NCHANGA OPEN PIT FLEET OPTIMIZATION FOR PRODUCTIVITY IMPROVEMENT

By

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Declaration

I, Gift Dembetembe, do declare that the work presented in this thesis is my original research work with exception of quotes and citation of other authors' work which has been duly referenced and acknowledged herein. No part of this dissertation has been presented or published for pursuit of any degree in this or any other university or college.

I, therefore, declare that this dissertation was written and presented according to the rules and regulations governing the award the of Master of Mineral Sciences degree of the University of Zambia.

Signature of author……………………………………………………..

Date…………………………………………………………………….

Certificate of Approval

This thesis by Gift Dembetembe has been approved as fulfilling the requirement for the award of Degree of the Master of Mineral Sciences by the University of Zambia.

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Dedication

To my unknown bride and family. I did this for you!

Acknowledgements

I am so thankful to God for making it possible for me to do my master's degree when I thought it was going to be difficult especially to finance my studies. On the same note I would like to thank my parents and friends who have always prayed for me.

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Abstract

Nchanga Open Pit (NOP) is facing a critical equipment planning decision after undertaking improvement projects at the processing plant namely Elevated Temperature Leaching, Heap Leaching and Cobalt/Copper separation. Elevated Temperature Leaching has resulted in 20% increase in the recovery of copper while cobalt/copper separation is anticipated to bring 77.5% increase in the value of the final product. The improvements at the processing plant have subsequently led to extension of life of mine to 4 years. As a result of the above, all upstream components of the value chain have to be harmonized with these improvements in order to maintain productivity at optimum level and curb loss of value. Currently, NOP is faced with a critical equipment planning decision where the current ore handling fleet has to be either re-capitalized or apportioned to exploit new mining areas.

Therefore this study was undertaken in order to optimize the fleet in terms of both size and performance.

In order to achieve the stated objective, production planning, fleet optimization and fleet management were reviewed and analyzed based on generic formulas, match factor theory, Overall Equipment Effectiveness (OEE) and queuing theory while analysis of fleet performance and simulation was done by using Talpac software. Results of study indicated that NOP needs to invest in machinery by either re-capitalizing the current fleet or resorting to a more cost effective fleet management approach.

Fleet optimization at NOP had six interacting factors which have attributed to low fleet performance. These factors are low machine availability, low machine utilization, mismatch between loaders and truck fleet sizes, double handling of ore, costly dust suppression system and flawed maintenance system. Furthermore, based on fleet deterioration, assessment of fleet performance using OEE showed low Overall Equipment Effectiveness of 7.2% for shovels, 13.6% for large excavators and 17.6% for trucks against a score of 85%.

The study has also established that the number of trucks needs to be increased from 15 to 28 if the current haulage system has to be maintained or alternatively use the conveyor belt system. However, to do this, a reliability and maintainability analysis has to be done which is beyond the scope of this study.

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Abbreviations and Acronyms

No.	Abbreviation	Description
1	NOP	Nchanga Open Pit
2	KCM	Konkola Copper Mines
3	OEE	Overall Equipment Effectiveness
4	FY	Financial Year
5	ETL	Elevated Temperature Leaching
6	HL	Heap Leaching
7	Co	Cobalt
8	Cu	Copper
9	LOM	Life of Mine
10	BCM	Bank Cubic Meter
11	FPC	Fleet Production and Cost analysis
12	CRO	Chingola Refractory Ore
13	OEM	Old East Mill
14	NWM	New West Mill
15	NEM	New Eest Mill
16	FEL	Front End Loader
17	Mb	meter bench
18	BP	Budget Plan
19	RTV	Rubber Tired Vehicle
20	COP F&D	Chingola Open Pit F&D
21	CUT II	Mining Cut number 2
22	TKPH	Tonne Kilometers per Hour
23	TMPH	Tonne Miles per Hour

CHAPTER 1 INTRODUCTION

1.1 Introduction

In fleet management there is no one size fits all concept applicable to solving all fleet problems. The reason is the stochastic nature of fleet optimization problems. They can be statistically modelled but cannot be precisely predicted by statistical means. There are always some on-the-ground realities such as unscheduled down time for critical equipment; operator error or efficiency; adverse weather; on-site operational deviations from established procedure and equipment purchase budget limitations. As a result there is need to establish some particular site's needs and priorities then assess how closely a system's capabilities can match site requirements. Another option will be to design a new algorithm specific to a particular site.

1.2 Fleet Optimization and Management

Fleet issues have two major aspects to them: there is fleet optimization and then fleet management. Fleet optimization looks at establishing a perfect fleet size and perfect individual component sizes where there is a perfect match between loading and hauling machines. This has to be done during mine start up and from time to time as open pit deepens such that haul road lengthens. Fleet management then looks at the appropriate method for sustaining a fleet at optimal performance. This includes fleet monitoring; machine guidance; production tracking; safety monitoring and maintenance management.

This research looks at both aspects interacting within shovel/truck haulage systems. Furthermore it seeks to optimize the fleet and install a fleet management system for the mine in question. All the optimization and management are in this case done in response to certain upgrades in the processing system and subsequent change in output value as well as increase in life of mine.

From literature review undertaken it is evident that surface mining is the most common mining method used worldwide and open pit operations account for more than 60% of all surface output (Hartman & Mutmansky, 2002). The mineral extraction process in an open pit operation involves the stripping of overburden followed by drilling, blasting and transportation of material using a system of loading and hauling equipment. Other various auxiliary operations like dewatering are also included. Loading of ore and waste is carried out simultaneously at several different locations in the pit and often in several different pits (Sarkar, 2009). Commonly a system of shovels or excavators and haul trucks is used. In open pit operations, haulage costs account for as much as 60% of the total operation costs (May, 2012). This goes to show how imperative it is to maintain an efficient materials handling system. In practice, if the haulage fleet size increases, shovel productivity increases while truck productivity decreases. This phenomenon must then prompt any mine management to choose a fleet size that will effectively utilize all pieces of equipment available. However it is not easy to determine the number of trucks required to meet production requirements as well as maximize efficiency. This is a consequent of the advancing nature of mining and the corresponding lengthening of haul roads.

1.3 Research Site

This section gives a brief description of the site where the research was be undertaken. It introduces the company in terms of its location, tonnage of Run-Off-Mine ore mined and the type of mining employed to mine the ore body.

Nchanga Open Pit (NOP), an enterprise owned by Konkola Copper Mines (KCM) Plc is situated on the Copperbelt province of Zambia. It is located in a crescent shaped structure 11 km long around the Zambian municipal town called Chingola. The pit covers nearly 30 km^2 and is the second largest open pit mine worldwide. The deepest part of the pit is 400m measured from the surrounding plateau. Besides the main Nchanga open pit there are nine medium sized satellite open pits that have also been in operation. An annual tonnage of 4 080 000t of copper is expected from the main pit and is mined using a shovel/truck system. The google map in Figure 1.1 shows the pit layout and its general location within Chingola town. The pit has two main sections namely CUT II and COP F&D. This research work was done basing on operations within these two sections.

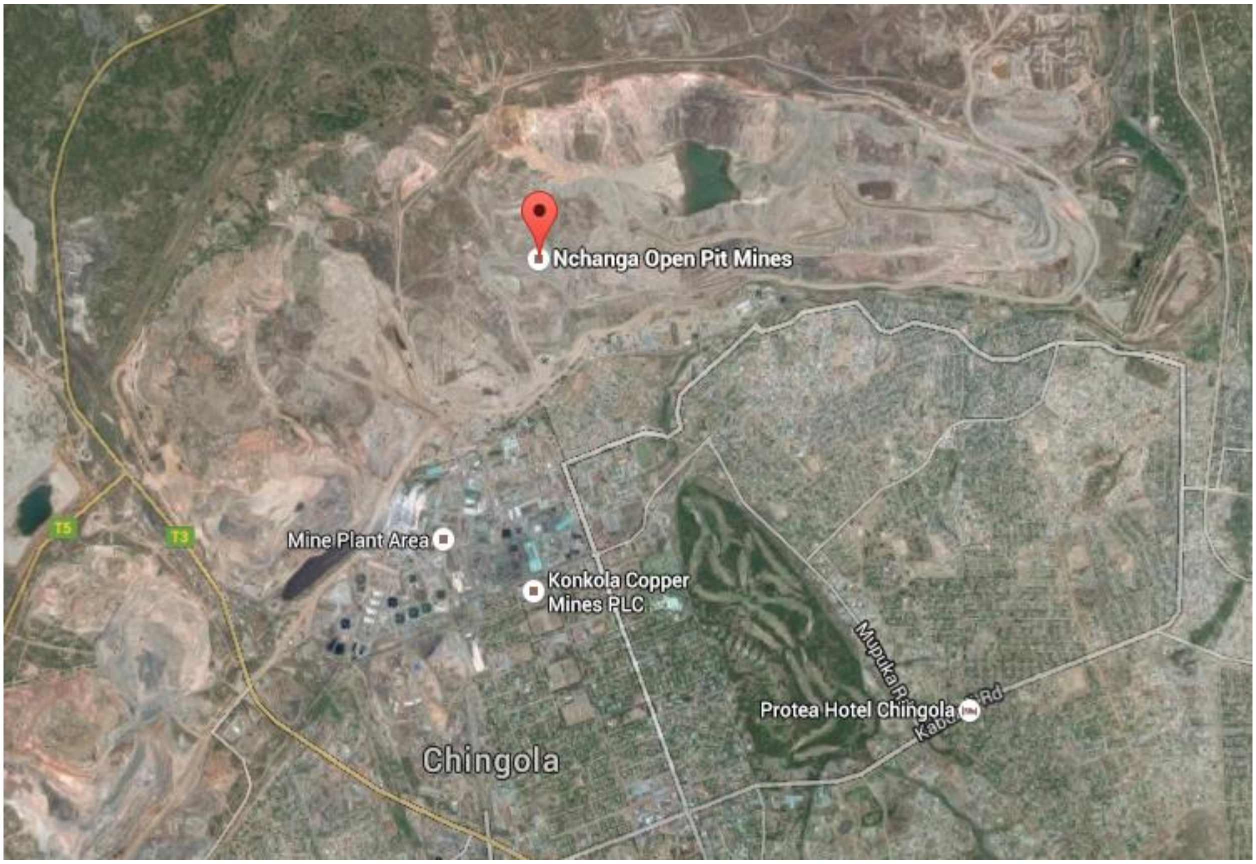


Figure 1.1: Location of Nchanga Open Pit Mines (google earth)

1.4 Statement of the Problem

KCM has embarked on three copper processing improvement projects shown in 'A' in Figure 1.2 namely Elevated Temperature Leaching (ETL), Heap Leaching (HP) and Cobalt/Copper Separation. Elevated temperature leaching has resulted in 20% increase in the recovery of copper while Cobalt/Copper separation has promised a 77.5% increase in the value of the final product. These improvement projects have effects of increasing the company's profitability as well as extending the life of mine (LOM). It is in the light of these two downstream effects that an optimization of upstream components of the value chain becomes imperative.

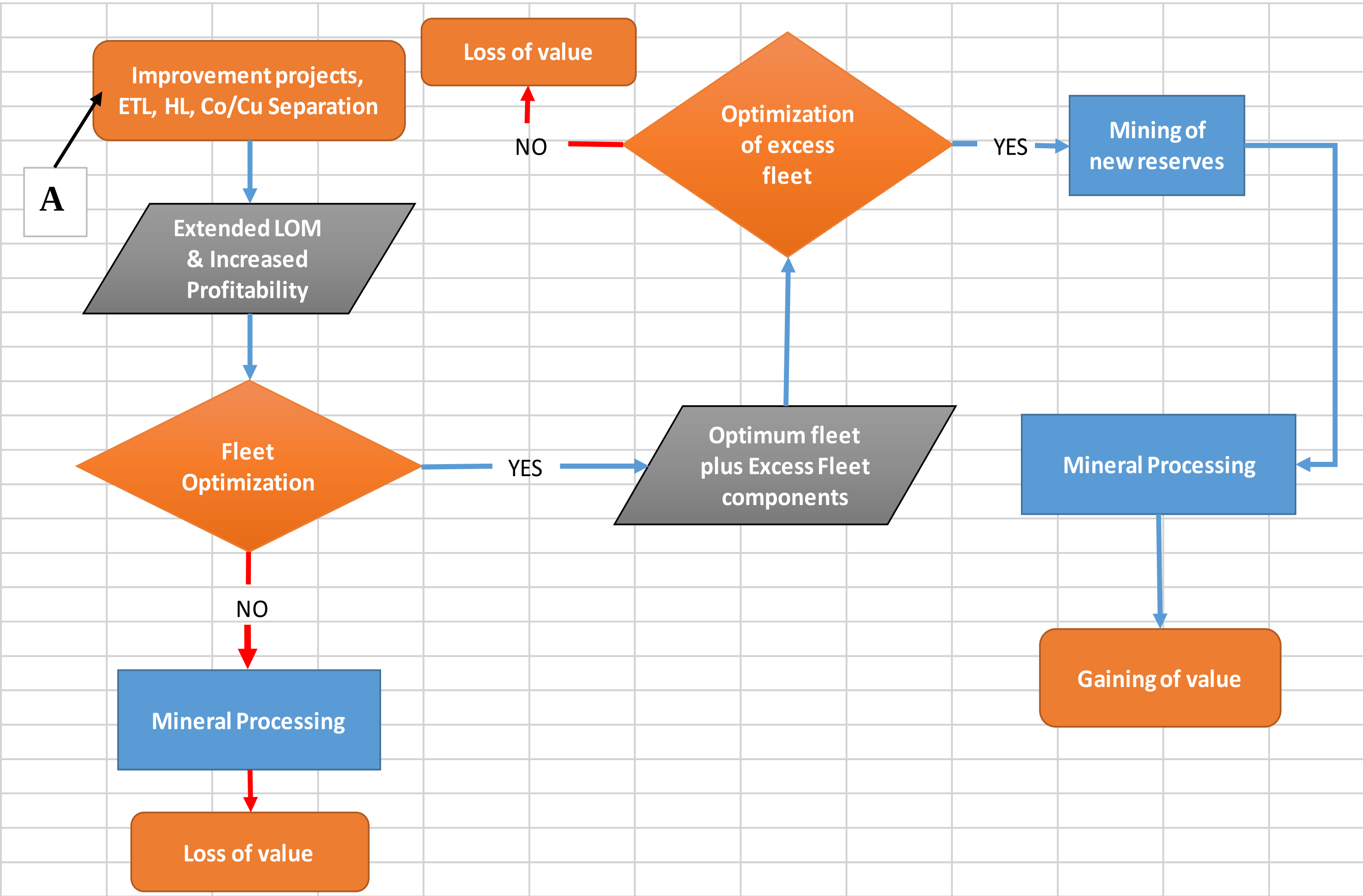


Figure 1.2: Copper processing improvement projects and their impact on NOP fleet

Secondly, NOP is faced with a critical equipment planning decision where the current ore handling fleet has to be either re-capitalized or apportioned to exploit new mining sites in response to increased profitability and extended LOM. In taking a glance at the current fleet performance, it can be seen from Figure 1.3 that production targets for CUT II section were met even with excess for close to 75% of the 2015/16 Financial Year (FY). However as shown in Figure 1.4 the opposite was true for COP F&D since no much production was budgeted for from that section.

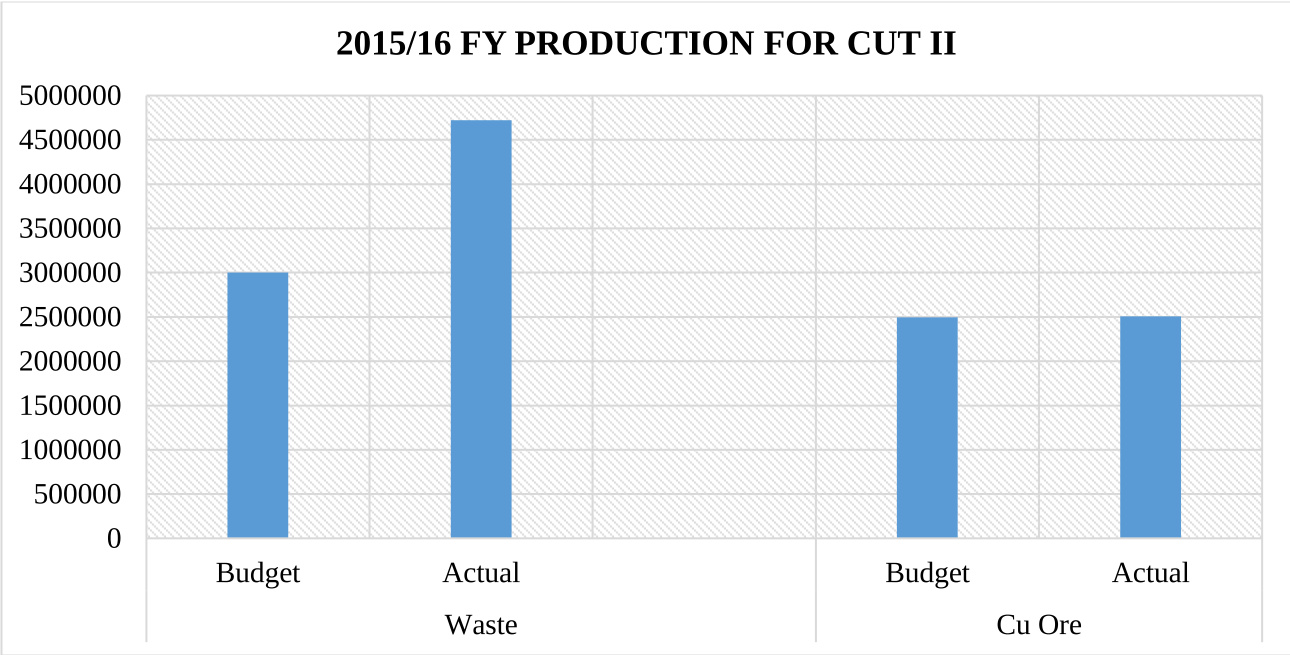


Figure 1.3: CUT II production tonnages for both waste and ore for 2015/16 FY

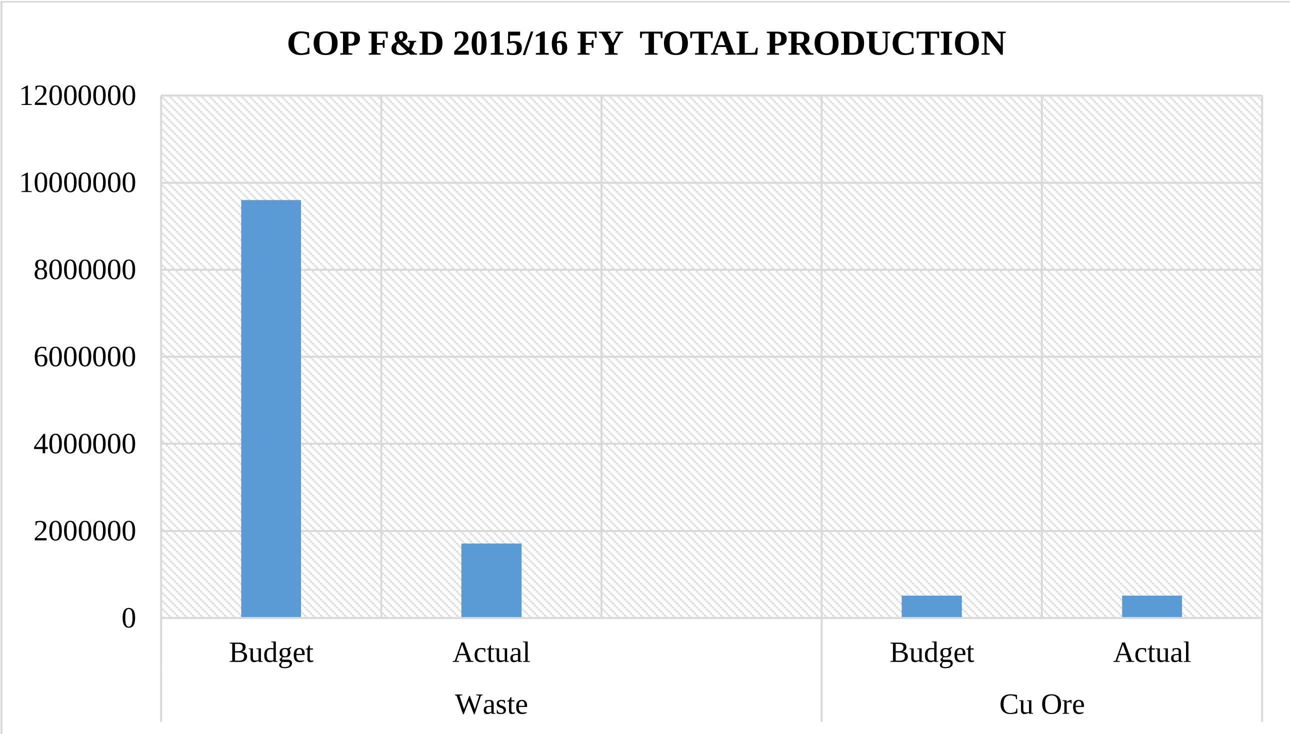


Figure 1.4: COP F&D tonnages for both waste and ore for the 2015/16 FY

However examination of the productivity of the loading and haulage fleet in use yielded the trends shown in Figures 1.5 and 1.6. Actual productivity can be seen to be trailing way below budget for every month by a wide margin.

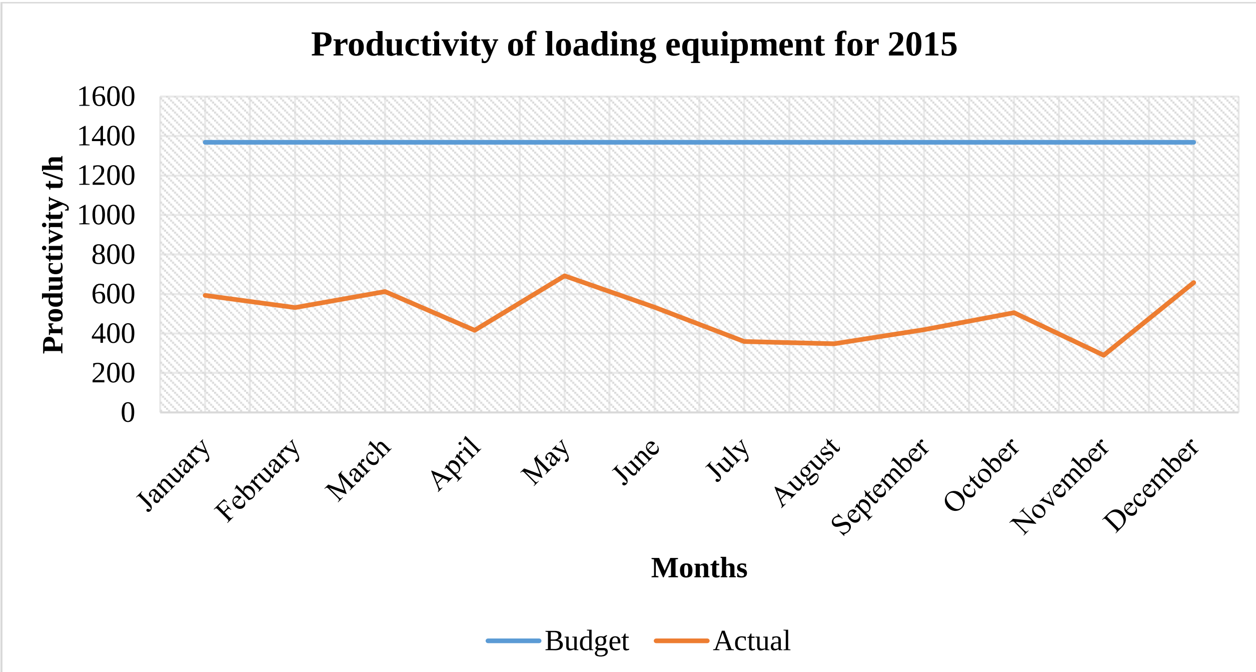


Figure 1.5: Average loader productivity for 2015

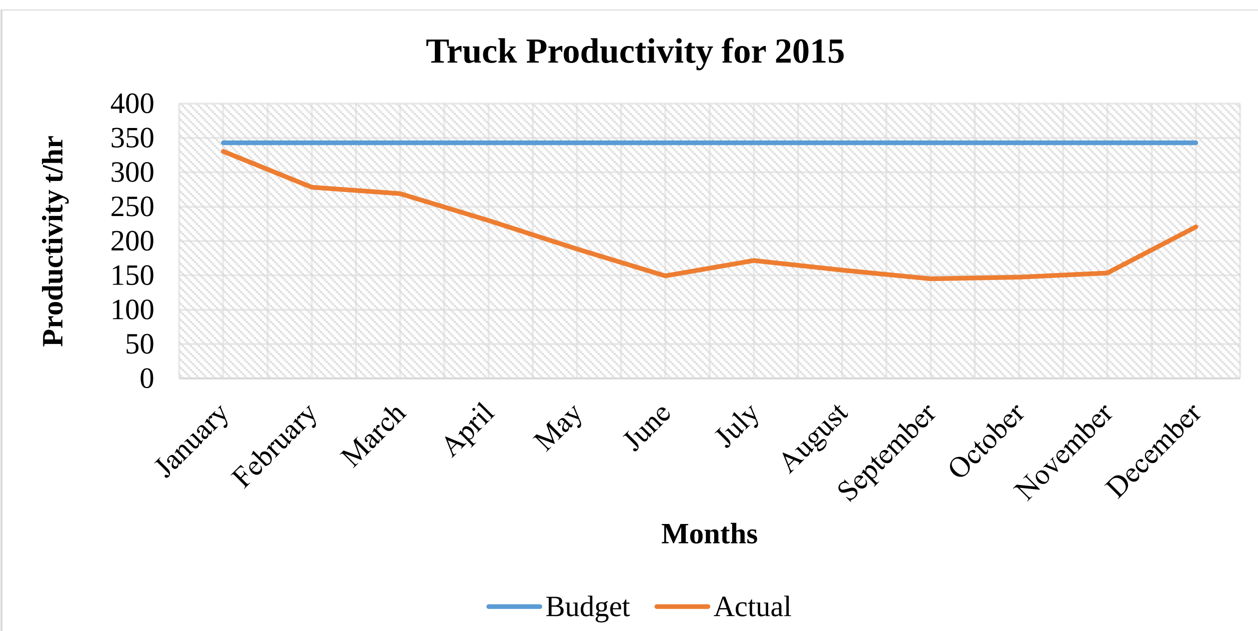


Figure 1.6: Average truck productivity for 2015

The discrepancy between production and productivity is due to the use of a big fleet size with low productivity on downscaled operations.

1.5 Justification

The fleet optimization problem at NOP has at least 7 interacting factors shown in Figure 1.7 that need modelling either individually or in batches. The modelling of these sub-problems cannot be done by simple application of available software or existing algorithms. Furthermore, there are loads of on-the-ground realities beneath each named factor and as a result there is need for a tailor made solution which makes it imperative to do a research aimed at solving the NOP fleet problem.

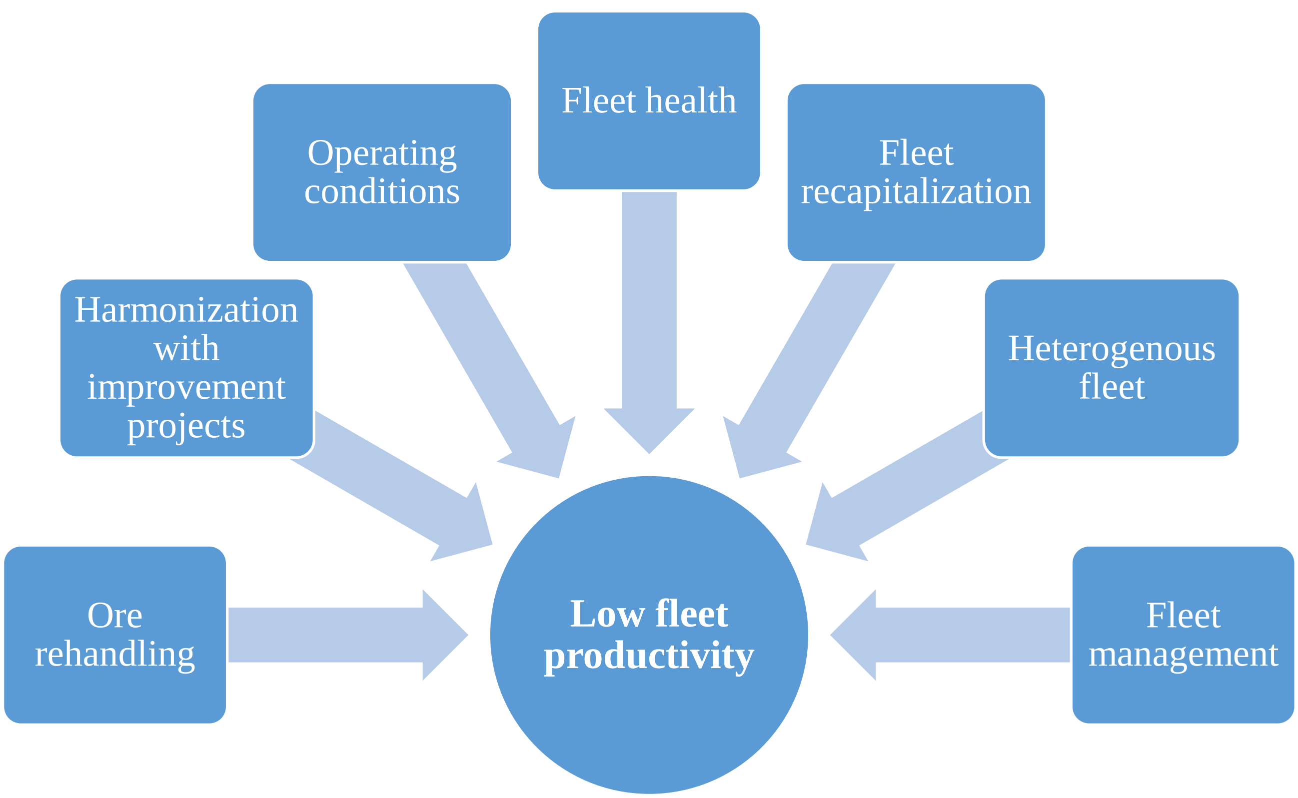


Figure 1.7: Factors interacting in NOP fleet optimization problem

It also follows, from literature, that a shovel/truck system is extremely complex due to its stochastic features and interactions between elements. It is practically impossible to derive a universal optimal solution algorithm to the truck dispatching problem and as a result every dispatching criterion is based on situational optimization. Some of the established shovel/truck modelling methods rely on empirical rules or trial and error while the mathematical ones require significant computational effort. A well-established procedure is computer simulation which allows the incorporation of the inherent variability and complexity of the system (Çetin, 2004).

