Optimizing the extractive capacity of the mining loading, and haulage fleet at Nchanga Open Pit mine, Zambia

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Nchanga Open Pit (NOP), a business unit under Konkola Copper Mines plc (KCM), has been undertaking processing plant improvement projects, namely elevated temperature leaching, heap leaching, and cobalt/copper separation, in order to scale up its operations. These improvements have extended the life of mine (LoM) by 4 years. Consequently, all upstream components of the value chain had to be harmonized with these improvements in order to curb loss of value. This study was undertaken in order to optimize the fleet in terms of size and remaining life. In order to achieve this aim, production planning, fleet optimization, and fleet management were reviewed and analysed based on generic formulae, match factor theory, and queuing theory, while fleet simulation was done using Talpac software. Results of the study indicate that there is need for NOP to invest in machinery by either re-capitalizing the current fleet or resorting to a more cost-effective haulage system.

Keywords:improvement projects; extended life of mine; match factor theory, Talpac simulation.

INTRODUCTION

The mineral extraction process in an open pit operation involves stripping of overburden followed by drilling, blasting, and transportation of material using a system of loading and hauling equipment. Other 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 operating costs (May, 2012). The loader/truck productivity problem then becomes to optimize the productivity of a truck and loader fleet (Burt and Caccetta, 2013).

Konkola Copper Mines plc (KCM) runs an open pit mine at its Nchanga Open Pit (NOP) business unit in the Copperbelt Province of Zambia. Around 2015, NOP was approaching resource depletion, and thatprompted the parent company to consider research into treating the formerly uneconomic low-grade copper ores both within the pit and forming part the dump. KCM thenembarked on three copper processing improvement projects (Figure 1):elevated temperature leaching (ETL), heap leaching (HL),and cobalt/copper separation. Elevated temperature leaching resulted in a 20% increase in the recovery of copper while cobalt/copper separation promised a 77.5% increase in the value of the final products. The LoM was also extended by 4 years.

Figure 1 illustrates how the mining fleet becomes affected by the extension of LoM. If the loading and haulage fleet is concurrently optimized following processing plant optimizations, it means the establishment of an optimum fleet for the main pit at NOP. Further optimization of any excess fleet components also means the excess fleet components can be used on the company's new reserves,thus conserving value. Otherwise, if the mining fleet is not optimized, there is potential loss of value despite the successful copper processing plant improvements.Hence these downstream changesmeant that an optimization of upstream components of the value chain became imperative.

