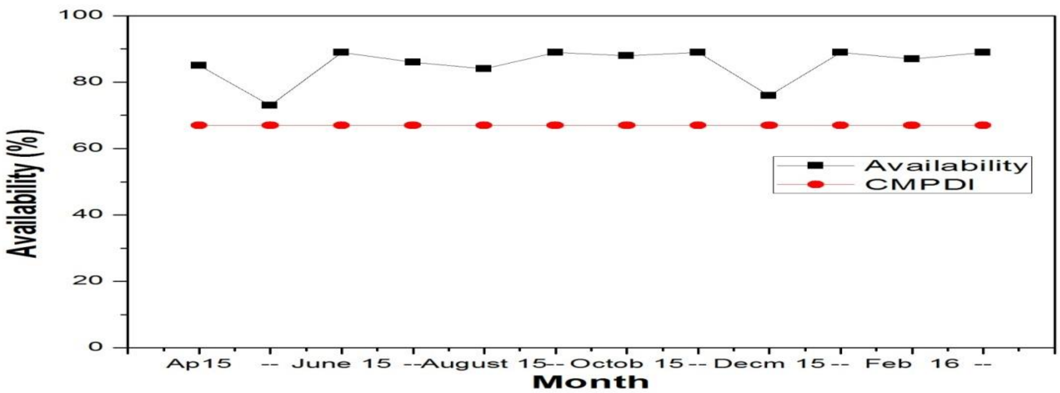



Fig 4.9: Graph shows percentage availability of shovel at OCL Langiberna

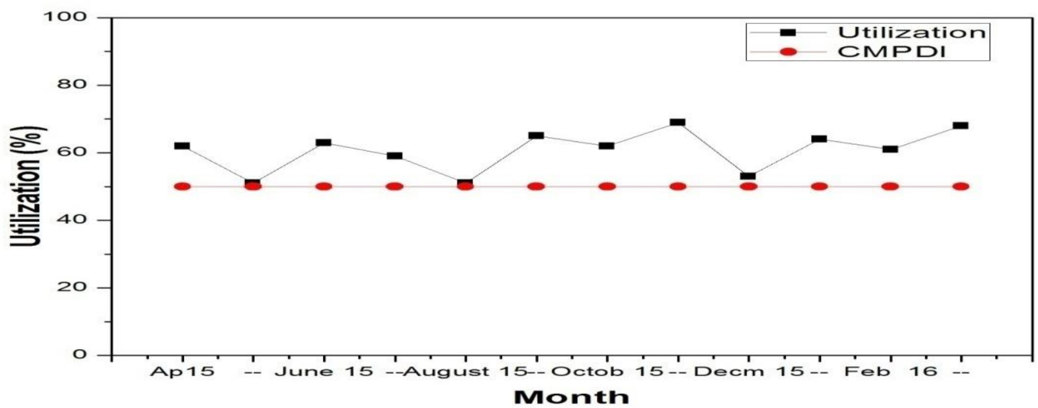



Fig.4.10: Graph shows percentage utilization of shovel at OCL Langiberna

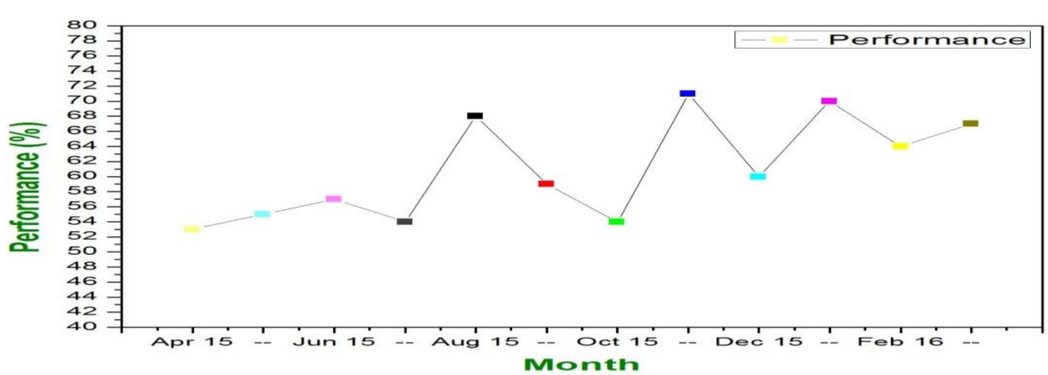



Fig. 4.11: Graph shows percentage shovel performance rate at OCL Langiberna.

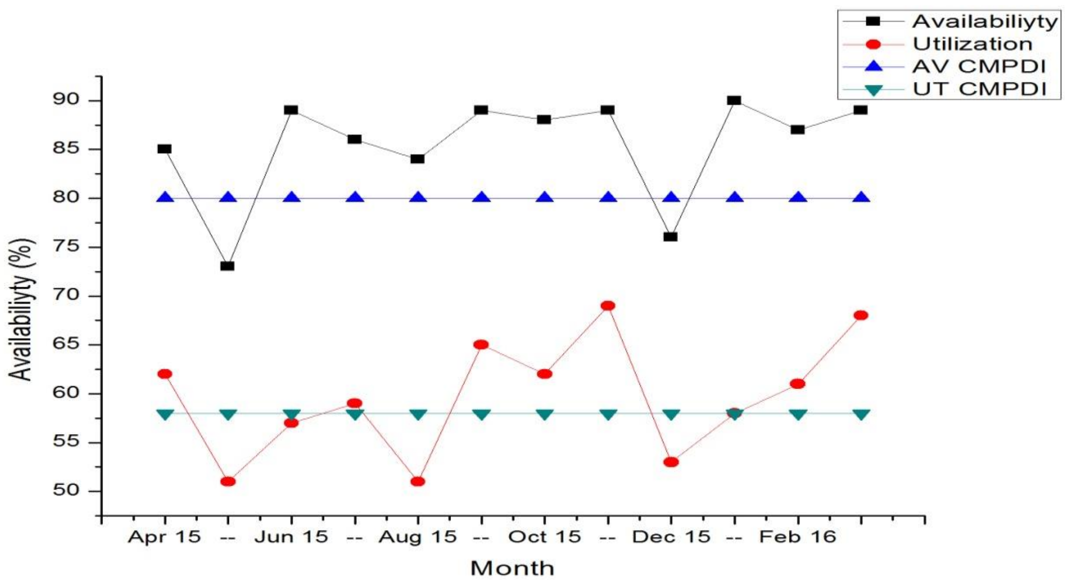



Fig 4.12: Graph shows percentage availability and utilization of shovel at OCL Langiberna.

As per fig 4.12 availability 73% was less in May-15 as compare to other months because breakdown and maintenance hours. And the utilization is 51% in month May-15 and Aug-15. Which is because of more idle hours that means no proper dozing operation and also no power supply availability all time.

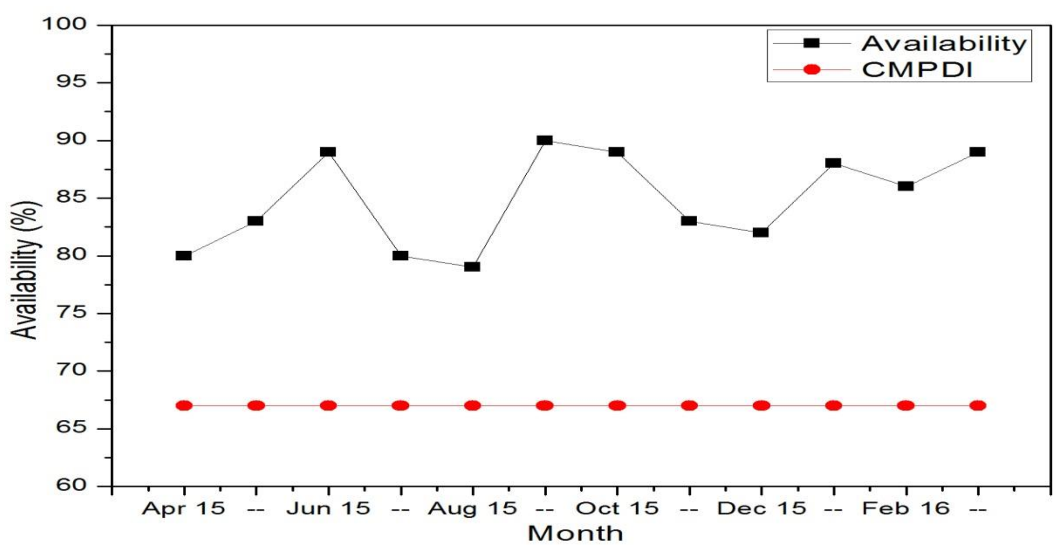



Fig 4.13: Graph shows percentage availability of dumper at OCL Langiberna.

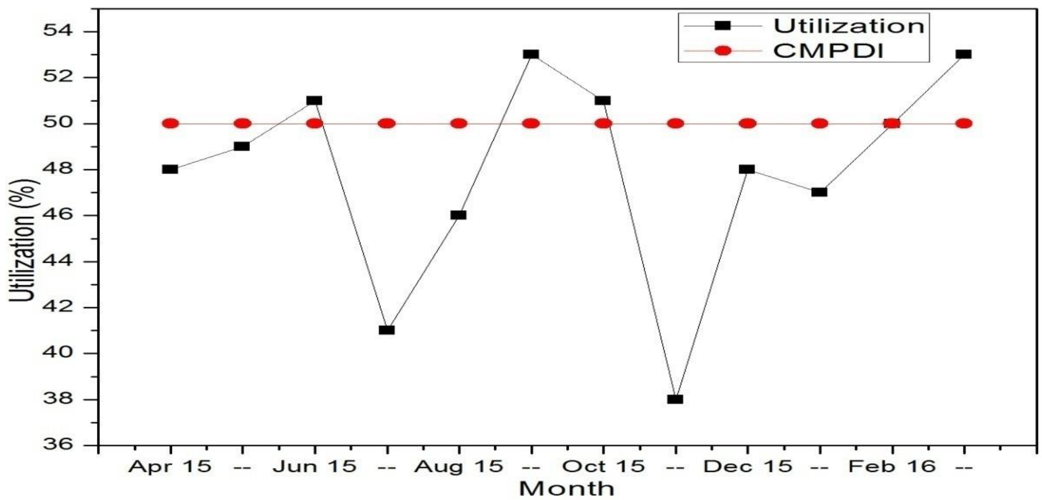



Fig 4.14: Graph shows percentage utilization of dumper at OCL Langiberna.

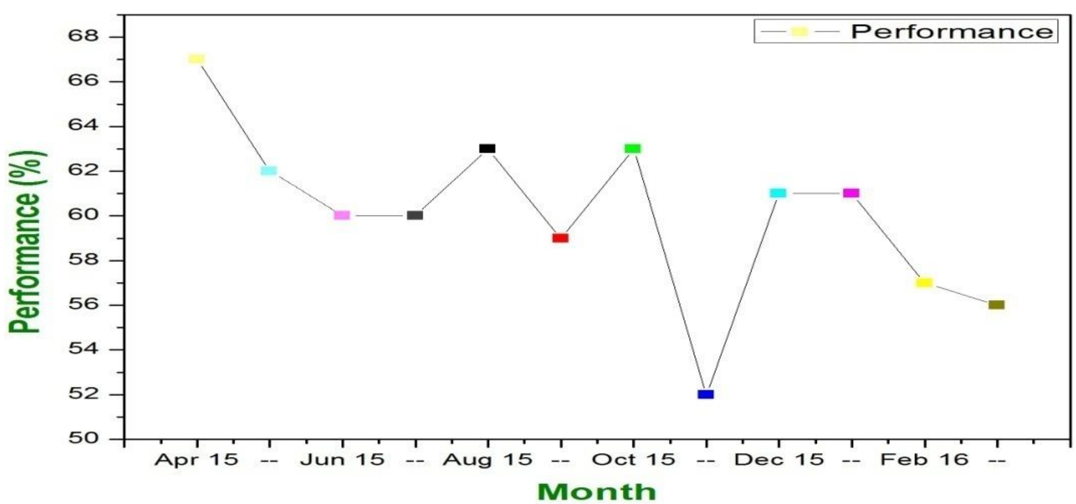



Fig 4.15: Graph shows percentage dumper performance rate at OCL Langiberna.

As per fig 4.16 Availability 79% were less in Aug-15 as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in month Aug-15 is 46%, July-15 is 41% and Nov-15 is 38% are much less. Which is because of no proper haul road and not sufficient loose blasted material and no proper dozing operation and due to more breakdown hours which is caused by machine repair work.