Random selection of available software and subsequent use of those software have limitations and high probability of error. Fleet problems are stochastic in nature hence the need for a tailor made solution. The drawbacks to simple software application are on-the-ground realities such as unscheduled downtime for some critical equipment; operator errors, adverse weather and equipment purchase budget limitations. As a result, what constitutes an optimized fleet tends to differ from site to site (Russell, 2012).

1.6 Research Questions

1. Is the current fleet still in harmony with the improved value of copper and extended LOM?
2. What is the current fleet performance and is it able to handle the extended LOM?
3. If improvement projects have resulted in extended LOM, can part of the existing fleet be allocated to satellite pits and ramp up total mine production?
4. Is there need for equipment re-capitalization?
5. Which other opportunities are available for fleet optimization?

1.7 Objectives of the Study

This research study has the following main and sub objectives:

1.7.1 Main objective

To optimize NOP fleet in an attempt to curb loss of value after current improvement projects have resulted in increased profitability and extended life of mine.

1.7.2 Sub-Objectives

The sub-objectives of this research are to:

1. To harmonize fleet productivity with the recent ETL, HL and Co/Cu separation improvement projects;
2. To assess current fleet performance;
3. To determine the new optimal fleet for the main pit;
4. To determine best fleet management approach with regards to exploitation of new reserves; and
5. To identify other fleet optimization opportunities at NOP.

1.8 Expected Outcomes of the Research

The single biggest outcome expected from this research was an optimally sized fleet with low haulage cost per tonne. This was realized through:

- An optimal fleet in terms of size and components for both the main and satellite pits;
- Increased machine productivity;
- Improved fleet utilization and availability;
- Increased component lives; and
- Reduced fuel burn.

1.9 Significance of the Study

The following are the anticipated contributions of the research study:

- Determination of a mining fleet harmonized with the recent improvement projects at KCM.
- Capitalization and capacitation of expansion projects as well as other investment centers on hold.
- Development of models for fleet monitoring and pit production management. Models to include:

- Queuing model
- Haul road design model
- Direct tipping model

The above models can be computer algorithms designed using either Microsoft excel or any of the Microsoft programming languages such as visual basic.

1.10 Scope and Limitation

This research was concerned with formulating a fleet management model so as to determine the optimal fleet size that could minimize haulage cost and production loss.

There are more closely related problems to this research such as mine production scheduling, production sequencing, equipment replacement, dispatch and allocation of trucks and equipment costing. All these problems were not discussed since the constraint of time could not allow.

Limitations to this research project included:

- Unavailability of funds to purchase software so as to test the validity of the models created.
- Time constraints to tackle all associated mine machinery operational problems.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

The research questions and study objectives in Sections 1.6 and 1.7 of Chapter 1 gave an indication of the type of literature that had to be reviewed in order to satisfy the goals of the research. The main literature areas that were surveyed include production planning, fleet management and fleet optimization.

2.2 Overview

Statistical analysis done by (Çetin, 2004) revealed that the effects of basic dispatching rules have little influence on loader/truck system performance. However the main factors affecting the performances are the number of trucks, the number of shovels, the distances between shovels and dump sites and the availability of shovels and trucks. Another factor is sometimes the complexity of the haul routes which may have varying grades and distances. Loading time is a function of shovel capacity, truck capacity and digging conditions. An efficient shovel/truck haulage system will depend on precise allocation of different truck types to shovels and the respective proper allocations of trucks to appropriate haul roads and dump sites. An accurate assessment of a shovel/truck system that meet certain economic and technical criteria is not easy but through some simplifying assumptions, fairly accurate results can be obtained by computer simulation packages for most practical purposes. The solution to an optimum system design lies in an efficient performance parameters prediction for various combinations of shovels and trucks under realistic assumptions.

Methods of reducing haulage costs include:

- Improving operating performance of the trucks resulting in higher efficiency and reliability,
- Increasing the payload capacity of trucks,
- Employing in-pit crushers and conveying systems with truck haulage,
- Using trolley-assisted trucks to reduce the truck cycle times,
- Use of driver-less trucks since this approach has the potential to reduce the labor costs.

2.3 Equipment Selection

In mining equipment selection, the selection of appropriate loader/truck type follows intuitively from the selected mining method. The loader/truck productivity problem then targets to optimize the productivity of a truck and loader fleet (Burt & Caccetta, 2013)

Figure 2.1 illustrates the equipment selection for mining and construction industries. It also depicts the different methods employed in mining method selection, equipment selection and optimization of shovel-truck productivity.

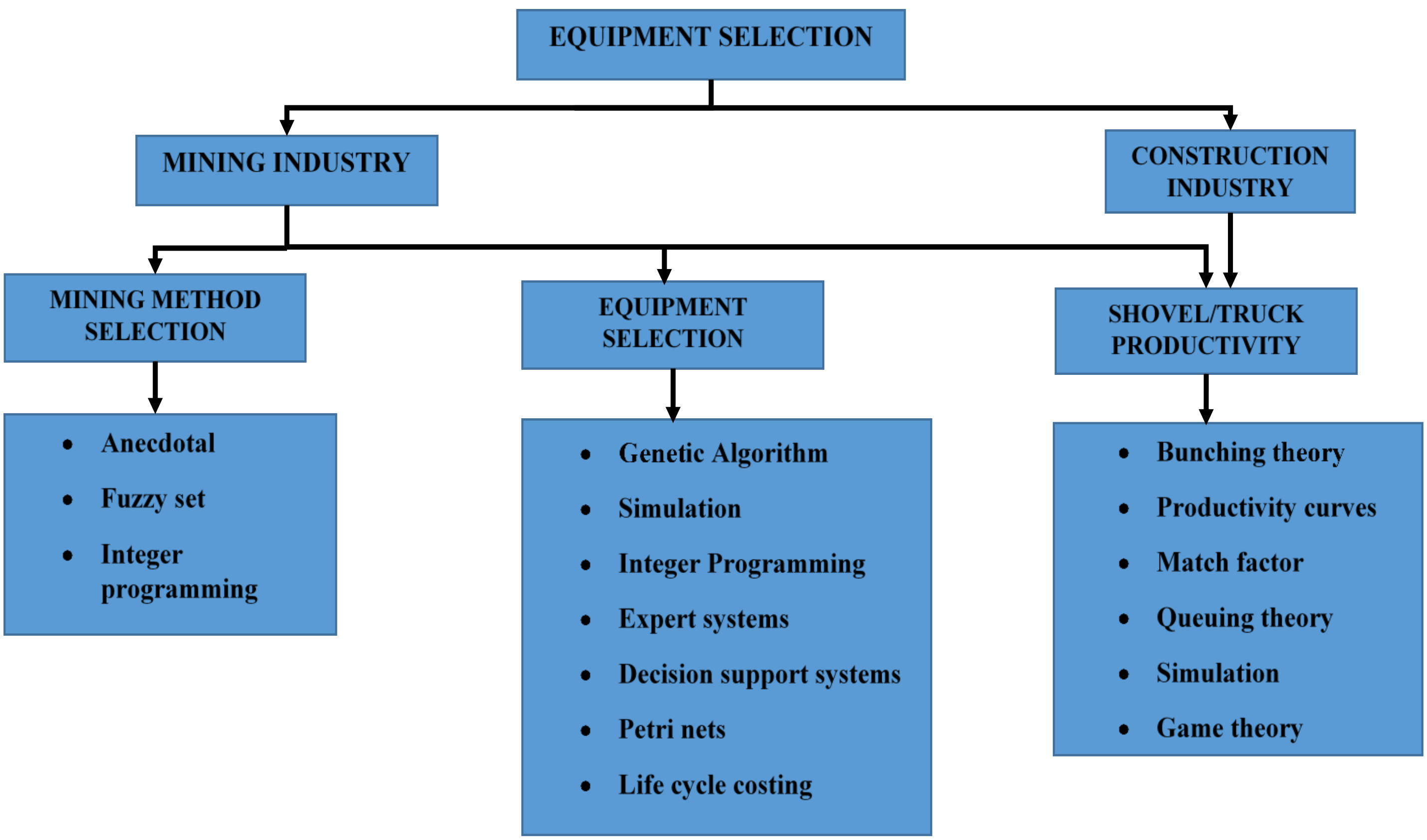


Figure 2.1: Equipment selection criteria for both mining and construction industries

There is a difference between achieving set production targets at any operation and operating efficiently, managing to sustain competitive commodity costs. In view of this statement, it is imperative to distinguish between production and productivity. Production is the total tonnes or bank cubic meters (BCM) loaded and hauled while productivity is the rate of production, usually per unit of time, per unit of capacity, per unit of expense, per machine, per man hour etc (Hardy, 2007). It follows then that focusing on production alone rather than a balanced consideration of efficiency, productivity and cost is a big impediment to best management practices and equipment selection for open pit mining (Hardy, 2007)

2.3.1 Open Pit Mining Equipment

The number and sizes of equipment for drilling, blasting, loading, and haulage of open pit ore and waste are the major influential factors to the capital and operating costs of open pit mines (Adler, 1992)

2.3.1.1 Size and Number of Open pit Drills

Parameters namely hole size and diameter and number of drills required all depend on the tonnage of ore and waste to be drilled off daily. A formula for estimating tonnes of ore or waste that is drilled off by a drill with a hole diameter of d inches in medium-drillable rock, with a penetration rate of 152m per shift is:

Tonnes of ore or waste T_p per day = $\mathbf{170\ d^2}$ [2.1]

For easily drillable rock, T_p per day = $\mathbf{230\ d^2}$ [2.2]

For hard drilling rock, T_p per day = $\mathbf{100\ d^2}$ [2.3]

Standard drill hole diameters are 102, 165, 200, 250, 270, 310, 336, and 380 mm; therefore drill selection will be limited to one of these sizes. Two drills of appropriate diameter should be chosen for tonnages up to 25,000 tpd (22.7 kt/day), while three drill should be enough for up to 60,000 tpd (54.4 kt/day), and four or more drills will be required for daily tonnages above 60,000 (Adler, 1992).

2.3.1.2 Size and Number of Shovels Required

The optimum shovel S in cubic yards of dipper size in relation to daily tonnage of ore and waste (T_p) to be loaded daily is:

$$\mathbf{S = 0.145\ T_p^{0.4}} \quad [2.4]$$

Same formula in cubic meters is:

$\mathbf{S = 0.111\ T_p^{0.4}}$ (after multiplying by a conversion factor of 0.765) [2.5]

The number of shovels N_s with dipper size S required to load a daily total of T_p tonnes of ore and waste becomes:

$$\mathbf{N_s = 0.011\ (T_p)^{0.8} / S} \quad [2.6]$$

After selecting a shovel with dipper size close to the calculated value from Equations 2.4 or 2.5, the number of required shovels, which usually comes out a fraction should be rounded off to the nearest smaller unit number. The omitted fractional number indicates the need for a smaller shovel or front end loader which is still capable to load into trucks previously loaded by shovels of dipper size *S* (Adler, 1992).

2.3.1.3 Size and Number of Trucks Required

The optimum truck size *t* in tonnes that matches shovels of S bucket size in cubic yards is

$$\mathbf{t = 9.0S^{1.1}} \quad [2.7]$$

In cubic meters,

$$\mathbf{t = 6.88S^{1.1}} \quad [2.8]$$

The total number of trucks N_t of t tonnes capacity to constitute the open pit truck fleet, plus an allowance for trucks under repair, is approximated using the formula:

$$\mathbf{N_t = 0.25\ T_p^{0.8}/t} \quad [2.9]$$

The above formula for N_t is generally applied under the typical conditions where the average haulage distance as gradient inside the pit periphery is less than the haulage distance and gradient inside the pit periphery. In cases where the waste and ore dumps over the primary crusher are well removed from the pit boundaries, or instances where the haulage road beyond the pit has a steep gradient, the truck fleet size may be increased to allow for the longer trip time per load (Adler, 1992).

2.4 Costs and Cost Estimations

2.4.1 Open Pit Capital Costs

Estimation formulas for various open pit operational costs are listed in SME Mining Engineering Handbook.

Waste stripping cost = $\$340\ T_w^{0.6}$ [2.10]

For rock requiring blasting, loading and haulage where T_w is tonnes of waste rock to be moved to expose an amount of ore to sustain 4 to 6 months of ore production.

Cost of drilling equipment = $N_d * \$20000d^{1.8}$ [2.11]

N_d is number of drills and d is hole diameter. This formula includes 25% for drilling and blasting supplies and accessory equipment.

Total loading equipment cost = $N_s * \$\ 510000S^{0.8}$ [2.12]

N_s is number of shovels and S is shovel dipper size. The cost includes shovels supplemented by auxiliary bulldozers and front end loaders.

Haulage equipment cost = $N_t * \$20400t^{0.9}$ [2.13]

N_t is number of trucks and t is truck size (in tonnes).

Cost of primary crushing plant = $\$15000T^{0.7}$ [2.14]

The cost excludes crusher cost but includes costs of foundation, crusher installation, construction of truck dump and grizzly, plus the coarse ore conveyor and feeder under the crusher.

2.4.2 Operating Costs for Open Pits/Day

Costs depend on numbers and sizes of drills, shovels and trucks. These in turn all depend on tonnes of ore/waste per day. In low grade ore open pits, the difference in the specific gravities, blasting characteristics, drillabilities of ore or waste and haulage distances do not differ much between ore and waste. Hence cost per tonne is approximately the same all the time between ore and waste.

Formulas for costs of open pit mining operations in terms of total ore and waste (T_p) mined/day are:

Drilling cost/day = $\$1.90T_p^{0.7}$ [2.15]

Blasting cost/day = $\$3.17T_p^{0.7}$ [2.16]

Loading cost/day = $\$2.67T_p^{0.7}$ [2.17]

Haulage cost/day = $\$18.07T_p^{0.6}$ [2.18]

General services cost/day = $\$6.65T_p^{0.7}$ [2.19]

Generally open pit transportation costs for most metal and non-metal open pit mines contribute to 60% of the total mining costs (Adler, 1992). As a result, haulage costs constitute a greater chunk of total mining costs and do become the biggest opportunity for cost reduction and effecting of savings (Adler, 1992).

2.5 Fleet Management

The goal of any fleet management exercise is to ensure a relatively smooth fleet purchase curve that gradually rises from project launch and then declines in the project final years. Such a curve should not have abrupt peaks and troughs that represent reactive remedies to unforeseen problems. (Russell, 2012)

2.5.1 Basic Concepts

There are two approaches to perfect fleet management. The first choice is to do it in-house by going for either internally developed policies and criteria or purchasing a commercially available software. The second choice is to sub-contract part or the whole fleet to be managed by a Fleet Management Services (FMS) company (Russell, 2012).

Mining companies wishing to increase production and reduce costs without recapitalizing equipment should target 'low hanging fruit.' There is a number of basic fleet performance related questions to be answered by equipment planners before considering more drastic measures (Hui, 2012). Some of the questions are:

- What is the shovel operators' one pass time?
- What is the bucket fill percentage and are the operators filling the bucket so that a five pass load doesn't turn into six passes?
- Is the loader operator getting the face ready while waiting for a new truck?

- Is there over or under trucking?
- Is shovel payload being tracked to accurately reconcile end of month surveyed tonnes?
- What are and how long are the major haul truck delays, including shift change?
- Is there hot changing to reduce equipment down time and if not, is this something that company should be considering?
- What is the truck operator’s spotting time?
- How many trucks are running at any given time and is this adequate to feed the crusher? Does the company need to start parking some trucks because of frequent queuing?
- What is the truck load profile and is it leaving some room at the back so that no spillage occurs?
- Are there truck scales and are they calibrated?
- Is there carry back in the trucks that should be addressed with a specific lining or a new truck box design?
- Are haul routes being entered along with equipment parameters into a haulage program to determine the target cycle time? Is the company achieving this cycle time? If not, why?

2.6 Fleet Optimization Theories

2.6.1 Match Factor

Match factor (see equation 2.20) is a dispatching rule whose value for different sub-systems or individual shovels can be used to assign a truck to a shovel where it will assist in balancing production.

$$\text{MF} = \frac{\text{Number of trucks} * \text{Loader cycle time}}{\text{Number of loaders} * \text{truck cycle time}} \qquad [2.20]$$

Where MF = Match Factor.

The cycle time in this equation does not include waiting times at the loading area. A match factor below 1.0 indicates under-trucking while a match factor above 1.0 indicates over-trucking. Therefore, match factor controls the utilization of shovels and minimize differences in productivity (Hadjigeorgiou, et al., 1995). Figure 2.2 shows the combination of relevant efficiencies of truck and loader fleets. Assigning the correct number and size of trucks to loaders aids in optimizing productivities and performances of both trucks and loaders. This is achieved as truck cycle time is improved while loader idle time is either minimized or eradicated (Masauso, 2008).

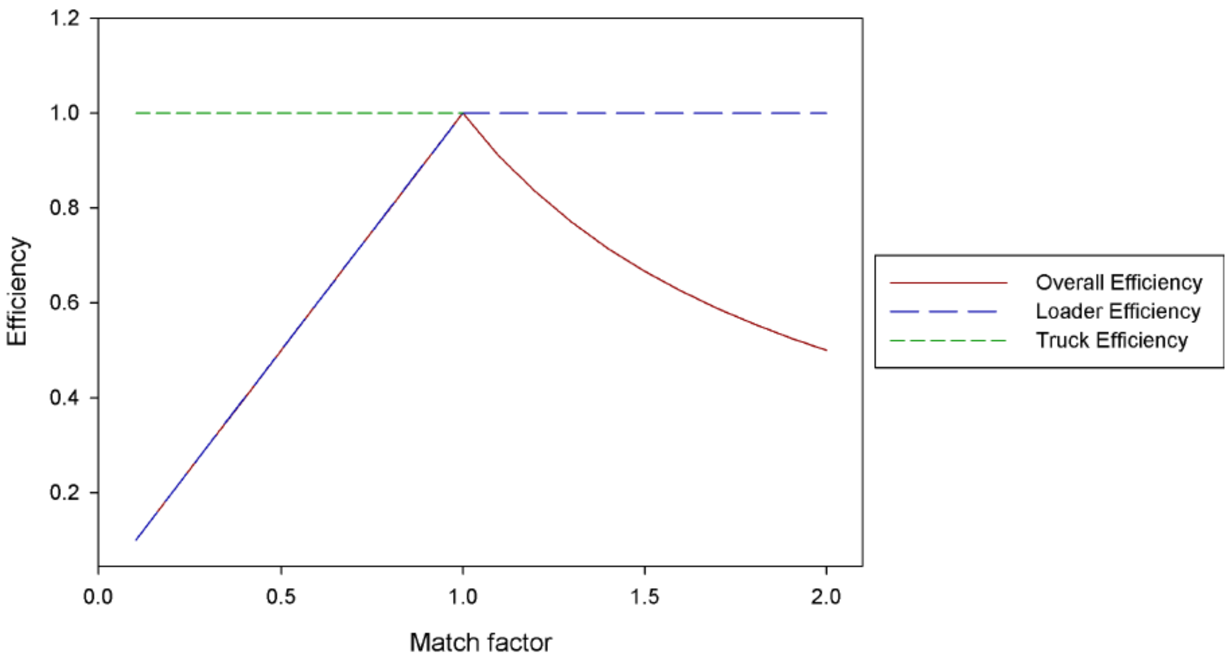


Figure 2.2: Combination of relative efficiencies of truck and loader fleets (Burt, 2008)

2.6.2 Queuing Theory

Queues are caused by two factors namely variation of arrival and service variation. In modelling queues there are two approaches and these are analytical models where equations are used to model simple cases and simulation for detailed and accurate analysis. Queues must be modelled so as to balance serving costs and waiting costs. Serving cost is ideally the cost of providing service while waiting cost in the context of trucks combines cost of production lost and idling cost. Therefore, the idea is to minimize cost.

2.6.2.1 Minimizing Cost

The main concern in queuing theory is total cost which is the sum of service cost and waiting cost. A business wants to locate the minimum of the total cost which is the point where the service and waiting costs intersect. Figure 2.3 shows minimum total cost point which any equipment service management must locate.

Figure 2.3: Total cost curve

2.6.2.2 Open pit fleet modelling

Table 2.1 shows an open pit fleet modelling template that can be used to determine optimum fleet size. The option that gives minimum total cost becomes the best choice.

Table 2.1: Template for open pit fleet modelling

Parameter	Number of shovels			
	1	2	3	4
Average time a truck waits (minutes)				
Waiting cost **No. of trucks*Average wait*wait cost/m**				
Service cost **No. of shovels*service cost/shovel**				
Total Expected Cost **Waiting cost + Service cost**				

2.6.2.3 Modelling a queue

This requires the following parameters: arrival rate, service rate, number of servers, maximum queue length and population size. The last two elements are however optional. There are various types of queues but of interest in analyzing shovel/truck systems are single-server, single-phase; single-server multi-phase; multi-server, single-phase and multi-server, multi-phase.

2.6.2.4 Queue Modelling Basics

Most common arrival distribution – The Poison Distribution

The Poison Distribution uses average arrival rate λ, to find the probability of a certain number of trucks arriving in a given time window as shown in equation 2.21.

$$P(X) = \frac{e^{-\lambda}\lambda^{x}}{x!} \qquad [2.21]$$

Where,

P(X) = Probability of 'X' number of trucks,

λ = arrival rate, and

x = actual number of trucks.

In a PDFs of various Poison distributions it can be noted that as λ increases the probability of having more trucks arriving increases.

Most common service distribution – The Exponential Distribution

It uses an average service time μ such that the exponential distribution gives the probability that service will exceed time *t*.

$$P(t) = e^{-\mu t} \qquad [2.22]$$

If a shovel can handle more trucks in a given time then it is faster.

2.6.3 Bunching Theory

Bunching occurs when the fastest trucks in a fleet catch up with the slowest trucks along the haul route such that all will be forced to move with the speed of the slowest trucks. Literature reviews that when there is a perfect match between a loader and trucks, the bunching effect is 20 to 30 % less. With availability of extra trucks, the bunching effect is minimized since there is always a queue of trucks waiting to be loaded (Assakkaf, 2003)

2.7 Fleet Optimization Software

There are packages written using general programming languages like FORTRAN and other packages based on simulation languages. The later packages are more recent; site specific and require knowledge of simulation languages (mostly used in academia and consultancy). The Caterpillar Fleet Production and Cost Analysis software (FPC) and the Talpac of Runge Mining are two of the most common software packages used in production scheduling. Both packages generally quantify costs of material handling job for different equipment and fleet size combinations (Nguyen & Golosinski, 1996).

2.7.1 Fleet Production and Cost Analysis

Fleet Production and Cost Analysis (FPC) is a software designed to estimate the productivity, cost, and time necessary for a wide variety of material handling operations to move material from one point to another over one or more haulage paths.

FPC takes into account site speed limits; haul road conditions – inclusive of gradients/Rolling resistance/distances; waiting times; Machine – availability/bucket fill factor/cycle times; site – material density; required volumes and operator efficiency. Using this information FPC can predict current and future capabilities. (Finning, 2016)

Capabilities of FPC together with Talpac include:

- Calculation of hauler travel time for the purpose of analyzing haul route alternatives
- Fleet and individual unit productivity estimation for use in both short and long term planning studies
- Estimating the material handling costs
- Selecting the most efficient equipment sizes
- Truck fleet size optimization
- Cost analysis for various production scenarios

A simplified FPC block diagram is given in Figure 2.4. This is a flow chart outlining steps in fleet modelling using FPC.

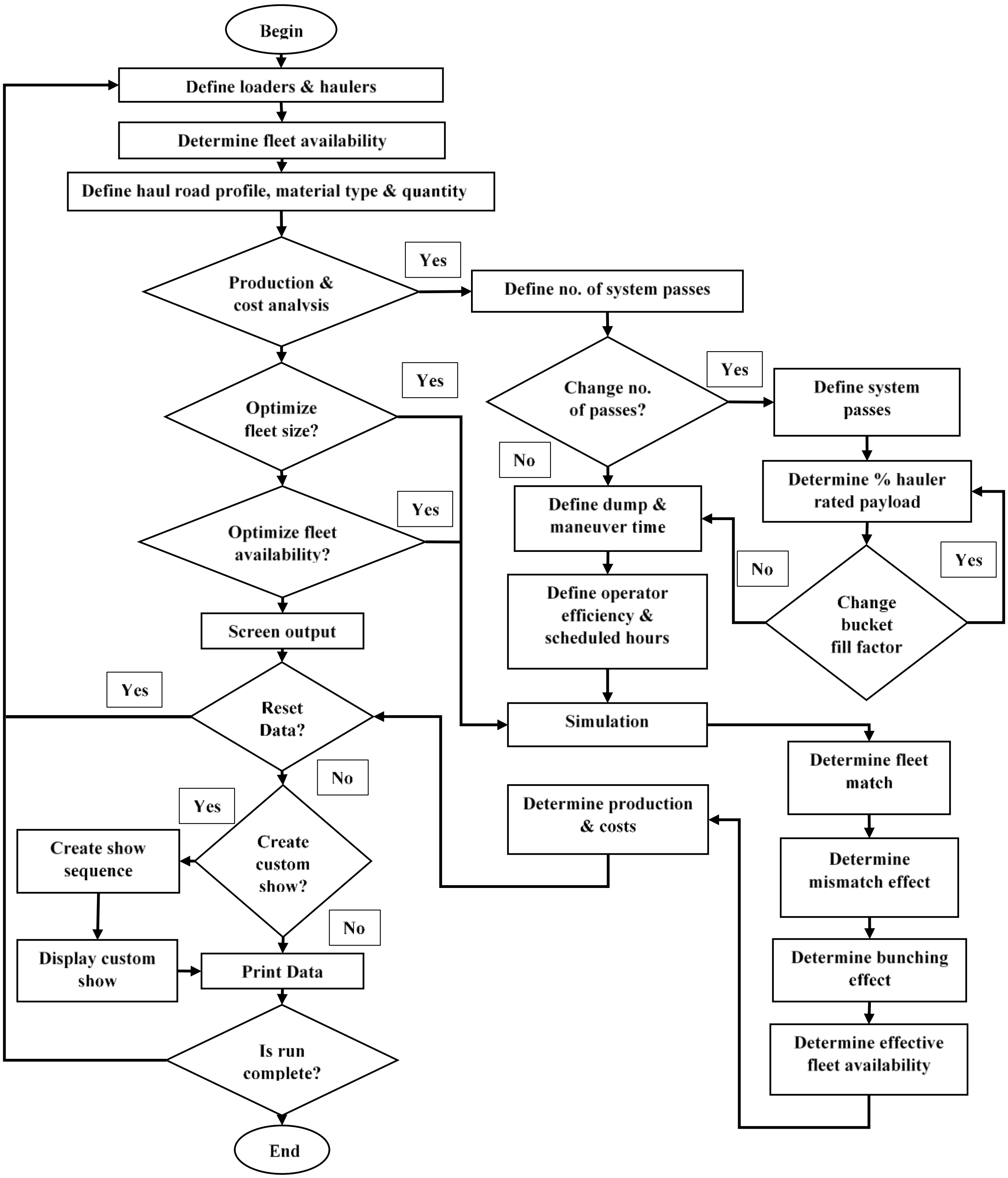


Figure 2.4: Simplified FPC block diagram *(Nguyen & Golosinski, 1996)*

2.7.2 Talpac

Talpac may be used to analyze the performance of existing fleets of equipment or to investigate the application of new equipment fleets in earthmoving and mining operations (Runge, 2007).

2.7.2.1 Operational Approach of Talpac

In either of the two cases mentioned in Chapter 2.7.2, Talpac may examine the performance of a single fleet, or make a comparison of two or more different fleets.

2.7.2.2 Typical Talpac Applications

- Calculation of truck travel time to allow a comparative analysis of haul route alternatives;
- Estimation of fleet productivities for use in long and short term planning studies;
- Estimation and comparison of productivities using various loading methodologies to determine the optimum loading technique or loading unit bucket size;
- Sensitivity analysis in road design criteria to assess the relative importance of road maintenance;
- Calculation of tire TKPH or TMPH ratings for use in tire selection;
- Estimation of fuel usage;
- Determination (using discounted cash flow methods) of haulage contract costs and pricing;
- Truck fleet size optimization to quantify the effect of over and under trucking;
- Incremental analyses, in which simulations can be automatically run for a range of haulage segment lengths and the results used to generate productivity curves;
- Equipment loading analysis to optimize loader bucket size, truck capacity and number of passes;
- Collation of results from calculations to examine the relationship between variables in the calculation, e.g. haul distance versus productivity, haul distance versus truck fleet size.

2.7.2.3 Talpac Overview

Talpac software makes use of five templates in order to do simulations and estimates. The templates, shown in Figure 2.5 require input data from the field while in certain general instances the software has some global factors that can be used. These templates guided the researcher into collecting the rightful data necessary for Talpac simulation.

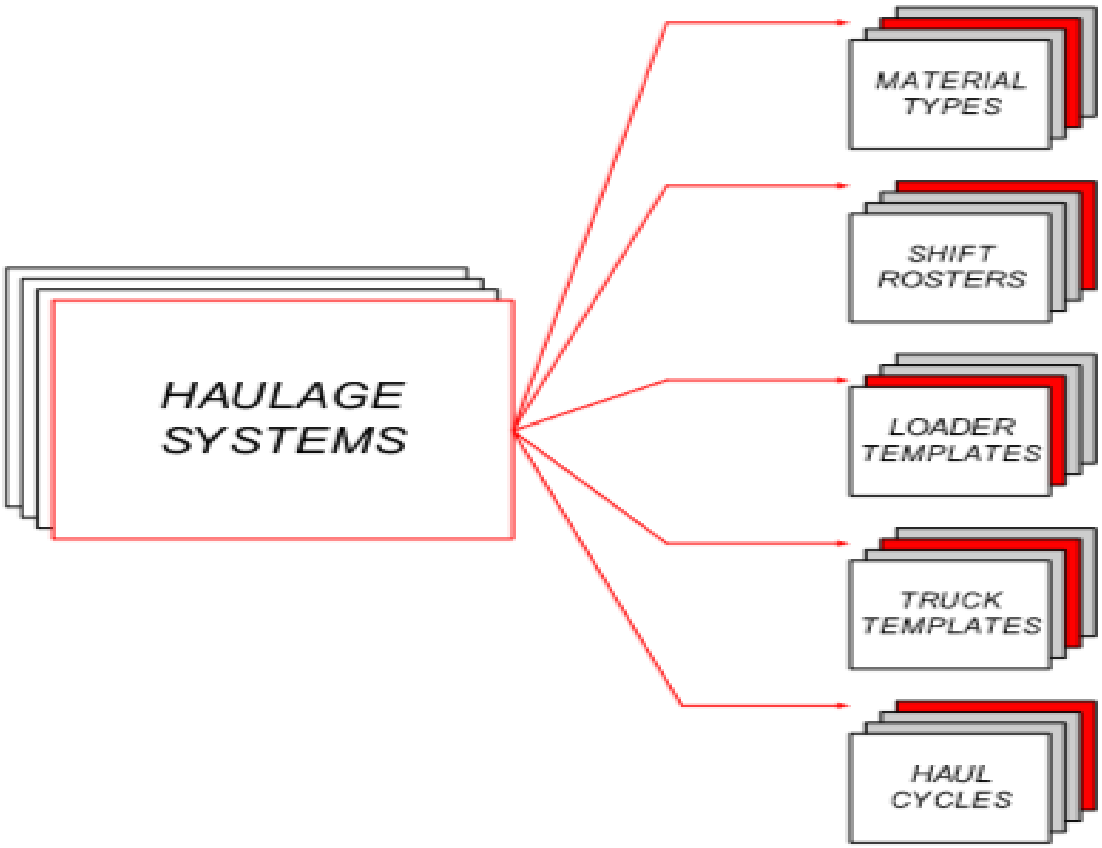


Figure 2.5: Templates that make up a Talpac haulage system *(Runge, 2007)*

A simplified block diagram for Talpac is shown in Figure 2.6. After all the templates highlighted in Figure 2.5 have had adequate data input, Talpac allows either a quick estimate or a full simulation both of which follow the computational stages highlighted in Figure 2.6.

