Quantifying the Life Cycle Cost of a High Pressure Grinding Roll in a Mineral Processing Plant

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Abstract

Accelerated advancement of technology and the global economic crisis have prompted the need to improve equipment reliability to reduce unpredicted equipment failures and operating costs. Increasingly, attention is focused on the life cycle cost to improve understanding of the equipment's operational and maintenance costs which are driven by the system maintainability, reliability and required replacement time. This goes hand-in-hand with data availability and quality which play a vital role in the success of life cycle cost implementation. The research provides insight to the field of life cycle cost, as well as to quantify the major cost drivers of the high pressure grinding roll during its operating and maintenance life cycle for a period of four years. From the research findings, it is evident that reliability and maintainability management must be regarded as a vital element corporate strategy. Successful implementation of this strategy is reliant on the support of senior management which in turn will ensure that organizational market share is increased and that competitive advantage is maintained.

Keywords
Life cycle cost, reliability, maintenance, data quality

1. Introduction

The term life cycle costing (LCC) has been researched and employed in literature since 1965. According to Dhillon (2012), LCC refers to a method of estimating the cost summation of the equipment incurred by consumer from acquisition to disposal of such equipment; in short it is the total cost of ownership. The cost of ownership can fluctuate from 20 to 200 times the equipment acquisition cost (Seif and Rabbani, 2014). As a result, industry continues to seek means of controlling and minimizing these costs.

Moreover, an emerging research trend shows growing concerns on stringent availability and performance constraints, specifically system reliability (Dersin, Péronne and Arroum, 2008). The trend extends focus on the equipment's operational costs which are primarily driven by the system and component-specific maintainability, as well as required replacement time (Hinow and Mevissen, 2011). According to Al-Chalabi, Lundberg, Wijaya and Ghodrati (2014), the prime objective is to identify key factors affecting both system availability and LCC. The aim is to provide valuable information with guidelines to achieve forecasted availability targets at considerably lower operational costs.

It is evident that the consumers' decision is not only dependent on the maturity of the product but predominantly on the LCC (Wang, Li, Yang and Dong, 2009). Thaduri, Verma and Kumar (2013) emphasized that the crucial consideration for consumers to purchase a particular product depends on the availability, maintainability and reliability costs of its entire life cycle.

2. Literature review

A review of the literature aimed to provide an in-depth insight to life cycle costing. This included understanding of the LCC concept, available LCC models, implementation of LCC analysis within an organization and the benefits thereof; as well as ways of quantifying LCC through the use of existing numerical formulae.

1.1 Life Cycle Cost Concept

There are many definitions of life cycle costing, commonly referred to LCC by many researchers (Goralczyk and Kulczycka, 2005). For this research, the definition by Blanchard (2004) is adopted: "LCC accounts for all system costs which are broken down into several categories to include development and design cost; construction and/ or manufacturing cost; operating and maintenance cost; and retirement and material disposal cost". It is worthwhile understanding the inter-relation of each life cycle phase as well as the distribution of each phase towards the overall LCC.

To illustrate the percentage distribution of costs for the entire life cycle, Jing, Qi, Desheng and Qin (2012) employed a Pareto curve as demonstrated in Figure 1. The horizontal axis denotes the life cycle phases and the vertical axis denotes cost accumulation in percentage. The solid line curve is based on estimate derived during the acquisition phase where 70% of the LCC is confirmed at the exploration phase. Prior to the development or validation phase, approximately 85% of the equipment's life cost is confirmed. 95% is confirmed after the development phase.

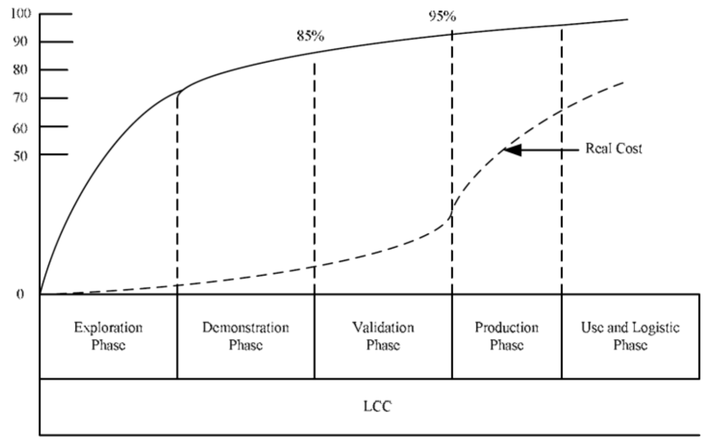

Figure 1: Pareto Curve of LCC (Jing *et al.*, 2012)

Contrary to this, the real cost curve as represented by the dashed line in Figure 1 indicates that the majority of the LCC equates to approximately 70% of the LCC during operating and maintenance phase (Jing *et al.*, 2012). Wang *et al.* (2009) supports the estimation by suggesting that approximately 50 – 60% of the LCC is accounted for in the operating and maintenance phase.