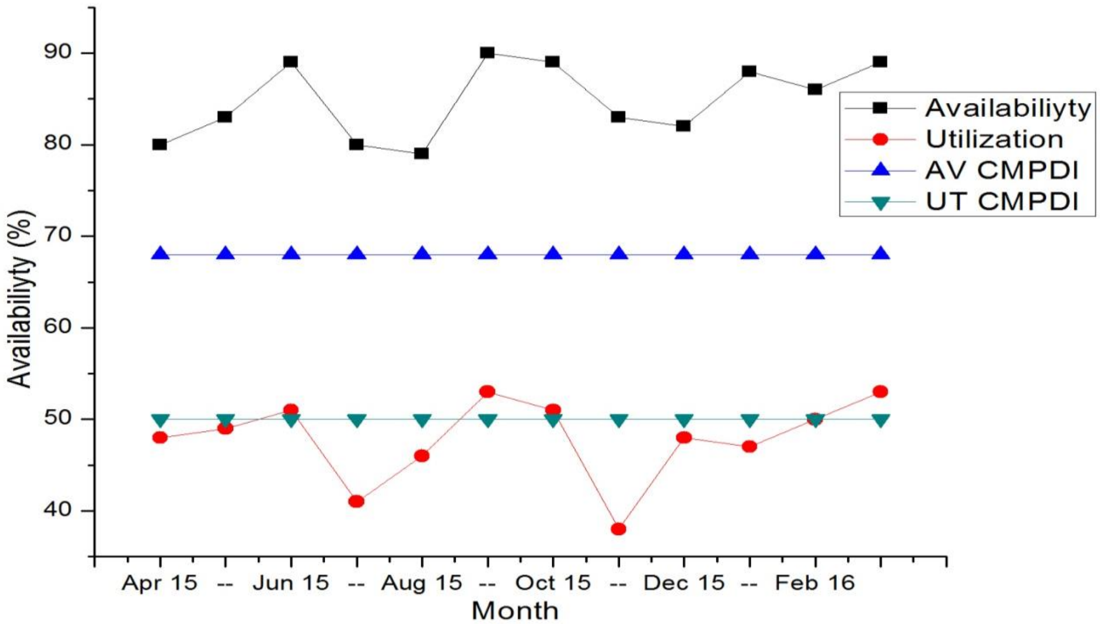



Fig 4.16: Graph shows percentage availability and utilization of dumper at OCL.

Table 4.8.3: OEE Calculation for Shovel at OCL.

| SL. NO. | ITEMS | TIME (Hours/Month) |
|---|---|---|
| 1 | Total Time | 482 |
| 2 | Working Hours | 251 |
| 3 | Breakdown hours | 17 |
| 4 | Maintenance Hours | 35 |
| 5 | Idle Hours | 179 |
| 6 | Availability | (482-17-35)/482<br>= 0.89 |
| 7 | Performance | (430-179)/430<br>=0.58 |
| 8 | Utilization | (482-17-34-179)/482<br>= 0.51 |
| 9 | OEE | (0.89^0.3) x (0.58^0.2) x (0.51^0.5)<br>=0.6141 |

Table 4.8.4: OEE Calculation for Dumper at OCL.

| SL. NO. | ITEMS | TIME (Hours/Month) |
|---|---|---|
| 1 | Total Time | 482 |
| 2 | Working Hours | 278 |
| 3 | Breakdown hours | 13 |
| 4 | Maintenance Hours | 38 |
| 5 | Idle Hours | 153 |
| 6 | Availability | (482-13-38)/482<br>= 0.89 |
| 7 | Performance | (431-153)/431<br>=0.65 |
| 8 | Utilization | (482-11-34-156)/482<br>= 0.57 |
| 9 | OEE | (0.88^0.3) x (0.534^0.2) x (0.47^0.5)<br>=0.67 |

## 4.9 AVEGARGE MONTHLY PERFORMANCE OF ALL SHOVEL AND DUMPER IN BELPAHAR OCP

Table 4.9.1: Performance of Shovel at Belpahar OCP.

| Month | WH | BD H | IDH | MTH | TH | %AV | %PR | %UT | OEE |
|---|---|---|---|---|---|---|---|---|---|
| **Jul14** | 287 | 49 | 342 | 41 | 720 | 87 | 46 | 40 | 0.52 |
| **Aug14** | 256 | 99 | 355 | 34 | 744 | 82 | 42 | 34 | 0.57 |
| **Sep14** | 259 | 52 | 396 | 37 | 744 | 88 | 39 | 35 | 0.47 |
| **Oct14** | 275 | 24 | 386 | 36 | 720 | 92 | 41 | 38 | 0.50 |
| **Nov14** | 277 | 44 | 386 | 37 | 744 | 89 | 42 | 37 | 0.49 |
| **Dec14** | 277 | 58 | 349 | 36 | 720 | 87 | 44 | 38 | 0.50 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Jan15** | 248 | 103 | 358 | 35 | 744 | 81 | 41 | 33 | 0.45 |
| **Feb15** | 274 | 122 | 311 | 37 | 744 | 79 | 47 | 37 | 0.49 |
| **Mar15** | 236 | 65 | 337 | 34 | 672 | 85 | 41 | 35 | 0.47 |
| **Apr15** | 262 | 65 | 338 | 49 | 744 | 86 | 46 | 35 | 0.48 |
| **May15** | 254 | 49 | 380 | 39 | 720 | 88 | 38 | 35 | 0.47 |
| **Jun15** | 254 | 119 | 332 | 39 | 744 | 79 | 43 | 34 | 0.46 |
| **AVG** | 263.25 | 70.75 | 355.83 | 37.83 | 730 | 85.25 | 42.5 | 35.916 | 0.48 |

Table 4.9.2: Average performance of Dumper at Belpahar OCP

| **Month** | **WH** | **BD H** | **IDH** | **MTH** | **SH** | **%AV** | **%PR** | **%UT** | **OEE** |
|---|---|---|---|---|---|---|---|---|---|
| **Jul14** | 178 | 303 | 206 | 33 | 720 | 53 | 46 | 25 | 0.35 |
| **Aug14** | 146 | 351 | 220 | 27 | 744 | 49 | 43 | 20 | 0.31 |
| **Sep14** | 176 | 285 | 251 | 32 | 744 | 57 | 41 | 24 | 0.35 |
| **Oct14** | 219 | 102 | 363 | 36 | 720 | 81 | 38 | 30 | 0.42 |
| **Nov14** | 190 | 177 | 341 | 35 | 744 | 71 | 36 | 26 | 0.37 |
| **Dec14** | 159 | 241 | 284 | 29 | 720 | 62 | 37 | 22 | 0.33 |
| **Jan15** | 193 | 211 | 314 | 34 | 744 | 67 | 37 | 26 | 0.37 |
| **Feb15** | 199 | 258 | 250 | 36 | 744 | 60 | 44 | 27 | 0.38 |
| **Mar15** | 181 | 281 | 179 | 30 | 672 | 54 | 50 | 27 | 0.38 |
| **Apr15** | 192 | 277 | 239 | 35 | 744 | 58 | 47 | 26 | 0.37 |
| **May15** | 181 | 306 | 213 | 34 | 720 | 53 | 44 | 24 | 0.34 |
| **Jun-15** | 161 | 310 | 240 | 33 | 744 | 54 | 40 | 22 | 0.32 |
| **AVG** | 181.25 | 258.5 | 258.33 | 32.83 | 730 | 59.916 | 41.916 | 24.91 | 0.357 |

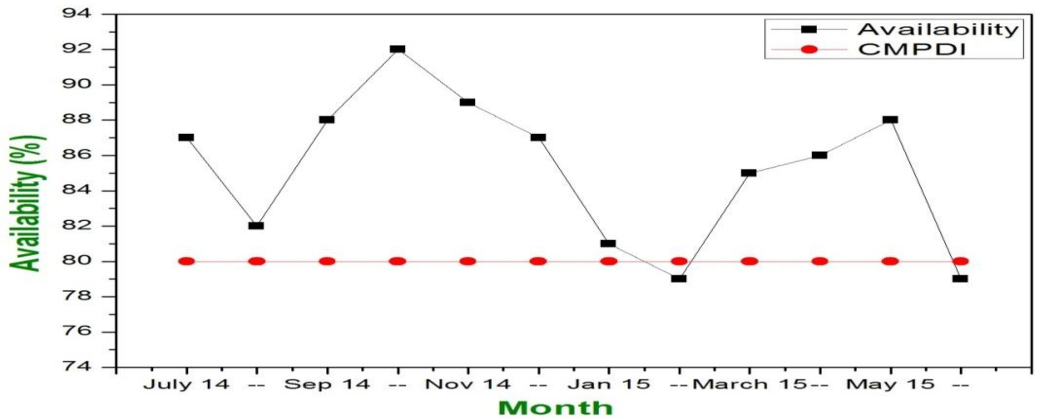



Fig 4.17: Graph shows percentage availability of shovel at Belpahar OCP.

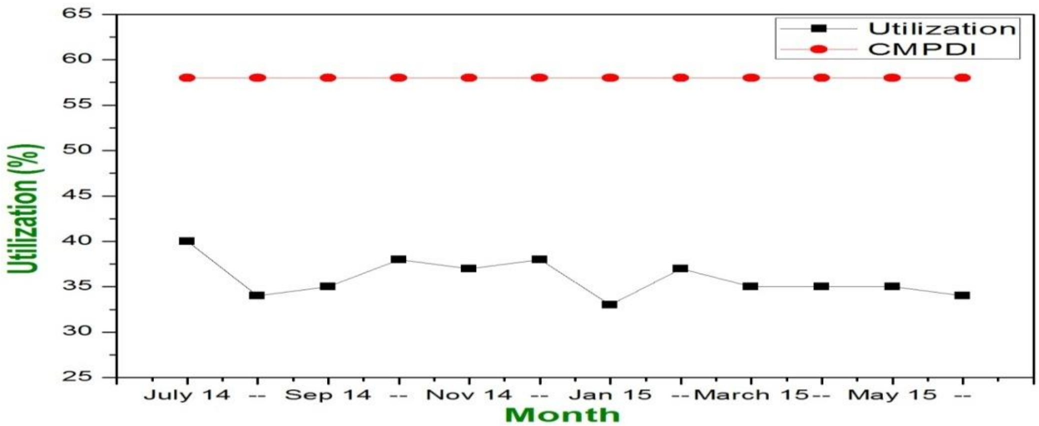



Fig 4.18: Graph shows percentage utilization of shovel at Belpahar OCP.

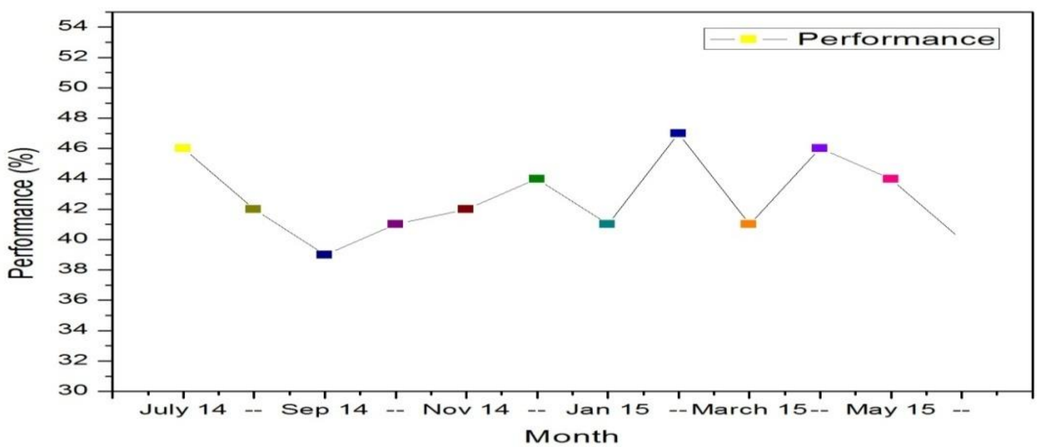



Fig 4.19: Graph shows percentage shovel performance rate at Belpahar OCP.

As per fig. 4.20 availability 79% was less in Feb-15and Jun-15 as compare to other months because breakdown and maintenance hours. And the utilization was less in all the month as per the norms. Which is because of more idle hours that means maintenance problem of machine and also waiting for the dumper and also waiting for the drilling operation.