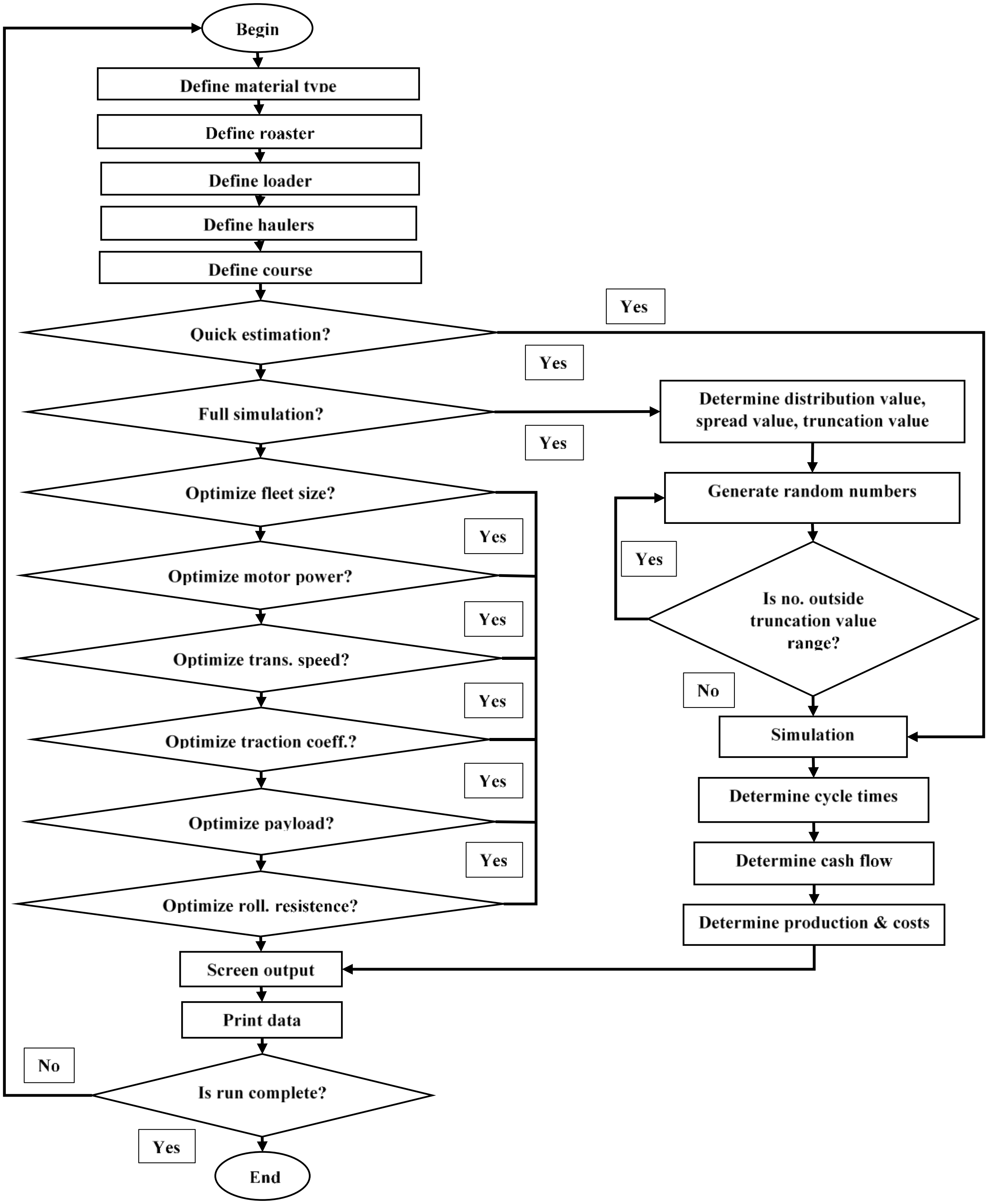


Figure 2.6: Simplified Talpac block diagram *(Nguyen & Golosinski, 1996)*

A more advanced fleet optimization software like HAULSIM by the same Runge Pincock Minarco Company could have been used but only Talpac was reviewed due to its accessibility for use.

2.8 Technical Analysis of Loading Equipment

The most involving parameters affecting the efficiency of loading equipment are the mechanical condition of each piece of equipment, capacity and number of hauling equipment and also rock fragmentation.

Field conditions have an impact on the loading capability of excavators. Material excavability which is a function of rock fragmentation affects the ease with which loading can take place. Therefore, if a blast is good, the loading equipment becomes more effective. The way rock is fragmented affects the efficiency of excavators in that it either reduces or increases its duty cycle time. If the material is poorly fragmented it takes more time to fill one truck. Fragmentation affects loading in two ways. It constitutes the scarifying factor which is the ease with which the loader bucket can scratch through and dip into a muck pile. Secondly in the event of oversized rock fragments, the loader will lose productive time selecting and side casting the boulders before it can load. Apart from losing productive time there is also an increase in loading costs through fuel, hydraulic oil, engine oils, wear and tear of bucket teeth, bearings and turntable mechanism.

The condition of a machine involves mechanical fitness of a machine which in turn determines the probability of readiness of the machine’s deployment or the equipment availability. How well the machine is used is also a matter of economics and this is called machine utilization. The combination of equipment use and its availability then eventually determines the equipment efficiency (Masauso, 2008).

2.9 Technical Analysis of Hauling Equipment

Productivity of the hauling equipment is a function of parameters that include mostly: distances between the working face and dumping area, ramp gradients, grade resistance of the haul roads, hauling speeds, excavator loading time, and number of dump trucks assigned to a particular excavator. All the above mentioned parameters are dependent variables of truck cycle time. In addition, mechanical availability of the trucks plays a vital role in truck productivity. A combination of truck utilization and availability results in trucks’ effective utilization. (Masauso, 2008).

% Effective Utilization = Availability x Utilization or

$$\% \text{ Effective Utilization} = \left(\frac{T_{op}-BD_t}{T_{op}}\right) * \left(\frac{E_t}{T_{op}-BD_t}\right) * 100 \qquad [2.23]$$

Where,

T_{op} = Total operating time,

BD_t = breakdown time, and

E_t = effective operating time.

Dump Truck Cycle Time

The cycle time of dump trucks at NOP involves the following:

a. Travel time full;
b. Spotting time at dumping site;
c. Dumping time at the waste dump or at the crusher;
d. Travel time empty;
e. Waiting time at the loading machine;
f. Spotting time at loader; and
g. Loading time.

However, travel time is a function of distance of the haul road and the speed of the trucks on the haul road. On the other hand, dump trucks speed is a function of the haul road grade resistance and speed as well as overtaking restrictions.

2.9.1 Comparison of Alternative Ore Haulage Systems

In-pit Crushing and conveyor system

Statistics from a number of large scale mines where in-pit crushing and conveying systems have been used reveal lower operating, maintenance, and overall unit costs compared to the costs of conventional truck haulage. It is noted that productivity is increased by reduced truck fleet requirements and shorter truck cycle times. Truck haulage costs increase with pit deepening and conversely in-pit crushing and conveying systems become economically attractive. Conclusively, belt conveying economics are attractive in large volume operations where haulage distances are longer than just a few kilometers (Hartman, 1992).

2.10 Overall Equipment Effectiveness

The use of larger equipment requiring intensive capital investment has been the open pit industry's approach towards increasing production rate over the years (Elevli & Elevli, 2010). At the same time low commodity prices (as being experienced today) have forced companies to decrease their unit cost by improving productivity. Improving productivity can be achieved through effective equipment utilization.

Overall Equipment Effectiveness (OEE) is one useful metric which combines availability, performance and quality. It was first applied in the mining industry in 2010.OEE takes six most common and important sources of productivity losses shown in Table 2.2 and quantifies them as availability, performance and quality and use them to estimate OEE as outlined in Equation 2.24.

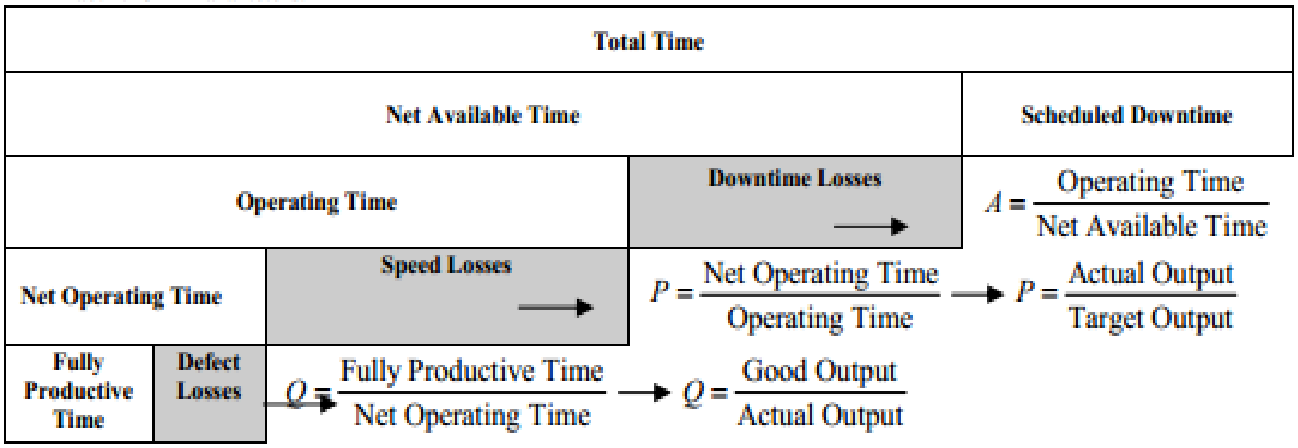
$$OEE = Availability * Performance * Quality \qquad [2.24]$$

Table 2.2: The 6 big productivity losses *(Elevli & Elevli, 2010)*

Six Big Loss Category	OEE Loss Category	OEE Factor
Equipment Failure	Downtime Losses	Availability (A)
Setup and Adjustment		
Idling and Minor Stoppages	Speed Losses	Performance (P)
Reduced Speed		
Reduced Yield	Defect Losses	Quality(Q)
Quality Defects		

Effective equipment operation means high level of performance in the 3 given parameters. Table 2.3 shows how Equation 2.24 factors are calculated.

Table 2.3: OEE parameters *(Elevli & Elevli, 2010)*



Availability takes into account lost time which involves any events that stop planned production for an appreciable length of time. Reasons may include equipment failures, waiting times etc. It is determined as shown in Equation 2.25.

$$\text{Availability} = \frac{\text{Net Available time} - \text{Downtime Loses}}{\text{Net Available time}} * 100 \qquad [2.25]$$

Performance takes into account some speed losses which include all factors that cause the equipment to operate below its maximum speed. Reasons may include substandard materials, operator inefficiency, and job conditions. Performance is determined as shown in Equation 2.26.

$$\text{Performance} = \frac{\text{Operating time} - \text{speed losses}}{\text{Operating time}} * 100 \qquad [2.26]$$

Quality looks into product loss and is determined as shown in Equation 2.27.

$$\text{Quality} = \frac{\text{Net Operating Time} - \text{Defect Losses}}{\text{Net Operating Time}} * 100 \qquad [2.27]$$

The calculated OEE value is then compared with an industrial benchmark value of 85%. An estimated OEE value below the benchmark reveals need for operational improvements (Littlefield, 2012).

2.10.1 Challenges of OEE application on mining equipment

Though OEE has managed to find application in the mining industry, there are still some factors that hamper its applicability. These factors include:

- Mining is a serial operation of drilling-blasting, loading, hauling and dumping. Therefore, the production of equipment used in each step depends on the production of previous equipment. That means utilization of each equipment affects the others;
- The capacity of mining equipment is huge. Therefore the effect of utilization on total production is very high;
- The physical environment under which mining equipment operates is less than ideal; and
- The operating environment of the mine is dynamic with many unknowns that can affect the equipment utilization drastically (Elevli & Elevli, 2010).

There is necessity to develop specific equipment classification framework for the losses associated with the components of availability, performance and quality. The required data will vary from equipment to equipment.

2.11 Summary

A study of literature around the fleet optimization subject reviewed different tools useful in solving fleet problems. From the several tools identified, the most applicable to the NOP fleet problem were Queuing Theory, Match Factor, Simulation and some generic formulas. The literature survey done showed how each tool can be used and the associated limitations to each tool's applicability. A number of fleet management principles that require attention in approaching a fleet optimization problem were also analyzed and subsequently implemented in this research.

CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This Chapter gives a description and rationale for the study type to be undertaken and data collection techniques employed. It also gives a highlight on data analysis techniques employed. All the tools used were determined after the literature survey in the previous chapter. Literature survey unveiled research tools that were used in previous studies which could be used also in this study.

3.2 Study type

A non-intervention study was carried out in which the truck-shovel system as well as support equipment were closely observed but not intervened. For instance parameters such as haul cycle times of trucks and loading times of shovels were determined through observation using a stopwatch. A quantitative research study was employed in which numerical data was collected in order to determine the behavior of the loader-truck system. Parameters such as shovel loading time, haul cycle time, capacities of trucks and shovels were determined and quantitatively analyzed to determine their contribution to trucks queuing at the loading site. Numbers of allocated trucks together with cycle times were assessed to investigate their impact on the match between loading and hauling units.

Details of productivity, availability and utilization of all pieces of equipment were assessed to determine root causes of low equipment productivity.

3.3 Data collection

3.3.1 Observations and Recordings

Observations on cycle times of loaders and trucks were made during loading and hauling shifts. A stopwatch was used to record times for the different tasks involved in loading and hauling material from the pit. Recorded times were logged into a book then transferred onto an excel sheet as typically shown in Appendix 1. Other data recordings were done on arrival rates and service rates of different machines. A typical record of arrival and service rates is shown again in Appendix 1.

More observations were done on queuing; bunching; bucket fill; ground prep; crusher jam; pay load tracking; truck delays; operator efficiency; labor availability; spillage; carrybacks & fuel burn.

3.3.2 Field measurements

Field measurements were done on fuel usage by trucks and loaders and haul road design. Measurements were done on crusher dimensions to assess viability of direct tipping.

3.3.3 Machine performance data capturing through dispatch

Status of each piece of equipment was ascertained and handed over to every in-coming shift using an equipment status handover report shown in Appendix 2. Every breakdown during each shift was recorded on the Dispatch field faulting/reporting register shown in Appendix 3. For each day availability data was captured onto the 24-hr availability report (Appendix 4). During shift time, hourly production of all loaders and trucks were recorded on the shovels and loaders hourly production sheet (Appendix 5). All the recorded data was then fed into the SAP system and used to calculate availability, utilization and reliability all typically shown in Appendix 6.

3.4 Data Analysis

Stepwise procedure of data analysis

1. **Determination of potential loss of value if fleet is not optimized in the wake of improvement projects**
    - Since improvement projects as mentioned in Section 1.4 of Chapter 1 resulted in an extension of life of mine, it became imperative to investigate capability of available fleet to bear the new demand. Data on NOP revised life of mine (Appendix 7) was collected from the planning department and used to mirror equipment capability. An equipment replacement register (Appendix 8) was used to provide detail on individual equipment remaining life as well as available equipment inventory. A Microsoft excel analysis was done to graphically assess the potential of the current fleet to go the additional years.
    - The match factor theory and generic formulas were employed in determining the optimum fleet size for the current operations.

- Fleet requirements for NOP at the current production rate and LOM were determined using Talpac software.

2. **Assessing current fleet performance**
    - Reviewing of mine records on availability, utilization and productivity was done. All the mentioned metrics were reviewed as budget against actual values for the 2015/16 FY.
    - Overall Equipment Effectiveness (OEE) was used to do an overall assessment of fleet performance.
    - An assessment was done on the equipment maintenance schedule and how the maintenance crew adheres to it.
    - Analysis of fleet performance particularly on cost and cycle times was done using Talpac software.
    - Since NOP equipment performance seemed to be impacted by the whole array of factors from availability, utilization, reliability and productivity, a production loss analysis was done using Microsoft excel to determine the main contributors to poor fleet performance.
    - Determination of root causes for poor performance and suggestions for solutions subsequently followed!

3. **Main pit fleet optimization**
    - Time and motion studies for loading and hauling cycles data was analyzed using queuing theory and results compared with those from Talpac software.
    - A suggestion was done on an optimum fleet for the main pit by either: determining fleet components with useful life of 4 years or suggesting an in-pit crusher and conveyor system.

4. **Fleet management for satellite pits**
    - Allocation of former main pit machines to satellite pits was suggested depending on anticipated results of the trade-off between the conveyor and truck haulage systems.

5. **Other fleet optimization opportunities**
    - A cost benefit analysis of back lashing against direct tipping was done.
    - Assessing effectiveness of the current dust suppression system in terms of cost was done using Microsoft excel models on owning and operating costs of dust suppression machines.
    - Models were created in Microsoft excel for cost evaluations on the two optimization opportunities.

3.5 Overall Approach

Adequately productive mining operations must also be efficient, and must sustain competitive commodity costs. It is important to differentiate between absolute production, i.e., the total tonnes or bank cubic meters (BCM) loaded and hauled, and productivity, i.e., the rate of production, usually, per unit of time, per unit of capacity, per unit of expense, per machine or per man-hour, and the like. Focusing on absolute production alone rather than a balanced consideration of efficiency, productivity and cost is often an impediment to best management practices and equipment selection for open pit mining.

3.6 Summary

This chapter explained the research design, methods and materials that were used in the research. The design adopted was a non-intervention study of the NOP fleet. Data collection methods included time and motions studies of equipment operations as well as collection of statistics on availability, utilization, productivity, production etc. The analysis methods employed included computation by generic formulas, simulation by Talpac and analysis using Microsoft Excel. Data was collected and analyzed procedurally following the research objectives mentioned in Section 1.7 of Chapter 1.

CHAPTER 4 DATA PROCESSING

4.1 Introduction

Data collection was done following the research methodology outlined in Chapter 3. The capturing system was mostly on Microsoft excel sheets and at times with models that could automatically make all required calculations. Analysis then followed using tools mentioned again in Chapter 3. These were basically generic formulas, match factor theory, Talpac software, OEE and queuing theory.

4.2 Assessing the Impact of Improvement Projects on NOP Fleet

As highlighted in Section 1.4 of Chapter 1, improvement projects have had impacts of increasing value of final output as well as extending life of mine. Examining the two we can detect a direct impact of the later on the mining fleet. Every individual mining equipment has a useful life beyond which its performance falls below optimum if not that it's only fit for scrapping. Figure 4.1 shows NOP revised life of mine following improvement projects and this now has to be superimposed with the equipment remaining life in Figure 4.2.

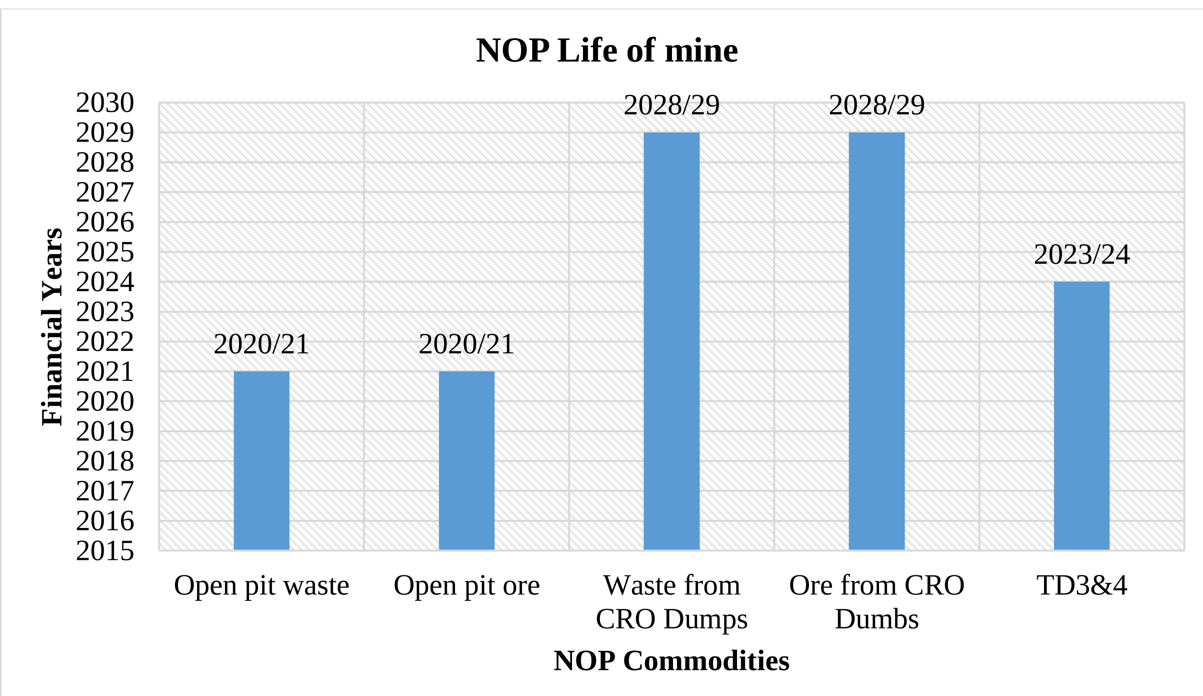


Figure 4.1: NOP revised LOM after improvement projects

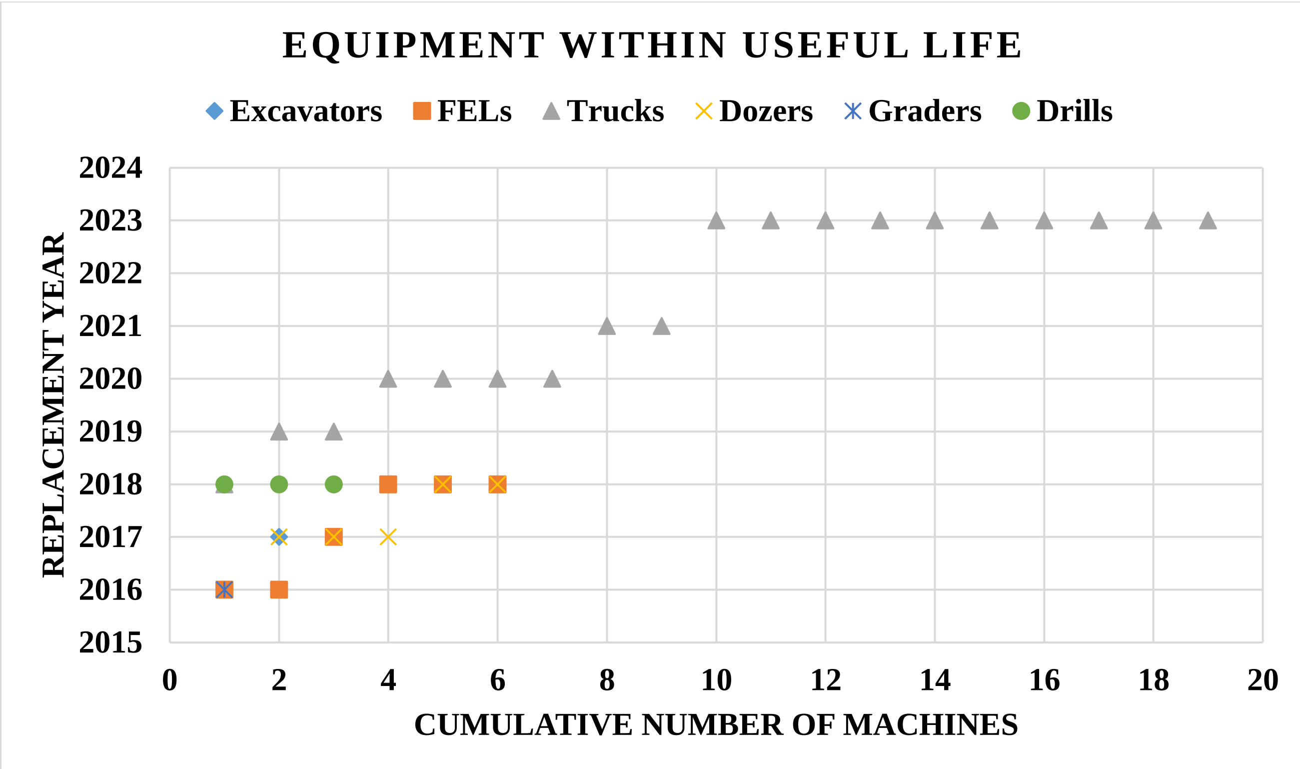


Figure 4.2: Maximum remaining useful life for each equipment category

Basing on equipment replacement dates determined on operated hour basis (Appendix 8), only the equipment shown in Figure 4.2 is still fit for use. Apparently the two operative shovels have gone double their useful life and are not in the picture. Excavators, drills, dozers and front end loaders will be out of operation by 2018. Only trucks can last up to the end of the new life on mine. This alone, however cannot conclude on the operability of equipment within useful life or the non-operability of those equipment out of useful life. An investigation on equipment reliability and maintainability is still necessary to arrive on such a conclusion.

4.3 NOP Fleet Size Review

Following the observed impact of improvement projects on the NOP fleet, it is necessary to redo equipment selection so as to determine a fleet that is in harmony with the recent downstream changes. The revised fleet size will be an ideal fleet whose components have to be fetched from the existing collection as well as the market. If optimization is neglected, a time will come when fleet productivity gets to trail way lower than budget hence beginning to starve the processing plant.

Three mills namely New East Mill (NEM), New West Mill (NWM) and Old East Mill (OEM) require ore from the various Nchanga investment centers. However NOP is responsible for feeding only the Old East Mill.

Processing capacity of OEM is such that there is a milling rate of 15000t/day and this rate translated to monthly capacity:

$= \frac{15000\text{t}}{\text{day}} * \frac{31+30}{2} =$ **457 000 t/month**

This tonnage has to be supplied from three NOP ore sources namely CUT II, COP F&D and CRO Dumps. Dissecting the 457000t OEM demand into the three ore sources and examining the current deliveries we get the trends shown in Figure 4.3 and Figure 4.4.