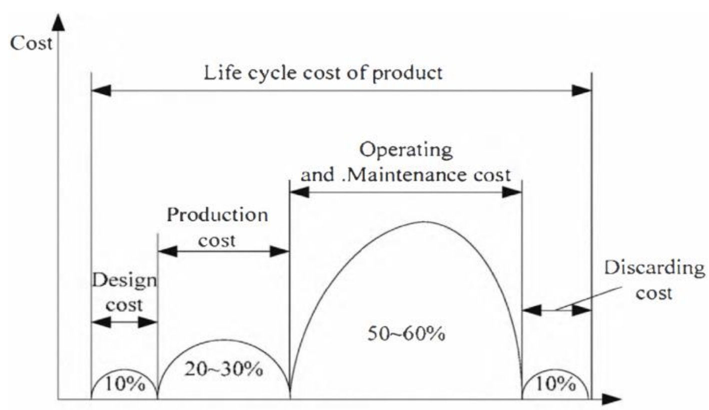

Figure 2: Life cycle phase cost proportion (Wang *et al.*, 2009)

However, LCC should be considered throughout the entire life cycle. It is evident that all phases of a product's life cycle are crucial as they contribute a percentage to the total LCC, illustrated in Figure 2. As noted above, LCC analysis is a method within the management accounting field which focuses on the total costs incurred during a product's life cycle (Ahmed, 1995). Hence, knowing the LCC of a product is a pre-requisite when considering acquisition or outsourcing of maintenance work to external contractors (Lindholm and Suomala, 2007).

Notwithstanding that the implementation of an LCC analysis can be laborious; it is possible to implement an LCC model in an organization.

1.2 Life Cycle Cost Implementation

The aim of introducing the LCC analysis as a vital consideration in the design phase enables cost targets to be identified as design-to-cost factor (Blanchard, 2004). This is crucial in identifying major cost drivers in order to implement a continuous improvement approach and cost management strategies to reduce costs.

The basic steps for implementing an LCC analysis within an organisation include the following (Blanchard, 2004): Define the system requirements; Describe the system life cycle and identify the activities of each phase; Develop a cost break-down structure (CBS); Identify data input requirements; Establish the cost for each CBS category; Select a suitable cost model for analysis and evaluation purposes; Develop a cost profile and summary; Identify major cost drivers and establish cause-and-effect relationships; Conduct sensitivity analysis; Construct a Pareto diagram and identify priorities for proposed problem solutions; Identify practical alternatives for design evaluation; and Evaluate the most practical alternatives and implement the preferred approach.

LCC analysis can be viewed as a new approach to the management of cost and not purely as a costing tool because it focuses on the product's performance from a long-term point of view by utilizing various management accounting methods (Waghmode and Patil, 2016). Hence, the key benefits for implementing a LCCA within an organization can be summarized as follows (Sacks, Nisbet, Ross, and Harinarain, 2012): it's a unique tool for decision making where selecting several options; all costs associated with the components/ system are clearly visible throughout the entire life cycle; major costs drivers can be easily identified and control measures can be implemented; the correlation between various business functions can be identified; and proper and more accurate budgeting as actual costs can be highlighted throughout the entire life cycle. The ability of an organization to compete is dependent on the quality as well as the cost of its product (*ibid*). Hence, it is crucial to understand the available models as well as suitability based on an organization's requirements in order to improve both product quality and cost.

1.3 Life Cycle Cost Models

It is worth noting that researchers present various LCC models; and that these models are structured as heuristic, analytical or conceptual (Kolarik, 1980; Gupta, 1983). Based on these classifications, the different models are presented below.

Activity Based Costing (ABC)
Activity based costing (ABC) advocates that services consume activities which in turn consume cost generating resources (Haroun, 2015). Hence, ABC evaluates cost drivers and quantifies cost incurred on performing an activity or service. This ensures that costs are accurate and distributed in proportion to the activities performed since cost estimates are derived from actual performed activity.

Parallel Machine Replacement Problem (PMRP)
Based on the failure rates of machine components, the LCC is assessed, modelled and incorporated to the parallel machine replacement problem (PMRP) with the consideration of capacity expansion. The problem is then modelled as mixed integer programming (MIP) with an objective to reduce the overall costs during the planning phase of various periods for similar operating machines of different ages (McClurg and Chand, 2002).

Cost Break-Down Structure (CBS)
Fabrycky and Blanchard (1991) presented a complex model which accounts for in-depth analysis of all costs associated with the product's entire life cycle. The CBS assists in establishing the framework for outlining the categories of LCC and offers a valuable platform for cost analysis and reporting as well cost control.

Integrated Life Cycle Assessment (LCA)
Life cycle assessment (LCA) is one of the environmental management tools which identify and assess the environmental impact caused by a product or equipment during its entire life cycle (Goralczyk and Kulczycka,

2005). Traditionally, LCA does not include economic aspects of the environmental impact and as a result the LCC is not conclusive and accurate to portray the actual cost incurred for the entire duration of the product life cycle.