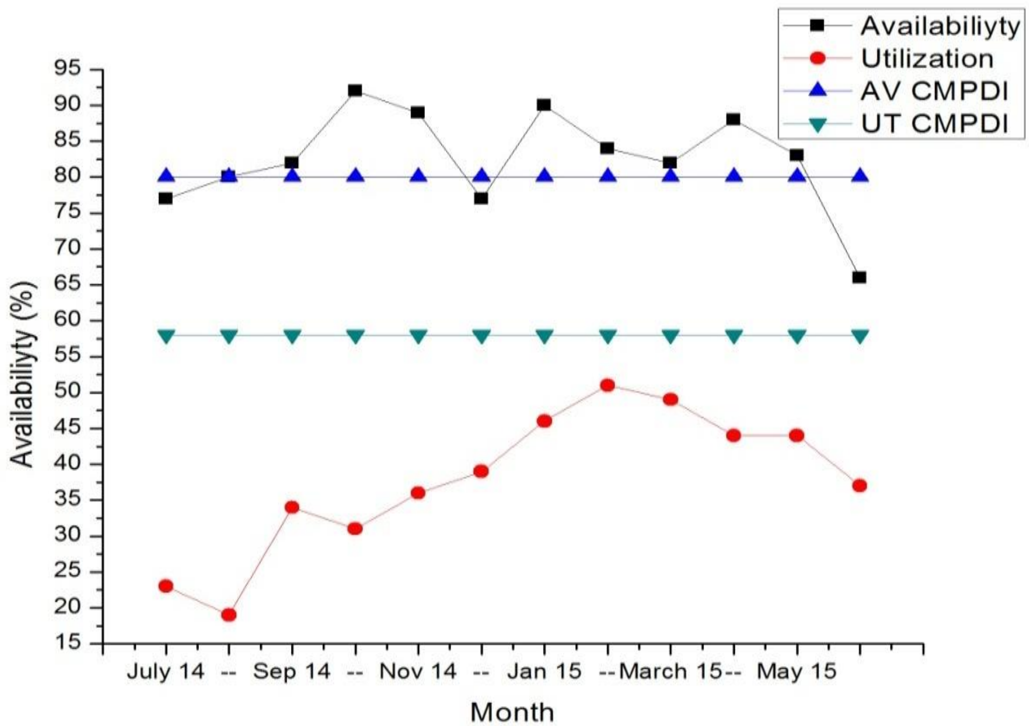



Fig 4.20: Graph shows percentage availability and utilization of shovel at Belpahar OCP.

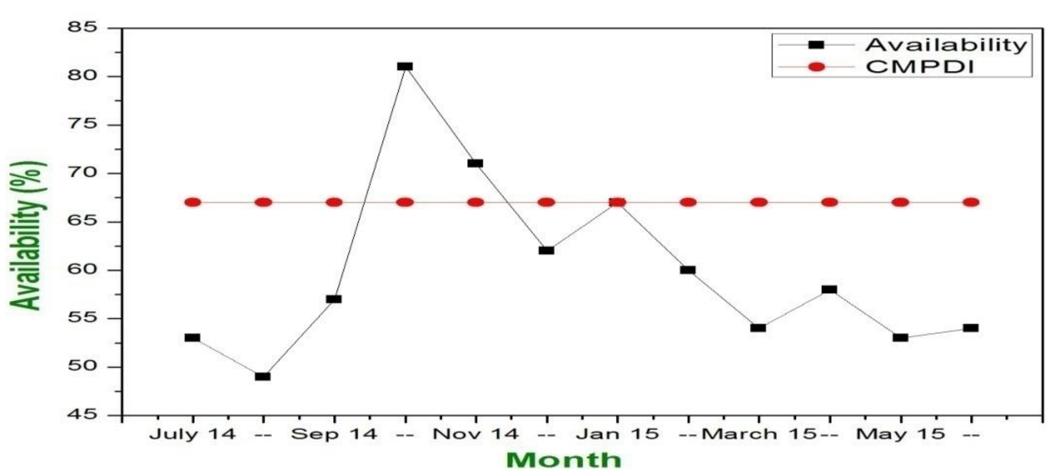



Fig 4.21: Graph shows percentage availability of dumper at MCL

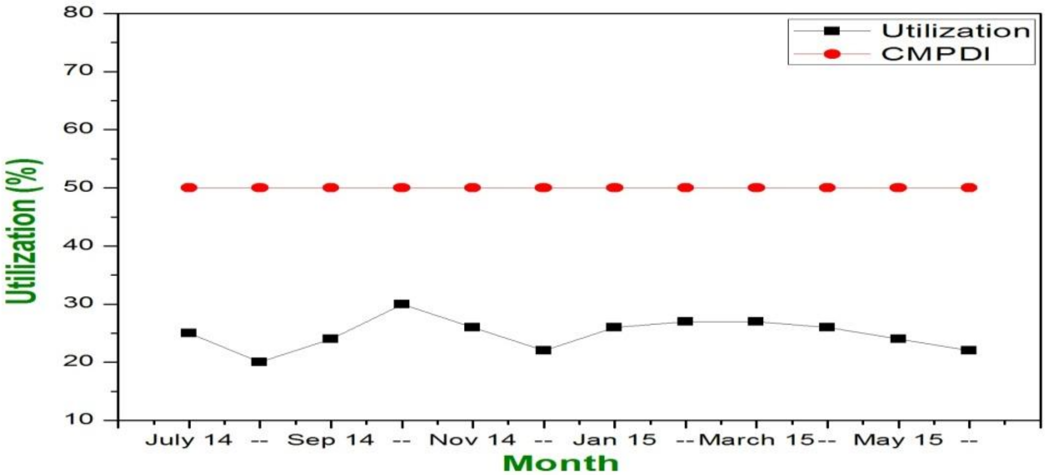
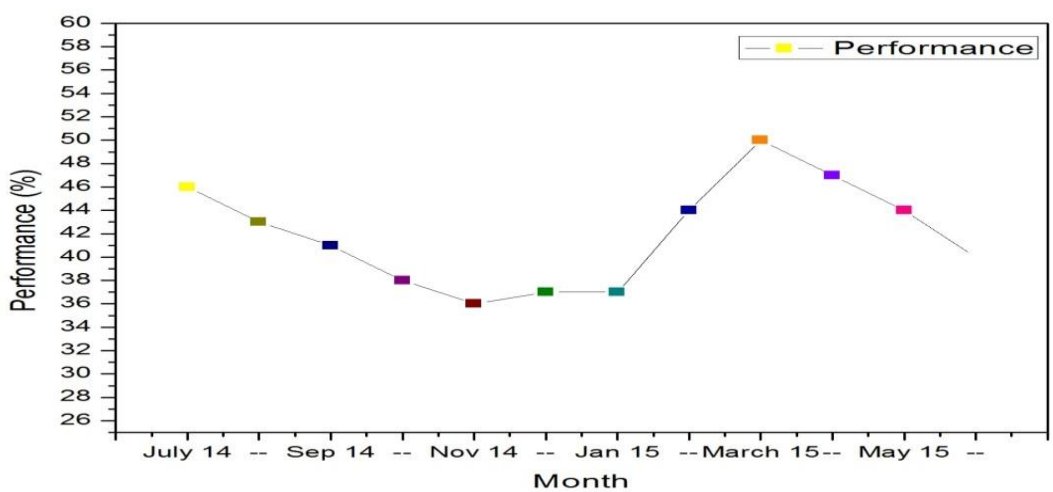



Fig 4.22: Graph shows percentage utilization of dumper at Belpahar OCP.




4.23: Graph shows percentage Dumper Performance rate at Belpahar OCP.

As per fig 4.24, Availability in month July (53%) Aug (49%) March (54%) Arp (47%) was less as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in all month are less than as per the norms. It is due to more breakdown hour which is caused by machine repair work and not proper haul road and due to maintenance problem of machine.

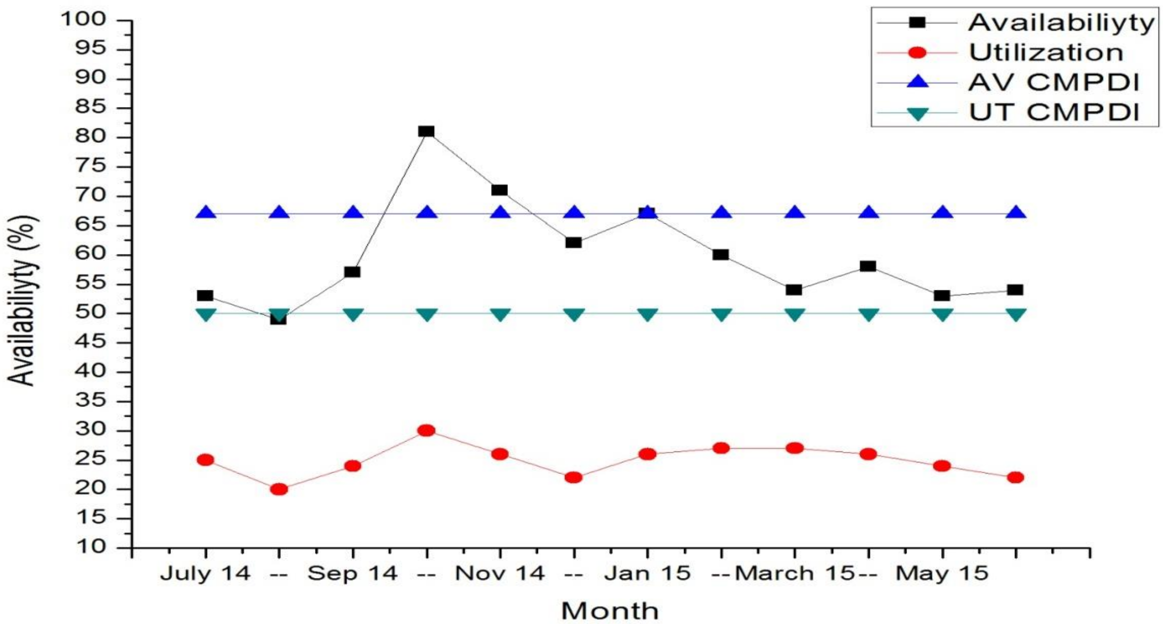



Fig 4.24: Graph shows percentage availability and utilization of dumper at Belpahar OCP

## 4.10AVEGARGE MONTHLY PERFORMANCE OF ALL SHOVEL AND DUMPER IN OCL

Table 4.10.1: Performance of Shovel at OCL.

| Month | WH | BD H | IDH | MTH | TH | %AV | %PR | %UT | OEE |
|---|---|---|---|---|---|---|---|---|---|
| **Apr15** | 248 | 9 | 196 | 28 | 482 | 92 | 53 | 52 | 0.62 |
| **May15** | 245 | 13 | 203 | 22 | 482 | 93 | 55 | 51 | 0.62 |
| **Jun15** | 261 | 17 | 172 | 34 | 482 | 90 | 57 | 54 | 0.64 |
| **Jul15** | 228 | 38 | 191 | 25 | 482 | 87 | 54 | 27 | 0.44 |
| **Aug15** | 319 | 3 | 149 | 11 | 482 | 97 | 68 | 66 | 0.75 |
| **Sep15** | 243 | 52 | 158 | 39 | 482 | 81 | 59 | 48 | 0.58 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Oct15** | 204 | 76 | 171 | 31 | 482 | 79 | 54 | 42 | 0.53 |
| **Nov15** | 308 | 27 | 124 | 23 | 482 | 90 | 71 | 63 | 0.72 |
| **Dec15** | 224 | 79 | 145 | 36 | 482 | 76 | 60 | 46 | 0.56 |
| **Jan16** | 276 | 53 | 112 | 41 | 482 | 80 | 70 | 57 | 0.66 |
| **Feb16** | 291 | 5 | 158 | 28 | 482 | 93 | 64 | 60 | 0.69 |
| **Mar16** | 285 | 18 | 136 | 43 | 482 | 87 | 67 | 59 | 0.68 |
| **AVG** | 261 | 32.5 | 159.58 | 30.083 | 482 | 87.083 | 61 | 52.083 | 0.624 |

Table 4.10.2: Performance of Dumper at OCL

| Month | WH | BD H | IDH | MTH | TH | %AV | %PR | %UT | OEE |
|---|---|---|---|---|---|---|---|---|---|
| **Apr15** | 262 | 37 | 129 | 54 | 482 | 81 | 67 | 54 | 0.64 |
| **May15** | 246 | 61 | 148 | 27 | 482 | 82 | 62 | 51 | 0.61 |
| **Jun15** | 219 | 74 | 146 | 43 | 482 | 76 | 60 | 46 | 0.57 |
| **Jul15** | 145 | 164 | 95 | 78 | 482 | 50 | 60 | 30 | 0.40 |
| **Aug15** | 273 | 29 | 158 | 22 | 482 | 89 | 63 | 57 | 0.66 |
| **Sep15** | 274 | 6 | 188 | 14 | 482 | 96 | 59 | 57 | 0.67 |
| **Oct15** | 268 | 29 | 156 | 31 | 482 | 88 | 63 | 55 | 0.65 |
| **Nov15** | 279 | 82 | 135 | 46 | 482 | 95 | 52 | 46 | 0.59 |
| **Dec15** | 228 | 76 | 144 | 34 | 482 | 77 | 61 | 47 | 0.57 |
| **Jan16** | 218 | 73 | 136 | 55 | 482 | 73 | 61 | 45 | 0.55 |
| **Feb16** | 197 | 109 | 147 | 29 | 482 | 71 | 57 | 41 | 0.52 |
| **Mar16** | 175 | 111 | 134 | 62 | 482 | 64 | 56 | 36 | 0.47 |
| **AVG** | 232 | 70.91 | 143 | 41.25 | 482 | 78.5 | 60.083 | 47.083 | 0.575 |

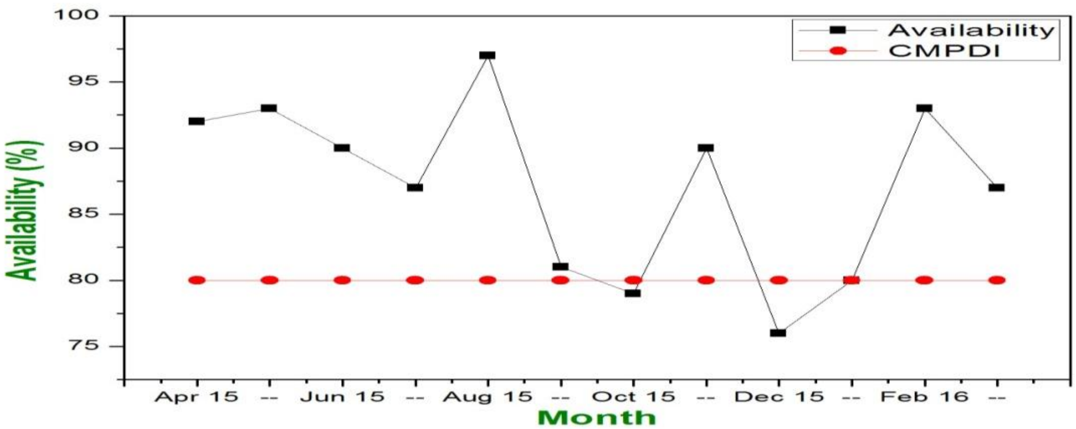



Fig 4.25: Graph shows percentage availability of shovel at OCL Langiberna.