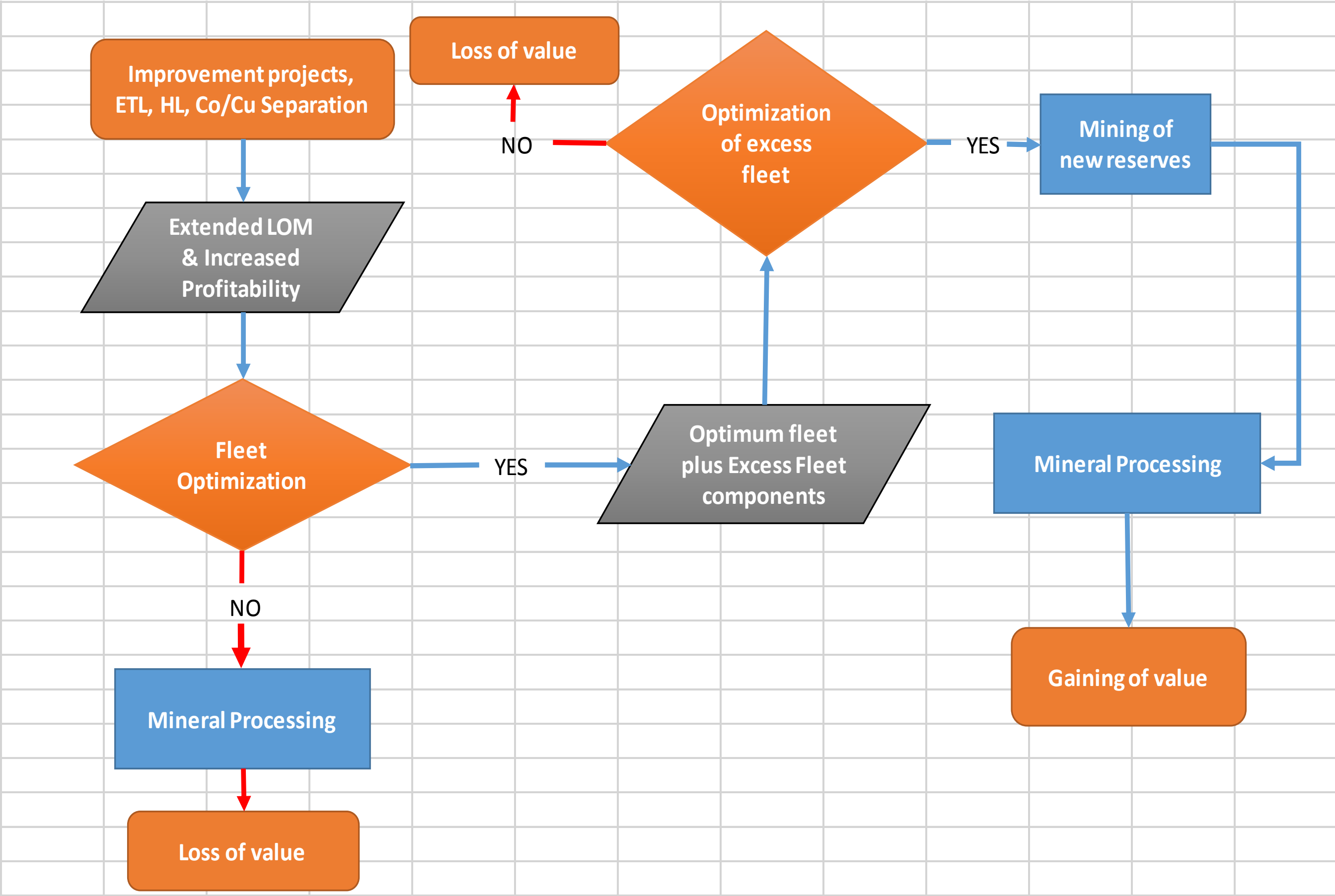

Figure 1. Copper processing improvement projects and their impact on NOP mining fleet.

Secondly,NOP became faced with a critical equipment planning decision, where the current ore handling fleet had to be either re-capitalized or apportioned to exploit new mining sites in response to the increased profitability and extended LoM.

NOP uses a truck and loader system comprising (both operational and parked) five shovels, five excavators, 25 trucks, four drills, seven dozers, five front-end loaders, and three graders. These machines vary in capacities and most of them have reached or gone beyond their useful life; hence some are parked and requiremajor repairs, or rather overhauls. Based on established literature, 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). However, 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). While attempting to optimize any fleet, it is important to keep in mind that mining companies wishing to increase production and reduce costs without recapitalizing equipment should target 'low-hanging fruit.' There are a number of basic fleet performance-related questions to be answered by equipment planners before considering more drastic measures (Hui, 2012).

MATERIALS AND METHODS

To determinethe potential loss of value if the fleet is not optimized in the wake of improvement projects, data on NOP and revisedLoM was collected from the planning department and used to mirror equipment capability. An equipment replacement register was used to provide details on theremaining life of the individual equipment items, as well as available equipment inventory. A Microsoft Excel® analysis was done to graphically assess the potential of the current fleet to function foran additional fouryears. Fleet requirements for NOP at the current production rate and LoMwere determined using Talpac software.The results obtained were further confirmed by a queuing theory analysis done through a Microsoft Excel® program.

Mining operations at NOP were being conducted at two separate sections of the main pit, namely Chingola Open Pit Section F&D (COP F&D) and Cut Number 2(CUT II). The research was therefore done based on the operations prevailing in these two sectionsof the pits.

An optimum fleet for the main pit was suggested by either determining fleet components with useful life of four years or suggesting an in-pit crusher and conveyor system.Information relating to continuous haulage that was used to make a comparison with the current haulage system was literature-based. Table I summarizes the collected data, data collection methods, and the respective analysis tools.

Table I.: Data collected, purpose of collection, data manipulation tools, and methods of data collection.

Objective	Analysis tool	Data used	Data collection method
Assessing usability of available machines over the extended LoM	Microsoft Excel	Machine types and operational status. Machine remaining life	NOP equipment replacement register (secondary source).
Determining NOP fleet requirements	Talpac software	Material characteristics, description of haul cycle, truck information, loader information, roaster, owning and operating costs	Secondary source information from mine technical service departments. On-site measurements on haul cycle, machine speeds, machines availabilities, and payloads.
Confirming Taplac results	Queuing theory program in Microsoft Excel	Truck arrival rate Loader service rate	Time and motion studies at the 135m bench in COP F&D
Selecting optimum haulage strategy	Comparing current against continuous haulage system	Prevailing truck/loader system requirements. Economics of continuous haulage system	Microsoft Excel, Talpac, and queuing theory results. Literature review.