Investment Decision Making

The establishment of the model was driven by the crucial planning and asset monitoring for the entire life cycle. This model is aimed at improving the value for money by accounting for all the cost factors pertaining to the equipment. Hence, with this model the investment options can be evaluated effectively as the impact of total life cycle cost is considered as opposed to only the acquisition costs (Woodward, 1997).

These models provide decision makers with an easy reference to understand the numerous available LCC analysis methodologies as well as to select the most appropriate and suitable method for an organization. Consequently, the LCC analysis can commence employing formulae utilized by these methods.

1.4 Life Cycle Cost Calculation Formulae

The LCC consist of a series of costs incurred throughout the equipment or product's life cycle. In order to quantify these costs various formulae are presented by researchers in the field (Jing *et al.*, 2012; Thaduri *et al.*, 2013; Waghmode and Patil, 2016).

LCC calculation using simulation based acquisition (SBA)

The simulation based acquisition approach is based on system engineering as it caters for all costs throughout the equipment or product's entire life cycle. Jing *et al.* (2012) shows the LCC is given by the equation below:

LCC=Acquisition + Operational + Failure + Support - Net Salvage (1)

Where:
Net Salvage Value = Salvage – Disposal (2)

From an empirical representation:

$$LCC = C_U + [F_O + P_A(i,t_d)C_O] + [P_A(i,t_d)C_f \frac{t_0}{MTTF} + [F_S + P_A(i,t_d)C_S] - [P_F(i,t_d)S] \quad (3)$$

Where:
CU – Acquisition cost = Design + Manufacturing + Transport + Construction costs
C0 – Annual operating cost *Cf – Cost per failure*
CS – Annual supporting cost *F0 – Fixed operating cost*
FS – Fixed supporting cost *i – Annual interest*
PA – Annual value *PF – Future value at end design life*
S – Salvage value *t0 – Operating hours/ year*
td – Design life in number of years
$\frac{t_0}{MTTF}$ *– Expected number of failures/ year (failure rate)*
$P_A(i, t_d)$ *– Annuity factor* $P_F(i, t_d)$ *– Single present value*
Time value for money is expressed as follows:

$$P_{F/A} = \frac{C}{(1+i)^{t_d}} \quad (4)$$

The LCC calculations contain variables which are assumed on instances where quality of the information is questionable. Therefore, it is crucial to define the objectives to be achieved as well as to assess the availability of quality information to derive accurate results and to minimize the number of assumptions during calculations.

1.5 Proposed Integrated LCC Framework

It is evident that for a more realistic LCC analysis, the entire life cycle as well as cost contributing factors must be considered. Hence, the researchers propose an integrated LCC framework which allows a combination of all the components within LCC analysis as illustrated in Figure 3. For this framework activity based costing and cost breakdown approaches are combined. Firstly, the reason for choosing the activity based costing approach is to ensure that each activity performed on the (high-pressure grinding roll) HPGR can be accounted for and that all associated costs can be included. Secondly, in support of the cost breakdown approach, the HPGR is broken down to various components and life cycle phases, for example planned major overhauls and mid-life refurbishments. Hence, each life cycle phase can be analysed and major cost drivers may be readily identified.

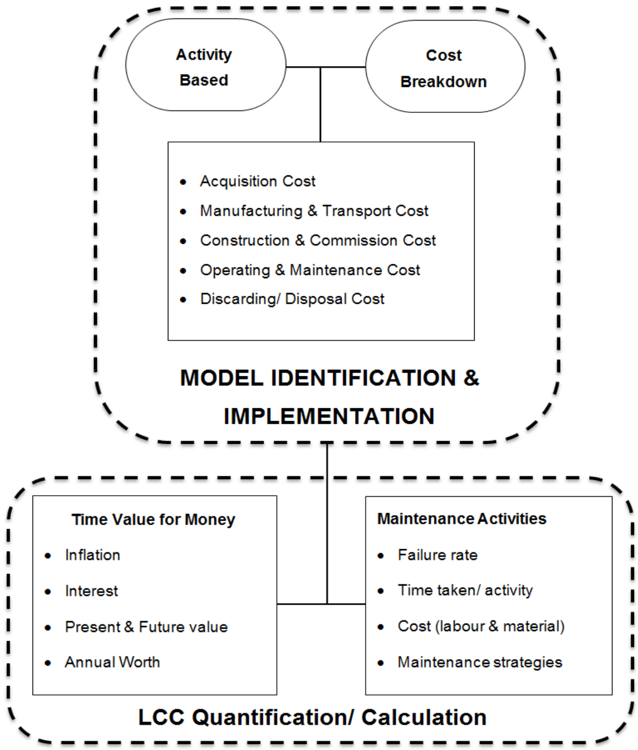

Figure 3: Proposed Integrated LCC Framework

3. Case Study – High Pressure Grinding Roll

The case study selected for the research is based on process plant of a mine located in the central part of Limpopo province which is the largest precious metal producer in South Africa. The mine forms part of a large precious metal group which consists of subsidiary mines in various provinces within South Africa and other parts of Europe. The annual production turnover of the mine is estimated at 650,000 tonnes depending on the availability for that year. During 2017, an HPGR was installed in the crushing and grinding section of the plant. The supplier takes pride in its products with over 200 successful installations world-wide ranging from major mineral industries which include diamonds, gold, cement, copper, iron ore and platinum. The HPGR is used for grinding brittle mill feed material from the field of rocks and associated products. It provides the separation between useful and waste minerals and produces adequate particle size distribution to other mineral processing equipment such screens, crushers and mills. The HPGR comprises of a number components which include the following as illustrated in Figure 4.