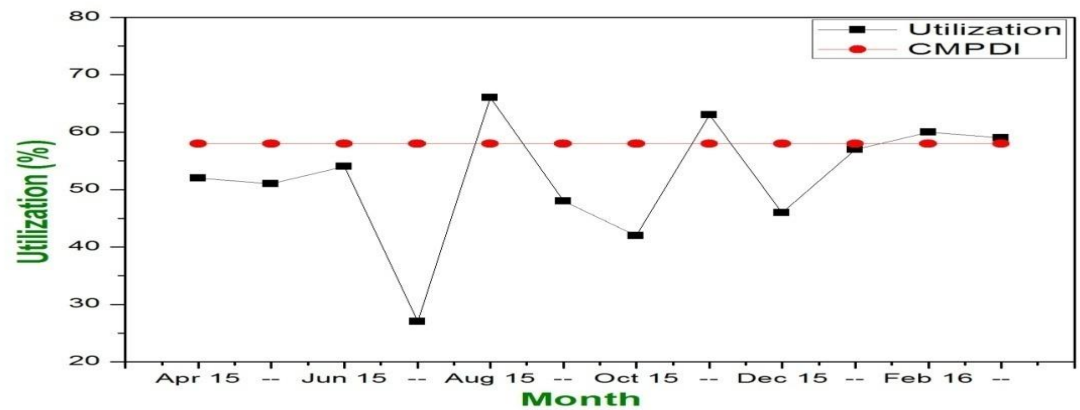



Fig 4.26: Graph shows percentage utilization of shovel at OCL Langiberna.

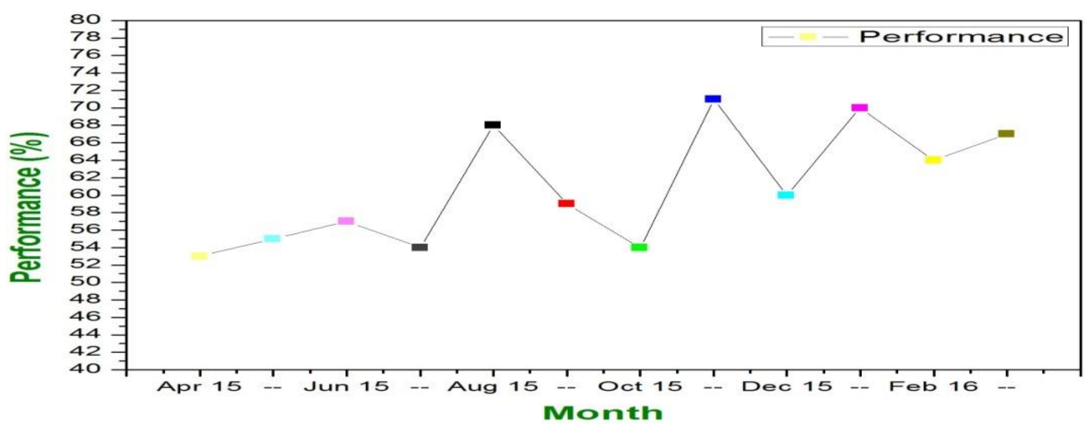



Fig 4.27: Graph shows percentage shovel performance rate at OCL Langiberna

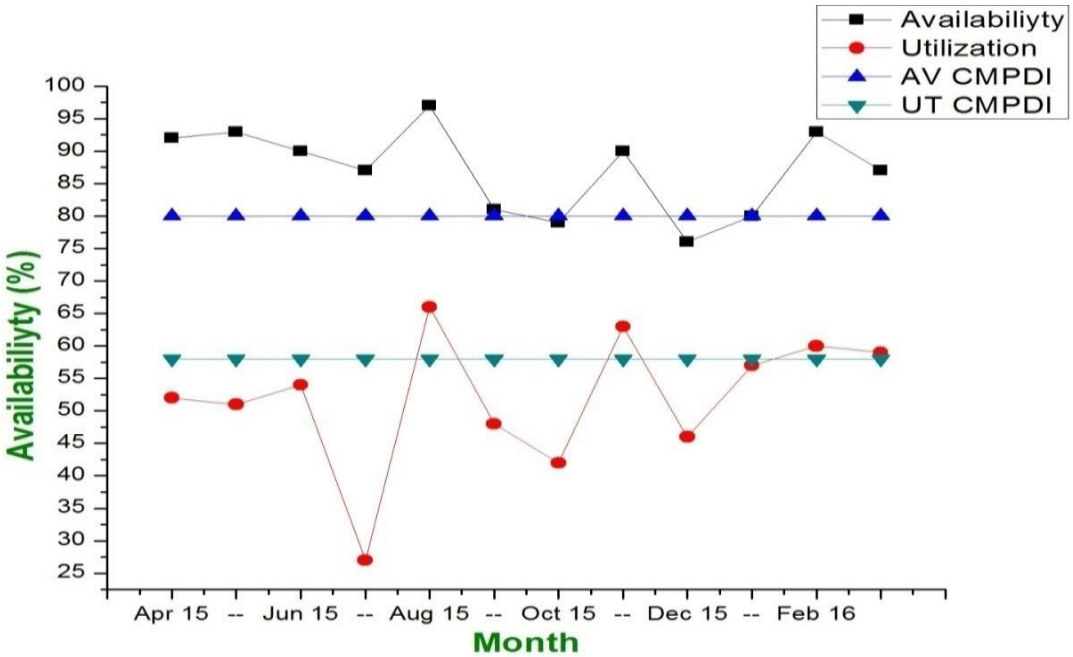



Fig 4.28: Graph shows percentage availability and utilization of shovel at OCL Langiberna.

As per figure 4.28, availability 79% in month of Oct-15 and 76% in month of Dec-15 was less as compare to the norms because of breakdown and maintenance hours. And the utilization was less in month of Apr. (52%) May (51%) July (27%) Oct. (42%) as per the norms. Which is because of frequent breakdown of the shovel, more idle hours that means maintenance problem of machine and also waiting for the dumper and also waiting for the drilling operation.

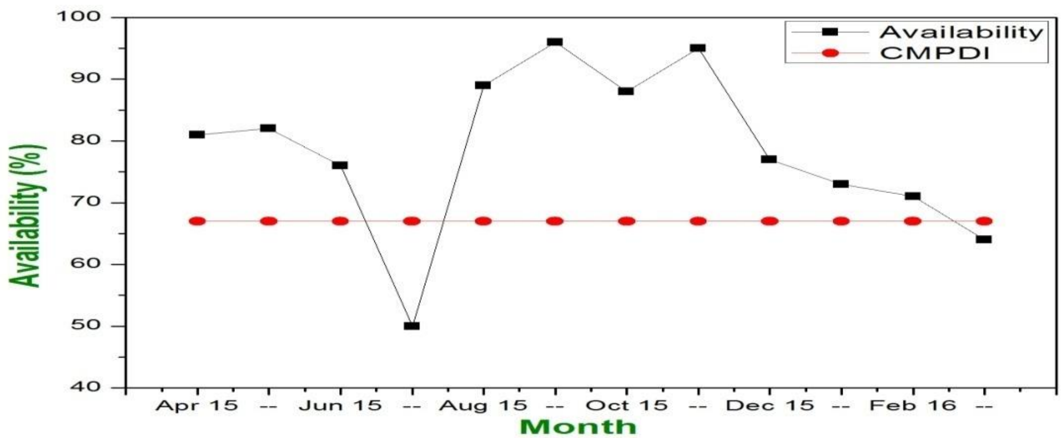



Fig 4.29: Graph shows percentage availability of dumper at OCL Langiberna.

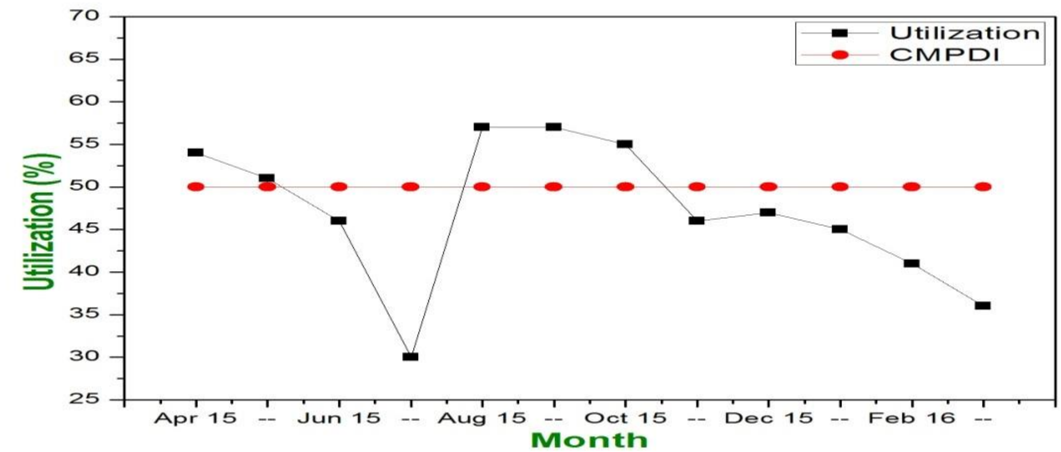



Fig 4.30: Graph shows percentage utilization of dumper at OCL Langiberna.

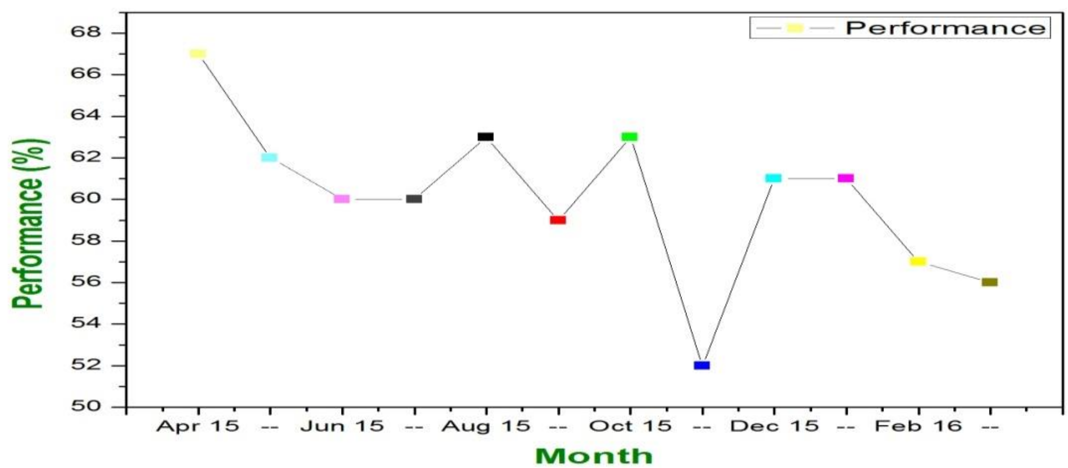



Fig 4.31: Graph shows percentage dumper performance rate at OCL Langiberna.

As per fig 4.32, Availability in month July (50%) March (64%) was less as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in month Jun (46%) July (30%) Dec (46%) Jan (47%) March (36%) was less than as per the norms. It is due to more breakdown hours which is caused by machine repair work and improper haul road management, under-loading of dumper, poor dust suspension and due to maintenance problem of machine and due to insufficient light.