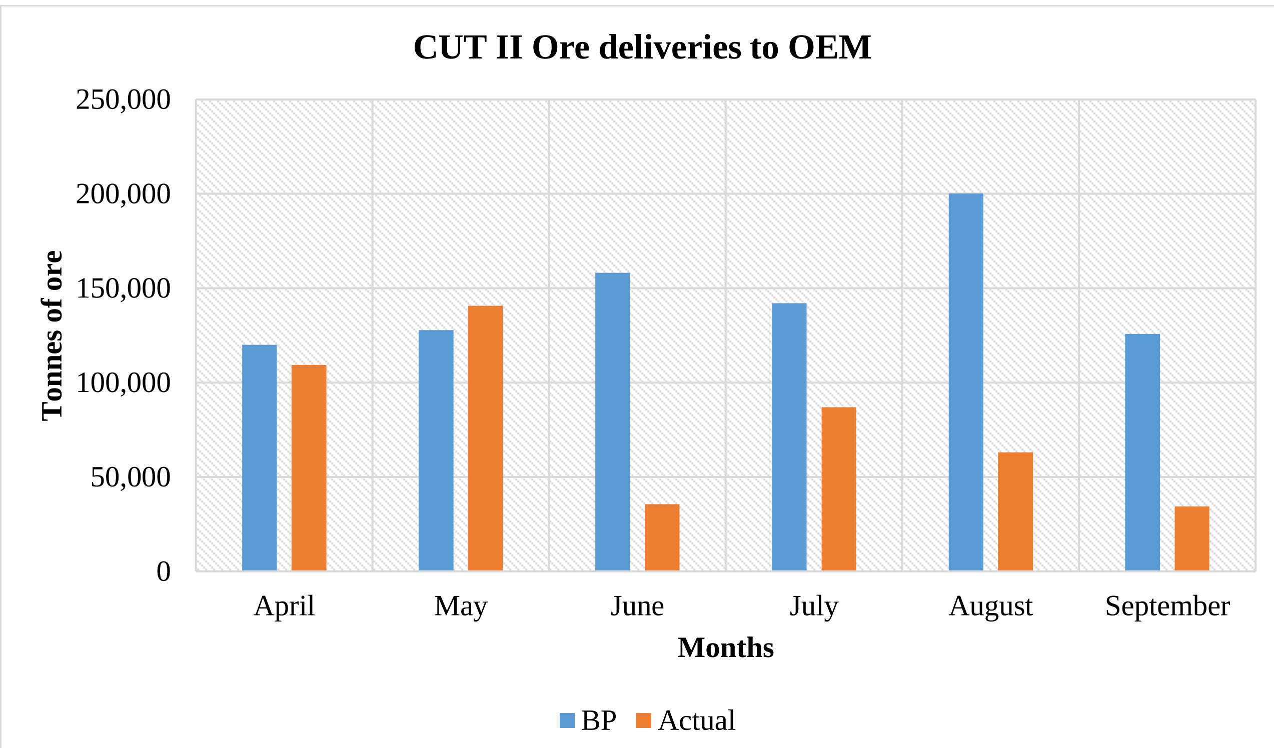


Figure 4.3: CUT II ore deliveries to the concentrator in the first half of the 2016/17 FY

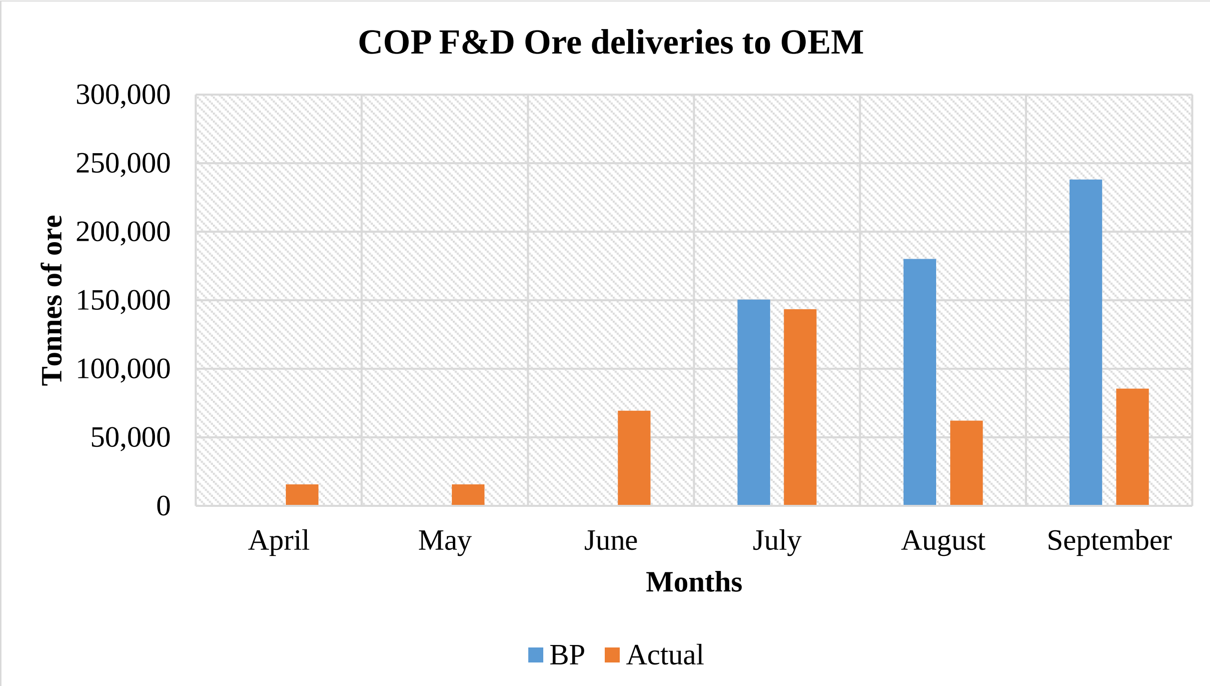


Figure 4.4: COP F&D ore deliveries to the concentrator in the first half of the 2016/17 FY

From the same targets in Figure 4.3 and Figure 4.4, average ore tonnages expected from CUT II and COP F&D are 145,683t and 189,543t respectively. Hence total average ore required from the open pit (excluding CRO dumbs) is

$145683 + 189543$ = **335,226t.**

Calculating from the source, CUT II ore mined for 2016/17 from the revised LOM in Appendix 7 is 2,250,562t copper and 232,700t Cobalt and for COP F&D there is 1,565,064t. Calculating average monthly production target using the tonnages obtained for CUT II and COP F&D,

$\frac{2250562+232700+1565064}{12}$ = **337, 360.5t**

Hence 337,360.5 tonnes becomes the monthly production target to be mined by the fleet to be selected.

From the same Appendix 7 waste to be stripped is for both CUT II and COP F&D is 5,554,102 and 8143049 respectively giving a monthly average of

$\frac{\mathbf{5554102+8143049}}{\mathbf{12}}$ = **1,141,429.25t**

The required fleet must excavate material of a total of

$337360.5 + 1141429.25 = \mathbf{1478789.75}\boldsymbol{t}$**/month (17745477t/year)**

Using Equations 2.1 to 2.9 in Section 2.3.1 of Chapter 2, the required fleet size for NOP was estimated as follows:

Size and number of open pit drills

Size of drills = $\sqrt{\frac{tonnage\ of\ ore\ and\ waste\ per\ day}{170}} = \sqrt{\frac{48484.9}{170}}$ = 16.89" = 422mm

Picking from the range of standard drill sizes it implies that a drill of **380mm** will be the most appropriate.

It follows again from Section 2.3.1 of Chapter 2 that number of drills considering a daily tonnage of 48484.9t is **3 drills**.

Size and number of shovels

Size of shovel = $S = 0.111\ T_p^{0.4}$ **=** $0.111(48484.9)^{0.4}$ = **31 m³**

Number of shovels = $N_s = 0.011\ (T_p)^{0.8}/\ S$ **=** $0.111(48484.9)^{0.8}/31$ = 1.99 = **2 shovels**

Size and Number of Trucks Required

Size of trucks = $t = 6.88S^{1.1} = 6.88(31)^{1.1}$ = 300.67 **= 300t**

Number of trucks = $N_t = 0.25\ T_p^{0.8}/t$ **=** $0.25(48484.9)^{0.8}/300$ **= 6 trucks**

NB: However as previously alluded to, the N_t value calculated is for a haulage system that is confined only within the pit peripheries. For a system that goes out, a different formula has to be applied.

Using Match Factor to Calculate Fleet Size

From Section 2.6.1 of Chapter 2, match factor,

$$\text{MF} = \frac{\text{Number of trucks} * \text{Loader cycle time}}{\text{Number of loaders} * \text{truck cycle time}}$$

$$1 = \frac{\text{Number of trucks} * 240}{2 * 2134.5}$$

Number of trucks = 17.79 = 18

4.4 Using Taplac Software to Calculate Fleet Size

4.4.1 COP F&D Fleet Selection

Simulations for COP F&D Fleet requirements were done using Talpac. Separate calculations were done i.e. one for waste and the other one for ore.

4.4.1.1 COP F&D Waste Haulage System Design

Major input parameters used were the use of the P&H 2300xpc shovel and KOMATSU 830E haulage trucks. Availability data from the field as well as equipment specifications from the manufacturer were used together with global bucket and pan fill factors. An excavation target of 18009100t from NOP revised LOM in Appendix 7 was used. However costing information included was mostly estimated as actual costs could not be obtained from site. Table 4.1 shows the simulation results.

Table 4.1: Simulation results for COP F&D waste loading and haulage system

Loader		*[PRJ] P&H 2300 XPA*	
Availability	%	72.00	
Bucket Fill Factor		0.98	
Average Bucket Load Volume	cu.metres	23.13	
Average Payload	tonne	46.26	
Operating Hours per Year	OpHr/Year	3,276.00	Op. hrs factored by availability
Average Operating Shifts per Year	shifts/Year	546.00	Shifts factored by availability
Average Bucket Cycle Time	min	0.83	
Production per Operating Hour	tonne	2,320.82	
Production per Loader Operating Shift	tonne	13,925	Max. prod. based on 100% avail.
Production per Year	tonne	7,603,022	Avg. production factored by avail.
Wait Time per Operating Hour	min	4.74	
Truck		*[PRJ] KOMATSU (HAULPAK) 830 E (2000hp 31.88C*	
Availability	%	80.00	
Payload in Template	tonne	225.49	
Operating Hours per Year	OpHr/Year	2,620.80	
Average Payload	tonne	231.00	
Production per Operating Hour	tonne	362.63	
Production per Loader Operating Shift	tonne	1,741	
Production per Year	tonne	950,378	
Queue Time at Loader	min/ Cycle	4.94	
Spot Time at loader	min/ Cycle	0.50	
Average Loading Time	min/ Cycle	3.33	
Travel Time	min/ Cycle	24.39	
Spot Time at Dump	min/ Cycle	0.50	
Average Dump Time	min/ Cycle	0.50	
Average Cycle Time	min/ Cycle	34.16	
Fleet Size		8	
Average No. of Bucket Passes		4.99	
Haulage System			
Production per Year	tonne/Year	7,603,022	
Discounted Capital Cost	$/tonne	0.82	***Loading Methodology***
Discounted Operating Cost	$/tonne	0.40	Single Sided
Discounted Average Cost	$/tonne	1.21	Full Truck
Excavation Target	tonne	18,009,100.00	Average for 150 Shifts
Time to move Excavation Target	Years	2.37	
Loader Hrs to move Target	Op. Hours.	7,760	
Total Truck Hrs to move Target	Op. Hours.	49,663	
Total cost to move Target	$	21,847,733	

4.4.1.2 COP F&D Ore Haulage System Design

By changing the excavation target as well as loader type for COP F&D ore haulage system, an estimated fleet size for ore haulage was calculated as shown in Table 4.2. More simulations were done for CUT II waste and CUT II ore and their results are in Tables 4.3 and 4.4 respectively. In each case, parameters changed were on the loader template and haul cycle. Material types were maintained for both waste and ore, shift roasters and truck types remained the same in all the four cases.

Table 4.2: Haulage system design for COP F&D ore

Loader		*[PRJ] CATERPILLAR 6030 (Cat)*	
Availability	%	47.00	
Bucket Fill Factor		0.93	
Average Bucket Load Volume	cu.metres	14.49	
Average Payload	tonne	28.98	
Operating Hours per Year	OpHr/Year	2,040.00	Op. hrs factored by availability
Average Operating Shifts per Year	shifts/Year	340.00	Shifts factored by availability
Average Bucket Cycle Time	min	1.13	
Production per Operating Hour	tonne	1,100.20	
Production per Loader Operating Shift	tonne	6,601	Max. prod. based on 100% avail.
Production per Year	tonne	2,244,414	Avg. production factored by avail.
Wait Time per Operating Hour	min	5.75	
Truck		*[PRJ] KOMATSU (HAULPAK) 830 E (2000hp 31.88G*	
Availability	%	80.00	
Payload in Template	tonne	225.49	
Operating Hours per Year	OpHr/Year	1,632.00	
Average Payload	tonne	230.44	
Production per Operating Hour	tonne	275.05	
Production per Loader Operating Shift	tonne	1,320	
Production per Year	tonne	448,883	
Queue Time at Loader	min/ Cycle	6.54	
Spot Time at loader	min/ Cycle	0.50	
Average Loading Time	min/ Cycle	7.88	
Travel Time	min/ Cycle	29.13	
Spot Time at Dump	min/ Cycle	0.50	
Average Dump Time	min/ Cycle	0.50	
Average Cycle Time	min/ Cycle	45.05	
Fleet Size		5	
Average No. of Bucket Passes		7.95	
Haulage System			
Production per Year	tonne/Year	2,244,414	
Discounted Capital Cost	$/tonne	1.42	***Loading Methodology***
Discounted Operating Cost	$/tonne	0.83	Single Sided
Discounted Average Cost	$/tonne	2.25	Full Truck
Excavation Target	tonne	4,695,872.00	Average for 150 Shifts
Time to move Excavation Target	Years	2.09	
Loader Hrs to move Target	Op. Hours.	4,268	
Total Truck Hrs to move Target	Op. Hours.	17,073	
Total cost to move Target	$	10,579,139	

4.4.2 CUT II Fleet Requirements

4.4.2.1 CUT II Waste Haulage System

Table 4.3: Waste haulage system for CUT II

Loader		[PRJ] P&H 2300 XPA	
Availability	%	63.00	
Bucket Fill Factor		0.98	
Average Bucket Load Volume	cu.metres	23.13	
Average Payload	tonne	46.26	
Operating Hours per Year	OpHr/Year	2,832.00	Op. hrs factored by availability
Average Operating Shifts per Year	shifts/Year	472.00	Shifts factored by availability
Average Bucket Cycle Time	min	0.50	
Production per Operating Hour	tonne	4,083.72	
Production per Loader Operating Shift	tonne	24,502	Max. prod. based on 100% avail.
Production per Year	tonne	11,565,106	Avg. production factored by avail.
Wait Time per Operating Hour	min	6.45	
Truck		**[PRJ] KOMATSU (HAULPAK) 830 E (2000hp 31.88**	
Availability	%	80.00	
Payload in Template	tonne	225.49	
Operating Hours per Year	OpHr/Year	2,265.60	
Average Payload	tonne	230.98	
Production per Operating Hour	tonne	510.47	
Production per Loader Operating Shift	tonne	2,450	
Production per Year	tonne	1,156,511	
Queue Time at Loader	min/ Cycle	2.77	
Spot Time at loader	min/ Cycle	0.50	
Average Loading Time	min/ Cycle	2.00	
Travel Time	min/ Cycle	18.10	
Spot Time at Dump	min/ Cycle	0.50	
Average Dump Time	min/ Cycle	0.50	
Average Cycle Time	min/ Cycle	24.36	
Fleet Size		10	
Average No. of Bucket Passes		4.99	
Haulage System			
Production per Year	tonne/Year	11,565,106	
Discounted Capital Cost	$/tonne	0.44	*Loading Methodology*
Discounted Operating Cost	$/tonne	0.24	Single Sided
Discounted Average Cost	$/tonne	0.68	Full Truck
Excavation Target	tonne	22,889,234.00	Average for 150 Shifts
Time to move Excavation Target	Years	1.98	
Loader Hrs to move Target	Op. Hours.	5,605	
Total Truck Hrs to move Target	Op. Hours.	44,840	
Total cost to move Target	$	15,529,202	

4.4.2.2 Ore Haulage System for CUT II

Table 4.4: CUT II ore handling system

Loader		*[PRJ] HITACHI EX 2500-6*	
Availability	%	60.00	
Bucket Fill Factor		0.93	
Average Bucket Load Volume	cu.metres	13.97	
Average Payload	tonne	27.94	
Operating Hours per Year	OpHr/Year	2,682.00	Op. hrs factored by availability
Average Operating Shifts per Year	shifts/Year	447.00	Shifts factored by availability
Average Bucket Cycle Time	min	1.00	
Production per Operating Hour	tonne	1,256.22	
Production per Loader Operating Shift	tonne	7,537	Max. prod. based on 100% avail.
Production per Year	tonne	3,369,190	Avg. production factored by avail.
Wait Time per Operating Hour	min	4.09	
Truck		*[PRJ] KOMATSU (HAULPAK) 830 E (2000hp 31.88G*	
Availability	%	80.00	
Payload in Template	tonne	225.49	
Operating Hours per Year	OpHr/Year	2,145.60	
Average Payload	tonne	224.46	
Production per Operating Hour	tonne	314.06	
Production per Loader Operating Shift	tonne	1,507	
Production per Year	tonne	673,838	
Queue Time at Loader	min/ Cycle	6.49	
Spot Time at loader	min/ Cycle	0.50	
Average Loading Time	min/ Cycle	7.04	
Travel Time	min/ Cycle	23.70	
Spot Time at Dump	min/ Cycle	0.50	
Average Dump Time	min/ Cycle	0.50	
Average Cycle Time	min/ Cycle	38.73	
Fleet Size		5	
Average No. of Bucket Passes		8.03	
Haulage System			
Production per Year	tonne/Year	3,369,190	
Discounted Capital Cost	$/tonne	1.03	***Loading Methodology***
Discounted Operating Cost	$/tonne	0.73	Single Sided
Discounted Average Cost	$/tonne	1.75	Full Truck
Excavation Target	tonne	5,754,035.00	Average for 150 Shifts
Time to move Excavation Target	Years	1.71	
Loader Hrs to move Target	Op. Hours.	4,580	
Total Truck Hrs to move Target	Op. Hours.	18,322	
Total cost to move Target	$	10,094,312	

4.5 Assessment of Current Fleet Performance Using OEE

As the name suggests, Overall Equipment Effectiveness (OEE) is a tool for assessing the effectiveness of either a piece or a collection of equipment taking into account three parameters namely availability, performance and quality.

4.5.1 OEE for Shovels

OEE for the shovels was calculated separately from the other loaders since each equipment category has different availability and utilization targets. Two shovels, both P&H 2300 XPA models with individual bucket capacities of 21.4m^3 were used in the calculations.

4.5.1.1 Availability

Average availability for all shovels for the 2015/16 FY from Figure 4.5 is 62%.

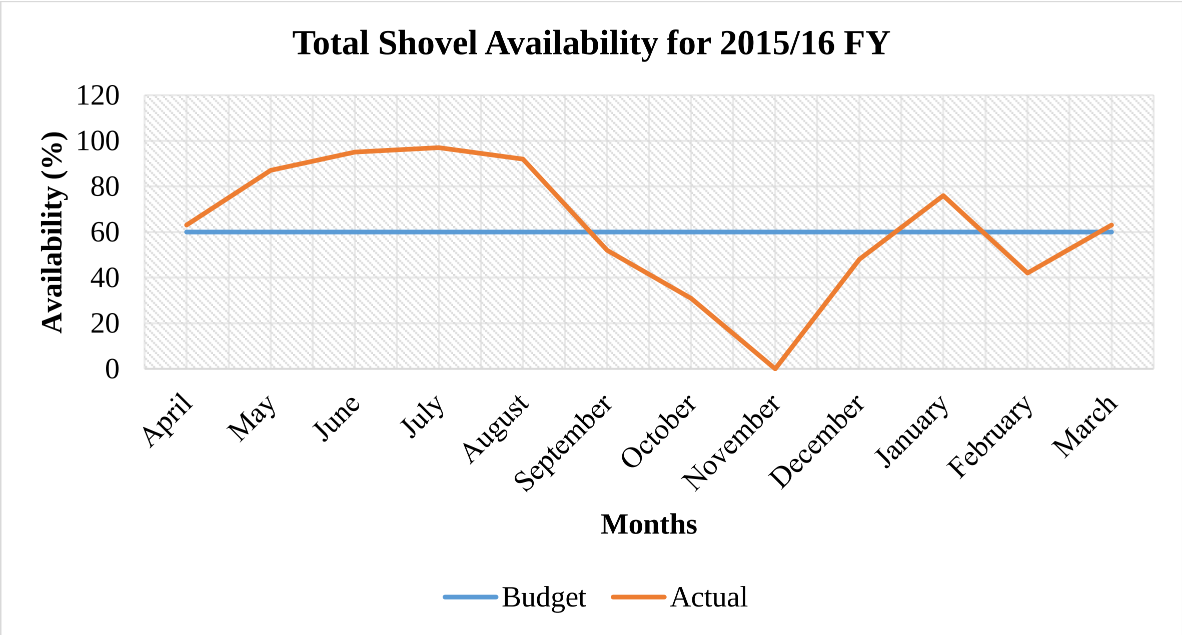


Figure 4.5: Total shovel availability for the 2015/16 FY

4.5.1.2 Performance

Performance as interpreted by OEE considers both utilization (a parameter that has nothing to do with inherent capabilities of the machine e.g. job conditions) and speed losses (which now considers inherent capabilities of the machine e.g. propel).

Figure 4.6 gives the 'utilization parameter' of shovel performance with an average monthly utilization of 19.6%.

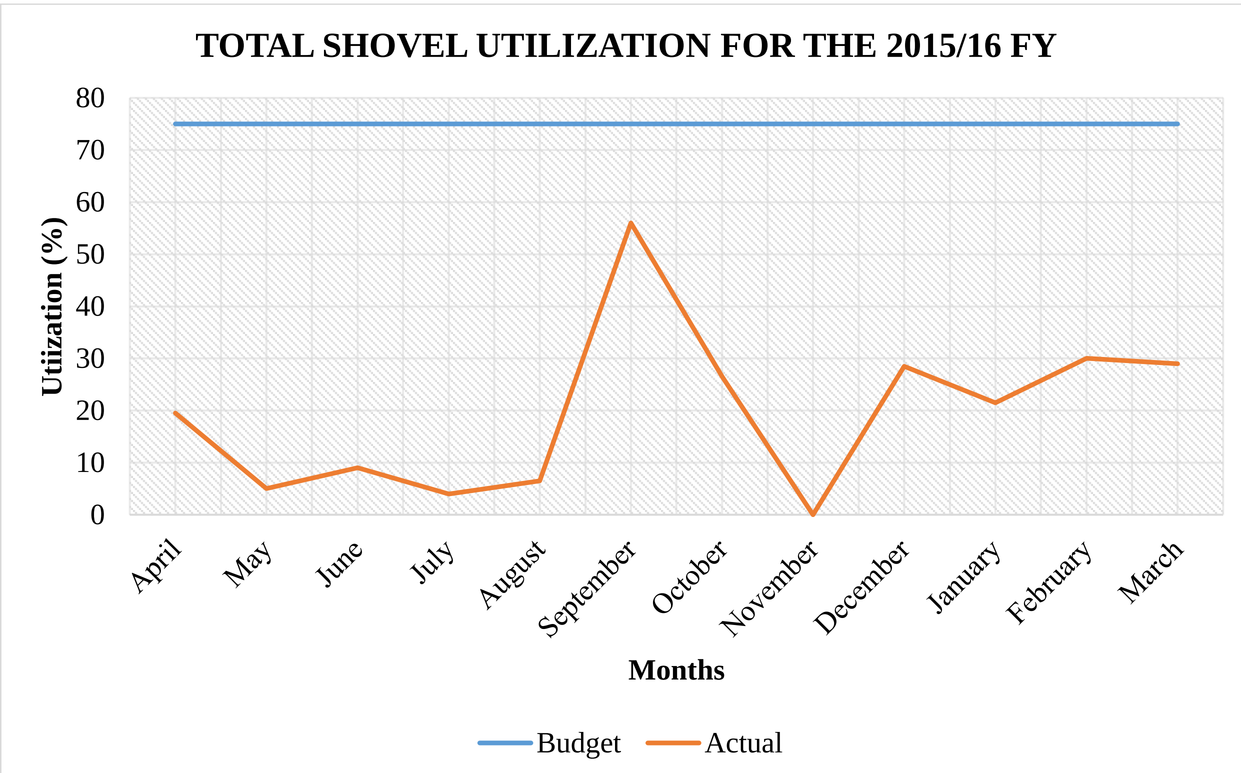


Figure 4.6: Total shovel utilization for the 2015/16 FY

Shovel utilization remained low despite an average truck availability of 62% as obtained from Figure 4.5 due to a number of industrial challenges. Industrial challenges observed include substation relocation, wait on geology, wait on blast, wait on dozer, fuel and service, shifting loader position, no lighting and cable re-routing. All together the delays contributed 30% towards low shovel utilization as shown in Figure 4.17 under Section 4.6.2 of Chapter 4. The biggest delay observed came from dozer clean-up operations. This factor alone had a 40% share among all the industrial delays put together. Evidently it can be seen that the mine is under-equipped in terms of dozers. As a rule of thumb, every dump and every loader must be equipped with a dozer, more so with NOP operations that are far from each other such that it's time consuming for one dozer to move from one location to the next. A rough estimate shows a need for 3 more dozers at NOP in order to raise shovel utilization.

Figure 4.7 gives a Talpac cycle time distribution for the shovel from which a mean value of 49.8 seconds was taken and used to calculate shovel performance.

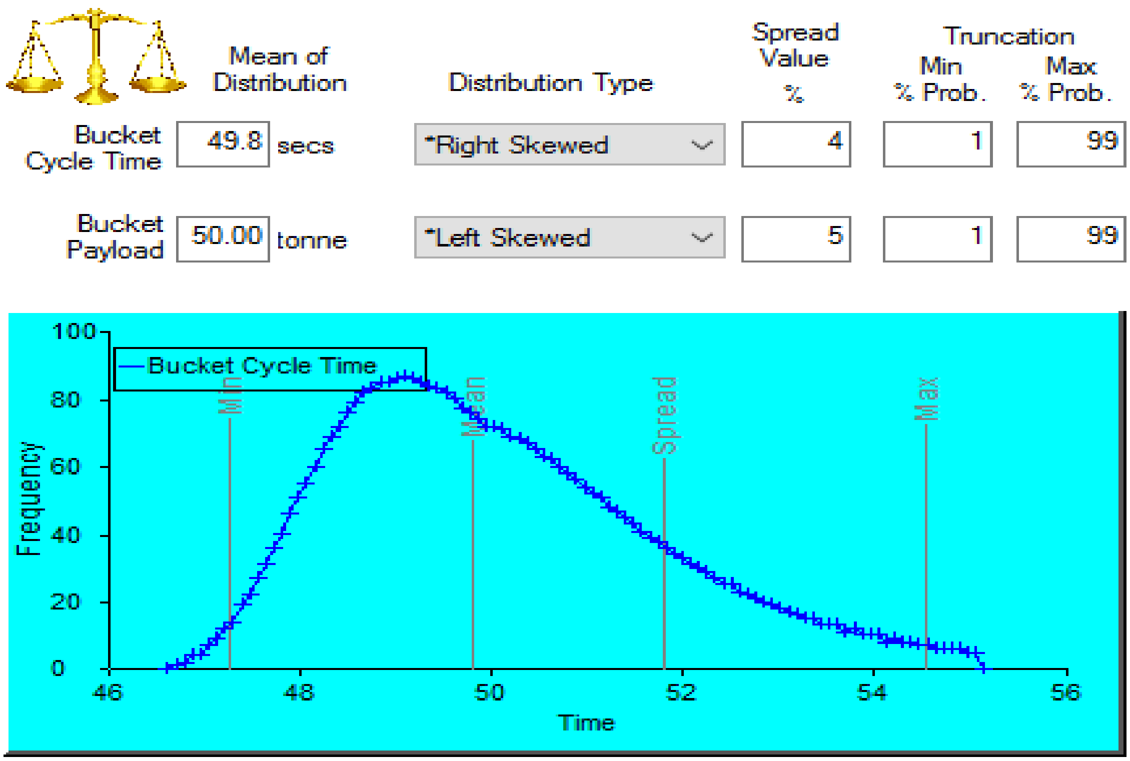


Figure 4.7: Bucket cycle time distribution for the P&H XPA 2300 shovels

The 49.8 seconds cycle time is against a database value of 30 seconds hence a subsequent speed loss of 19.8 seconds. This goes to show from Equation 2.26 in Section 2.10 of Chapter 2 that,

$$\text{Performance} = \frac{\text{Operating time} - \text{speed losses}}{\text{Operating time}} * 100\%$$

$$\text{Performance} = \frac{49.8-19.8}{49.8} * 100\% \ = 60.2\%$$

Incorporating the 'utilization parameter,'

$$\text{Performance} = \ 0.196 * 0.602 * 100 = \mathbf{12\%}$$

4.5.1.3 Quality

The next parameter to be determined for the OEE computation was Quality. Quality with regards to shovel operation was determined from bucket fill factor. Therefore, bucket fill factor for the shovel was determined from the Talpac loading unit template shown in Figure 4.8.

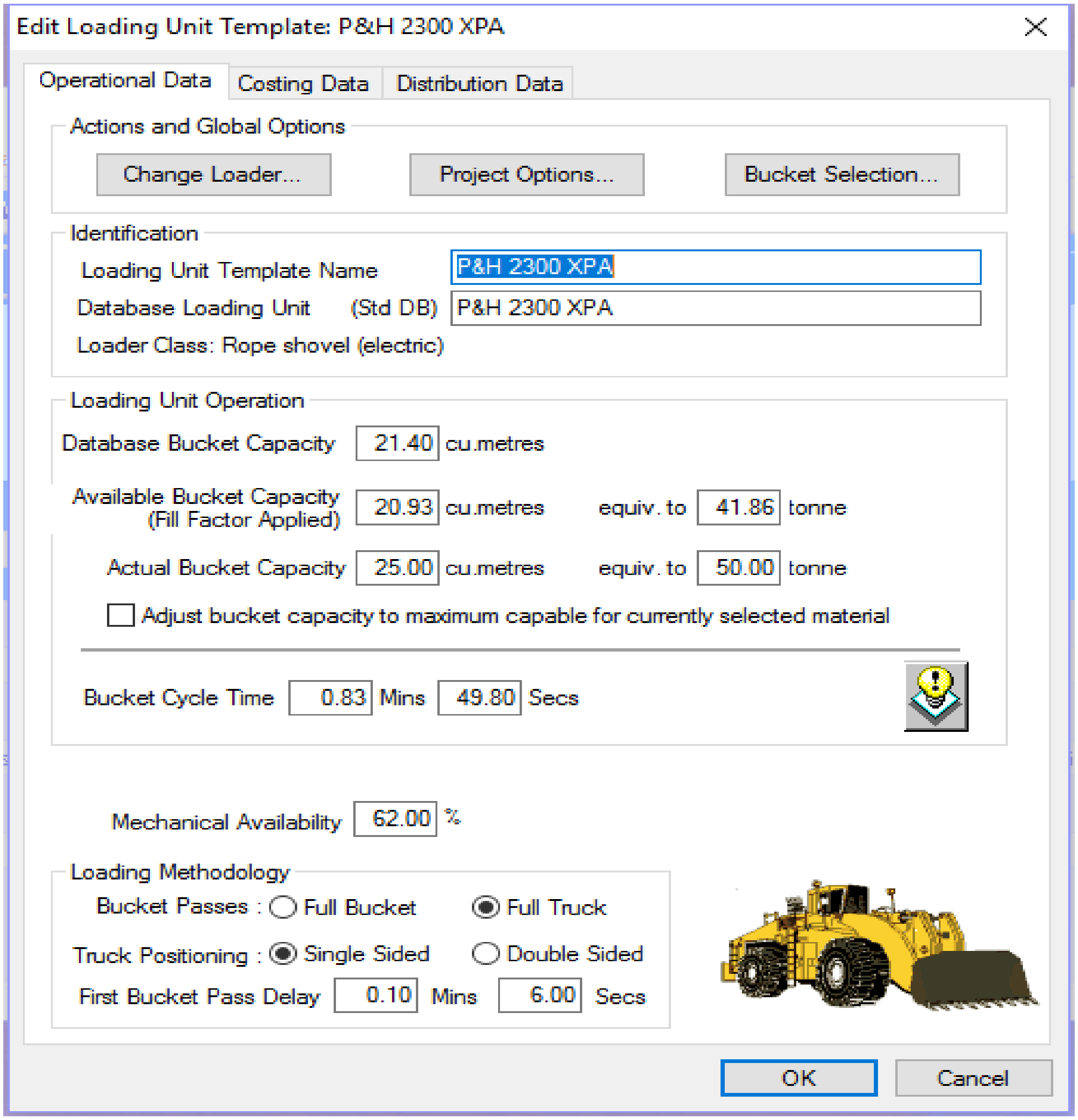


Figure 4.8: Loader template parameters for the P&H 2300 XPA shovel

Considering bucket fill factor as shown in Figure 4.8, a value of 97% can be obtained for quality.

$$\text{OEE} = \text{Availability} * \text{Performance} * \text{Quality}$$

$$\text{OEE} = 0.62 * 0.12 * 0.97 * 100 = \mathbf{7.2\%}$$

The calculated OEE value is then compared with an industrial benchmark value of 85%.