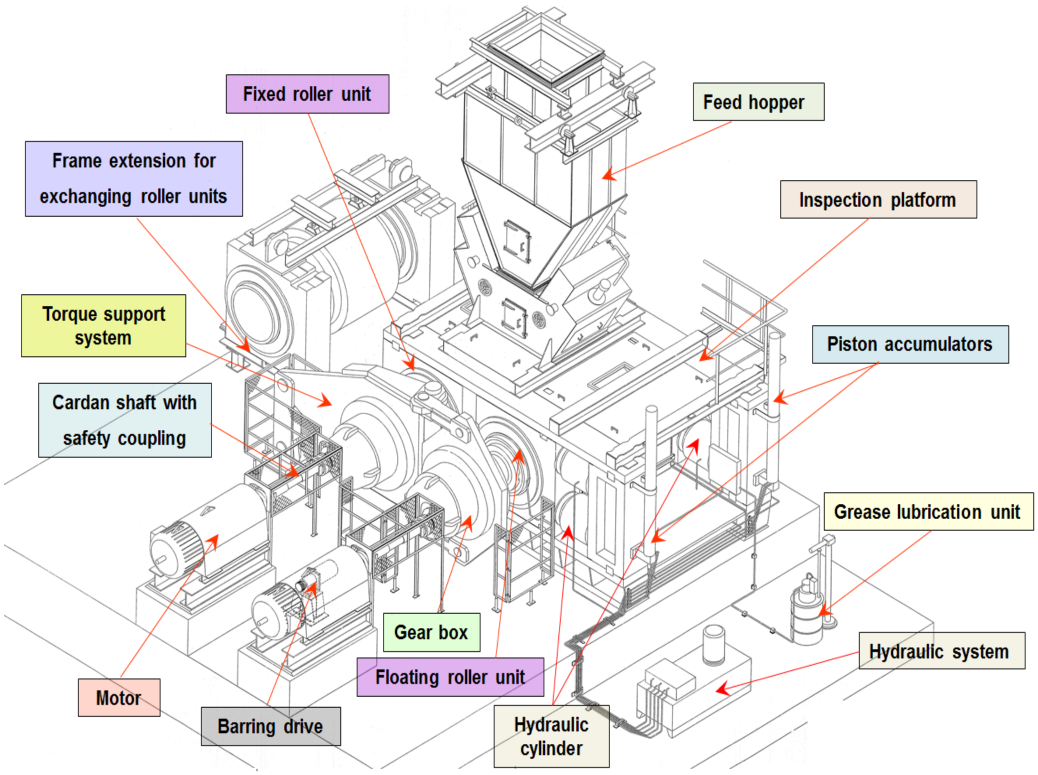

Figure 4: HPGR components (sourced from supplier's technical training documents)

All the major mechanical, electrical and instrumentation components, as well as the total quantity which constitutes the HPGR, were included in the LCC analysis. In order to narrow the focus of this research, excluded components were structural parts that were less likely to fail, for example the roll frame, pressure blocks, transport frames and platforms; as well as minor components such as cabling, piping and instruments and parts which were not originally in the supplier's scope of supply.

4. Data Analysis and Discussion of Results

The LCC analysis commences with the acquisition cost followed by the operating and maintenance costs. The primary focus of the LCC is on the operating and maintenance phase from 2014 to 2017.

Acquisition cost

The acquisition cost of the HPGR is the summation of the following costs: design, engineering, fabrication, transportation, installation (including crainage), commissioning, maintenance tools, training and warranty; as well as the costs for maintenance, commissioning and strategic spares. Acquisition cost accumulated to R70 000 000.

Operating costs

The operating costs of the HPGR calculates the cost of operating the machine. These costs are categorized into three cost buckets, namely power consumption of all electric motors, consumables and labour. The annual power consumption by the drives was based on the formula below.

$$Annual\ electricity\ cost = Power \times Annual\ Running\ Hours \times Availability \quad (5)$$

Where:
Annual electricity – ZAR Power – kW Availability - %

In summation of all the above costs, the total operating cost for the HPGR for the period of observation equated to approximately R84 million which is 20% above the acquisition cost of R70 million. The year-on-year operating cost follows a linear increase as depicted in Figure 5. This trend is expected due to the price escalation of electricity cost, steel price, inflation and labour annual increase. The overall percentage increase of the total operating cost from 2014 to 2017 equates to over 21%.