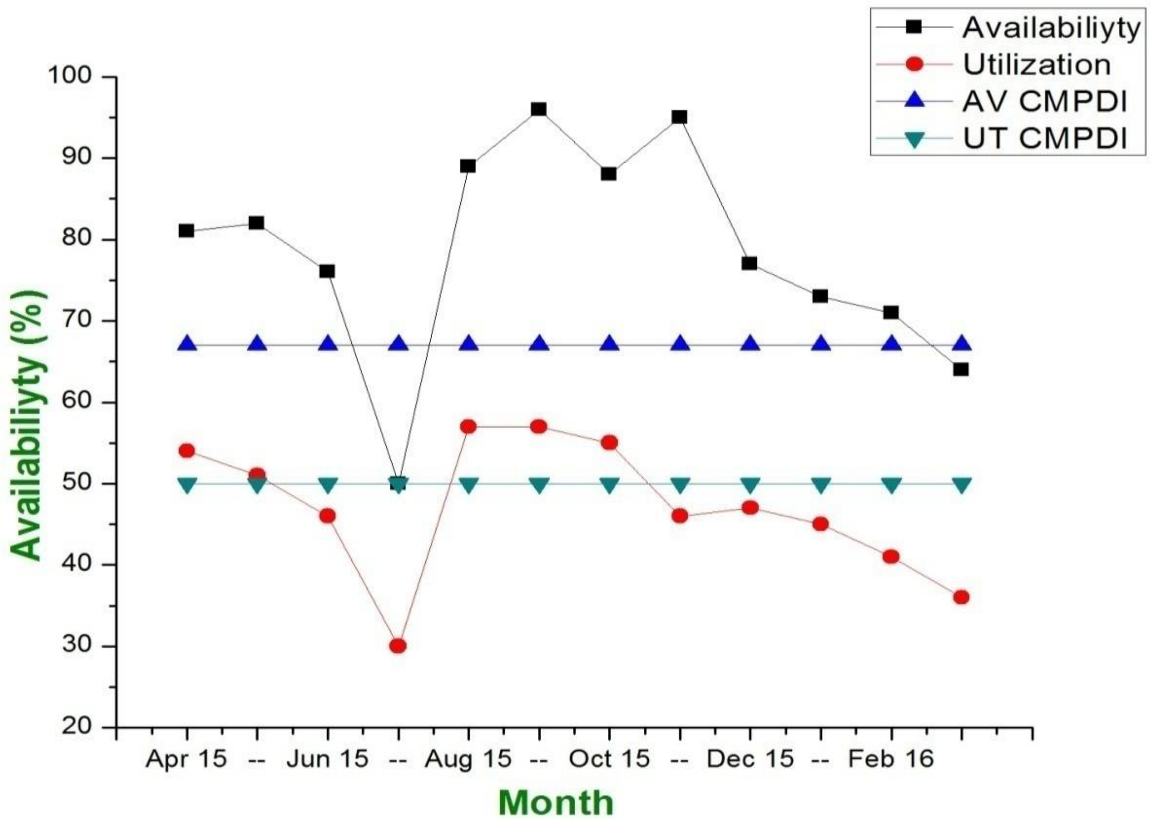



Fig 4.32: Graph shows percentage availability and utilization of dumper at OCL Langiberna.

# *CHAPTER 5*

## *QUEUING THEORY*

## 5.1 INTRODUCTION

Queuing theory was developed to provide models capable of predicting the behaviour 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. There are six basic characteristics that are used to describe a queuing system: arrival distribution of customers, service distribution of servers, queue discipline, system capacity, number of service channels, and number of service stages [30].

### 5.1.1 CUSTOMER ARRIVALS

In most queuing situations the arrival process of new customers to the system is stochastic. In these case it is necessary to know the distribution of the times between successive customer arrivals, or the inter-arrival times. It is also important to understand the behaviour of customers upon entering the system. Some customers may wait for service no matter how long the queue is, while others may see that a queue is too long and decide not to enter the system. When this happens the customer is described as having balked. Other customers may enter the system, but lose patience after waiting in the queue and decide to leave the system. These customers are said to have reneged. In situations with two or more parallel waiting lines a customer who switches from one line to the other is said to have jockeyed for position. Any or all of these behaviours may be present when a queuing system has what are classified as impatient customers. Impatient customers cause state-dependent arrival distributions, since the arrival pattern of new customers depends on the amount of congestion in the system at the time of their entry.

### 5.1.2 SERVICE DISTRIBUTIONS

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, 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. A common example of a queuing system utilizing batch service involves waiting in line for a roller coaster. In this scenario, the people waiting in line are the customers and the roller coaster car is the server. A single line is formed to wait, and when the roller coaster car arrives the first four people in line who get into the car receive simultaneous batch service.

In some case the service process may be dependent upon the number of customers waiting in the queue. The server may work more quickly due to the lengthening queue, or alternately the server may become flustered by the large number of customers waiting and the service rate may slow as a result. Situations in which the service rate depends on the number of customers in the queue for service are referred to as state dependent services.

### 5.1.3 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 served, or FCFS, where customers receive service in the order in which they arrived. This discipline is also commonly referred to as FIFO, or first in, first out. Another common queue discipline is LCFS, or last come, first served. This is commonly used in inventory situations where the most recently placed items waiting to be used are the most easily reached to be selected. RSS is a service discipline in which customers are selected for service in random order, independent of their order arriving to queue. There are a variety of different priority queue disciplines where different classes of customers are given higher priorities than other classes. In these disciplines the customer with the highest priority will be selected for service ahead of lower priority customers, regardless of how long each customer has been in the queue. If the queue discipline is pre-emptive, a customer with the highest priority is allowed to receive service immediately upon arrival at the server, even if a lower priority customer is already in service. The lower priority customer whose service is pre-empted resumes service after the higher priority customer has left. In non-pre-emptive cases the highest priority customer that arrives at the server moves to the head of the queue, but must wait until the customer currently being serviced has left [31].

### 5.1.4 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 maximum system size. If capacity is reached, no additional customers are allowed to enter system.

### 5.1.5 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 channel service station, there is only one path that customers can take through the system. Figure 5.1 below shows the path customers, represented by circles, take through a single service channel queuing network. The customers arrive at the server, represented by the rectangle, and form a queue to wait for service if it is not immediately available, and then proceed through the system once service has been completed.

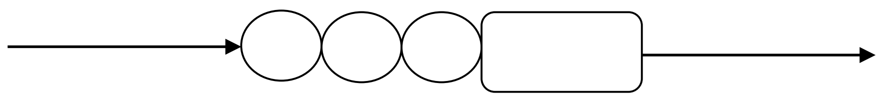


Figure 5.1: Single Channel Queuing System

When there are multiple servers available operating in parallel, incoming customers can either wait for service by forming multiple queues at each server, as shown in (a) of figure, or they can form a single queue where the first customer in line goes to the next available server, depicted in (b). Both of these types of queues are commonly found in day-to-day life. At the grocery store individual lines are formed at each cashier, but a single line is generally formed when customers are waiting in line at the bank. The first customer in line then proceeds to the next available teller. A single queue waiting for multiple servers is generally the preferred method, as it is more efficient at providing service to the incoming customers.

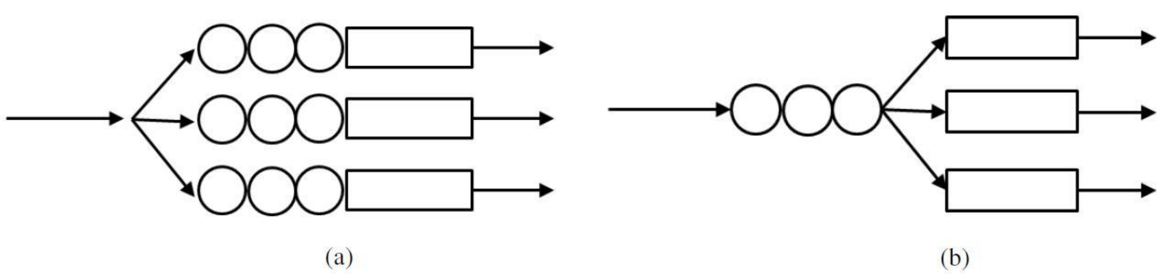



Fig 5.2: Multi channel queuing system

## 5.2NOTATION

Queuing processes are frequently referred to by using a set of shorthand notation in the form of (a/b/c/): (d/e/f) where the symbols a through f stand for the characteristics shown below in Table 5.1.

**Table 5.1: Queuing Notation Abbreviations**

| Symbol | Characteristics |
|---|---|
| a | Arrival Distribution |
| b | Service Distribution |
| c | Number of Parallel Servers |
| d | Service Discipline |
| e | Maximum number of units that can be in the system at one time |
| f | Population Size |

The symbols a through f will take different abbreviations depending on what type of queuing process is being described. Symbols a and b both represent types of distributions, and may contain codes representing any of the common distributions listed in Table 5.2.

**Table 5.2: Distribution Abbreviations**

| Symbol | Explanation |
|---|---|
| M | Markovian: exponentially distributed inter-arrival or service times |
| D | Deterministic: constant distribution |
| E*l* | Erlang distribution with parameter *l* |
| G | General Distribution |

Symbols c, e, and f all represent discrete values and are represented with the appropriate number or ∞ if there is no limit to the system size or population source. The service discipline, d, may be represented by any of the abbreviations explained below in Table 5.3.

Table 5.3: Service Disciplines

| Symbol | Explanation |
|---|---|
| **FCFS** | First come, first served |
| **FIFO** | First in, first out (same as FCFS) |
| **LCLS** | Last come, first served |
| **RSS** | Random selection for service |
| **PR** | Priority |
| **SIRO** | Service in random order |

The (*d/e/f*) term is often omitted, and in such cases the default assumptions are (FCFS/∞/∞). For example, an (M/D/3) queue would have exponential inter-arrival times, deterministic service rates, and three servers working in parallel. While not explicitly stated, a service discipline of first come, first served and infinite queue capacity and an infinite calling population are generally implied.

## 5.3 QUEUING SYSTEMS IN MINING

In mining operations, queues frequently form during the haulage process as dumper arrive at loaders, crushers, and dump locations and have to wait their turn in line. This process can be represented using queuing networks where the haul trucks represent the customers in the system and the servers are the loaders or crushers that the dumper are waiting for.

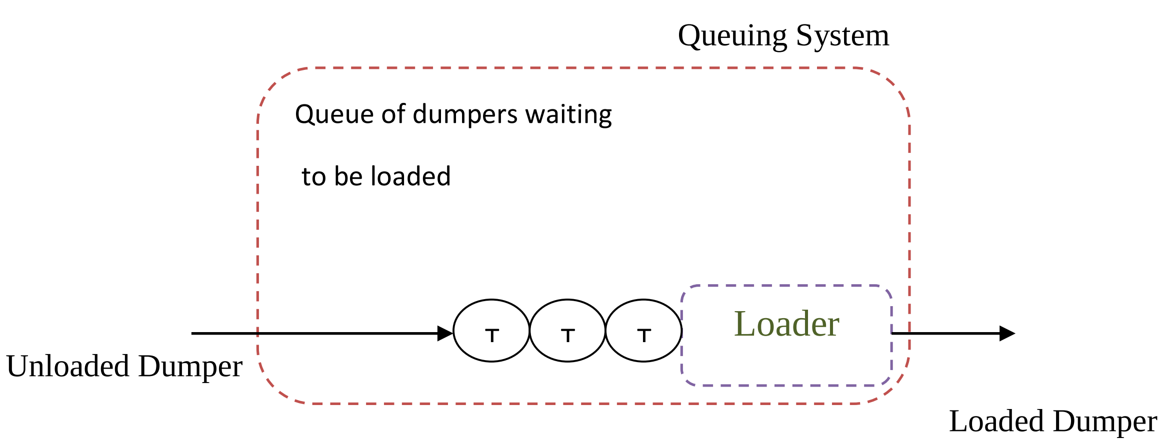



Figure 5.3: Dumper and Loader Queuing System

When representing loading operations with queuing systems, the time a dumper spends positioning and spotting at the loader can be included either as part of the loading cycle time or as part of the time the dumper was waiting in the queue for service. Figure 5.3 below depicts a basic mining queuing system composed of haul dumper and excavators.

Most basic haul routes have four main components: loading, loaded travel time, dumping of material, and unloaded travel time. These stages are repeated in sequence throughout the haulage system, and are easily represented by a cyclic queue, as shown below in Figure. In some case the haul routes can be classified as servers in addition to the loader and the crusher, since the haul routes are necessary steps in the production cycle, and the amount of time it will take individual dumpers to complete the trip is not constant throughout the production shift, so it is possible to assign a service distribution to the haul routes and treat them as servers, even though no queues will form since multiple dumpers can be on the haul roads at the same time.