RESULTS AND DISCUSSION

Based on equipment replacement dates, determined on operated-hour basis, only the equipment shown in Figure 2 was found to be still fit for use. Apparently, the two operative shovels haveexceeded double their useful life and are therefore missing from Figure 2. Graders, excavators, drills, dozers, and front end loaders would be out of operation by 2018 against a four-year LoMending in 2020. Only trucks could last up to the end of the new LoM. This alone, however, could not conclude on the operability of equipment within useful life or the non-operability of equipment past its useful life. An investigation on equipment reliability and maintainability remained necessary to arrive at such a conclusion.

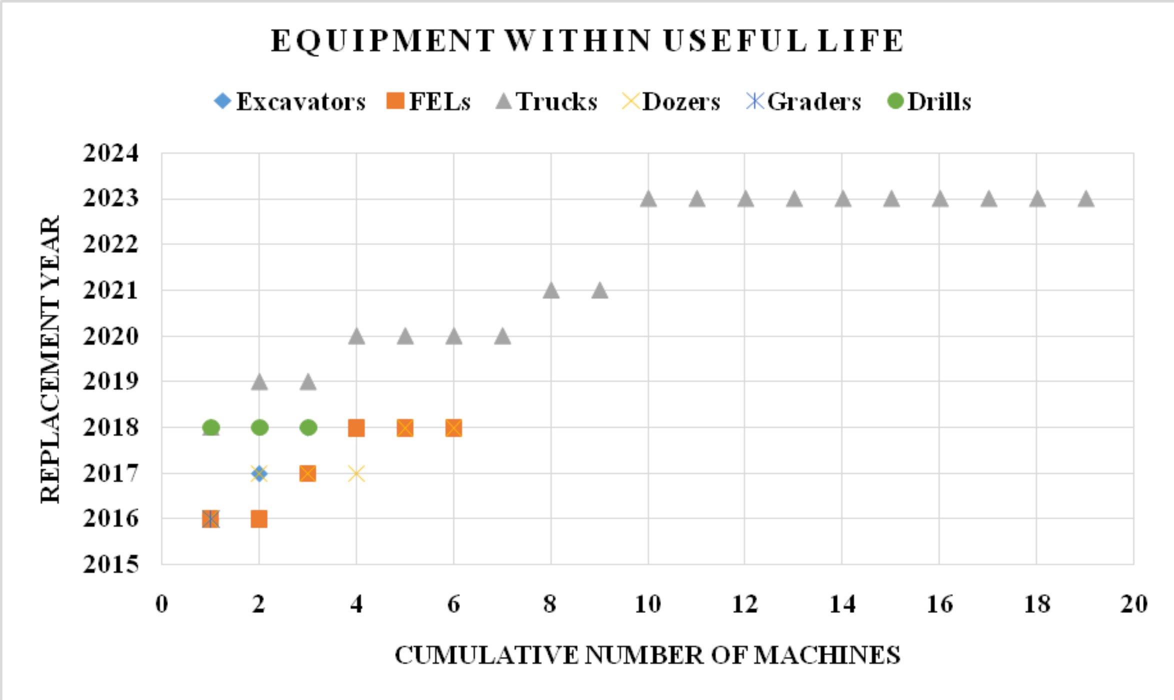

Figure 2. Maximum remaining useful life for each equipment category.

The required fleet was supposed to excavate material to a total of 1478789.75 t/month (17745477t/a).

Using Equations[1] through [5](Adler, 1992), the required fleet size for NOP was estimated and is summarized in Table II.

$T_p = 170\ d^2$, *where* T_p is tons of ore or waste and *d*is drill size [1]

$S = 0.111\ T_p^{0.4}$, where S is shovel dipper size [2]

$N_s = 0.011\ (T_p)^{0.8}/S$, where N_s is number of shovels [3]

$t = 6.88S^{1.1}$,where t is truck capacity [4]

$$Match\ Factor = \frac{Number\ of\ trucks * Loader\ cycle\ time}{Number\ of\ loaders * truck\ cycle\ time}$$ (Hadjigeorgiou *et al.*, 1995) [5]

Table II.: A summary of fleet components required for NOP main pit.