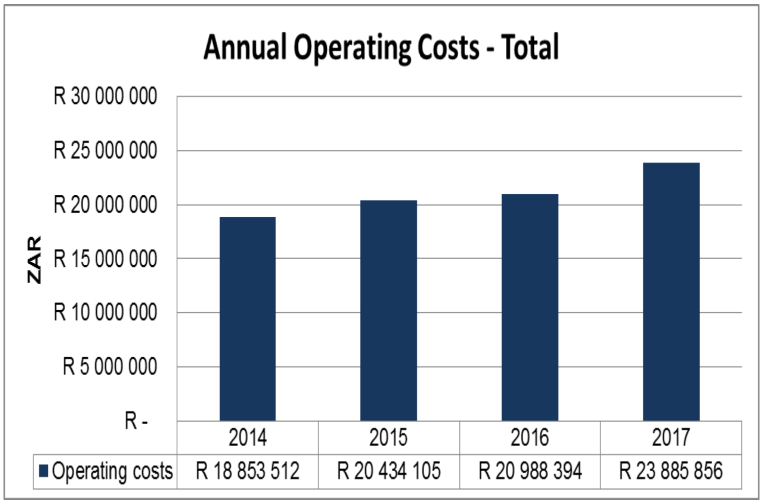

Figure 5: Annual operating costs (2014 – 2017)

In analyzing the operating costs, it is evident that the labour cost contributes a large percentage of 56% followed by power consumption cost at 37% and lastly consumables at 7%. Figure 6 provides a graphical breakdown of the operating cost. At the start of data analysis the researcher anticipated that power consumption costs would surpass labour costs. However, the result indicates that labour costs contribute a larger percentage. In support of these results, research by Turner (2017) indicates that labour costs is the major contributor of operating cost.

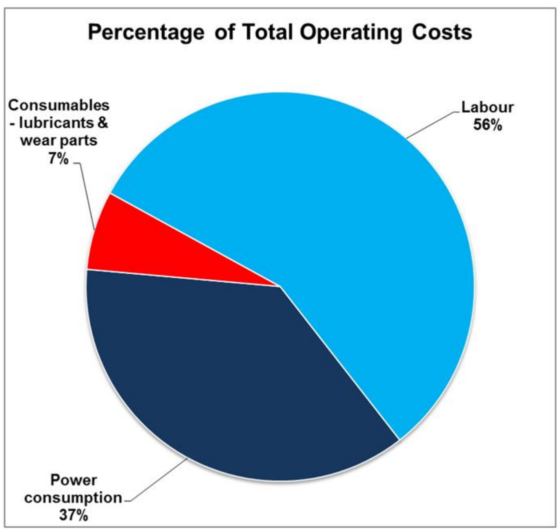

Figure 6: Percentage breakdown of operating costs (2014 – 2017)

Maintenance costs

According to Obiajunwa (2013) maintenance is an essential support role for machinery and plant processes in order to ensure that production targets as well as the annual profit anticipated by shareholders are met. Maintenance costs are categorized as spare parts, service assistance and technical assistance. The maintenance costs were considered annually from 2014 to 2017 to ascertain whether a trend existed on the major cost drivers. Figure 7 indicates that service and technical assistance costs are the highest contributor at over R63 million which equates to almost 50% of the total maintenance cost for the period of observation. The second highest cost contributor is the roll unit assembly at over R39 million; the reason being the replacement of gearbox and torque, as well as several roll and gearbox refurbishments.

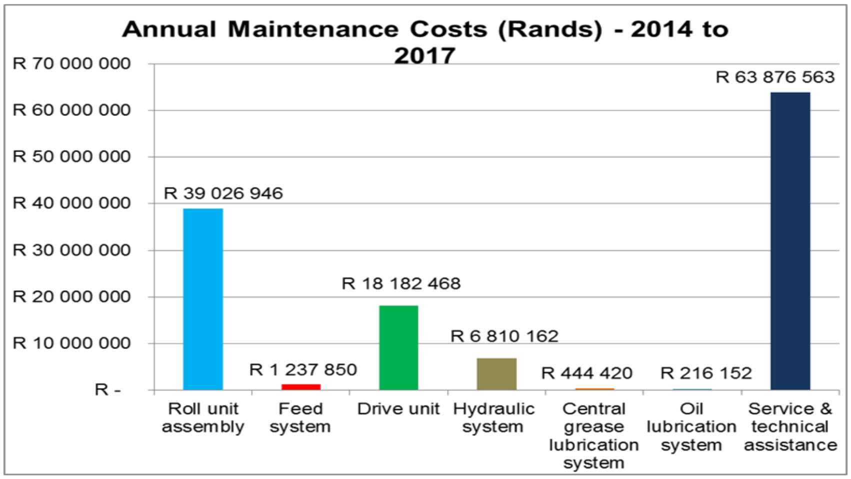

Figure 7: Total maintenance costs (2014 – 2017)

From Figure 8 it is evident that four major costs contribute to the annual maintenance costs, namely service and technical assistance at 49%, followed by the roll unit assembly cost at 30%, the drive unit cost at 14% and lastly the hydraulic system at 5%.