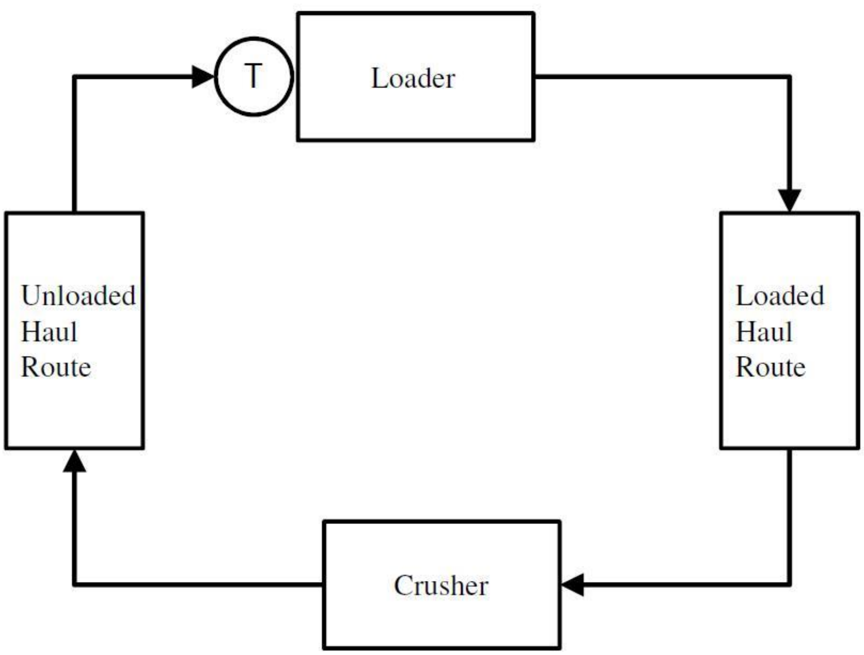



Figure 5.4: Cyclic Queuing System

The above cyclic queuing model can be adjusted to include multiple loaders, operating in parallel. Figure below shows a possible configuration with three loaders with a single queue formed for dumper to wait to be loaded, but any number of loaders could be used.

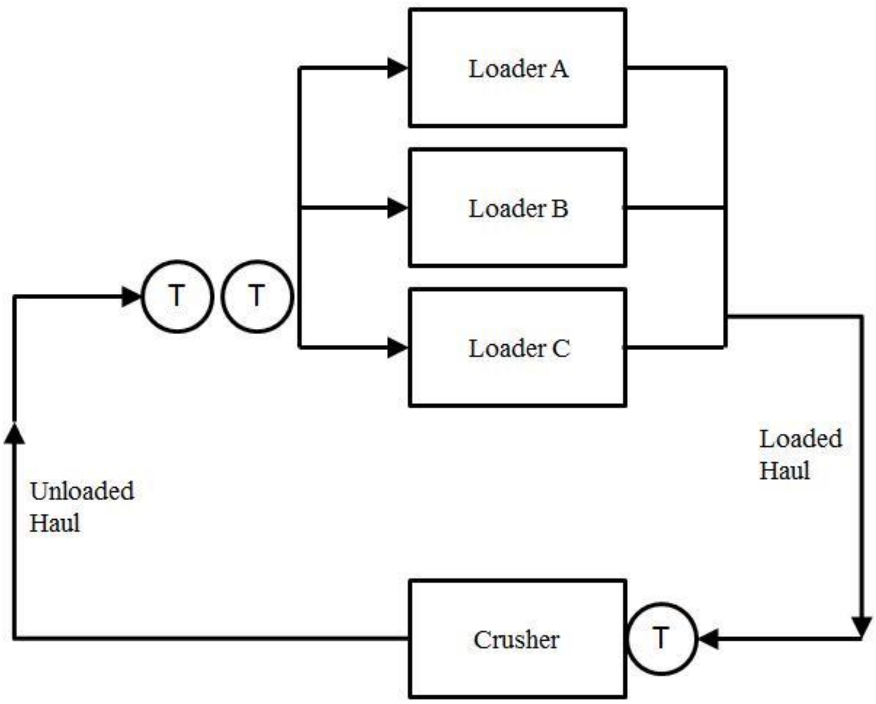



Figure 5.5: Cyclic Queuing System with Parallel Loaders

The cyclic queues represented above model the haulage systems for basic mine layouts. As the complexity of mining operations increases more intricate queuing systems must be used to represent operations. A network queue, such as the one depicted below in Figure 5.6 can be used when there are multiple paths available to the haul dumper. For this type of queuing model to work, metrics are necessary to determine the likelihood of each path being taken throughout the haul cycle. This could depend on the congestion of part of the system, the characteristics of each individual server, the contents of the dumper's load, or a myriad of other factors.

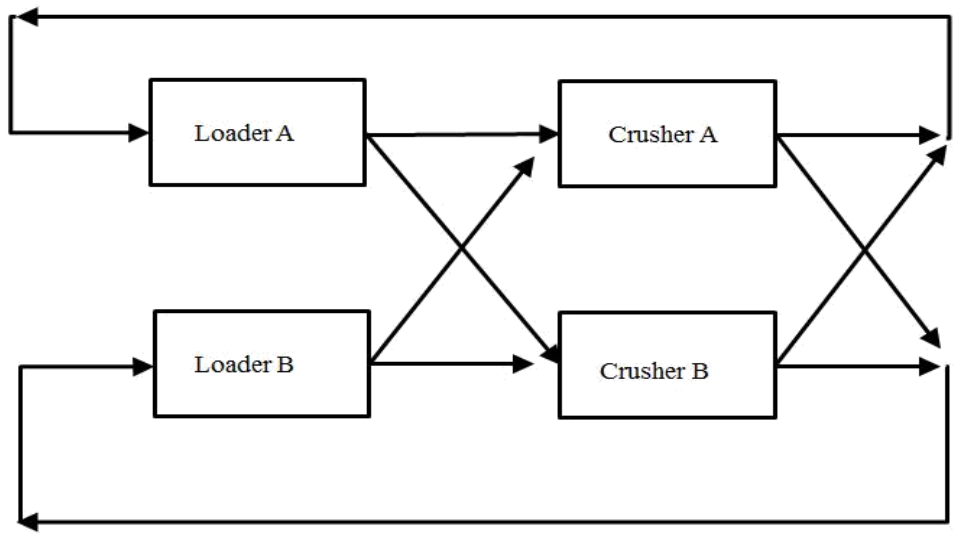


Figure 5.6: Network Queuing System

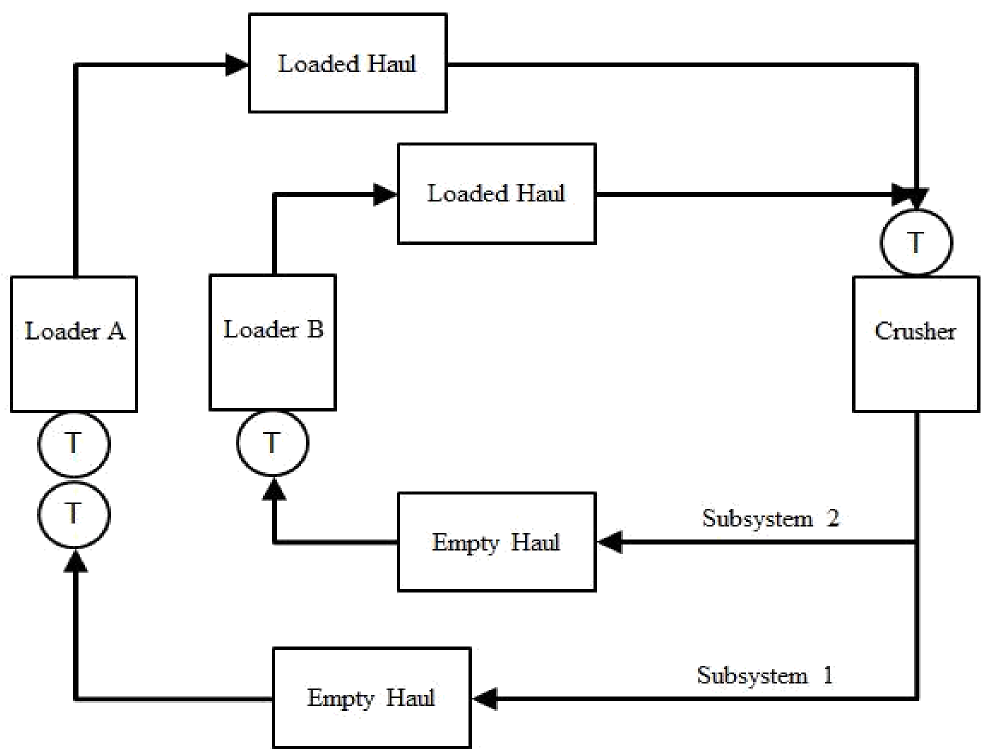


Figure 5.7: Queuing Schematic with Multiple Pits

Mines that are simultaneously operating from more than one pit can treat each pit as separate, independent queuing networks provided they do not share any resources. If they do share resources, for example two separate pits sharing a single crusher, the operation must be treated as one queuing network with subsystems for each pit. An example of this type of configuration is shown on the following page in Figure5.7.

## 5.4 QUEUING MODEL

A model of a Dumper and Shovel system for an open pit mine with multiple loaders operating within the pit was constructed. This was done with the goal of providing a middle ground between very simplistic deterministic methods of analyzing haul dumper fleet performance and complex, full-blown simulations that incorporate every aspect of mine activity. The rate of new haul dumper arrivals and the loading rates of the excavators were both assumed to be exponential. An (M/M/c) queuing model was selected to follow this assumption of exponential service and inter-arrival times and to allow for various numbers of loaders to be selected. An (M/M/c) model is one in which each server has an independent and identically distributed exponential service-time distribution and an exponential arrival process. This model of pit behaviour is versatile and can be used to model pit behaviour for a variety of different haulage configurations and mine layouts. The service discipline used is first come first served, with the assumption that there are no special classes of dumper.

### 5.4.1 Input Variables

To use this model, the values for the number of loaders operating, the arrival rate of new trucks, and the service rate per loader must be known to be used as inputs to the model. The necessary inputs are outlined on the following page in Table 4.

Table 5.4: Queuing Model Input Variables

| Symbol | Explanation |
|---|---|
| $\Lambda$ | Average Arrival Rate of new dumper |
| $\mu$ | Average service rate per loader |
| C | Number of loader operated |

The arrival rate, λ, is the average rate at which new dumper arrive at the loader. The service rate, μ, is the service rate of an individual loader. In cases with more than one loader in operation, all loaders are assumed to be equivalent, so μ would be the average service rate of the loaders. The arrival rate, λ, and service rate, μ, should both be input variables in the form of dumper per hour. Both the arrival rate and the service rate are independent of queue length. The queue will not have impatient customers, since it would be unrealistic for haul dumpers to not join the line to be loaded, regardless of how many dumpers are already waiting. There would also be no jockeying for position since dumpers form a single line to wait to be loaded, with the first dumper going to the next available loader. The model uses this information to calculate a variety of outputs about the dumper and shovel system.

Equations:

Based on this queuing system and input variables, the variables r and ρ are defined as,

$$r = \lambda/\mu \qquad \text{……………} (7)$$

and

$$\rho = r/c = \lambda/c\mu \qquad \text{……………} (8)$$

Where r is the expected number of dumper in service, or the offered workload rate, and ρ is defined as the traffic intensity or the service rate factor [32]. This is a measure of traffic congestion. When ρ > 1, or alternately λ > cμ where c is the number of loaders, the average number of dumper arrivals into the system exceeds the maximum average service rate of the system and traffic will continue back up. For situations when ρ > 1, the probability that there are zero dumper in the queuing System is defined as:

$$p_0 = \left(\sum_{n=0}^{c-1} \frac{r^n}{n!} + \frac{r^c}{c!\,(1-\rho)}\right)^{-1}$$

………… (9)

Where n is the number of dumper available in the haulage system. Even in situations with high loading rates, it is extremely likely that dumper will be delayed by waiting in line be loaded.

The queue length will have to no definitive pattern when arrival and service rates are not deterministic, so the probability distribution of queue length is based on both the arrival rate and the loading rate [30].

The expected number of dumper waiting to be loaded, can be calculated based on using the following equation.

$$L_q = (\frac{r^c \rho}{c!\,(1-\rho)^2}) p_0$$

……………... (10)

The average number of dumper in the queuing system, L, and the average time a dumper spends waiting in line, can be found by applying Little's formula which states that the long term average number of customers in a stable system, L, is equal to the long term average effective arrival rate, λ, multiplied by the average time a customer spends in the system, W [30]. Algebraically, this is expressed as

$$L = \lambda W \qquad \text{………………} (11)$$

and can also be applied in the form

$$L_q = \lambda\, W_q \qquad \text{………………} (12)$$

The average time a dumper spends in the system, W, is defined as

$$W = W_q + 1/\mu \qquad \text{…………………..} (13)$$

The model currently supports up to seven loaders operating in parallel, but could easily be adjusted to include more. There is no limit on haul dumper fleet size, provided the arrival rate of dumpers to the loading system does not increase to the point of overwhelming the loading capacity. This model is only valid for values of ρ, the traffic intensity per server, that are less than one. If ρ were to increase above one, the system would back up indefinitely, as the arrival rate of empty trucks would be greater than the loaders are capable of handling.