4.5.2 OEE for Large Excavators

OEE for large excavators was determined following the same procedure used for shovels. The large excavators used were 3 backhoes of $15m^3$ each. Two of the backhoes were CAT 6030 models while one was a HITACHI EX 2500 model.

4.5.2.1 Availability

Average availability for all large excavators for the 2015/16 FY from Figure 4.9 is 53.2%.

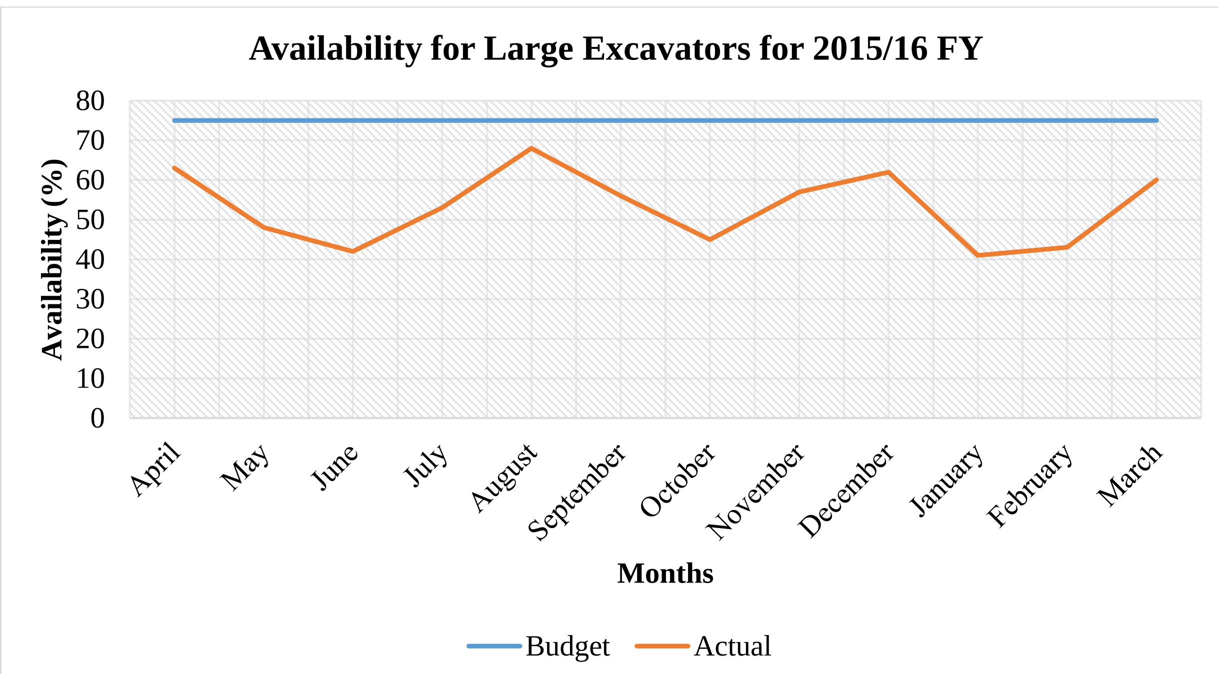


Figure 4.9: Availability for large excavators for the 2015/16 FY

4.5.2.2 Performance

The utilization parameter for large excavator performance is 55% as extracted from Figure 4.10.

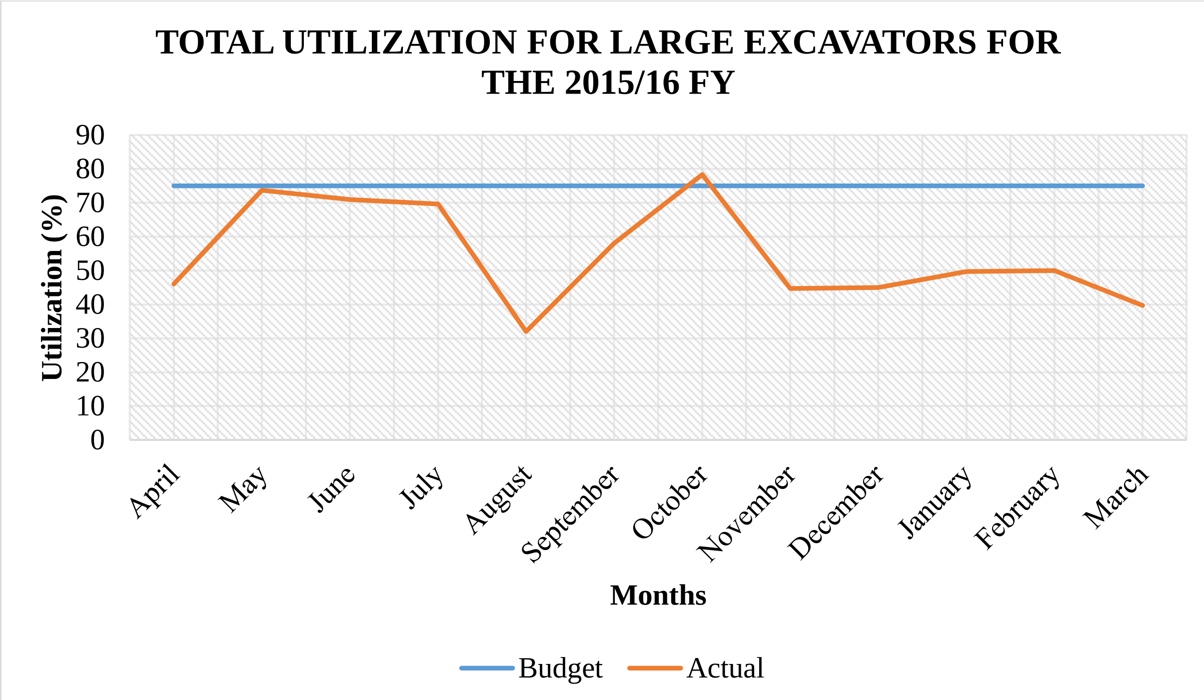


Figure 4.10: Total utilization for large excavators

Large excavators constitute two CAT 6030 backhoes and one HITACHI EX 2500 each with a bucket capacity of 15m^3. Their utilization is planned at 75% which for most of the 2015/16 FY was never achieved due to the same industrial challenges that were seen to affect shovel utilization under Section 4.6.3. The target was only achieved in the months of May and October. However in October utilization went above budget by about 3%. Elimination of the loader utilization inhibitors aforementioned under the same Section 4.6.3 could only have raised utilization to the 75% budget plan. Therefore, foregoing some calendar based activities such as planned maintenance, preventive maintenance, blasting clearance (in cases where blasting has been halted and mining is done on soft overburden), dozer clean up, pre-shift service and increased availability of RTVs could have contributed to the overshot.

Figure 4.11 gives bucket cycle time distribution with a mean of 60 seconds. The given mean is against a database value of 30 seconds.

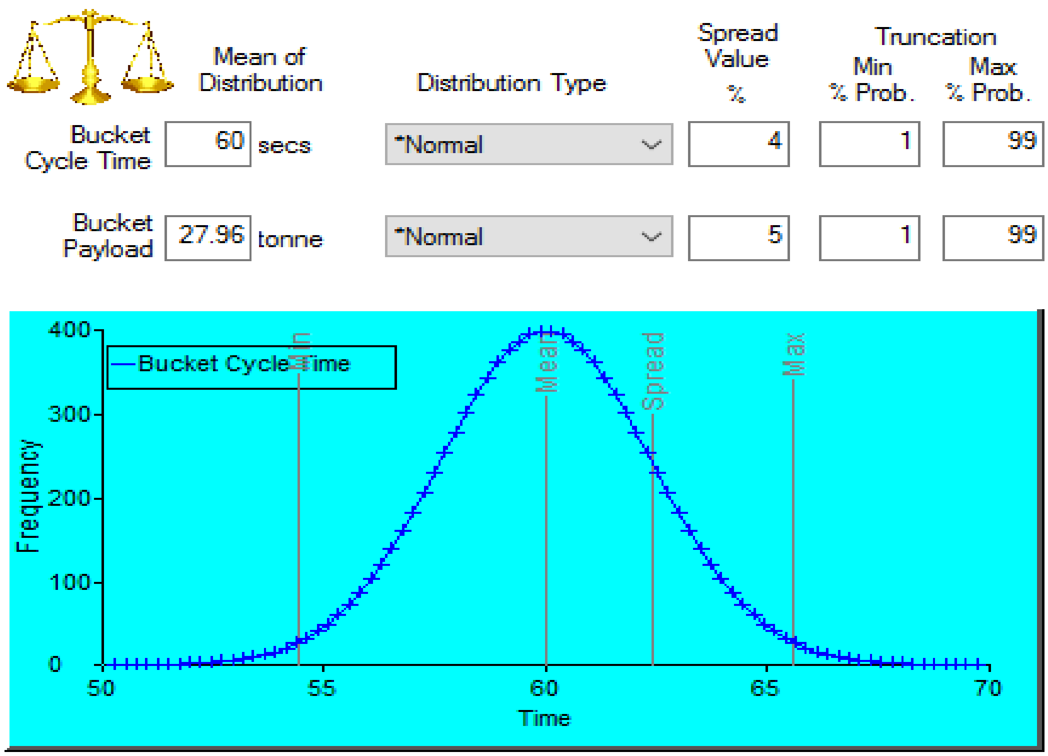


Figure 4.11: Bucket cycle time distribution for large excavators

Considering the discrepancy between the computed cycle time and the database cycle time,

$$\text{Performance} = \frac{60-30}{60} * 100 \ = 50\%$$

Incorporating the 'utilization parameter:'

$$\text{Performance} = \ 0.55 * 0.50 * 100 \ = \mathbf{27.5\%}$$

4.5.2.3 Quality

The quality parameter for the large excavators was calculated as bucket fill factor. All the 3 excavators in operation had the same bucket capacities, digging mechanism, bucket design and were digging the same ground hence comparable fill factors. As a result the HITACHI EX 2500-6, was randomly picked and used to determine bucket fill factor for the large excavators. Figure 4.12 shows the operational data from a Talpac loading unit template which was used to compute loader bucket fill factor.

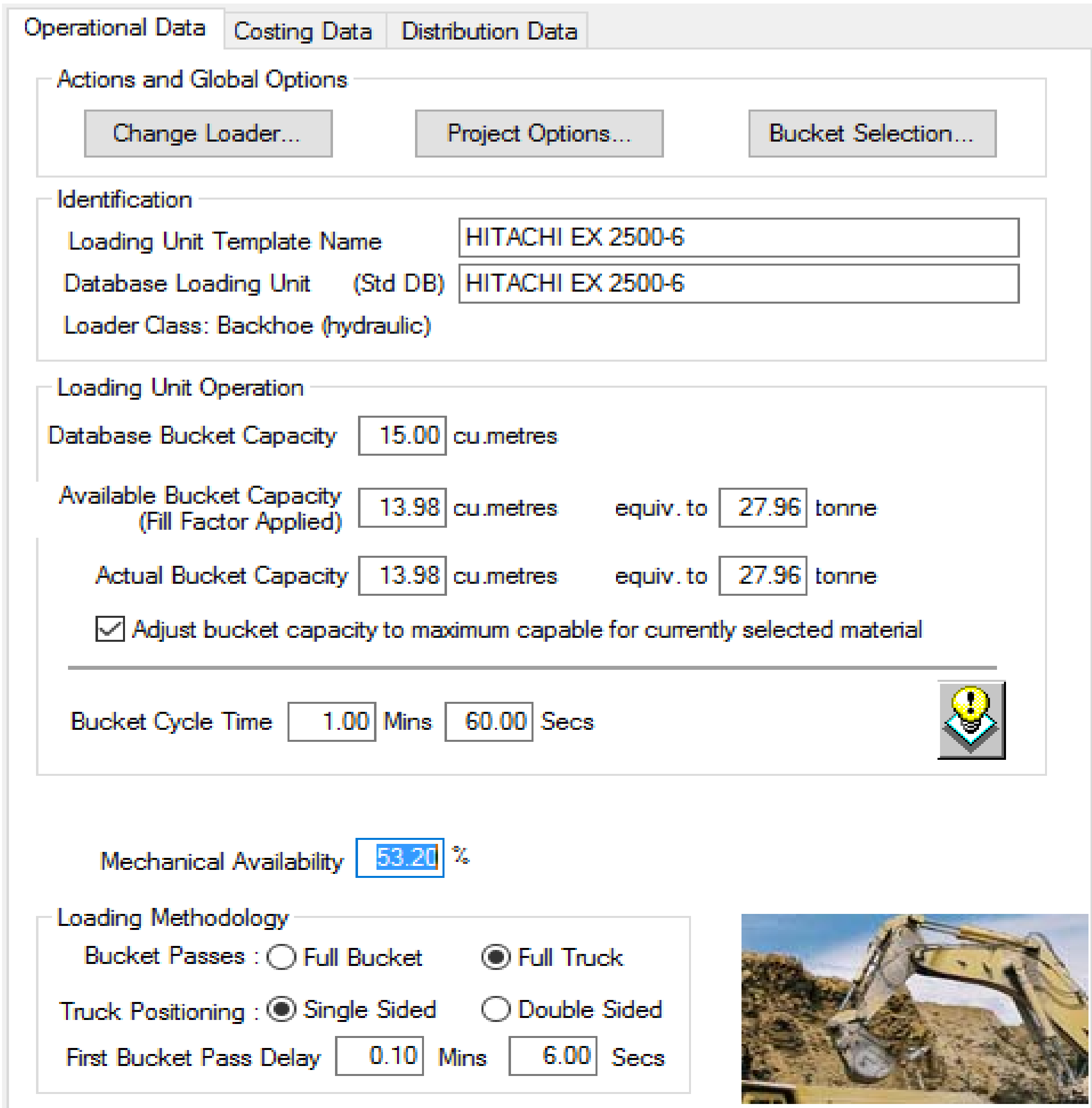


Figure 4.12: Excavator operational data

From Figure 4.12 we can calculate quality from bucket fill factor which is **93.2%.**

Hence,

$$\text{OEE} = 0.532 * 0.275 * 0.932 * 100 = \mathbf{13.6\%}$$

Again the calculated OEE value is then compared with an industrial benchmark value of 85%.

4.5.3 OEE for Trucks

The last OEE score to be calculated was that for trucks. The NOP truck fleet was a heterogeneous fleet comprising 240t, 170t and 86t trucks. The 240t trucks which form the bulk of trucks in operation were chosen as a case study in the computation of truck OEE.

4.5.3.1 Availability

Average availability for trucks as reflected in Figure 4.13 is 84.25%.

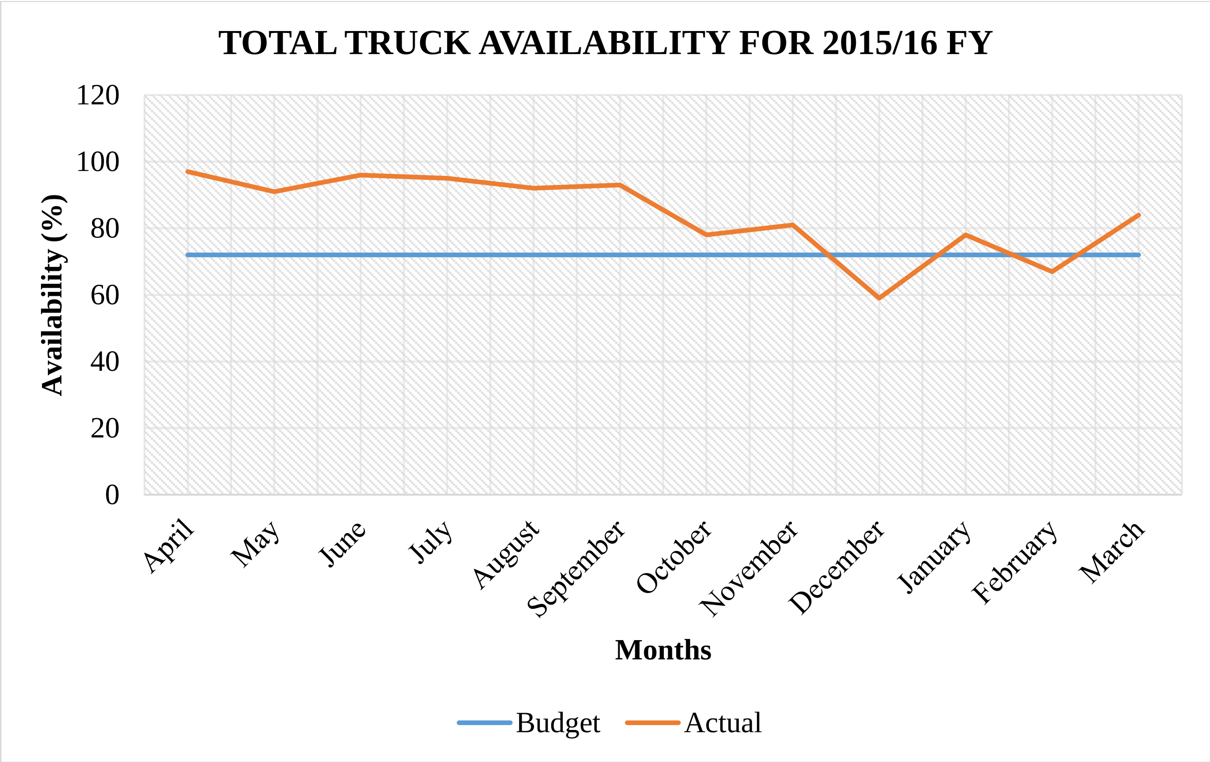


Figure 4.13: Total truck availability for the 2015/16 FY

4.5.3.2 Performance

Performance as interpreted by OEE considers both utilization (a parameter with nothing to do with inherent capabilities of the machine e.g. job conditions) and speed losses (which now considers inherent capabilities of the machine).

Utilization for the 830E trucks for the 2015/16 FY is shown in Figure 4.14 and has an average value of 37%.

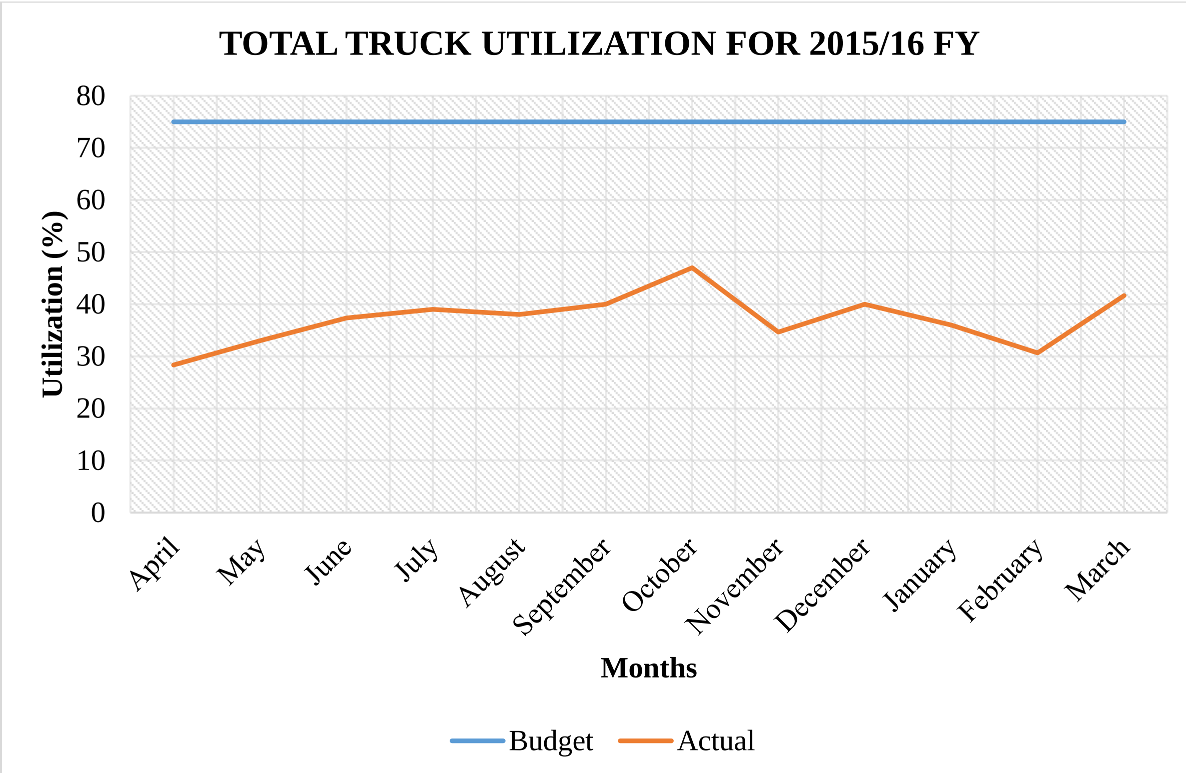


Figure 4.14: Total 830E truck utilization for the 2015/16 FY

Average speed calculated for 3 trucks hauling waste from East Extension (Phase 3) to East Extension Temporary dump gave a value of 14.24km/hr. Different speeds per each section of the haul route were extracted from an Accutrak time line given in Appendix 9. The calculated vehicle speed is against an allowable maximum of 20km/hr for the haul route.

Performance in terms of speed losses is therefore,

$$= \frac{14.24}{20} * 100\% = 71.2\%$$

However, this value should not be taken alone as there is a utilization parameter missing. Including utilization, performance becomes:

$$37\% * 71.2\% = \mathbf{26\%}$$

4.5.3.3 Quality

Rated payload for the trucks is 240t yet actual payload is 190t from mine operational data. Hence quality is:

$$= \frac{190}{240} * 100\% = \mathbf{79.2\%}$$

$$\text{OEE} = 0.792 * 0.26 * 0.8425 = \mathbf{17.6\%}$$

Again the calculated OEE value is then compared with an industrial benchmark value of 85%.

4.6 Production Loss Analysis

Production Loss Analysis, in other words Productivity Analysis is done to identify areas for potential productivity improvement projects in a process based on gathered statistical data. The analysis basically singles out critical points of delays and interruptions that do call for some action plans (Institute, 2016) .

What contributes more to low OEE? OEE incorporates both availability and utilization with the later subtly hidden behind the performance parameter. It is necessary to isolate the critical of the two metrics and offer it thorough diagnosis.

On the same note, productivity, i.e. tonnes produced per hour, comprises availability and utilization metrics. However, there is a question - what mostly affects productivity? A production loss analysis was done to ascertain the impacts of both availability and utilization on fleet productivity. The analysis done considered production losses for the financial year 2015/16.

4.6.1 Production Loss Analysis for Loaders

In order to determine the factor(s) most contributive to low equipment performance, two OEE parameters namely availability and utilization were analyzed for all loaders. Figure 4.15 shows production loss analysis results for all the loaders at NOP. A positive tonnage denotes a loss while a negative tonnage denotes a gain. Productivity loss was not considered in analyzing the results as it is only a product of availability and utilization among other factors.

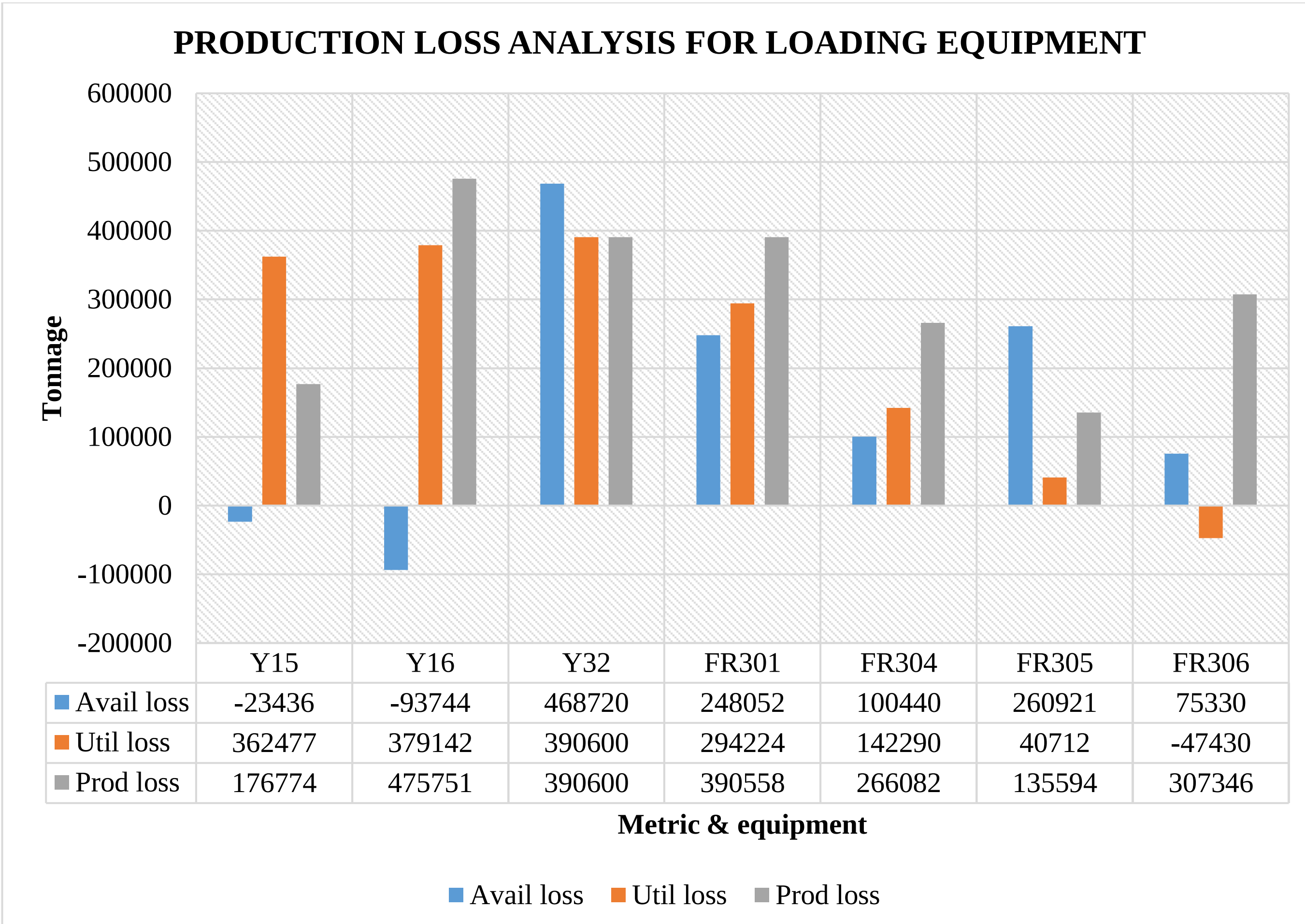


Figure 4.15: Production loss analysis for loaders

The machine identification numbers Y15, Y16 and Y32 all represent electric shovels while FR301, FR304, FR305 and FR306 represent backhoes. Y15 and Y16 have each one a bucket capacity of 21.4m^3 while Y32 has 11.5m^3 bucket size. The productivity budget plan for Y15 and Y16 used was 1400t/hr and for large backhoes i.e. FR301, FR304 and FR305 the budget was 1300t/hr. For the smaller backhoe, FR305 with a bucket size of 7.5m^3, the budget plan was 900t/hr. The analysis for loading equipment shows that shovel losses (putting aside Y32 which was not in operation) were only due to utilization while backhoe losses were attributed to both utilization and availability.

4.6.2 Production Loss Analysis for Trucks

Trucks were divided into 830E old, 830E new1 and 830E new2 all of which are KOMATSU 240t trucks. Their productivity target was 378t/hr. Production losses for trucks in Figure 4.16 show availability as the dominant contributor to production loss.

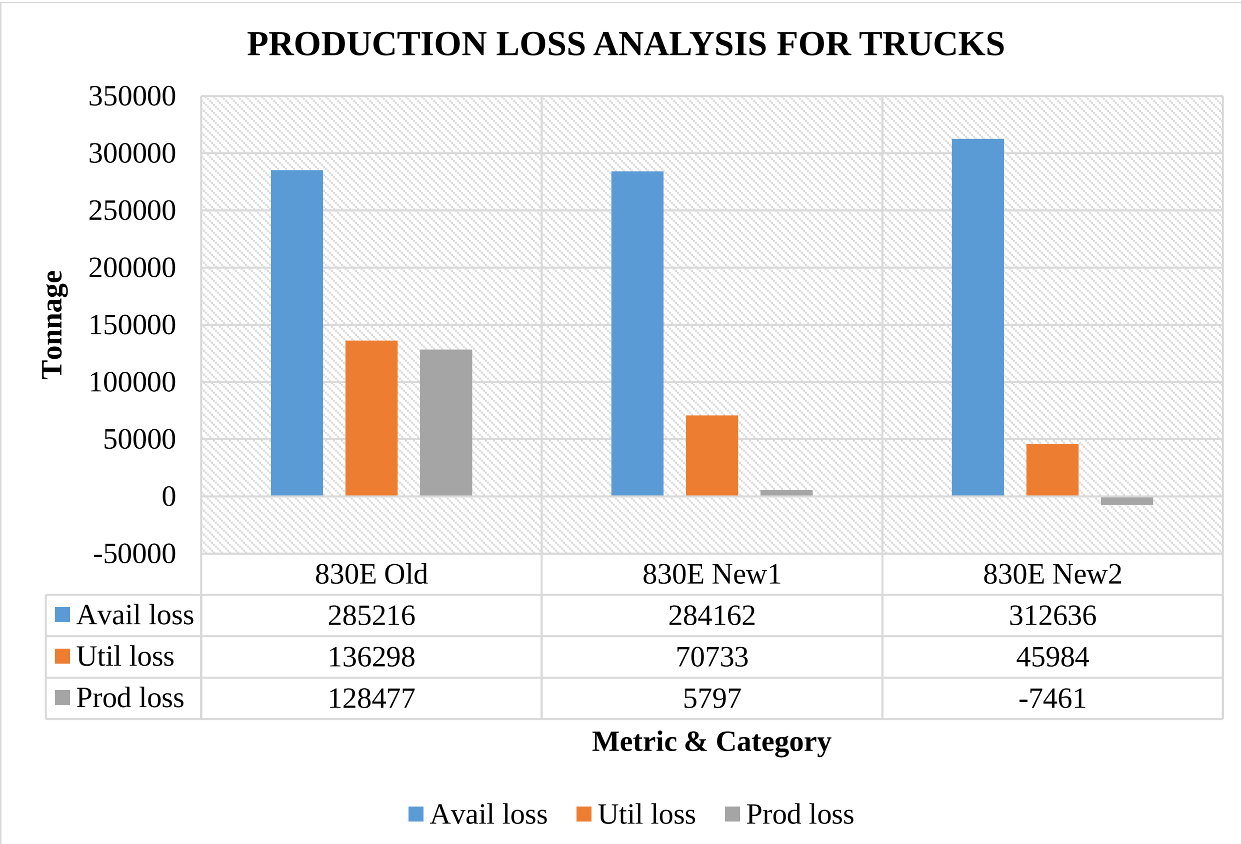


Figure 4.16: Production loss analysis for trucks

4.6.3 Analyzing Loader Utilization Loss

Factors that affect loader and shovel utilization are the same and shown in Figure 4.17. An analysis of these factors was done for the month of May picked at random. This exercise could not be done for a longer period because data was being captured manually on hard copy log books and the process of interpreting the data then presenting it electronically was time consuming. Figure 4.17 gives industrial delays, labor, environment, pre-shift service, shift change, access, short-of-rubber tired vehicles and meal breaks as the contributors to low loader utilization.