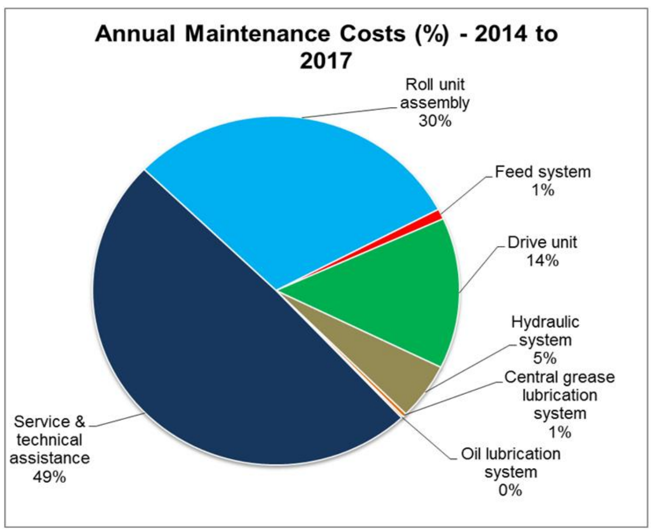

Figure 8: Percentage breakdown of maintenance costs (2014 – 2017)

Total Life Cycle Cost – not considering Net Present Value (NPV)

From the calculations, the total life cycle cost of the HPGR not considering NPV is tabulated in

Table 1. The table comprises of yearly costs for the operating and maintenance as well as the acquisition cost and net salvage value which remains constant for the period of observation as the original contract value. The total LCC is well over R282 million which equates to over four times the original acquisition cost. Furthermore the table includes the total LCC in Rand (ZAR) value which is then converted to Rands per ton based on the calculated annual tonnage output considering the overall availability.

Table 1 – Total life cycle cost of the HPGR – Not Considering NPV

TOTAL LIFE CYCLE COST OF HPGR (Without NPV)						
	2014	2015	2016	2017	TOTAL	%
Acquisition cost	R 70 000 000	R 70 000 000	R 70 000 000	R 70 000 000	R 70 000 000	24.7%
Operating costs	R 18 853 512	R 20 434 105	R 20 988 394	R 23 885 856	R 84 161 867	29.7%
Maintenance costs	R 18 734 166	R 21 442 509	R 39 401 939	R 50 215 946	R 129 794 561	45.9%
Net salvage cost		R 496 104		R 496 104	R 992 208	0.4%
				TOTAL	R 282 964 220	100%
				ZAR/t	R 16.25	
				US$/t	$ 1.23	
				€/t	R 1.05	

Apart from the constant acquisition cost, the first observation is that operating and maintenance costs in 2014 was fairly equal at just under R19 million. Secondly, maintenance costs demonstrate an increasing trend from 2015 to 2017 which resembles an exponential curve and reaches a total of approximately R50 million in 2017, equating to 71% of the acquisition cost.

In breaking down the total LCC of the HPGR in Figure 9, it is evident that the maintenance costs contribute the major portion of the LCC at 46%, followed by operating costs at 30% and lastly by acquisition costs at 25%. Net salvage costs is minor at 0.4%. In summary, operating and maintenance costs total 76% of the total ownership costs. The data is supported by research presented by Jing *et al.* (2012) that finds that approximately 70% of the product's life cycle is confirmed during the operating and maintenance phase. Furthermore, in support to this estimation, Wang *et al.* (2009) suggests that approximately 50% to 60% of the LCC is accounted for in the operating and maintenance phase.

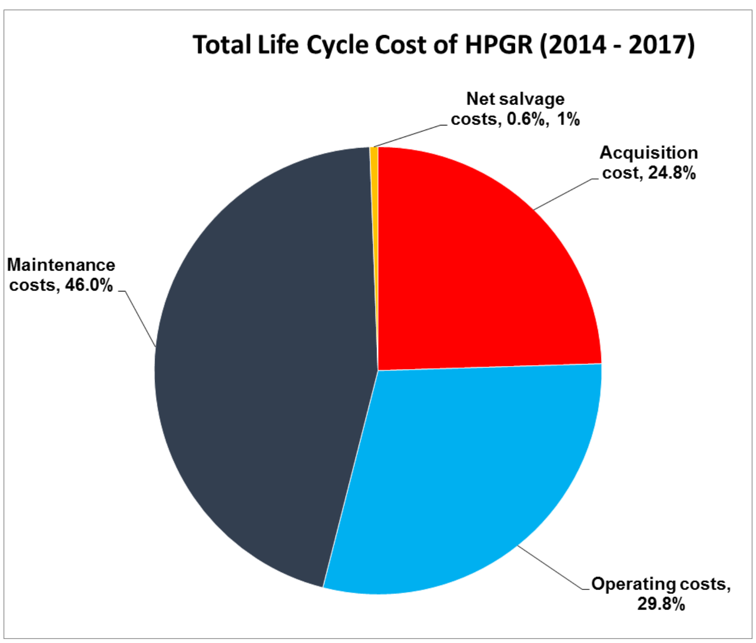

Figure 9: Total life cycle cost – Percentage breakdown

Total Life Cycle Cost – Considering NPV

Table 2 comprises yearly costs for the operating, maintenance and net salvage value as well as the acquisition cost which remains constant for the period of observation as the original contract value. The total LCC is almost reaches R284 million; and the operating and maintenance costs in 2014 are based on the actual costs derived from archive records. These are taken as future values and converted to present values in 2017. Thereafter the NPV is derived for each of the year of operation. Meanwhile, the net salvage value is based on the scrap value for all the saleable components and allows for disposal costs incurred. The annual interest is based on 6% with the number of periods at 20 years.