### 5.4.2 Outputs

When given the appropriate inputs, the model calculates and outputs values for various aspects of pit activity. These include loader utilization, the average time a truck spends in the system, the average time a dumper spends waiting to be loaded, the average number of dumper waiting in line, the average number of dumper in the system, and the system output in dumper per hour. Table 5 below lists the outputs created by the model and the appropriate units for each variable.

Table 5.5: Queuing Model Output

| Variable | Units | Description |
|---|---|---|
| **P** | % | Loader Utilization |
| **W** | Hours | Time spend in system |
| **Wq** | Hours | Time spend in queue |
| **L** | Number of dumper | Number of loader in System |
| **Lq** | Number of dumper | Number of loader in Queue |
| **ϴ** | Dumper per Hours | Output of System |

### 5.4.3: Calculation of Dumper/Shovel Haulage Systems

Surface mining is the most common mining method worldwide, and open pit mining accounts for more than 60% of all surface output. Haulage costs account for as much as 60% of the total operating cost for these types of mines, so it is desirable to maintain an efficient haulage system. As the size of the haulage fleet being used increases, shovel productivity increases and dumper productivity decreases, so an effective fleet size must be chosen that will effectively utilize all pieces of equipment. One method of fleet selection involves the application of queuing theory to the haul cycle.

Queuing theory was developed to model systems that provide service for randomly arising demands and predict the behaviour of such systems. A queuing system is one in which customers arrive for service, wait for service if it is not immediately available, and move on to the next server or exit the system once they have been serviced. Most mining haul routes consist of four main components: loading, loaded hauling, dumping, and unloaded hauling to return to the loader. These components can be modelled together as servers in one cyclic queuing network, or independently as individual service channels.

The south pit of the mine described operates with either two or three loaders in the pit depending on the shift and the haul dumper dump ore at the crusher and waste material at the dump site as previously described. Figure 5.8 below is a queuing schematic of the haulage operations for the south pit.

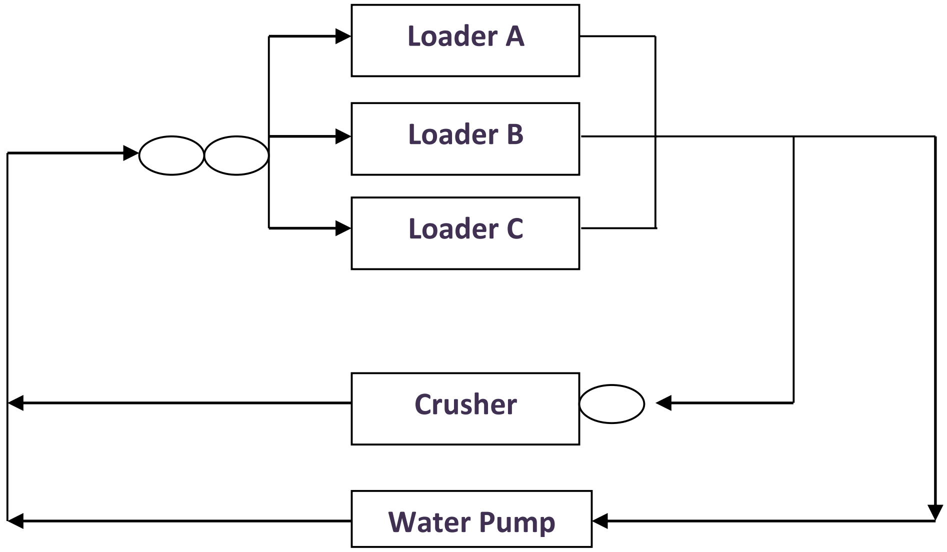


Figure 5.8: Queuing Schematic of Mine Haulage Route

The queuing model developed can be applied to the pit operations of this mine, represented by the top half of the above schematic. The arrival and service distributions for the south pit operations have been confirmed to fit exponential distributions, so an (M/M/3) queuing model is appropriate for this application. Loaded haul dumper exiting the queuing system of the pit will either travel to the crusher or the waste dump before returning to the pit to be loaded again. Which dumping location a dumper will utilize is dependent upon whether the loader filled the dumper with ore or waste material, and varies according to the geology of the ore body in the pit and the cut-off grade the mine is using. A metric that includes this information would be necessary to expand the current queuing model to apply to the entire haulage system, and is beyond the scope of this project.

Haul dumper data from eight hour shift the day 2nd March 2014 was examined and used to verify the queuing model created. A table of all relevant data from this eight hour operating period is available in table. The service and arrival rates for this shift were confirmed to fit exponential distributions. This shift began operations with three loaders and 12 haul dumper. Table 5.6 below contains the loading data, analyzed on an hourly basis. The number of new arrivals was calculated for each hour, and a service rate of 13.33 dumper per hour was used for the entire shift, since it is difficult to get a good measure of the service rate by only looking at one hour's worth of data at a time. In order to have an actual value to which the model output variables can be compared, the total number of dumper in the system, L, was calculated at three-minute time intervals for this particular shift. This was done by isolating all of the data points for dumper inside of the pit and counting the number of different dumper IDs during any given three-minute interval. A three-minute interval was selected to ensure that the sampling window would be large enough to include a data point from each dumper in the pit. Three minutes is also shorter than the majority of the service times, so it was selected as the interval to be used when determining the actual number of dumper in the system. The loading rate and average arrival rates for each hour segment were entered into the queuing model, using an (M/M/3) model for eight hours of the shift since the number of loaders in operation changed during the shift.

Table 5.6: Calculation of Queuing parameters based on input variables.

| Time (Hours) | C | $\lambda$ (Arrive/Hrs) | µ (Loaders/Hrs) | $L_q$ | L | $W_q$ (Hours) | W (Hours) | ρ (%) |
|---|---|---|---|---|---|---|---|---|
| **1** | 3 | 32 | 13.33 | 2.58 | 4.96 | 0.0806 | 0.155 | 80.0 |
| **2** | 3 | 30 | 13.33 | 1.91 | 4.14 | 0.0630 | 0.138 | 76.6 |
| **3** | 3 | 31 | 13.33 | 2.01 | 4.30 | 0.0648 | 0.139 | 77.1 |
| **4** | 3 | 28 | 13.33 | 1.14 | 3.22 | 0.0407 | 0.115 | 70.2 |
| **5** | 3 | 29 | 13.33 | 1.39 | 3.56 | 0.0479 | 0.123 | 72.5 |
| **6** | 3 | 30 | 13.33 | 1.91 | 4.14 | 0.0630 | 0.138 | 76.6 |
| **7** | 3 | 30 | 13.33 | 1.91 | 4.14 | 0.0630 | 0.138 | 76.6 |
| **8** | 3 | 31 | 13.33 | 2.01 | 4.30 | 0.0648 | 0.139 | 77.1 |
| **Avg.** | 3 | 3.125 | 13.33 | 1.85 | 4.09 | 0.0609 | 0.135 | 0.76 |

Table below contains the outputs generated by the queuing model, based on the inputs. The model calculated the actual number of dumper in the pit system (L), the number of dumper waiting for service (Lq), the actual amount of time dumper spent in the pit system (W), the amount of time dumper spent waiting for service ($W_q$), and server utilization (ρ).

**Table 5.7: Average Output during Operation**

| No. of Loader | $\lambda$ | μ | $L_q$ | L | $W_q$ | W | ρ | $\theta$ |
|---|---|---|---|---|---|---|---|---|
| **3 Loader** | 30.125 | 13.33 | 1.85 | 4.09 | 0.0609 | 0.135 | 0.76 | 39 |

And table below show the predicted number of shovel and dumper arrival rate and service rate in the system.

**Table 5.8: Actual predicted output during operation**

| No. of Loader | $\lambda$ | μ | $L_q$ | L | $W_q$ | W | ρ | $\theta$ |
|---|---|---|---|---|---|---|---|---|
| **3 Loader** | 36 | 13.33 | 0.735 | 3.435 | 0.0204 | 0.0954 | 0.9 | 39 |

The output variables indicate the idle time of the dumper used in a one particular shift. Based on this values the total cost of the dumper at particular sift are calculated. And also fleet selection is based on this output.

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# *CHAPTER 6*

## RESULT AND DISCUSION

## 6.1 RESULT BASED ON OEE

Table 6.1: Shovel (G-5A) and Dumper (BH-50) at Belpahar OCP (Monthly basis).

| **Surface Miners** | **Availability %** | | **Utilization %** | | **Performance Rate %** | | **OEE** | | **BDH** | | **IDH** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Max.** | **Min.** | **Max.** | **Min.** | **Max.** | **Min.** | **Max** | **Min** | **Max** | **Min** | **Max.** | **Min.** |
| G-5A Shovel | 92 | 66 | 51 | 19 | 61 | 24 | 0.69 | 0.30 | 207 | 22 | 452 | 219 |
| Dumper BH-50 | 92 | 24 | 47 | 11 | 56 | 36 | 0.58 | 0.18 | 526 | 0 | 367 | 90 |

Table6.2: Comparative availability of shovel (G-5A) and dumper (BH-50) at Belpahar OCP.

| **Surface Miners** | **CMPDI Norms%** | **Availability % (Avg.)** | **Month Below Norms** | **Remark** |
|---|---|---|---|---|
| G-5A Shovel | 80 | 82.5 | July-14, Dec-14, Jun-15 | Average % availability was found to be more as per the norms. |
| Dumper BH-50 | 67 | 73.16 | July-14, Feb-15, March-15 | Average % availability was found to be more as per the norms. |

Table 6.3: Comparative utilization of shovel (G-5A) and dumper (BH50) at Belpahar as per the CMPDI norms.

| **Surface Miners** | **CMPDI Norms %** | **Utilization % (Avg.)** | **Month Below Norms** | **Remark** |
|---|---|---|---|---|
| G-5A Shovel | 58 | 37.75 | All month | Average % utilization was found to be less as per the norms for all years. |
| Dumper BH-50 | 50 | 35 | All Month | Average % utilization was found to be less as per the norms for all years. |

Table 6.4: Shovel (TATA-7) and Dumper (BH-50) at OCL (Monthly basis).

| Surface Miners | Availability % | | Utilization % | | Performance Rate % | | OEE | | BDH | | IDH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Max.** | **Min.** | **Max.** | **Min.** | **Max.** | **Min.** | **Max** | **Min** | **Max** | **Min** | **Max.** | **Min.** |
| TATA-7 Shovel | 90 | 73 | 69 | 51 | 78 | 64 | 0.76 | 0.61 | 88 | 3 | 156 | 93 |
| Dumper BH-50 | 90 | 79 | 53 | 38 | 66 | 46 | 0.64 | 0.50 | 62 | 7 | 218 | 137 |

Table 6.5: Comparative availability of shovel(TATA-7) and dumper (BH-50) at OCL.

| Surface Miners | CMPDI Norms % | Availability % (Avg.) | Month Below Norms | Remark |
|---|---|---|---|---|
| TATA-7 Shovel | 80 | 85.41 | Apr-15, March-16 | Average % availability was found to be more as per the norms. |
| Dumper BH-50 | 67 | 84.83 | May-15, Dec-15 | Average % availability was found to be more as per the norms. |

Table 6.6: Comparative utilization of shovel(TATA-7) and dumper(BH50) at OCL as per the CMPDI norms.

| Surface Miners | CMPDI Norms % | Utilization % (Avg.) | Month Below Norms | Remark |
|---|---|---|---|---|
| G-5A Shovel | 58 | 56.66 | May-15, Jun15, Aug15, Dec-15 | Average % utilization was found to be less as per the norms for all years. |
| Dumper BH-50 | 50 | 47.916 | Apr, May, July, Aug, Nov, Dec-15, Jan-15 | Average % utilization was found to be less as per the norms for all years. |

Table 6.7: Shovel and Dumper at Belpahar OCP (Monthly basis).

| Surface Miners | Availability % | | Utilization % | | Performance Rate % | | OEE | | BDH | | IDH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | Max. | Min. | Max | Min | Max | Min | Max. | Min. |
| Shovel | 92 | 79 | 40 | 33 | 47 | 38 | 0.57 | 0.45 | 122 | 24 | 396 | 311 |
| Dumper | 81 | 49 | 30 | 20 | 50 | 36 | 0.42 | 0.31 | 310 | 102 | 363 | 179 |

Table 6.8: Comparative availability of shovel and dumper at Belpahar OCP

| Surface Miners | CMPDI Norms % | Availability % (Avg.) | Month Below Norms | Remark |
|---|---|---|---|---|
| Shovel | 80 | 85.25 | Feb-15, Jun-15 | Average % availability was found to be more as per the norms. |
| Dumper | 67 | 59.91 | July, Aug., Sep., Dec-14, Feb., March, Apr., May, Jun-15 | Average % availability was found to be less as per the norms. |