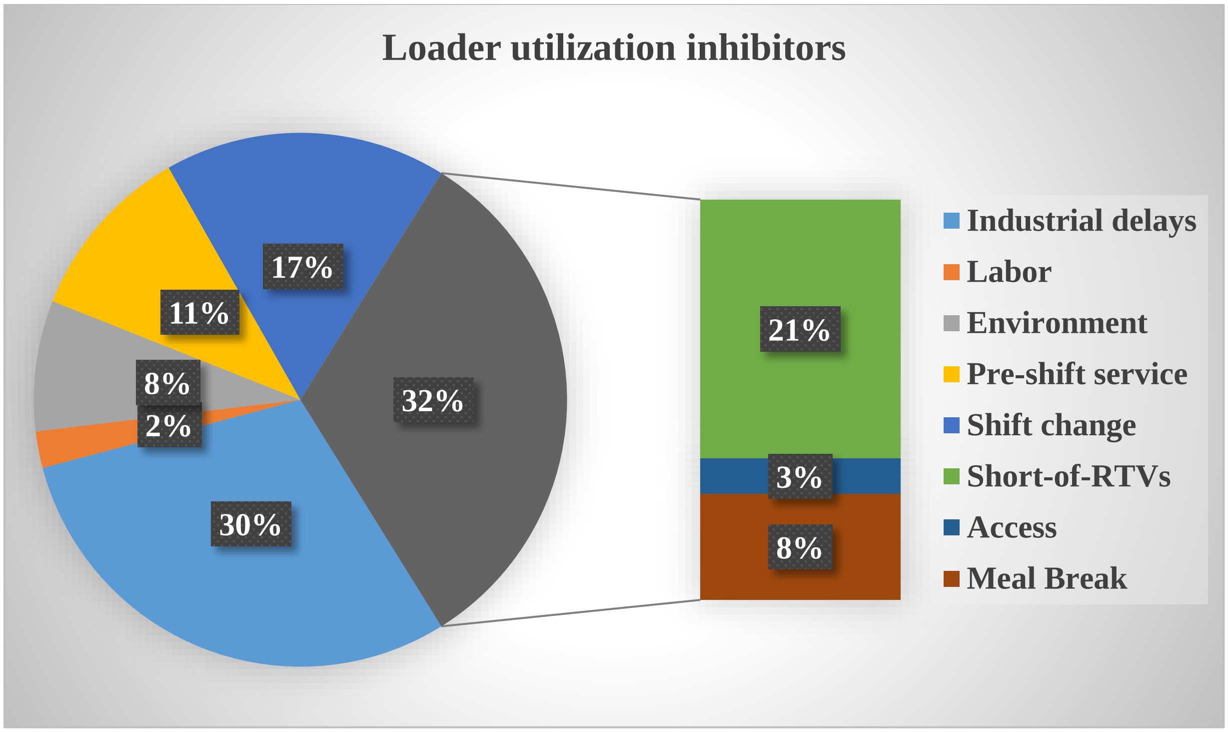


Figure 4.17: Distribution of factors underpinning low loader utilization

Critical loader utilization areas

- Industrial delays
- Environment - dust
- Shortage of Rubber Tired Vehicles (RTVs)

4.6.3.1 Industrial delays

Industrial delays observed involved substation relocation, wait on geology, wait on blast, wait on dozer, fuel and service, shifting loader position, no lighting and cable re-routing as indicated in Figure 4.18. However all activities are almost inevitable except for some portion of the wait on dozer component. This component needs to be broken down to distinguish between the inevitable dozer clean up and the avoidable wait on dozer. Dozer clean up just has to be allowed as shovel needs heaped material for operation and trucks require not a boggy area nor deep soft earth on loading bay. Now waiting on dozer can be avoided through ensuring an optimum number of dozers in the feet.

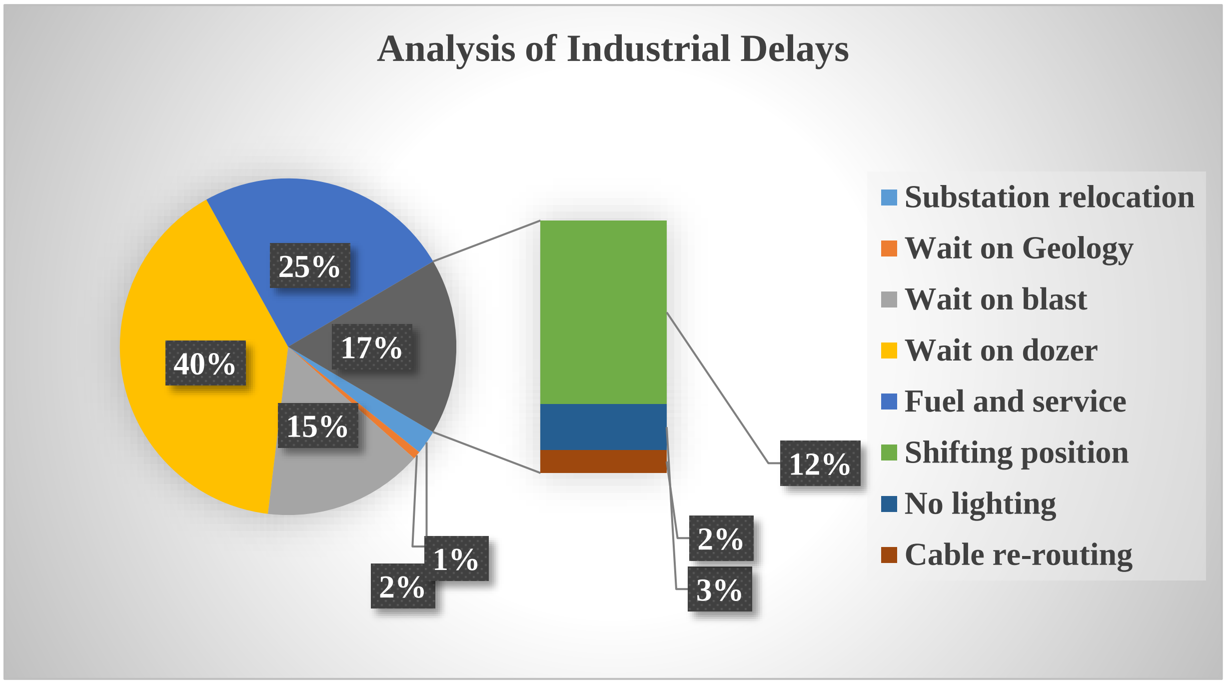


Figure 4.18: An analysis of the industrial delays lowering loader availability

4.6.3.2 Environmental Delays

Environmental delays constituted boggy ground and dusty rumps. Boggy ground was witnessed only once in the selected month while dusty ramps contributed the bigger chunk of the environmental delays. The issue of dusty ramps requires an action plan.

4.6.3.2.1 Current Dust Suppression Plan

Apparently NOP uses a single water cart as a means of suppressing dust. Two water carts are supposed to be doing the job but apparently budget limitations keeps the other one in its broken down state. Owning and operating costs were calculated using a Microsoft excel model. Certain costs such as capital cost landed for equipment were based on international estimates since actual figures could not be obtained from the company. Owning costs for the current dust suppression system for the 2015/16FY are shown in Table 4.5 while the corresponding operating costs are shown in Table 4.6. The two water carts in use were the K430 and K431 carts.

Table 4.5: Owning costs for the current dust suppression system

OWNING COST	% (where applicable)	Unit	Amount	Total
Capital cost- Landed		$ (Million)	2.7	
Average annual Investment		$ (Million)	1.485	
Interest charges per annum	0.12	$ (Million)	0.18	
Insurance charges per annum	0.0175	$ (Million)	0.03	
Depriciation per annum		$ (Million)	0.270	
Total cost per annum		$ (Million)	0.47	
Owning Cost		$ /Hr.	34.51	**69.02**

Table 4.6: Hourly operating costs for current dust suppression system

Operating Cost		**Amount per machine**		**Total**
Category	**Unit**	**K430 Cart**	**K431 Cart**	
Fuel Consumption	Lit/Hr.	71.5	61.1	
Fuel cost	$/Hr.	91.5	78.2	
Lube Cost (Considering 10% of fuel cost)	$/Hr.	9.15	7.82	
Repair & Maintenance Cost (Including taxes)	$/Hr.	30	30	
Tyre cost/hr of life @ 8000hrs	$/Hr.	23	23	
Operator Wages	$/Hr.	7.2	7.2	
Operating Cost	$/Hr.	**160.85**	**146.22**	**307.07**

From Tables 4.6 and 4.7 it can be seen that hourly owning and operating costs for the current dust suppression system are $69.02 and $307.07 respectively. The cost of running the current system as well as its inefficiencies exhibited by the 8% contribution to low fleet utilization should be weighed against other possible dust suppression options.

Using a case of 1374 equipment operating hours per year for one water cart for the 2015/16 FY shown in Table 4.8, total cost of running two water carts can be found to be:

Total dust suppression cost/year = 2*1374* (307.07+69.02) **= $1 033 495.32**

Table 4.7: Operational details for each water cart

Description	Units	Quantity
Life of equipment	Yrs	10
Equipment operation per year	Hrs	1,374
Economic life of the equipment	Hrs	65,000

4.6.3.3 Shortage of RTVs

RTVs shortage can be both an availability and a quantity issue. Availability of RTVs was analyzed under Section 4.6.5.

4.6.3.3.1 Assessing RTV Quantity Using Queuing Theory

An excel queue analysis was done for the case of waste haulage at the 135mb in COP F&D. The analysis, as shown in Tables 4.8 through 4.10, used input values of a truck arrival rate of 8 trucks/hour and a loader service rate of 14 trucks/hour. Cost of service and cost of waiting had to be stated in the same units with arrival and service rate for the template used. The total cost for the current system based on queue is shown in Table 4.11.

Table 4.8: Color key for the queue analysis tables

Color Key
Model Input (change)
Model Output (read)
Decision Metric (act on)

Table 4.9: Input parameters for the excel queue analysis done at the COP F&D 235mb

Input Data		
Arrival rate (λ)	8	hour
Service rate (μ)	14	hour
Cost of Service	253	hour
Cost of Waiting	93	hour

Table 4.10: Excel queue analysis results for the case of waste haulage at the 135mb in COP F&D

Queue Performance/Operating Characteristics		
Average server utilization (ρ)	57.1%	busy
Average number of customers in the queue (L_q)	0.381	in queue
Average number of customers in the system (L)	0.952	in system
Average waiting time in the queue (W_q)	0.048	hour
Average time in the system (W)	0.119	hour
Probability (% of time) system is empty (P_0)	0.429	empty

Table 4.11: Total cost for the current system

Total cost based on queue for the current system		
Service cost ($)	Wait cost ($)	Total cost ($)
253	35.43	288.43

The results obtained showed a server utilization of 57.1% which obviously means sever underutilization. It becomes therefore logically correct to raise the arrival rate of trucks. Further analysis results on the raising of arrival rates are shown in Tables 4.12 and 4.13. The new arrival rate should be close but not equal to service rate, else the system will blow up. As a result, an arrival rate of 13 can be used but will this be optimum in terms of costs as well as loader target utilization?

Table 4.12: Input parameters for the queue analysis

Input Data		
Arrival rate (λ)	**13**	hour
Service rate (μ)	**14**	hour
Cost of Service	**253**	hour
Cost of Waiting	**93**	hour

Table 4.13: Analysis results for a proposed rise in arrival rate

Queue Performance/Operating Characteristics		
Average server utilization (ρ)	92.9%	busy
Average number of customers in the queue (L_q)	6.036	in queue
Average number of customers in the system (L)	6.964	in system
Average waiting time in the queue (W_q)	0.464	hour
Average time in the system (W)	0.536	hour
Probability (% of time) system is empty (P_0)	0.071	empty

Apparently Table 4.13 shows that increasing arrival rate will raise utilization to 92.9% however the average number of trucks in the queue becomes worrisome. This is further confirmed by an increase in service cost shown in Table 4.14.

Table 4.14: Total cost of new system

Total cost based on queue for new system			
Arrival rate (hrs)	Service cost ($)	Wait cost ($)	Total cost ($)
8	253	35.43	288.43
8	253	35.43	288.43
9	253	53.81	306.81
10	253	83.04	336.04
11	253	133.96	386.96
12	253	239.14	492.14
13	253	561.32	814.32

Nevertheless, it is wise to pick a truck arrival rate that matches loader utilization so as to optimize total cost. Budget plan shovel utilization for the particular P&H shovel (Y16) was 75%. Results of Tables 4.15 and 4.16 analysis show that an arrival rate of 10.5 trucks/hour is the one that results in the target shovel utilization of 75%.

Table 4.15: Input parameters for the queue analysis

Input Data		
Arrival rate (λ)	**10.5**	hour
Service rate (μ)	**14**	hour
Cost of Service	**253**	hour
Cost of Waiting	**93**	hour

Table 4.16: Arrival rate resulting in the 75% target utilization

Queue Performance/Operating Characteristics		
Average server utilization (ρ)	75.0%	busy
Average number of customers in the queue (L_q)	1.125	in queue
Average number of customers in the system (L)	1.875	in system
Average waiting time in the queue (W_q)	0.107	hour
Average time in the system (W)	0.179	hour
Probability (% of time) system is empty (P_0)	0.250	empty

Total cost for the optimum system can be extracted from Table 4.17 to be $357.63 per operating hour. Furthermore from Figure 4.19 the number of trucks corresponding to an arrival rate of 10.5 trucks/hour shows that 7.86 (approximately 8) trucks are needed to fully utilize the Y16, P&H shovel mining waste at the 135mb in COP F&D.

Table 4.17: Total cost for the optimum system with arrival rate of 10.5 hour

Total cost based on queue for the new system			
Arrival rate (hrs)	Service cost ($)	Wait cost ($)	Total cost ($)
8	253	35.43	288.43
8	253	35.42	28.43
8.5	253	43.63	296.63
9.5	253	66.61	319.61
10.5	253	104.63	357.63
11.5	253	175.7	428.7
12.5	253	345.98	598.98

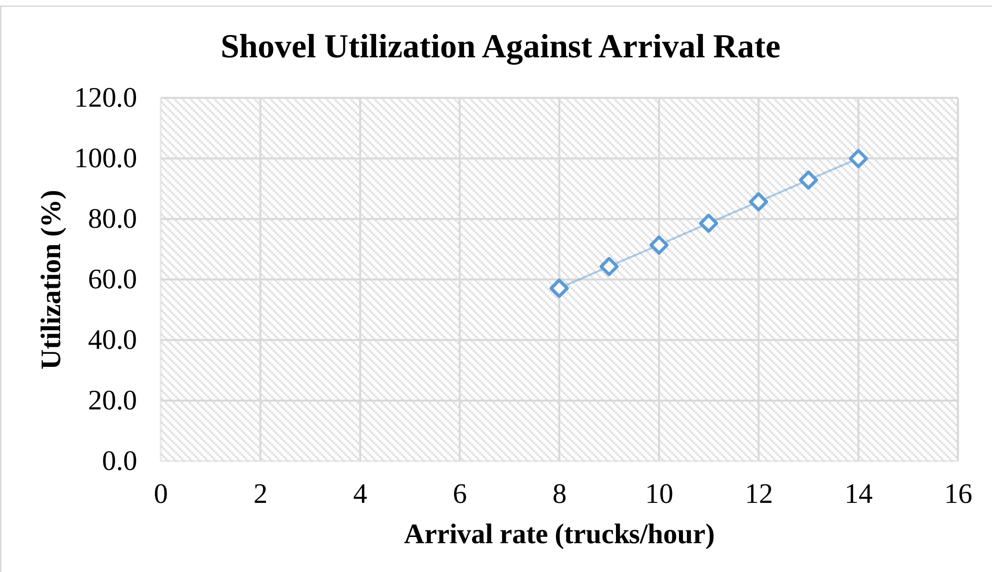


Figure 4.19: Shovel utilization against truck arrival rate

Figure 4.19 was used to determine the arrival rate that corresponds to a target utilization of 75% for the shovel. Since the problem with shovels is under-utilization it became imperative to peg truck arrival rate at a level corresponding with the target utilization. Using the 10.5 trucks/hour arrival rate from Figure 4.19, Figure 4.20 goes on to show how to arrive at the number of trucks that would give the required arrival rate and through that process 8 trucks were determined.

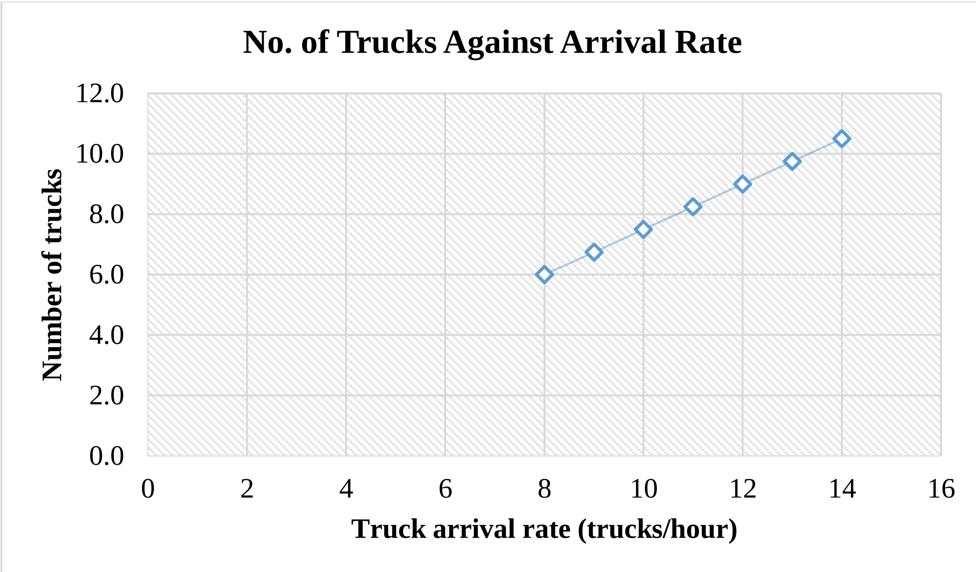


Figure 4.20: Number of trucks against truck arrival rate

4.6.4 Analysis of Loader Availability

Analysis of loader availability was done by manually interpreting data for the month of October picked at random from the mine log books. Figure 4.21 shows that shovel electrical faults with 42% followed by mechanical faults with 37% mainly contribute to low availability. A root cause analysis in Figure 4.25 clarifies the underlying reasons for the availability challenge. Spares and consumables cannot be ignored and again more corrective repairs (5%) than preventive maintenance (2%) reveals a flawed maintenance strategy.

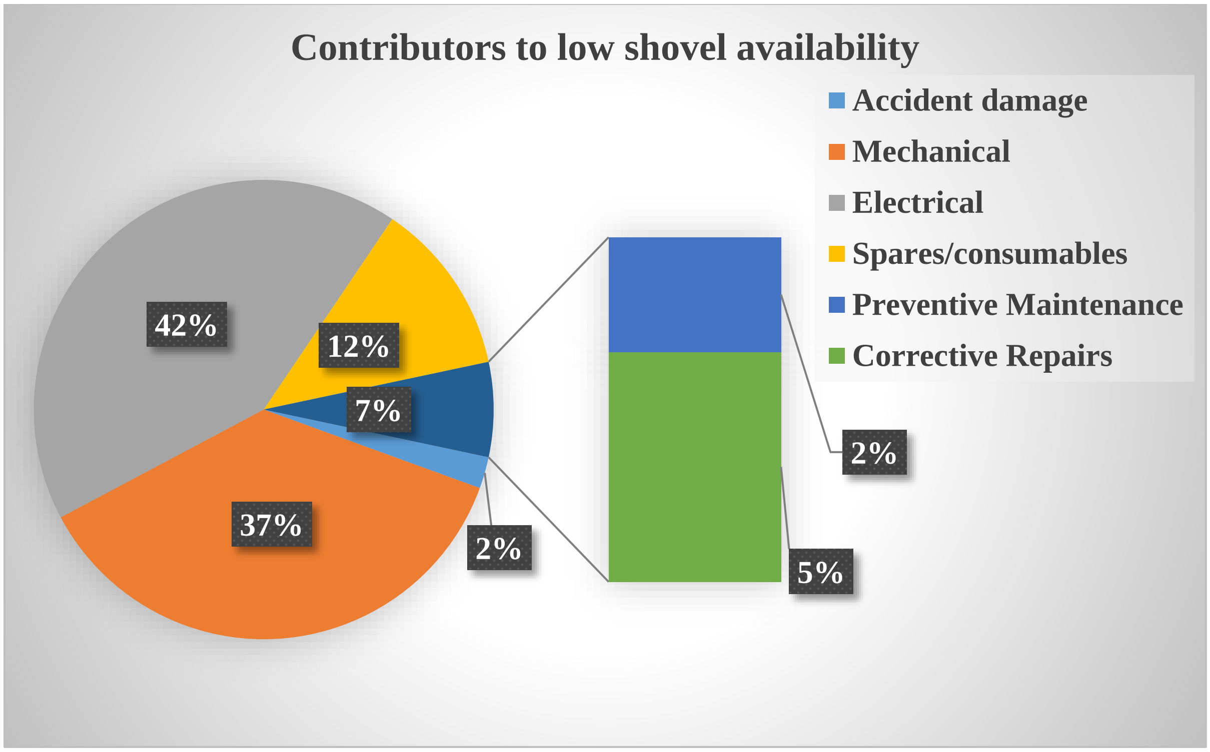


Figure 4.21: Factors contributing to low shovel availability

Electrical Challenges

- Tripping out
- No start
- Trip motor not working
- Loss of power
- Power supply switch loose
- Monitoring panel not showing
- Scanning card not responding
- Electrical checks

From Figure 4.22 backhoes are mainly affected by mechanical problems with a 58% magnitude followed by hydraulics with 14% then spares and consumables with 11%. Fortunately, preventive maintenance was observed to be higher than corrective repairs for the loaders notwithstanding that it could be only holding true for the randomly selected month.

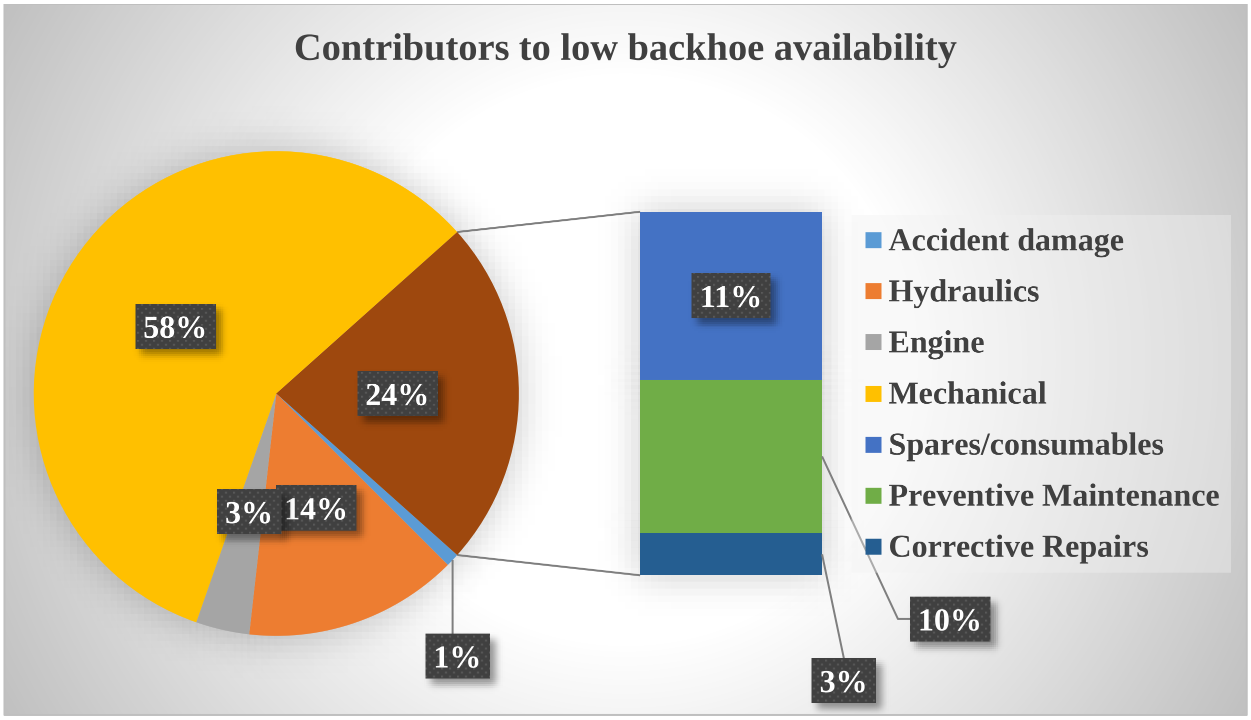


Figure 4.22: Factors contributing to low loader availability

Problems with hydraulics

- Hydraulic temperature high
- Hydraulic oil levels low
- Hydraulic oil leaks

Engine problems

- Engine cut off

Spares and consumables

- Retainer plate
- Air receiver
- No coolant
- No enough slake cable (shovels)
- No cap lamp
- Bucket tooth missing
- Suspension ropes worn out (shovels)

Mechanical problems affecting both shovels and loaders

- No motions – no swing, no bucket lift, no bucket tilt
- Boom up lift weak
- Trip rope broken
- V-belt rubbing against guard
- Toggle link pin off position
- Grease pipe not lubricating
- Hoist ropes off the drum
- Water leaks
- Propel brakes not holding
- Track chain not propelling
- Hoist revolvers faulty
- Coolant overheating
- Low revs
- Swing pump temperature high
- No power under load

4.6.5 Analysis of Truck Availability

From the productivity loss analysis in Figure 4.16 it was shown that 882014t were lost in the 2015/16 FY due to truck availability problems as compared to 253015t lost due to low utilization. Furthermore, loader utilization analysis revealed shortage of RTVs as one of the biggest factors impacting utilization. It becomes therefore more reasonable to focus on improving availability through first understanding the factors hampering truck availability. The analysis of Figure 4.23 gives a distribution of these factors. A lack of spares/consumables (27%), mechanical problems (19%), electrical/electronic problems (15%), Engine problems (14%) and hydraulic problems (5%) topped the list in that order.

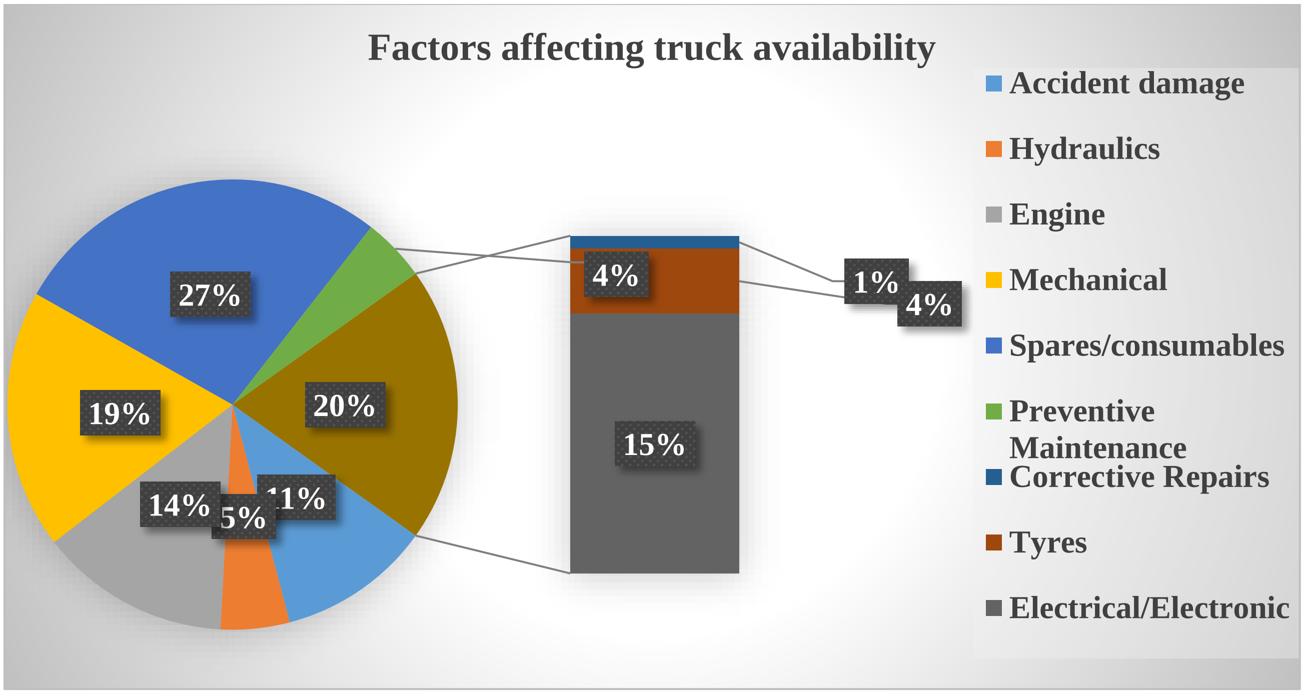


Figure 4.23: Distribution of factors affecting truck availability

Spares and consumables needed

- Filters
- Studs and nuts
- Hoist cylinder
- Main alternator
- Lube

Mechanical problems

- Suspension riding low
- Self-braking
- Doors/windows not opening
- No power under load
- Rock ejector bent
- No propel/cutting propel
- Stiff steering
- Convertor and brake temperature high

- Brakes not holding

Electrical/electronic

- Accumulator light on
- Fire from grid box
- Air con not working
- Head lamps not shining
- Circuit breaker light on

Engine problems

- Engine checks or repairs

Hydraulic problems

- Hydraulic oil leaks
- Hose leaking
- Hydraulic oil temperature high

4.7 Root Cause Analysis

A root cause analysis was done through maintenance department with an aim of underpinning the causes of frequent machine breakdowns. The analysis considered the whole fleet, picking different equipment at random from loading, hauling and support categories. This investigation was done through the use of 'why analysis' tools in which questions in the form of 'why's are asked until the root cause is identified for each phenomena. Different identified root causes were categorized and their frequency is shown in Figure 4.24.