Table 2 – Total life cycle cost of the HPGR – Based on NPV

TOTAL LIFE CYCLE COST OF HPGR (With NPV)						
	2014	2015	2016	2017	TOTAL	%
Acquisition cost	R 70 000 000	R 70 000 000	R 70 000 000	R 70 000 000	R 70 000 000	30%
Operating costs	R 18 853 512	R 19 984 723	R 21 183 806	R 22 454 834	R 82 476 875	35%
Maintenance costs	R 18 734 166	R 19 858 216	R 21 049 709	R 22 312 692	R 81 954 784	35%
Net salvage costs		R 845 880		R 950 431	R 1 796 311	0.8%
TOTAL					**R 232 635 349**	**100%**
ZAR/t					**R 13.36**	
US$/t					**R 1.02**	
€/t					**R 0.87**	

The operating and maintenance costs start at approximately R19 million in 2014. In breaking down the total LCC of the HPGR in Figure 10, both operating and maintenance costs contribute a large percentage of 35% each followed by acquisition cost at 29% and lastly by the net salvage costs at 1%. The reason for similar percentages for operating and maintenance costs is attributed to the similar future values of over R 18 million in 2014 which was converted to present value for 2017.

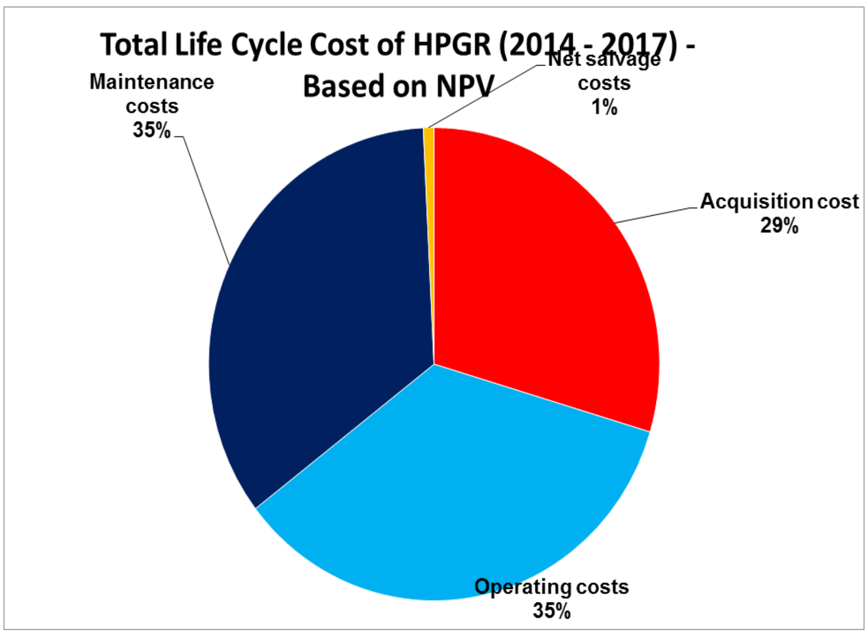

Figure 10: Total life cycle cost – Percentage breakdown (Based on NPV)

Total Life Cycle Cost – Major Cost Drivers

From the results it can be noticed that the highest cost driver is contributed by the labour cost portion at over 22%. In descending order, this value is followed by roll refurbishment at 10%, gearbox refurbishment at 8%, hard metal studs at 7.4%, main motors at 5.4%, conveyor drives at 5.3%, gearbox supply at 5.3%, refurbishment (torque arm, gearbox and roll change) at 4.9% as well as the remainder of the components between 0.2 to 3.7%.

5. Conclusions

The research findings confirm that certain components have a higher influence on the overall LCC. The approach without considering NPV is more applicable where cost information is available and of good quality; whilst the approach considering NPV also provides a better understanding on anticipated future costs which can assist in better planning and decision making on investment.

The results indicate that the LCC during the operation and maintenance phase was significantly higher than the acquisition cost. This was possibly due to factors which could not be foreseen during the design and acquisition phase, such as unplanned events and repeated breakdowns and failures.

It is evident that much work has been carried out to develop LCC models with an attempt to aid organizations to make informed decisions and manage costs associated with a product or equipment. The following conclusions are drawn from the current research: data availability and quality plays a vital role in the success of LCC analysis; implementation of LCC is reliant on proper record keeping and an efficient enterprise resource planning system; practical implementation of LCC models and analysis within organizations is still noted as a challenge; successful implementation of an LCC analysis should be viewed as a long-term project and can only be implemented if it were supported by top management and relevant personnel in the company.