Table 6.9: Comparative utilization of shovel and dumper at Belpahar OCP as per the CMPDI norms.

| Surface Miners | CMPDI Norms % | Utilization % (Avg.) | Month Below Norms | Remark |
|---|---|---|---|---|
| Shovel | 58 | 39.916 | All month | Average % utilization was found to be less as per the norms for all years. |
| Dumper | 50 | 24.916 | All Month | Average % utilization was found to be less as per the norms for all years. |

Table 6.10: Shovel and Dumper at OCL (Monthly basis).

| Surface Miners | Availability % | | Utilization % | | Performance Rate % | | OEE | | BDH | | IDH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | Max. | Min. | Max | Min | Max | Min | Max. | Min. |
| Shovel | 97 | 76 | 66 | 27 | 71 | 53 | 0.75 | 0.44 | 79 | 3 | 191 | 112 |
| Dumper | 96 | 50 | 57 | 30 | 67 | 52 | 0.67 | 0.47 | 310 | 102 | 363 | 179 |

Table 6.11: Comparative availability of shovel and dumper at OCL.

| Surface Miners | CMPDI Norms % | Availability % (Avg.) | Month Below Norms | Remark |
|---|---|---|---|---|
| Shovel | 80 | 87 | Oct-15, Dec-15 | Average % availability was found to be more as per the norms. |
| Dumper | 67 | 78.5 | July-15, March-16 | Average % availability was found to be more as per the norms. |

Table 6.12: Comparative utilization of shovel and dumper at OCL as per the CMPDI norms.

| Surface Miners | CMPDI Norms % | Utilization % (Avg.) | Month Below Norms | Remark |
|---|---|---|---|---|
| Shovel | 58 | 52.082 | All month | Average % utilization was found to be less as per the norms for all years. |
| Dumper | 50 | 47.083 | All Month | Average % utilization was found to be less as per the norms for all years. |

### 6.1.1 Analysis of Performance in Mines

The following discussion is made on the performance of shove and dumper used in Belpahar OCP and OCL India langiberna open cast mine.

#### Belpahar OCP (Monthly basis)

1. For Shovel (G-5A), the average %availability and %utilization are observed to be 82.5% and 37.75% respectively. And the average breakdown hours and idle hours observed to be 87.16 and 328.91 respectively. The estimated OEE is found to be 0.467. Availability % and utilization % of shovel according to CMPDI norms is 80% and 58%. As per fig. Availability (66%) was poor in Jan-15 as compare to other months because breakdown and maintenance hours were much more than other month. And the utilization in all the month are much less. Which is because of more idle hours that means not no proper dozing operation was not done and also no power supply availability all time.

2. For Dumper (BH-50), the average %availability and %utilization are observed to be 73.166% and 35% respectively. And the average breakdown hours and idle hours observed to be 147.41 and 277.083 respectively. The estimated OEE is found to be 0.467. Availability % and utilization % of Dumper according to CMPDI norms is 67% and 50%. As per fig. Availability 24% and 27% were poor in March-15 and Feb-15 as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in month Jan-15 is 36% also are much less. Which is because of not sufficient loose blasted material and no proper dozing operation and due to more breakdown hours which is caused by machine repair work.

OCL INDIA Langiberna (Monthly basis)

1. For Shovel, the average %availability and %utilization are observed to be 85.416% and 59.66% respectively. And the average breakdown hours and idle hours observed to be 30.41 and 117 respectively. The estimated OEE is found to be 0.686. Availability % and utilization % of Shovel (TATA-4cum) according to CMPDI norms is 80% and 58%. As per fig. Availability 73% was less in May-15 as compare to other months because breakdown and maintenance hours. And the utilization is 51% in month May-15 and Aug-15. Which is because of more idle hours that means no proper dozing operation and also no power supply availability all time.

2. For Dumper, the average %availability and %utilization are observed to be 84.83% and 47.916% respectively. And the average breakdown hours and idle hours observed to be 33.08 and 173.83 respectively. The estimated OEE is found to be 0.586. Availability % and utilization of Dumper (BH-50) according to CMPDI is 67% and 50%. As per fig. Availability 79% were less in Aug-15 as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in month Aug-15 is 46%, July-15 is 41% and Nov-15 is 38% are much less. Which is because of no proper haul road and not sufficient loose blasted material and no proper dozing operation and due to more breakdown hours which is caused by machine repair work.

### Belpahar OCP (Average of all Shovel and Dumper)

1. For Shovel, the average %availability and %utilization are observed to be 82.25% and 35.916% respectively. And the average breakdown hours and idle hours observed to be 70.75 and 355.83 respectively. The estimated OEE is found to be 0.48. Availability % and utilization % of Shovel According to CMPDI norms is 80% and 58%. As per fig. Availability 79% was less in Feb-15and Jun-15 as compare to other months because breakdown and maintenance hours. And the utilization was less in all the month as per the norms. Which is because of more idle hours that means maintenance problem of machine and also waiting for the dumper and also waiting for the drilling operation.

2. For Dumper, the average %availability and %utilization are observed to be 59.916% and 24.91% respectively. And the average breakdown hours and idle hours observed to be 258.5 and 258.33 respectively. The estimated OEE is found to be 0.357. Availability % and utilization % of Dumper (BH-50) according to CMPDI norms is 67% and 50%. As per fig. Availability in month July (53%) Aug (49%) March (54%) Arp (47%) was less as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in all month are less than as per the norms. It is due to more breakdown hour which is caused by machine repair work and not proper haul road and due to maintenance problem of machine.

### OCL INDIA Langiberna (Average of all Shovel and dumper)

1. For Shovel, the average %availability and %utilization are observed to be 87.083% and 52.083% respectively. And the average breakdown hours and idle hours observed to be 32.5 and 159.58 respectively. The estimated OEE is found to be 0.624. Availability % and utilization % of Shovel according to CMPDI norms is 80% and 58%. As per fig. Availability 79% in month of Oct-15 and 76% in month of Dec-15 was less as compare to the norms because of breakdown and maintenance hours. And the utilization was less in month of Apr. (52%) May (51%) July (27%) Oct. (42%) as per the norms. Which is because of frequent breakdown of the shovel, more idle hours that means maintenance problem of machine and also waiting for the dumper and also waiting for the drilling operation.

2. For dumper, the Average %availability and %utilization are observed to be 78.5% and 47.08% respectively. And the average breakdown hours and idle hours observed to be 70.91 and 143 respectively. The estimated OEE is found to be 0.575. Availability % and utilization % of Dumper (BH-50) according to CMPDI norms is 67% and 50%. As per fig. Availability in month July (50%) March (64%) was less as compare to other months because breakdown hours and no proper maintenance of machine. Utilization in month Jun (46%) July (30%) Dec (46%) Jan (47%) March (36%) was less than as per the norms. It is due to more breakdown hours which is caused by machine repair work and improper haul road management, under-loading of dumper, poor dust suspension and due to maintenance problem of machine and due to insufficient light.

## 6.2 RESULT BASED ON QUEUING THEORY

The actual and predicted average arrival rates and service rates were calculated and used as inputs for the model. These results are shown below in Table 6.13 and Table 6.14.

Table 6.13: Queuing Model Outputs for Entire Shift

| No. of Loader | $\lambda$ | μ | $L_q$ | L | $W_q$ | W | ρ | $\theta$ |
|---|---|---|---|---|---|---|---|---|
| **3 Loader** | 30.125 | 13.33 | 1.85 | 4.09 | 0.0609 | 0.135 | 0.76 | 39 |

Table 6.14: Queuing model output on predicted number of shovel and dumper for entire shift.

| No. of Loader | $\lambda$ | μ | $L_q$ | L | $W_q$ | W | ρ | $\theta$ |
|---|---|---|---|---|---|---|---|---|
| **3 Loader** | 36 | 13.33 | 0.735 | 3.435 | 0.0204 | 0.0954 | 0.9 | 39 |

The output variables indicate the idle time of the dumper used in a one particular shift. Based on this values the total cost of the dumper at particular sift are calculated. And also fleet selection is based on this output.

### 6.2.1 Analysis of Queuing Theory Based on the Actual and Predicted Values

This queuing model is useful for analyzing the efficiency of mining haulage and loading operations for the configurations in which they are currently operating. The amount of time dumper spends waiting to be loaded, $W_q$, and the server utilization, $\rho$, are both indicators of how efficiently the system is operating. The larger the values of $W_q$, the longer dumper are spending idling waiting at the loaders, burning fuel without contributing to the haulage process. The server utilization indicates what proportion of operational time loaders are actually in use.

Here pit system operating with three loaders, an arrival rate of 30 dumpers per hour, and a service rate is found to have a loader utilization of 76%, a system output of 39 dumpers per hour, and an average of 0.0609 hours spent waiting in the queue per dumper for each loading cycle. Since each dumper passing through the system would potentially have to spend time waiting at the loader, the system output multiplied by the average time spent waiting in the queue is the average amount of time dumper are idling in the pit per hour. Over an eight-hour shift, this comes to a combined total of 19 hours of dumper idling time. Based on the loader utilization, each loader was not in use for 26% of the shift. This comes to a total of 10.14 hours of idle time between the three loaders for the eight-hour period. And based on the predicted number of shovel and dumper arrival rate and service rate by the respective mines we have to found a loader utilization of 90%, a system output of 39 dumpers per hour and an average of 0.0204 hours spend waiting in the queue per dumper for each cycle. Over an eight-hour shift, this comes to combine total of 7.48 hours of dumper idle time. There is some difference between actual and predicted system. If the haulage operations were adjusted, either by changing the number of loaders operating or adjusting the fleet size, the new arrival rate that results can be used to run the model again, and see whether the changes made would be valuable to the system in terms of the cost to operate unnecessary equipment.

If there are usually multiple dumper waiting for the loaders, as indicated by $L_q$, it would likely be beneficial to decrease the fleet size to reduce the amount of time dumper are spending waiting to be loaded. Changes to the queuing model can be made by adjusting the arrival rate of new dumper to the system to see how the system would react to dumper arriving more or less frequently. While this is similar to comparing the effects of adding or removing dumper to the system, the amount of change in arrival rate caused by changing the fleet size will vary depending on the specific characteristics and layout of each mine.

As the model currently exists, the effects of changes to fleet size can only be examined if the changes are actually made in the pit, the new inputs are determined, and the model is run again. This is due to the fact that arrival rate, which is a necessary queuing input, is dependent upon more than just the number of dumper in the system. To determine an optimal fleet size for a given mine layout and loading configuration without running a full simulation, it may be more useful to use models involving stochastic simulation, such as Monte Carlo simulation to incorporate haul routes, travel times, and fleet sizes. This would allow various fleet sizes and configurations to be compared without having to make real world changes to acquire additional inputs for the model, as would be necessary for queuing model. Queuing model can analyze the efficiency of haulage systems as they currently exist, but it cannot be used alone to optimize haulage operations, since arrival rate being used in the model depends on more than simply the number of dumper in operation.

# *CHAPTER 7*

**CONCLUSION**

**FUTURE SCOPE**

## 7.1 CONCLUSION

The performance of shovel and dumper are analysed by using models which developed at Belpahar OCP of Mahanadi Coalfield Limited (MCL) and at OCL INDIA Langiberna on monthly basis. In that model are based on Overall Equipment Effectiveness (OEE) and by using queuing theory. OEE is a simple tool used to measure the effectiveness of equipment by effectively using its availability and performing it's given functionality effectively. In this OEE is calculated based on the availability, utilization and performance rate with different weights. These weight are taken after considering the importance of given parameter using Analytic Hierarchy process (APH). By analysing the model, performance of OCL Langiberna is better than the Belpahar OCP. This is due to the better utilization of the machinery in OCL Langiberna.

Queuing theory can be used to model dumper and shovel behaviour in open pit mines. The (M/M/c) model developed is consistent with data from one open pit operation. Exponential inter-arrival times and exponential service time are consistent with the data from this mine, so assumptions of the model are valid for some operation. Changes in fleet size only possible when actual change are made in the pit. This is due to that the arrival rate, which is a necessary queuing input, is dependent upon more factors than just the number of dumper in the system. The queuing model can analyze the efficiency of haulage systems as they are currently exist based on their fleet size.

When fleet size is considerably change in mine pit by minimizing the number of dumper in the cycle, then there is actually change in waiting time of dumper in system, which considerably reduce the idle time of dumper. Hence from that effectively utilization of shovel and dumper are increased. And overall performance of the shovel and dumper is also improved.

## 7.2 FUTURE SCOPE

- The (M/M/c) model developed can be expanded upon and customized to individual mine layouts to include the rest of the haulage route, and not just the activities located in the pit.
- In future, a software can be developed to calculate all these assessments in a nutshell. In addition to these we can also add financial assessment.

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