EQUIPMENT	QUANTITY	CAPACITY
Drills	**3**	**422mm drill**
Shovels	**2**	**31m^3**
Trucks	**18**	**300t**

However, the fleet shown in Table II is ideal for a greenfield project rather than a brownfield with only four years remaining before resource depletion. As a result, optimizing the already available fleet components proved more economic. Therefore, a haulage simulation of available machines was run using Talpacsoftware. Simulation of a single loader and its truck fleet was done for both waste and ore excavations for the two pits on site. Talpac simulation results are summarized in Table III.

Table III. A summary of Talpac simulation results. All the displayed figures except for totals were calculated by Talpac.

Main Pit section	No. of loaders	Truck fleet size	Discounted av. cost
COP F&D waste	1*P&H 2300XPA	8	$1.21
COP F&D ore	1*CAT 6030	5	$2.25
Cut II waste	1*P&H 2300XPA	10	$0.68
Cut II ore	1*HITACHI EX2500	5	$1.75
Totals	4	28	

The Talpac simulation results in Table III were confirmed by a Microsoft Excel queuing theory analysis (Figure 3). This exercise was done at the COP F&D waste mining section where one loader was used to serve an increasing number of trucks. The number of trucks arriving for service at the loader in an hour, also called the truck arrival rate, was observed and a graph of this rate against the number of trucks was plotted.

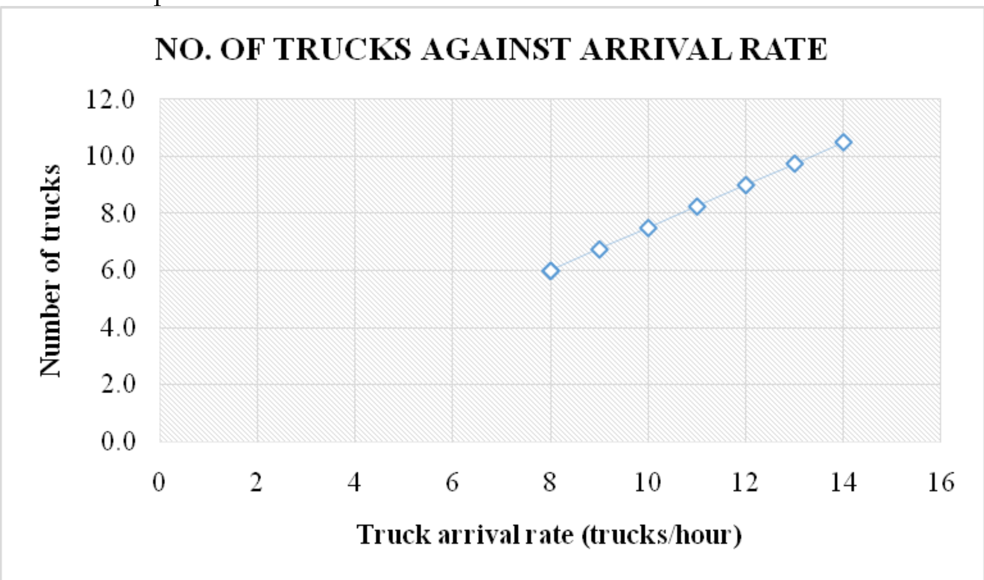

Figure 3.Number of trucks versus truck arrival rate.

The analysis done for COP F&D waste haulage showed that 7.86 (approximately 8) trucks are required to fully utilize the P&H shovel in that location. The queuing theory analysis was done only for the COP F&D waste mining section, and since the results obtained were similar to the Talpac simulation results for the same section, it was concluded that Talpac results were reliable. Hence the Talpac results shown in Table IIIwere used for further analysis of the entire fleet requirements.

The results in Table IIIreveal that NOP, with an inventory of operational 2*21.4m^3 bucket shovels and 3*15m^3 bucket backhoes seems well served in terms of loading equipment. However, the reliability of the available loaders needs assessment. On the other hand, truck requirements for NOP surpass the available fleet size as only 14 trucks with a maximum payload of 218 t are on site. As a result,14 more trucks with a 218 t payload are needed to reach the 28 truck fleet size shown by Talpac simulation results in Table III.