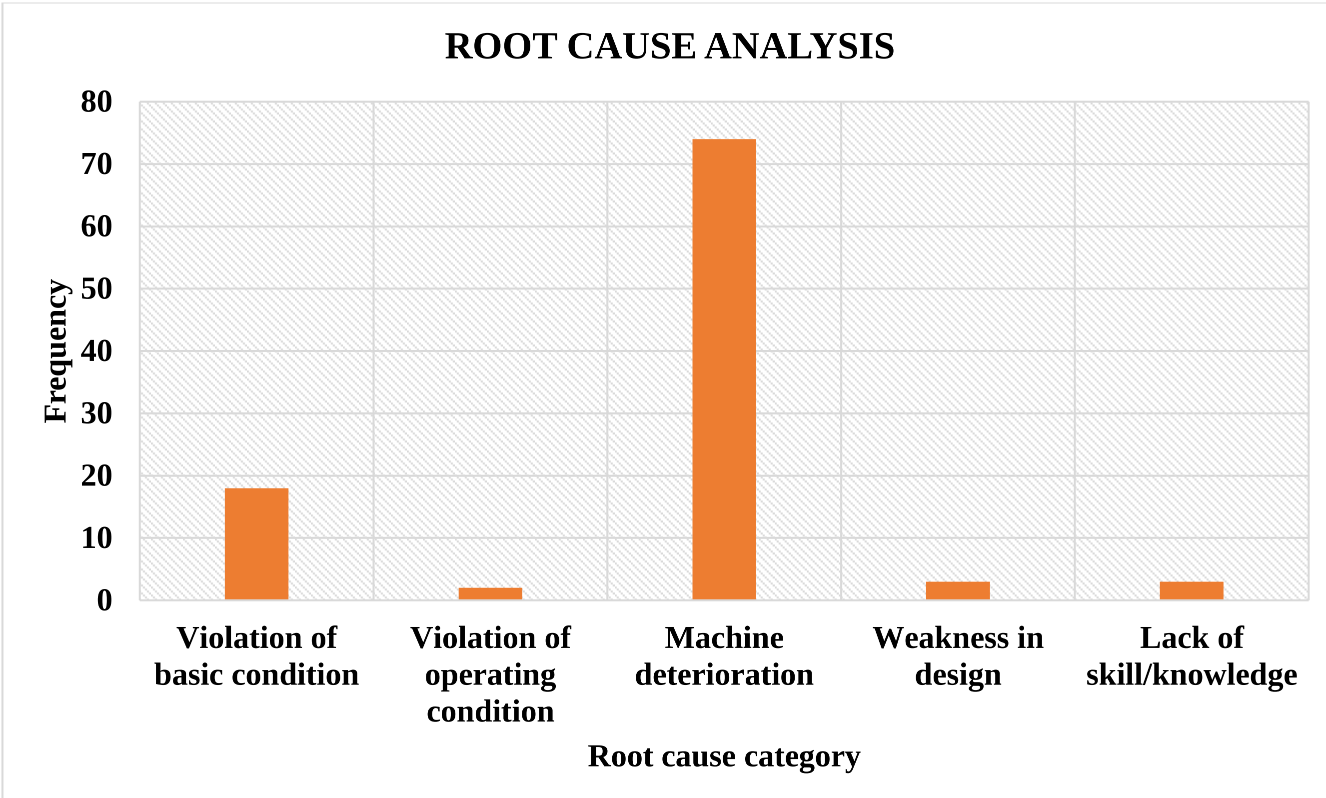


Figure 4.24: Root cause analysis results

4.8 Harvesting Other Optimization Opportunities

4.8.1 Investigating Cost Reduction through Direct Tipping

The current ore handling system at NOP involves dump trucks hauling ore from CUT II, COP F&D and Stock piles then dumping it at the Old East Mill (OEM) stock pile. From the OEM ore is then re-handled and fed into the crusher using front end loaders (FELs).

Reasons behind ore re-handling are:

- To allow for blending between open pit ores and CRO from dumps;
- The constriction of the crusher opening which makes it difficult for the 240t trucks to tip;
- To allow elimination of boulders which may jam the crusher; and
- To allow for visual identification and removal of metallic objects from the ores.

However under the double handling of ore being done at Old East Mill crusher, the mine is losing $708 685.8 per annum running one front end loader. Tables 4.18 and 4.19 show results from a Microsoft excel model used to calculate the cost of running one front end loader at OEM. Again certain values e.g. capital cost landed were researcher's estimates as actual figures could not be obtained from the company.

Table 4.18: Hourly owning costs for one FEL at OEM

OWNING COST	%(where applicable)	Unit	Amount
Capital cost- Landed		$ (Million)	1
Average annual Investment		$ (Million)	0.58
Interest charges per annum	12%	$ (Million)	0.07
Insurance charges per annum	1.75%	$ (Million)	0.01
Depriciation per annum		$ (Million)	0.167
Total cost per annum		$ (Million)	0.25
Owning Cost		$ /Hr.	4.06

Table 4.19: Operating and total owning and operating costs for running one FEL at OEM

Operating Cost		**Amount per machine**
Category	**Unit**	**FEL**
Fuel Consumption	Lit/Hr.	74.2
Fuel cost	$/Hr.	94.976
Lube Cost (Considering 10% of fuel cost)	$/Hr.	9.4976
Repair & Maintenance Cost (Including taxes)	$/Hr.	30
Tyre cost/hr of life @ 8000hrs	$/Hr.	23
Operator Wages	$/Hr.	7.2
Operating Cost	$/Hr.	**164.67**
Owning & operating cost	**$/Hr.**	**168.73**

Statistics for the first half of the 2015/16 FY shows average monthly operated hours to be 350 hours. Yearly owning and operating cost for one FEL becomes:

Yearly owning & operating cost = 350*12*168.73 = **$ 708 685.8**

4.9 Summary

Data on material type, shift schedule, loader characteristics, truck fleet characteristics and haul cycle were collected and analyzed using Talpac software. Time and motion studies were done and the collected data was analyzed using queue templates in Microsoft excel. Match factor and generic formulas were also used to calculate other fleet requirements. Finally, machine costing on fleet optimization opportunities was done using formulas embedded in Microsoft excel.

CHAPTER 5 DISCUSSION OF RESULTS

5.1 Introduction

This Chapter discusses the findings of Chapter 4 where collection and analysis of data was done. Following the analysis of data, in this chapter various options are weighed and a financial bearing tagged to each option before conclusions can be drawn. The results were discussed in relation to the study objectives of Section 1.7 of Chapter 1.

5.2 Fleet size

Following the revised NOP LOM and equipment within useful life as seen in Figures 4.1 and 4.2, Figure 5.1 was developed to show how the equipment quantity lags behind LOM.

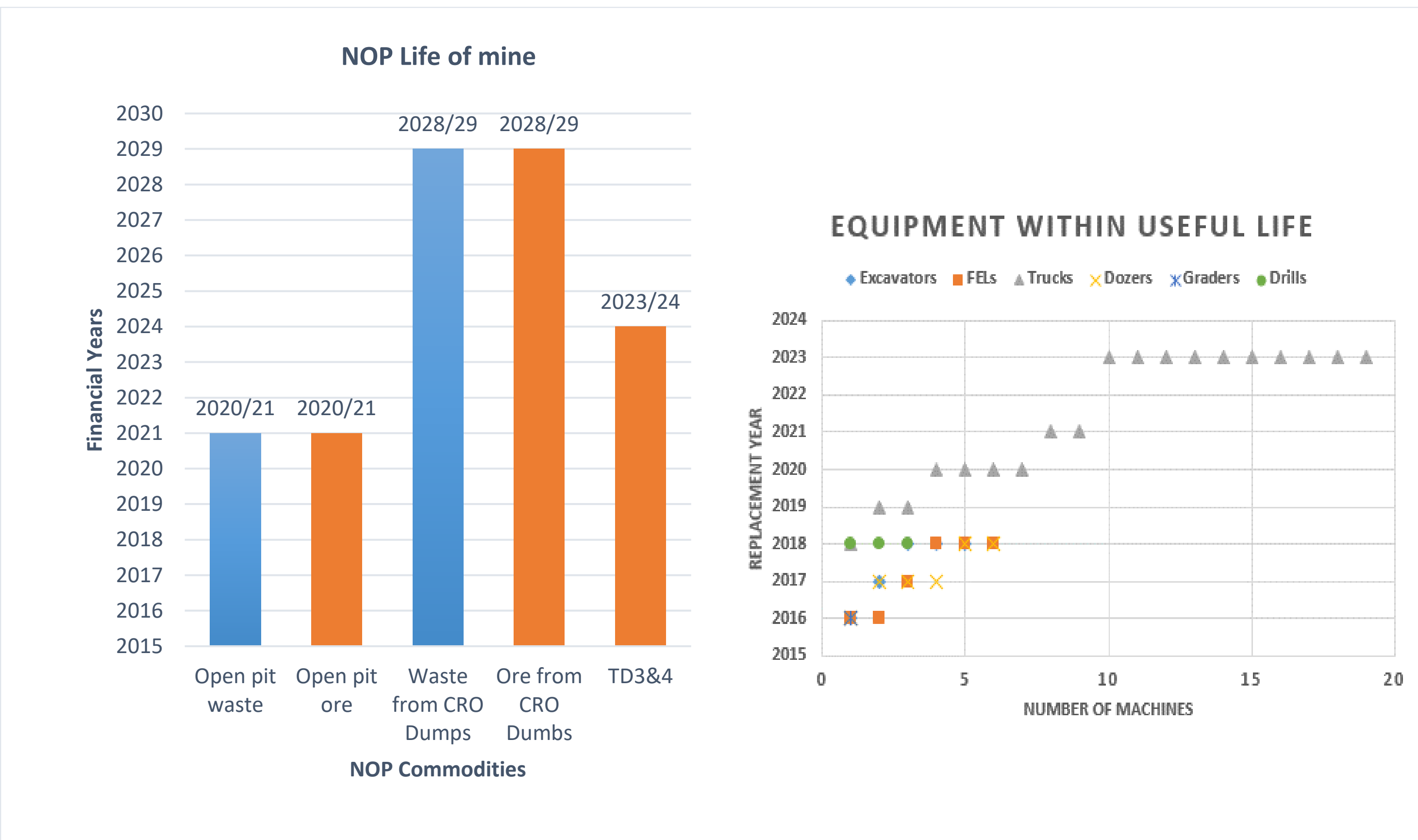


Figure 5.1: NOP LOM compared with equipment remaining useful life

If the two graphs of Figure 4.1 and 4.2 are superimposed as shown in Figure 5.1, it can be seen that equipment useful life lags behind expected life of mine. This therefore, makes it imperative to consider an equipment recapitalization scheme.

Looking at the open pit alone (for which fleet optimization was a concern), Figure 5.1 shows that only 12 trucks can last up to the 2020/21 FY. Drills, Excavators, Front End Loaders, Dozers and graders all expire 3 years prior to the end of mine life. Noteworthy, no shovel is observable in the graph simply because the 3 shovels apparently in use have all exceeded their useful life by more than twice the 60 000 hours maximum. Apparently it follows that there is need to consider equipment recapitalization.

However, this move has to be done against the auspices of plummeting metal prices on the international market. That means any company's equipment purchase budget is bound to be limited under these conditions. The single most applicable strategy becomes that of harvesting any low hanging fruit and optimize what is already at the company's disposal. In this research this was achieved through the use of Talpac software and established algorithms incorporated in the Microsoft excel program.

5.2.1 Required fleet size using generic formulas and match factor theory

As calculated in Section 4.3 of Chapter 4 the required fleet must excavate material of a total of

$337360.5 + 1141429.25 = \mathbf{1478789.75}\boldsymbol{t}$**/month = 17.7 mt/yr**

Using Equations 2.1 to 2.9 in Section 2.3.1 of Chapter 2, the required fleet size for NOP was estimated and summarized in Table 5.1.

However, the determined fleet size is a perfect fit for a green field project. The current equipment selection should focus on machines to be used basically for 4 years and doing with the available machines is the best approach. This is not only logical with respect to LOM but also in the view of equipment purchase budget limitations compounded by plummeting international copper prices.

Table 5.1: Summary of fleet size calculated using generic formulas and match factor

Equipment	Quantity	Capacity
Drills	3	422mm drill
Shovels	2	$31m^3$
Trucks	18	300t

Going forward, a haulage simulation was run using Talpac software. Simulation of a single loader and its truck fleet was done for both waste and ore excavations for the two pits. Results obtained are as shown in Tables 4.2 through 4.5. Picking the most crucial points from the simulation results, Table 5.2 was generated.

Results shown in Table 5.2 reveal that NOP with an inventory of $2*21.4m^3$ bucket shovels and $3*15m^3$ bucket backhoes seems perfect in terms of loading equipment. However, the available loaders need assessment in terms of reliability.

Table 5.2: Summary of NOP fleet requirements interpreted from Talpac simulations

Section	Loader	Fleet Size	Discounted average cost
COP F&D Waste	P&H 2300 XPA	8	$1.21
COP F&D Ore	CAT 6030	5	$2.25
CUT II Waste	P&H 2300 XPA	10	$0.68
CUT II Ore	HITACHI EX2500	5	$1.75
Totals	4	28	$1.47

The truck requirements for NOP surpasses the available fleet size as only 14 trucks with a maximum payload of 218 tonnes are on site. As a result there is need to invest in the haulage system requirements.

For the month of November 2016, the budget mining costs for COP F&D and CUT II pits were $1.11/t and $1.80/t respectively. This gives an average cost of $1.46/t which is comparable to the average cost per tonne of $1.47 projected using Talpac. However it should be noted that the major contributing factor to higher mining costs is haulage distance. For instance the $2.25/t for COP F&D ore corresponds to a haulage distance of 10.57km while the $1.75/t for CUT II ore corresponds to a haulage distance of 4km. All distances were measured from each pit bottom to OEM stock pile.

Basing on the same idea of an increase in mining cost due to increase in haulage distance it behooves any investigator to consider a haulage system whose costs are favored by long distance.

5.3 Fleet performance

Fleet performance was analyzed using OEE. Results from Section 4.5 of Chapter 4 reveal alarmingly low percentages of OEE for shovels, large excavators and trucks as summarized below.

$$OEE = Availability * Performance * Quality$$

- **Shovels - 7.2%**
- **Large Excavators - 13.6%**
- **Trucks - 17.6%**

The obtained scores were then compared with an industrial benchmark OEE value of 85%. It is very difficult for any company to reach that level but it can be taken as a ceiling close to which an industry’s equipment can be said to be performing effectively.

Since the estimated OEE values were all below the benchmark it reveals a need for operational as well as equipment conditional improvements. The question now is on which areas are improvements needed? Tackling the first two input variables of OEE, availability and utilization (embedded in performance), production loss analysis were done in Figures 4.15 and 4.16. Further investigation of factors contributing to low availability and utilization were further analyzed and analysis results shown in the form of pie charts on Figures 4.17, 4.18, 4.21, 4.22 and 4.23.

In the case of low utilization three dominant contributors were identified. These are industrial challenges, environment and shortage RTVs.

5.3.1 Industrial challenges

Industrial challenges noticed offered not much opportunity for optimization but the dozer operation delays required attention. However the precise study on NOP dozer requirements has been left out of the scope of this study but generally each dump and each loader needs to be equipped with a dozer. This leaves NOP generally short of 3 dozers for the equipment of all loading and dumping points.

5.3.2 Environment

Environmental challenges consisted mainly of dusty ramps. From the field surveys loading and haulage operations were seen to be halted due to dust. Dust decreases visibility thereby increasing risk of machine accidents. Again dust enters the air filters and impact engine performance.

The current dust suppression means of using two water carts had inefficiencies in terms of availability and high owning and operating costs. In cases of water cart break downs, a single water cart would be overwhelmed since water as a dust suppressant is effective only for 3 or 4 hours in the hot season. Again the demand consists of two pits that are altogether about 15km apart. The moment a single water cart finishes watering one pit ramp dust would have accumulated in the other. The situation is further worsened if the single apparently operational water cart breaks down. All loading and haulage operations stop. At the same time reliance on one water cart means it won't have service time which negatively impacts on its reliability.

The second draw back of the current system is cost. Calculations done for the 2015/16 FY showed that:

Total dust suppression cost/year = 2*1374* (307.07+69.02) **= $ 1 033 495.32**

5.3.2.1 Suggested solutions to the dusty ramps problem

Two solutions were envisaged for the dusty ramps problem. The first one was the use of chemical dust suppressants and the second one was the installation of sprinklers along the haul road.

5.3.2.1.1 Use of a haul road dust suppressants

A number of chemical dust suppressants are in use across the world. The most common ones are water, chlorides, enzymes, sugar molasses, tall oil emulsions, bituminous emulsions and synthetic polymers. Many issues can be discussed around the subjects of dust suppressants but most importantly duration of suppressant effect; application method; resistance to weather elements; environmental impact and cost should be considered.

Drawbacks

- Most of the chemicals still require the costly water cart application;

- Most are washed away in areas of medium to high rainfall e.g. enzymes, chlorides;
- The water resistant ones, particularly bituminous emulsion tend to be toxic to the environment; and
- Those that can suit the Nchanga weather patterns as well as being environmentally friendly are still expensive. An example is the synthetic polymer which costs $5, 805 per kilometer of 7m wide road. This means $\$0.83/m^2$. The cost includes material, application and maintenance per 12 months.

NOP has 30m wide roads which means cost of material, application and maintenance per year for the pit ramps and haul road connecting both pits is:

0.83*30*14700 = **$365, 715**

5.3.2.1.2 Installation of sprinklers alongside haul road

A steel pipe can be installed along the haul road with sprinklers at certain intervals that correspond to the chosen sprinkler trajectories. The most economical way can be using water from the pit bottom or sump after taking it through a mini coagulation or sedimentation tank.

In underground mining operations, a formula for estimation of piping systems is suggested in SME Mining Engineering as:

Cost of pipe installation = $\$2.80\ L^{0.9}C^{0.3}$, where L is length of haul road and C is compressed air pressure. In the case of surface mine application, the compressed air parameter can be left out or rather assigned unit value.

NOP CUT II Case study of pipe installation

Using a distance of 4.2 km measured on site from pit bottom to the re-fuelling station,

Installation cost = $\$2.80 * 4200^{0.9} * 1^{0.3}$ **= $5 106**

COP F&D Case study of pipe installation

Using a distance of 10.57km measured on site from pit bottom to the re-fuelling station,

Installation cost = $\$2.80 * 10570^{0.9} * 1^{0.3}$ = **$11 717.25**

Total pipe installation becomes 5 106 + 11 717.25 = $16 823.25.

This cost is incurred once then the operational works can be handed to the already available dewatering department.

5.3.3 Shortage of RTVs

This problem resulted from two factors – availability and quantity. An investigation of the required quantity under Section 4.6.3.3 of Chapter 4 using queuing theory on a case study done at the 135mb in COP F&D waste showed that 7.86 trucks are needed to fully utilize the P&H shovel. This is approximately equal to the 8 trucks required by the same shovel as determined by Talpac software analysis for COP F&D waste haulage.

Availability of trucks was seen to be the main contributor to truck production loss in Figure 4.16. Reasons for low availability were shown in Figure 4.23. Lack of spares/consumables and mechanical problems with 27% and 19% respectively contributed more to low availability. These two challenges reflect a flawed maintenance system. Investigations done at the maintenance department indicated that the company had a crippling maintenance budget making it impossible to service the machines. However savings from the cost reduction measures suggested in this research, particularly on dust control and double ore handling should make necessary funds availability.

5.4 Optimum Fleet for Main Pit

Two important key result areas have been identified in this research. The NOP fleet is not optimum in terms of both size and fleet health. Talpac, Queuing theory and Match factor results have shown a need to increase the number of trucks to about 28. OEE, Productivity analysis as well as Root Cause Analysis have revealed poor fleet health mainly attributed to machine deterioration.

The obvious solution for NOP fleet issues is therefore, fleet recapitalization. However, as mentioned earlier, a mere replacement of exactly the same fleet components and same haulage system in use may not yield cost effective results. Under prevailing plummeting international metal prices, low priced approaches have to be adopted. Precisely an in-pit crusher/conveyor system has to be adopted.

5.4.1 Economic considerations

Conveyors, within the current state of the art, are the lowest cost method of handling bulk materials. For a truck haulage, 60% of the fuel energy goes to moving the truck weight and only 40% is used to move the payload. On the other side for belt haulage, the corresponding relationship is 20% to belt weight and 80% to payload. Using diesel fuel costs of $0.82/l and electricity costs of $0.1025/kWh, energy costs favor conveyor haulage by a factor of 4 to 1.

Following adoption of an in-pit crusher/conveyor system, the fleet components presently in use at NOP, can then be utilized to exploit satellite KCM pits.

5.4.1.1 More Advantages of Conveyor Belt Systems

Conveyor belts have a number of merits over truck haulage systems and some of the merits include:

- Conveyor belts have an automatic and instantaneous start-up as well as continuous operations;
- They have high level reliability as they achieve availabilities between 90 and 95%. This exceeds NOP target availability by a maximum of 15%;
- Conveyor belt operation is not impaired by weather elements which often affect truck haulage systems;
- Conveyor belts require less labor; a 100-men crew operating and maintaining a truck fleet can be replaced by a 10-men crew handling an equivalent amount of material via a conveyor belt;
- Conveyor belts can operate efficiently at a grade of up to 30% while trucks can only sustain a maximum of 10% grade; and
- Conveyor belts lower the need to remove much overburden and establish haul roads since they can operate on a steeper gradient. Hence conveyors improve the operating ore to overburden ratio and reduce costs.

5.5 Exploitation of New Reserves

Following the optimized haulage system ascertained for the main pit, which of cause is most likely to be the conveyor system, 15 fleet components are likely to be parked. Instead of parking these machines, further optimization of those machines and their allocation to satellite pits becomes commendable.

5.6 Other Optimization Opportunities

Two cost reduction opportunities were identified in Sections 4.8 of Chapter 4 and 5.3.2 of Chapter 5 and these were the use of sprinklers instead of water carts as dust suppression means and the improvising of a direct ore tipping means at OEM.

5.6.1 Cost Reduction Measures on the Double Handling of Ore

Three measures can be improvised to cut ore re-handling costs at the crusher. The identified measures are mere direct tipping; direct tipping coupled with the use of a grizzly and rock breaker and the use of an in-pit crusher and conveyor system.

5.6.1.1 Mere direct tipping

The inhibitors of direct tipping listed above can be addressed:

1. For ore blending, tramming ore as per mill requirements can be a solution. In this case ore of required grade is trammed and tipped directly into the crusher. This can be viable since stock piling isn't feasible with the short deliveries reflected in Figures 4.4 and 4.5;
2. Big trucks can still fit into the crusher opening. Operator training is needed to avoid past few accidents on tipping;
3. Secondary blasting can be done in the pit to allow tramming of ore of only required fragmentation; and
4. Metal detection has not been found to be a cause of concern.

5.6.1.2 Direct tipping coupled with the use of a grizzly and a rock breaker

A grizzly will keep boulders from entering the crusher while the rock breaker reduces boulder size to crusher required size. Design of a grizzly and rock breaker tipping point and its simulation can be done using GPSS/H software.

5.6.1.3 Use of an in-pit crusher and conveyor belt system

The economics of an in-pit crusher/conveyor system previously discussed is further complimented by the possibility of direct tipping, installation of metal detectors on the belt and ensuring of correct fragmentation through the in-pit crushing plant. The in-pit crusher/conveyor system can also be designed and simulated using GPSS/H software.

5.7 Reliability Check

The root cause analysis results of Figure 4.24 prove beyond doubt that machine deterioration is the single most significant cause of poor machine performance or in particular low availability. This identification goes to justify the consideration of equipment recapitalization. Two possible approaches may be machine overhauls or machine scrapping. However, more considerations have to be made before settling on one option. A trade-off between costs of machine overhaul against new purchases is necessary. Secondly the choice of new equipment won't be just a mere replacement of exactly the same fleet components as currently in use.

With budget limitations and facing an ending LOM it is necessary to consider making do with the same old or new but limping equipment but of cause after some mechanical upgrades. Now to go ahead with equipment recapitalization it is necessary to assess the inherent, individual component health of the current fleet and see if at all some fleet components can either be straight away roped into the new fleet or rather overhauled or revamped for inclusion in the new fleet. Another perspective will be adopting the proposed conveyor transportation and then allocate the current haulage equipment to satellite pits.

If the current fleet components shall ever be considered for continued use they have to be assessed on two metrics – reliability and maintainability. This assessment can be carried out using Weibull analysis through Microsoft Excel or Matlab software.

5.8 Summary

The discussion of results helped uncover underlying detail behind results obtained in Chapter 4. Different scenarios were compared on possible solutions to each problem. Cost implication was the dominant deciding factor in determining optimal solutions for the NOP fleet. Subsequently best courses of action were identified for the various factors underpinning the NOP fleet optimization problem.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Fleet optimization at NOP had six interacting factors which were found to be contributive to low fleet performance. These factors were low machine availability; low machine utilization; mismatch between loader and truck fleet sizes; double ore handling; costly dust suppression system and a flawed maintenance system. Compounding the low machine performance was the need to harmonize extended life of mine with fleet size and capability. The major conclusions drawn from the research include:

- Simulation using Talpac software revealed a need to raise the truck fleet size from 15 to 28 if the current haulage system has to be maintained. Average cost per tonne for operating such a haulage system was $1.47. This average cost was only $0.01 more than the average $1.46 that is apparently obtaining on the ground;
- Assessing current fleet performance using OEE showed percentages of 7.2 for shovels, 13.6 for large excavators and 17.6 for trucks against an industrial benchmark of 85%. This has revealed a serious need to do equipment conditional and operational diagnosis;
- A root cause analysis done on a number of machines picked at random showed that machine deterioration was the main cause of poor fleet performance. Scraping these machines has proved impractical in the light of equipment purchase budget restrictions and an almost ending LOM;
- Optimization of current ore handling system with a view of minimizing costs and raising machine utilization revealed two opportunities. One opportunity was to scrape the water cart dust suppression system, costing the mine $1 033 million and replace it with sprinklers costing $16, 823 along the haul road. The second one was to eradicate the double handling of ore which was costing the mine at least $708, 000 per year;
- The best fleet management approach for Nchanga Open Pit was found to be the installation of a conveyor belt for both CUT II and COP F&D pits. The conveyor belt proved more favorable over truck haulage in terms of energy usage, energy costs, reliability, operating costs and cost reduction by optimizing the ore to burden ratio; and

- The study remained open ended as it gave birth to another extensive investigation on the reliability and maintainability of machines. These two metrics can be determined for each machine using the Matlab software or Weibull Analysis. The cost of rebuilding the machines that pass the reliability and maintainability tests plus the cost of adding more 13 trucks as well as operating costs for that system should then be weighed against costs of procurement, installation and operating a conveyor belt.

6.2 Recommendations

Following the conclusions drawn from this research, the following recommendations are being suggested for adoption at NOP:

- Eradicating the double handling of ore at OEM crusher by installing a grizzly and rock breaker or most preferably in-pit crusher and conveyor belt;
- Investing in equipment maintenance as the unavailability of spares and consumables was seen to contribute 27% to low truck availability. Operating trucks as well as loaders or even support equipment without basic maintenance reduces machine reliability. Consumables in the form of filters, oil and grease are just necessary, else the trucks should be parked; and
- Carry out a study on machine reliability and maintainability so as to confirm further usefulness of available fleet components. Compare cost of rebuilding maintainable machines and adding 13 more trucks with installing a conveyor belt.