A limitation of the research is that the LCC was modeled on one HPGR where not all the relevant information could be obtained. However, sufficient knowledge has been provided in this research to quantity the life cycle cost of the HGPR and to confirm major cost drivers. Future research may consider the following: reliability of the HPGR in comparison with the calculated life cycle cost; the improvement of reliability on cost control; and how maintenance strategies could be implemented to improve LCC.

References

Ahmed, N.U., A design and implementation model for life cycle cost management system. *Information & Management*, 28(4), pp.261-269,1995

Al-Chalabi, H., Lundberg, J., Wijaya, A. and Ghodrati, B., Downtime analysis of drilling machines and suggestions for improvements. *Journal of Quality in Maintenance Engineering*, 20(4), pp.306-332, 2014.

Blanchard, B.S., Logistics engineering and management. *Prentice Hall*, 2004.

Dersin, P., Péronne, A. and Arroum, C., Selecting test and maintenance strategies to achieve availability target with lowest life-cycle cost. *In Reliability and Maintainability Symposium*, 2008. RAMS 2008. Annual (pp. 301-306). IEEE, 2008

Dhillon, B.S., 2012. Robot reliability and safety. *Springer Science & Business Media*.

Fabrycky, W.J. and Blanchard, B.S., Life-cycle cost and economic analysis. Prentice Hall, 1991.

Goralczyk, M. and Kulczycka, J., 2005. LCC application in the Polish mining industry. *Management of Environmental Quality: An International Journal*, 16(2), pp.119-129, 2005.

Gupta, Y.P., Life cycle cost models and associated uncertainties. *In Electronic Systems Effectiveness and Life Cycle Costing-Springer Berlin Heidelberg*, pp. 535-549, 1983.

Haroun, A.E., Maintenance cost estimation: application of activity-based costing as a fair estimate method. *Journal of Quality in Maintenance Engineering*, 21(3), pp.258-270, 2015.

Hinow, M. and Mevissen, M., Substation maintenance strategy adaptation for life-cycle cost reduction using genetic algorithm. *IEEE Transactions on Power Delivery*, 26(1), pp.197-204, 2011.

Jing, G., Qi, L., Desheng, L. and Qin, G., Research on Life Cycle Cost model of SBA for complex equipment. *IEEE Symposium on Robotics and Applications (ISRA)*, 2012.

Kolarik, W.J., Life cycle costing and associated models. *In Proceedings of the American Institute of Industrial Engineers 198,* Spring Annual Conference, (pp. 58-64), 1980.

Lindholm, A. and Suomala, P., Learning by costing: Sharpening cost image through life cycle costing?. *International journal of productivity and performance management*, 56(8), pp.651-672, 2007.

McClurg, T. and Chand, S., A parallel machine replacement model. *Naval Research Logistics (NRL)*, 49(3), pp.275-287, 2002

Obiajunwa, C.C., Skills for the management of turnaround maintenance projects. *Journal of Quality in Maintenance Engineering*, 19(1), pp.61-73, 2013.

Sacks, A., Nisbet, A., Ross, J. and Harinarain, N., Life cycle cost analysis: a case study of Lincoln on the Lake. *Journal of Engineering, Design and Technology*, 10(2), pp.228-254, 2012.

Seif, J. and Rabbani, M., Component based life cycle costing in replacement decisions. *Journal of Quality in Maintenance Engineering*, 20(4), pp.436-452, 2014.

Thaduri, A., Verma, A.K. and Kumar, U., Comparison of reliability prediction methods using life cycle cost analysis. *In Reliability and Maintainability Symposium (RAMS)*, 2013 Proceedings-Annual (pp. 1-7). IEEE, 2013.

Turner, P., The negative impact of Eskom's MYPD3 proposal. *Centre for Research and Continued Engineering Development*. Sibanye Gold, South Africa, 2017.

Waghmode, L.Y. and Patil, R.B., Reliability analysis and life cycle cost optimization: a case study from Indian industry. *International Journal of Quality & Reliability Management*, 33(3), pp.414-429, 2016.

Wang, Y., Li, F., Yang, Y. and Dong, Z., Reliability and maintainability optimization of mechanical system based on the life cycle cost. *In Technology and Innovation International Conference 2009 (ITIC 2009)*, (pp. 1-4). IET, 2009.

Woodward, D.G., Life cycle costing-theory, information acquisition and application. *International journal of project management*, 15(6), pp.335-344, 1997.

Biography

Njabulo S. E. Buthelezi started his engineering career ten years ago working as a Design Engineer for a consulting firm specializing in the design of smelting equipment, sub-merged arc furnaces. During this time, he accumulated a vast knowledge in the design, construction and commissioning of a various mining system including fume extraction, cooling water, screening, feed system and material handling. He is currently employed as a Lead Engineer for a Product Support Department which provides after-sale service to various mining customers. He leads a team of engineers and draughtsman which provides on-going technical support to ensure their customers meet their anticipated production levels. His interests revolve around the topics of reliability and maintainability as well as equipment optimization. He obtained a Bachelor's Degree in Mechanical Engineering from the University of Johannesburg, and he is currently pursuing his Masters in Engineering Management.

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