For one particular month, November 2016, the budget mining costs for COP F&D and CUT II pits were $1.11 and $1.80 per ton respectively. This gives an average cost of $1.46 per ton, which is comparable to the average cost per ton of $1.47 that can be obtained after averaging the four sectional discounted average mining costs shown in Table III. However, it should be noted that the major contributing factor to higher mining costs is haulage distance. For instance the $2.25 per ton for COP F&D mining section ore corresponds to a haulage distance of 10.57km, while the $1.75 per ton for CUT II section ore corresponds to a haulage distance of 4km. All distances were measured from the pit bottom to the Old East Mill stockpile. Based on the same idea of an increase in mining cost due to increase in haulage distance, it behoves any investigator to consider a haulage system for which the costs are favoured by long distance.

Apparently, two fleet choices existed for KCM. One was to either recapitalize the current haulage fleet, while the other was to scrap it in exchange for an in-pit crusher and conveyor system (IPCC). To go ahead with equipment recapitalization it was necessary to assess the condition of the available machines in the existing fleet and ascertain whether some fleet components could either be immediately incorporated into the new fleet or rather overhauled for inclusion in the new fleet. Another possibility was to adoptconveyor transportation in the main pit and allocate the available haulage equipment to satellite pits (new reserves).

If the current fleet components were going to be considered for continued use they had to be assessed on two metrics – reliability and maintainability. This assessment, although omitted in this research, can be carried out using Weibull analysis through Microsoft Excel or Matlab software.

Envisioning an optimum fleet for the main pit underprevailing plummeting international metal prices, low-priced approaches have to be adopted. In effect, an IPCC system had to be suggested. Both literature studies and experience show that conveyors, within the current state of the art, are the lowest cost method of handling bulk materials. According to Hartmann (1992), for truck haulage, 60% of the fuel energy is expended on moving the truck weight and only 40% is used to move the payload. On the other hand, for belt haulage the corresponding relationship is 20% to belt weight and 80% to payload. Diesel fuel costs of $0.82 per litre(Banda, 2016)and electricity costs $0.1035 per kilowatt-hour(Cossen, 2016).Thus energy costs favour conveyor haulage by a factor of 4 to 1. Moreover conveyors have an automatic and instantaneous start-up as well as continuous operations. They have a high level of reliability as they achieve availabilities between 90 and 95%(Hartman, 1992). This exceeds NOP's target availability by a maximum of 15%.Conveyor operation is not impaired by adverse weather conditions, which often affect truck haulage systems. Conveyors require less labour; a 100-man crew operating and maintaining a truck fleet can be replaced by a 10-man crew handling an equivalent amount of material via conveyor. Conveyors can operate efficiently at a grade of up to 30%, while trucks can only sustain a maximum of 10%. Conveyors reduce the need to remove 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(Hartman, 1992).

CONCLUSIONS AND RECOMMENDATIONS

Simulation using Talpac software revealed a need to increase the truck fleet size from 14 to 28 if the current haulage system was to be maintained. The average cost per ton for operating such a haulage system was $1.47. This is only $0.01 more than the average $1.46 that is apparently obtained on the ground. The best equipment selection approach for NOP was assumed to be the installation of a conveyor belt for both the Cut II and COP F&D pits. The conveyor belt proved more favoured over truck haulage in terms of energy usage, energy costs, reliability, operating costs, and cost reduction by optimizing the ore to burden ratio.However, the study remained open-ended as it gave birth to another extensive investigation on the reliability and maintainability of available machines. The cost of rebuilding the machines that pass the reliability and maintainability tests plus the cost of adding 14more trucks as well as operating costs for that system should then be weighed against the costs of procuring, installing, and operating a conveyor belt.

ACKNOWLEDGEMENTS

The authors would like to thankKonkola Copper Mines plc for the opportunity to undertake this study at NOP. More thanks go to Messrs. H. Banda, C. Lambwe, G. Siaciti, L. Mbiri, and M. Nonde, who assisted with some of the technical information.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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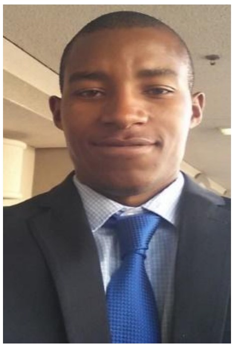
AUTHORS' CVs



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From 2011 to 2014 he served as Permanent Secretary in the Ministry of Mines, Energy and Water Development. During his tenure he oversaw the Mines Modernisation Program, development of mining policy (2013), and implementation of the gemstone auctioning system in Zambia. He served as Non-Executive Director for Konkola Copper Mines plc,Luanshya Mine plc, NFCA plc,Kansanshi Mine plc,Maamba Collieries plc,Chambeshi Copper Mines plc, and Mopani Mines plc from 2012 to 2014.

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