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Appendices

Appendix 1

TRUCK	CYCLE TIMES				
Machine : Komatsu 830E					
Capacity : 240t					
Loader : Cat 6030 Excavator (R305)					
Route : CUT 2 pit floor					
Route length : 4km					
Material loaded : Cu Ore					
Activity	Observation				
	1	2	3	4	5
Travel from waiting place/min	1	1	1	1	
Spotting/min	2	2	2	3	
Loading/min	21	29	27	33	
Tramming(loaded)/min	11	11	11	13	
Spot at dump/min	0.5	0.5	0.5	0.5	
Dumping/min	0.5	0.75	0.5	0.5	
Turning from dump	0.5	0.25	0.25	0.25	
Tramming (Empty)/min	9	9	10	9	
Waiting in line	14	11	15	10	
Delays-Waiting for platform building by loader	4	2	4		

LOADER SERVICE RATE						TRUCK ARRIVAL RATE		
Minutes/truck		Number of passes				Number of trucks		Time/hrs
5		6				7		1
4		4				8		1
4		4						
4		4						
5		5						
6		5						
Que length	3							
# of servers	1							
Loader waiting (idle)/mins - 4/3/4.5/4/6								
Truck queuing for access to dumping site/mins 3/2/4/8/3/5								
Other delays - highwall collapse - dust- machine moves away/mins - 6								

Appendix 2

Konkola Copper Mines Plc — vedanta — **NOP-EQUIPMENT STATUS HANDOVER REP**

NCHANGA MINE — **DATE..**

CO-ORDINATOR............... **SAFETY!!** **SHIFT..**

SHOVELS

	UP	DOWN	LOCATION	MATERIAL	DESTINATION	REMARKS
Y15						
Y16						
Y32						
R301						
R304						
R305						
R306						

CRUSHERS

	UP	DOWN	LOCATION	MATERIAL	DESTINATION	REMARKS
OLD EAST MILL						
NEW EAST MILL						

LOADERS

	UP	DOWN	LOCATION	MATERIAL	DESTINATION	REMARKS
R114						
R115						
R116						
R117						

DRILLS

	UP	DOWN	LOCATION	REMARKS
W33				
W43				
W44				

PUMPS

	UP	DOWN	LOCATION	REMARKS
45 MB				
60 MB				
75 MB				
90 MB				
150/165 MB				
195 MB				
210 MB				
SURFACE				
PHASE 1				
PHASE 2				
PHASE 3				
BLOCK A				
EAST EXTENSION				
NOP SUMP				
MISOSHI B/HOLES				

SUPP0RT EQUIPMENT

	TOTAL	TRUCKS	TOTAL
DOZERS		830 E	
GRADERS		793C CAT	
LOADERS		730 E	
BOWSERS		777F	
WATER CARTS		R802	

TALLY

	T/MATERIAL (BCMS)	WASTE	CU- MINED	NEW MILL	OLD MILL
D/S					
A/S					
N/S 7th					
Total					

EQUIPMENT SCHEDULED FOR SERVICE

Appendix 3

KONKOLA COPPER MINES plc

Nchanga Mine

Month: ___________

NOP DISPATCH/MCO FIELD FAULTING REPORTING REGISTER

Year: _____________

ORDER

PARAMETERS TO BE CAPTURED

No	EQUIP No	EQUIPMENT DESC No	ORDER No	NOTIFICATION No	DESCRIPTION OF THE PROBLEM	DURATION	BREAKDOWN START DATE	BREAKDOWN START TIME	BREAKDOWN END DATE	BREAKDOWN END TIME
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										

Prepared by: _______________________

Approved by: ____________________

Date: ____________________

Appendix 4

KONKOLA COPPER MINES PLC

NCHANGA MINE

NCHANGA OPEN PIT 24HR-AVAILABILITY SUMMARY

DATE

EQPT	AVAILABLE HOURS - 2A PLAN DAY	A/N	NIGHT	24 HRS	PLAN HOURS	VAR	PLAN 2A FLEET SIZE	AVAIL M/CS AT 06:00 HRS	MTD AVAIL HOURS	MTD PLAN HOURS	MTD VAR HOURS	MTY OPER HOURS
830E TRUCKS (OLD)							5					
830E TRUCKS (NEW)					204.0		9					
830E TRUCKS (LATEST)					110.0		1					
793C TRUCKS					122.0		6					
777F TRUCKS							2					
730E TRUCKS					102.0		1					
J115 F/BOWSER												
WATER CARTS					95.0		2					
Y15							1					
Y16							1					
Y32												
							1					
W33												
W43							1					
W44							1					
W51							1					
							1					
R301												
R304							1					
R305							1					
R306							1					
DOZERS (V5, V7)					180.0		5					
GRADERS (T2, T3)					144.0		6					
CAT992					95.0		6					
MOBILE CRANES					134.0		4					
FOLKLIFTS					115.0		4					

Appendix 5

KONKOLA COPPER MINES PLC - NCHANGA MINE

NOP SHOVELS & LOADERS HOURLY PRODUCTION SHIFT : ____________ DATE : ____________

BENCH																																
SHOVEL		Y15	Y15	Y15		Y16	Y16	Y16		Y32	Y32	Y32		R301	R301	R301	R301		R304	R304	R304	R304		R305	R305	R305	R305		R306	R306	R306	R306
MATERIAL																																
DESTNATION																																
1																																
2																																
3																																
4																																
5																																
6																																
7																																
8																																
FACTOR																																

COPPER AND COBALT ORE CRUSHED (TONNES)

		HOUR 1		HOUR 2		HOUR 3		HOUR 4		HOUR 5		HOUR 6		HOUR 7		HOUR 8	
SOURCE	F.E.L	CRUSHER	CSP	CRUSHER	CSP	CRUSHER	CSP	CRUSHER	CSP	CRUSHER	CSP	CRUSHER	CSP	CRUSHER	CSP	CRUSHER	CSP
OLD MILL																	
NEW MILL																	

HOURLY OVERBURDEN TRAMMED (BCMS) COPF/D

								Y15
								R304
								R306
								TOTAL
1	2	3	4	5	6	7	8	

HOURLY COPPER ORE TRAMMED (TONNES) CUT-2

1	2	3	4	5	6	7	8

HOURLY COPPER ORE TRAMMED (TONNES) COPF/D

								Y15
								R304
								R306
								TOTAL

HOURLY COBALT ORE TRAMMED (TONNES) CUT-2

HOURLY OVERBURDERN TRAMMED (BCMS) CUT-2

CUT 2									
VARIANCE									HRLY
PHASE 3									ACT
VARIANCE									VAR

HOURLY TOTAL MATERIAL TRAMMED (BCMS) CUT-2

Appendix 6

NOP KEY EQUIPMENT (01-30 June 2016 MTD)

S/No	Key Equipment Details	Availability - %		Utilisation - % MTD		Mttr - hrs		Mtbf - hrs	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual
	Loading								
1	FR301,EX2500 HITACHI EXCAVATOR	85	34	75	55	4	13	16	6
2	R304 - CATERPILLAR 6030 EXCAVATOR	85	29	75	2	4	17	16	6
3	R305 - CATERPILLAR 6015 EXCAVATOR	85	34	75	52	4	15	16	7
4	R306 - CATERPILLAR 6030 EXCAVATOR	85	77	75	79	4	3	16	12
	Shovels and Drill								
1	W 33 Drill	70	95	75	43	4	1	16	22
2	Y15 Shovel	60	76	75	71	4	4	16	13
3	Y16 Shovel	70	65	75	57	4	5	16	10
	Hauling 830E trucks								
1	X101	83	74	75	42	4	5	16	16
2	X103	83	87	75	51	4	2	16	19
3	X104	83	87	75	31	4	3	16	21
4	X106	88	87	75	60	4	3	16	20
5	X107	88	88	75	73	4	2	16	21
6	X108	88	85	75	51	4	3	16	20
7	X109	88	86	75	53	4	3	16	20
8	X110	88	80	75	81	4	4	16	19
9	X111	88	93	75	55	4	2	16	21
10	X112	88	47	75	62	4	12	16	10
11	X113	88	0	75	0	4	24	16	0
12	X202	75	96	75	74	4	1	16	23
13	X208	75	0	75	0	4	24	16	0
14	Water Cart K430	75	3	75	0	4	23	16	1
15	Water Cart K431	75	67	75	72	4	6	16	13
	Support Front End Loaders								
1	992K FRONT END LOADER R114	75	78	75	67	6	4	16	15
2	992K FRONT END LOADER R115	75	6	75	96	6	22	16	1
3	992K FRONT END LOADER R116	75	57	75	90	6	9	16	11
4	992K FRONT END LOADER R117	75	87	75	89	6	2	16	20
	Support dozers								
1	V804	70	0	75	0	4	24	16	0
2	V805	70	0	75	0	4	24	16	0
3	V806	70	70	75	76	4	6	16	15
4	V807	70	98	75	67	4	0	16	23
	Support Drills, graders and fuel Bowser)								
1	Roc L8 drill W44	60	40	65	25	4	12	16	7
2	T305 - Graders	60	93	65	4	4	2	16	22
3	J115 - Fuel Bowser	70	100	60	25	4	0	16	24

Appendix 7

NOP Life of Mine		PROBABLE	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
NOP CUT 2 Cobalt Co		**RESERVES**	**PLAN**	**PLAN**	**PLAN**	**PLAN**											
Ore Mined	T	**595,627**	232,700	111,526	251,401												
Tcu	%	**1.13%**	1.43%	0.90%	0.96%												
ASCu Grade	%	**0.34%**	0.31%	0.29%	0.40%												
TCo	%	**0.29%**	0.23%	0.33%	0.32%												
ASCo Grade	%	**0.05%**	0.03%	0.05%	0.06%												
Cont'd Cu	T	**6,752**	3,335	1,004	2,413												
Cont'd Co	T	**1,707**	534	368	804												
NOP CUT2 Copper Cu																	
Waste Mined	T	**22,889,234**	5,554,102	9,234,700	8,100,432												
Ore Mined	T	**5,158,408**	2,250,562	728,421	2179425												
Tcu	%	**0.97%**	1.01%	1.00%	0.92%												
AICu Grade	%	**0.57%**	0.69%	0.51%	0.46%												
ASCu Grade	%	**0.40%**	0.32%	0.49%	0.46%												
Cont'd Cu	T	**50,147**	22,812	7,284	20,051												
Chingola A Cu																	
Waste Mined	T	**5,182,555**				5,182,555											
Ore Mined	T	**869,135**				869,135											
Tcu	%	**1.520%**				1.52%											
AICu Grade	%	**0.53%**				0.53%											
ASCu Grade	%	**0.99%**				0.99%											
Cont'd Cu	T	**13,211**				13,211											
Chingola D&F Cu																	
Waste Mined	T	**18,009,100**	8143049	6,033,181	3832870												
Ore Mined	T	**4,695,872**	1,565,064	1,657,534	1,473,274												
Tcu	%	**1.302%**	1.31%	1.34%	1.25%												
AICu Grade	%	**1.05%**	1.03%	1.12%	0.99%												
ASCu Grade	%	**0.24%**	0.28%	0.23%	0.21%												
Cont'd Cu	T	**61,163**	20,490	22,257	18,416												
Mimbula Conventional Cu																	
Waste Mined	T	**18,155,715**		801,000	7,239,061	6,057,827	4,057,827										
Ore Mined	T	**6,560,345**		1,188,252	1,473,475	2,473,435	1425182.261										
Tcu	%	**1.51%**		1.55%	1.56%	1.31%	1.79%										
AICu Grade	%	**0.74%**		0.75%	0.44%	0.78%	0.97%										
ASCu Grade	%	**0.77%**		0.80%	1.12%	0.53%	0.82%										
Cont'd Cu	T	**99,384**		18,418	29,831	32,466	25,466										
Mimbula Refractory																	
Waste Mined	T	**0**															
Ore Mined	T	**23,950,000**	2,270,576	12,912,479	2,724,540	6,042,405											
Tcu	%	**1.07%**	0.86%	1.10%	1.07%	1.07%											
AICu Grade	%	**0.57%**	0.38%	0.60%	0.55%	0.58%											
ASCu Grade	%	**0.50%**	0.48%	0.50%	0.52%	0.49%											
Cont'd Cu	T	**255,241**	19,527	58,805	29,153	64,654	0	0									
			3,148	6,814	7,302	7,157	6,442	10,500	10,500	10,500	10,500						

TOTAL CRO DUMPS SP 6,12&16 (Grades To be factored @80%)			2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
Waste	T	**3,000,000**	0	0	0	3,000,000	4,000,000	3,000,000	2,500,000	2,600,000	2,300,000	2,100,000	4400000	2,600,000	1,900,000	0	0
Ore	Kt	**125,934**	11,349	10,842	4,658	8,877	8,592	8,027	9,075	10,500	10,500	10,500	10,500	10,500	12,014		
%TCU	%	**0.84%**	1.14%	0.68%	0.87%	0.82%	0.80%	0.84%	0.79%	0.74%	0.89%	0.89%	0.80%	0.84%	0.38%		
%ASCU	%	**0.58%**	0.57%	0.59%	0.75%	0.59%	0.55%	0.60%	0.54%	0.53%	0.69%	0.57%	0.53%	0.58%	0.19%		
Cont'd Tcu	T	**1,063,944**	128,906	73,579	40,554	73,138	68,734	67,769	72,041	77,554	93,855	93,045	83,792	88,653	45,563	0	
Cont'd ASCu	T	**728,792**	65,044	63,971	34,919	52,513	47,554	48,286	48,636	55,685	72,430	59,333	56,136	61,140	22,945	0	
		1,007,183															

CRO DUMPS SP 12			2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
Waste	T	**0**															
Ore	Kt	**26,326**	11,349	10,842	4,135												
%TCU	%	**0.94%**	1.35%	0.68%	0.68%												
%ASCU	%	**0.65%**	0.68%	0.59%	0.60%												
Cont'd Tcu		**238,887**	128,906	73,579	36,402												
Cont'd ASCu		**160,953**	65,044	63,971	31,938												

CRO DUMPS SP 16			2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
Waste	T	**21,400,000**				3,000,000	4000000	3,000,000	2,500,000	2,600,000	2,300,000	2,100,000	1900000				
Ore	Kt	**71,677**			523	8,877	8,592	8,027	9,075	10,500	10,500	10,500	5,083				
%TCU	%	**0.82%**			0.79%	0.82%	0.80%	0.84%	0.79%	0.74%	0.89%	0.89%	0.70%				
%ASCU	%	**0.57%**			0.57%	0.59%	0.55%	0.60%	0.54%	0.53%	0.69%	0.57%	0.45%				
Cont'd Tcu		**585,870**			4,152	73,138	68,734	67,769	72,041	77,554	93,855	93,045	35,581				
Cont'd ASCu		**410,305**			2,981	52,513	47,554	48,286	48,636	55,685	72,430	59,333	22,887				

CRO DUMPS SP 6			2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
Waste	T	**0**											2500000	2,600,000	1,900,000		
Ore	Kt	**21,253**											5,417	10,500	5,336		
%TCU	%	**0.87%**											0.89%	0.84%	0.85%		
%ASCU	%	**0.60%**											0.61%	0.58%	0.43%		
Cont'd Tcu		**182,426**											48,211	88,653	45,563		
Cont'd ASCu		**117,334**											33,249	61,140	22,945		

CRO DUMPS SP 12		INFERRED	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
Waste	T	**0**															
Ore	Kt	**6,678**													6,678		
%TCU	%	**0.85%**													0.85%		
%ASCU	%	**0.60%**													0.60%		
Cont'd Tcu		**56,761**													56,761		
Cont'd ASCu		**40,200**													40,200		

TD3&4		PROBABLE	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2028/29	2029/30
Waste	T	**0**															
Ore	Kt	**46,115**	5,840	6,070	6,360	6,360	6,360	6,360	5,985	2,780							
%TCU	%	**0.67%**	0.74%	0.74%	0.69%	0.63%	0.63%	0.63%	0.63%	0.63%							
%ASCU	%	**0.46%**	0.54%	0.54%	0.49%	0.42%	0.42%	0.42%	0.42%	0.42%							
Cont'd Tcu		**307,442**	43,216	44,918	43,884	40,068	40,068	40,068	37,706	17,514							
Cont'd ASCu		**212,427**	31,536	32,778	31,164	26,712	26,712	26,712	25,137	11,676							

Appendix 8

Equipment Number	Equipment Model	Equipment Type	Equipment Serial Number	Cummulative Age	Expected Life	Capacity	Commisssion Date	Remaining Life	Remaining Days	Repacement Date _Operated Hours Basis	Repacement Date _ Commission-Date Basis	Status
FR301	HITACHI EX 2500	EXCAVATOR	1067	22,829	40,000	15 CU MTRS	12-Sep-08	17,171	1,030.05	15-Dec-16	10-Sep-18	Operational
FV102	CATERPILLAR D10T	D10T BULL DOZER	RJG 01306	18,782	30,000	570 HP	17-Jul-08	11,218	672.95	23-Dec-15	15-Jul-18	Operational
R702	WA800-3A	FRONT END LOADER	50086	14,180	30,000	16.0 CU MTRS	22-Mar-08	15,820	949.01	25-Sep-16	20-Mar-18	Operational
R802	KOMATSU PC600-7	EXCAVATOR	20225	6,921	30,000	2.0 CU MTRS	1-Jun-07	23,079	1,384.46	4-Dec-17	29-May-17	Operational
R114	992K	FRONT END LOADER	KCH4C00498	19,400	40,000	12.2CU MTRS	13-Mar-11	20,600	1,235.75	8-Jul-17	10-Mar-21	Operational
R115	992K	FRONT END LOADER	4C00499	13,868	40,000	12.2CU MTRS	25-Mar-11	26,132	1,567.61	5-Jun-18	22-Mar-21	Operational
R116	992K	FRONT END LOADER	4C00533	16,128	40,000	12.2CU MTRS	28-Jul-12	23,872	1,432.03	21-Jan-18	26-Jul-22	Operational
R117	992K	FRONT END LOADER	CAT0992KHZMX00401	10,531	40,000	12.2CU MTRS	22-Aug-12	29,469	1,767.79	22-Dec-18	20-Aug-22	Operational
R901	CAT 966H	FRONT END LOADER	A6G03107	14,387	30,000	4.5 CU MTRS	17-Aug-08	15,613	936.59	12-Sep-16	15-Aug-18	Operational
T305	CATERPILLAR 16H	GRADER	JATS00283	30,218	30,000	275 HP	20-May-04	-218	-13.08	**5-Feb-14**	18-May-14	Operational
T306	CATERPILLAR 16H	GRADER	JATS00284	21,523	30,000	275 HP	20-May-04	8,477	508.52	12-Jul-15	18-May-14	Parked
T402	KOMATSU GD825A-3	GRADER	12384	14,694	30,000	209 HP	2-Apr-07	15,306	918.18	25-Aug-16	30-Mar-17	Operational
V604	CATERPILLAR 834G	WHEEL DOZER	ABPC00170	15,904	30,000	450 HP	26-May-04	14,096	845.59	13-Jun-16	24-May-14	Parked
V605	CATERPILLAR 834G	WHEEL DOZER	ABPC00171	9,423	30,000	450 HP	26-May-04	20,577	1,234.37	7-Jul-17	24-May-14	Scrapped
V802	CATERPILLAR D10T	TRACKED DOZER	RJG00695	20,044	30,000	570 HP	22-Dec-06	9,956	597.24	9-Oct-15	19-Dec-16	Parked
V804	CATERPILLAR D10T	TRACKED DOZER	RJG03093	7,138	30,000	570 HP	20-May-12	22,862	1,371.45	21-Nov-17	18-May-22	Operational
V805	CATERPILLAR D10T	TRACKED DOZER	RJG03094	6,974	30,000	570 HP	20-May-12	23,026	1,381.28	1-Dec-17	18-May-22	Operational
W33	GD 120	DRILL	1092	90,066	65,000	12.25" DRILL	17-Jul-97	-25,066	-1,503.68	**7-Jan-10**	**15-Jul-07**	Operational
W34	GD 120	DRILL	1102	85,668	65,000	12.25" DRILL	8-Dec-97	-20,668	-1,239.83	**28-Sep-10**	**6-Dec-07**	Parked
W43	ROC L8-30	DRILL	AV 008A1543/8992005574	5,148	30,000	ATLAS COPCO DRILL	21-Nov-08	24,852	1,490.81	20-Mar-18	19-Nov-18	Operational
W44	DRILL - ATLAS COPCO	DRILL	AV 008A1480/8992005573	1,597	30,000	ATLAS COPCO DRILL	22-Nov-08	28,403	1,703.84	19-Oct-18	20-Nov-18	Operational
W51	CM780D	DRILL - INGERSOLL-RAND	G78305HN	3,817	30,000	ATLAS COPCO DRILL	30-Jan-06	26,183	1,570.67	8-Jun-18	28-Jan-16	Parked
X101	KOMATSU 830E-AC	DUMP TRUCK	KMTHDO 16N 61 A 30090	27,791	65,000	240 TONNES	8-Nov-07	37,209	2,232.09	31-Mar-20	5-Nov-17	Operational
X102	KOMATSU 830E-AC	DUMP TRUCK	KMTHDO 16N 61 A 30091	27,563	65,000	240 TONNES	15-Nov-07	37,437	2,245.77	13-Apr-20	12-Nov-17	Operational
X103	KOMATSU 830E-AC	DUMP TRUCK	KMTHDO 16N 61 A 30092	27,465	65,000	240 TONNES	5-Nov-07	37,535	2,251.65	19-Apr-20	2-Nov-17	Operational
X104	KOMATSU 830E-AC	DUMP TRUCK	KMTHD0 16N 61 A 30104	26,759	65,000	240 TONNES	9-Jan-08	38,241	2,294.00	1-Jun-20	6-Jan-18	Operational
X105	KOMATSU 830E-AC	DUMP TRUCK	KMTHD0 16N 61 A 30105	9,219	65,000	240 TONNES	9-Feb-08	55,781	3,346.19	19-Apr-23	6-Feb-18	Operational
X106	KMTHD0 16N 61 A 30822	DUMP TRUCK	KMTHD0 16N 61 A 30822	8,341	65,000	240 TONNES	5-Nov-12	56,659	3,398.86	10-Jun-23	3-Nov-22	Operational
X107	KMTHD0 16N 61 A 30823	DUMP TRUCK	KMTHD0 16N 61 A 30823	8,992	65,000	240 TONNES	6-Nov-12	56,008	3,359.81	2-May-23	4-Nov-22	Operational
X108	KMTHD0 16N 61 A 30831	DUMP TRUCK	KMTHD0 16N 61 A 30831	7,721	65,000	240 TONNES	15-Dec-12	57,279	3,436.05	18-Jul-23	13-Dec-22	Operational
X109	KMTHD0 16N 61 A 30832	DUMP TRUCK	KMTHD0 16N 61 A 30832	7,782	65,000	240 TONNES	15-Dec-12	57,218	3,432.39	14-Jul-23	13-Dec-22	Operational
X110	KMTHD0 16N 61 A 30833	DUMP TRUCK	KMTHD0 16N 61 A 30833	6,747	65,000	240 TONNES	15-Dec-12	58,253	3,494.48	14-Sep-23	13-Dec-22	Operational
X111	KMTHD0 16N 61 A 30867	DUMP TRUCK	KMTHD0 16N 61 A 30867	5,281	65,000	240 TONNES	12-Jun-13	59,719	3,582.42	11-Dec-23	10-Jun-23	Operational
X112	KMTHD0 16N 61 A 30868	DUMP TRUCK	KMTHD0 16N 61 A 30868	5,683	65,000	240 TONNES	12-Jun-13	59,317	3,558.31	17-Nov-23	10-Jun-23	Operational
X113	KMTHD0 16N 61 A 30874	DUMP TRUCK	KMTHD0 16N 61 A 30874	5,899	65,000	240 TONNES	12-Jun-13	59,101	3,545.35	4-Nov-23	10-Jun-23	Operational
X202	CATERPILLAR 777F	DUMP TRUCK	JRP00987	20,148	65,000	86 TONNES (95 TONS)	1-Jan-08	44,852	2,690.58	2-Jul-21	29-Dec-17	Operational
X208	CATERPILLAR 777F	DUMP TRUCK	JRP01465	21,270	65,000	86 TONNES (95 TONS)	2-Oct-08	43,730	2,623.28	26-Apr-21	30-Sep-18	Operational
X209	CATERPILLAR 777F	DUMP TRUCK	JRP01147	8,122	65,000	86 TONNES (95 TONS)	2-Oct-08	56,878	3,412.00	23-Jun-23	30-Sep-18	Parked
X401	KOMATSU 730E	DUMP TRUCK	32626	68,673	65,000	170 TONNES	12-Nov-96	-3,673	-220.34	13-Jul-13	10-Nov-06	Scrapped
X402	KOMATSU 730E	DUMP TRUCK	32627	70,745	65,000	170 TONNES	12-Nov-96	-5,745	-344.63	11-Mar-13	10-Nov-06	Parked
X403	KOMATSU 730E	DUMP TRUCK	32644	72,599	65,000	170 TONNES	1-Dec-96	-7,599	-455.85	20-Nov-12	29-Nov-06	Parked
X404	KOMATSU 730E	DUMP TRUCK	32645	78,145	65,000	170 TONNES	13-Dec-96	-13,145	-788.54	23-Dec-11	11-Dec-06	Parked
X405	KOMATSU 730E	DUMP TRUCK	32646	71,696	65,000	170 TONNES	16-Dec-96	-6,696	-401.68	13-Jan-13	14-Dec-06	Scrapped
X406	KOMATSU 730E	DUMP TRUCK	32647	74,567	65,000	170 TONNES	21-Dec-96	-9,567	-573.91	25-Jul-12	19-Dec-06	Coverted to K430
X407	KOMATSU 730E	DUMP TRUCK	32654	79,758	65,000	170 TONNES	24-Jan-97	-14,758	-885.30	17-Sep-11	22-Jan-07	Operational
X408	KOMATSU 730E	DUMP TRUCK	32655	79,758	65,000	170 TONNES	22-Jan-97	-14,758	-885.30	17-Sep-11	20-Jan-07	Operational
X410	KOMATSU 730E	DUMP TRUCK	32657	81,476	65,000	170 TONNES	12-Jan-97	-16,476	-988.36	6-Jun-11	10-Jan-07	Parked
X802	CATERPILLAR 793C	DUMP TRUCK	ATY00695	29,937	65,000	240 TONNES	20-Jun-04	35,063	2,103.36	23-Nov-19	18-Jun-14	Parked
X803	CATERPILLAR 793C	DUMP TRUCK	ATY00707	36,298	65,000	240 TONNES	13-Aug-04	28,702	1,721.78	6-Nov-18	11-Aug-14	Parked
X806	CATERPILLAR 793C	DUMP TRUCK	ATY00735	29,372	65,000	240 TONNES	15-Sep-04	35,628	2,137.25	27-Dec-19	13-Sep-14	Parked
Y15	P&H 2300XPA	SHOVEL	54765	118,937	65,000	21.4 CU MTRS	20-Jun-04	-53,937	-3,235.60	11-Apr-05	18-Jun-14	Operational
Y16	P&H 2300XPA	SHOVEL	54305	115,610	65,000	21.4 CU MTRS	15-Sep-04	-50,610	-3,036.00	27-Oct-05	13-Sep-14	Operational
Y32	P&H 2100 BLE	SHOVEL	53865	102,438	100,000	11.5 CU MTRS	25-Sep-87	-2,438	-146.28	25-Sep-13	22-Sep-97	Operational
R304	CAT 6030	HYDRAULIC EXCAVATOR	120478	855	30000	$15m^3$	15-Jul-14	29,145	1,748.35	3-Dec-18	12-Jul-24	Operational
R305	CAT 6015	HYDRAULIC EXCAVATOR	40333	652	30000	$7.5m^3$	11-Jul-14	29,348	1,760.53	15-Dec-18	8-Jul-24	Operational
R306	CAT 6030	HYDRAULIC EXCAVATOR	120282	828	30000	$15m^3$	13-Aug-14	29,172	1,749.97	4-Dec-18	10-Aug-24	Operational
V806	CATERPILLAR D10T	TRACKED DOZER	RJG04828	696	30000	950 HP	20-Aug-14	29,304	1,757.89	12-Dec-18	17-Aug-24	Operational
V807	CATERPILLAR D9	TRACKED DOZER	WDM03962	651	30000	432 HP	23-Aug-14	29,349	1,760.59	15-Dec-18	20-Aug-24	Operational
LP04	70599L00	LIGHTING PLANT	MLS4-L		40000	120/240V						Parked
LP01	78091U01	LIGHTING PLANT	MLS4-L/B		40000	120/240V	15-MAR-01					Operational
LP14	35640080048	LIGHTING PLANT	GE600 SX/GS		40000	6.5 KW	10-SEP-08					Parked
E214	CATERPILAR DP20NT	FORKLIFT	T18C-00503			2 TONNE	30/08/07					Operational
E215	CATERPILAR DP150N	FORKLIFT	T39A-10052			15 TONNE	30/08/07					Operational

Appendix 9

Trakload

Vehicle Timeline

Printed on 08/11/2016 at 11:05

From 07/11/2016 to 08/11/2016

Vehicle : X104

Section	Section Def	Started	Ended	Time (Sec) Total	Stopped	Engine	Event	Ore Source	Excavator	Spd (kmh)	Distance (km)	Trip	Cycle
Gate Control	Other	07/11/2016 06:46:10	07/11/2016 06:51:38	328	328	179				0.02	0.01		
		07/11/2016 06:51:38	07/11/2016 06:52:08	30		79				30.61	0.26		
Re-Fuel Station	Fuel Stop	07/11/2016 06:52:08	07/11/2016 06:52:22	14						15.15	0.03		
		07/11/2016 06:52:22	07/11/2016 06:53:37	75		65				28.69	0.61		
East Mill stockpile	Destination	07/11/2016 06:53:37	07/11/2016 06:54:00	23		60				21.62	0.15		
		07/11/2016 06:54:00	07/11/2016 06:54:07	7						19.28	0.04		
East Mill Crusher	Destination	07/11/2016 06:54:07	07/11/2016 06:54:23	16						18.22	0.08		
		07/11/2016 06:54:23	07/11/2016 06:57:48	205		195				29.51	1.66		
East Extension Temporal Dump	Destination	07/11/2016 06:57:48	07/11/2016 06:59:43	115		122				26.54	0.86		
		07/11/2016 06:59:43	07/11/2016 06:59:51	8						21.91	0.05		
East Extension(PHASE 3)	Source	07/11/2016 06:59:51	07/11/2016 07:03:41	230		261				18.47	1.19		
		07/11/2016 07:03:41	07/11/2016 07:03:49	8						12.74	0.03		
East Extension(PHASE 3)	Source	07/11/2016 07:03:49	07/11/2016 07:11:21	452	443					5.51	0.06		
		07/11/2016 07:11:21	07/11/2016 07:14:38	197	197	219				0.29	0.11		
East Extension(PHASE 3)	Source	07/11/2016 07:14:38	07/11/2016 07:21:43	425	366	451				4.82	0.25		
		07/11/2016 07:21:43	07/11/2016 07:22:02	19		61				13.87	0.08		
East Extension(PHASE 3)	Source	07/11/2016 07:22:02	07/11/2016 07:26:37	275		255				15.43	1.23		
		07/11/2016 07:26:37	07/11/2016 07:27:06	29	15					5.44	0.05		
East Extension Temporal Dump	Destination	07/11/2016 07:27:06	07/11/2016 07:27:13	7		66				13.45	0.03		
		07/11/2016 07:27:13	07/11/2016 07:27:28	15						15.89	0.07		
East Extension(PHASE 3)	Source	07/11/2016 07:30:17	07/11/2016 07:30:42	25	25		Discharge			0.05	0.00		
East Extension(PHASE 3)	Source	07/11/2016 07:30:42	07/11/2016 07:32:34	112	11	151				16.61	0.49		
		07/11/2016 07:32:34	07/11/2016 07:32:49	15						13.95	0.06		
East Extension Temporal Dump	Destination	07/11/2016 07:32:49	07/11/2016 07:33:09	20		64				14.82	0.10		
		07/11/2016 07:33:09	07/11/2016 07:33:36	27	15					6.97	0.05		
East Extension(PHASE 3)	Source	07/11/2016 07:33:36	07/11/2016 07:38:20	284		315				14.96	1.14		
		07/11/2016 07:38:20	07/11/2016 07:38:35	15						13.70	0.06		
East Extension(PHASE 3)	Source	07/11/2016 07:38:35	07/11/2016 07:44:56	381	306	371				8.40	0.24		
		07/11/2016 07:44:56	07/11/2016 07:45:15	19						13.04	0.08		
East Extension(PHASE 3)	Source	07/11/2016 07:45:15	07/11/2016 07:50:27	312		306				14.04	1.25		
		07/11/2016 07:50:27	07/11/2016 07:50:43	16						11.91	0.05		
East Extension Temporal Dump	Destination	07/11/2016 07:50:43	07/11/2016 07:50:50	7		62				13.48	0.03		
		07/11/2016 07:50:50	07/11/2016 07:51:06	16						13.49	0.06		
East Extension(PHASE 3)	Source	07/11/2016 07:51:06	07/11/2016 07:53:43	157	37	123				13.94	0.57		
East Extension(PHASE 3)	Source	07/11/2016 07:53:43	07/11/2016 07:54:07	24	24		Discharge			0.08	0.00		
East Extension(PHASE 3)	Source	07/11/2016 07:54:07	07/11/2016 07:59:46	339	258	398				17.72	0.46		
		07/11/2016 07:59:46	07/11/2016 08:00:00	14						24.88	0.10		
East Extension Temporal Dump	Destination	07/11/2016 08:00:00	07/11/2016 08:02:32	152		127				21.59	0.93		