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Exploring Strategies for Reducing Cost of Maintenance on Heavy Mobile Mining Equipment

The Case of Golden Star Wassa Limited

BY

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DECLARATION

I hereby declare that this submission is my work towards the MSc Project Management and that, to the best of my knowledge, it contains no material previously published by another person, nor material which has been accepted for the award of any other degree of this university or elsewhere, except where due acknowledgement has been made in the text.

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DEDICATION

I would want to dedicate this thesis to my wife, Mrs. Theresa Oware, for her support morally and spiritually. I love you!

ACKNOWLEDGMENTS

I want to thank the Almighty God for giving me strength and good health during the thesis. I also want to thank the entire maintenance staff of Golden Star Wassa Mines for the incredible support and opportunity to undergo this thesis with the company.

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ABSTRACT

This study explored strategies for reducing cost of maintenance on 'heavy mobile mining equipment.' 'Maintenance operations' consume a significant portion of the operating cost of these fleets. Three objectives were set to enable the researcher achieved the primary goal of the study. ‘Surface mining equipment ' has a finite economic life that occurs before the end of the equipment’s physical life. This research initially intended to collect and pre-process the maintenance work database through questionnaires and interview of key personnel in the industry. To obtain a better model for each of the available equipment classes, 'data mining analysis ' was used to compare different algorithms. These trend analyses and models will help the equipment manager to take decisions related to 'equipment maintenance cost. The results showed that operating cost has a significant impact on the cost of maintaining 'heavy mobile mining equipment.' Large companies do economic analysis, as recommended by the equipment suppliers. They incorporate the quantifiable factors of' increased 'maintenance cost,' decreased performance and technological improvements. Smaller mining companies and contractor companies generally only consider historical cost and performance trends, and there is scope for improving the replacement decision of their 'heavy mobile mining equipment.' The study made the following recommendations; all mining and contracting companies to draft and introduce a formal policy for the replacement of their 'earthmoving equipment,' the equivalent annual cost (EAC) model is the most suitable model for the replacement of 'heavy mobile mining equipment,' and 'maintenance strategy' should be adopted once it has been implemented

Keywords: Earthmoving equipment, Maintenance, Heavy mining mobile equipment.

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GSR	Golden Star Resource
TPM	Total Productive Maintenance

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

In the arena of heavy mining equipment, equipment management, which include ways of maintenance cost reduction has blossomed as a vital topic. Vorster (2003) stated that managing equipment primarily comprises of operational, financial and aspects relating to the mechanical factors of the equipment. The primary obligation of managers of equipment is to affirm their support for the activities relating to mining by providing the equipment requirement to meet the schedule within a low-cost budget. The mechanical and financial aspects of an equipment are very essential to the availability of the equipment of different mining projects at a sensible price. Vorster (2003) states that one who manages equipment has to check and ascertain that all activities relating to the equipment is being done according to a schedule. The equipment should be operated at an optimal ownership and operational cost. The constituents of the operational cost include the cost of tire, cost of fuel the wages of the operator and the cost involved in maintaining the equipment. The cost of maintenance forms a significant component of the budget for operating the equipment. These equipment maintenance costs differ according to the type and model of the equipment. Costs for maintenance may vary for the same equipment because of different manufacturers.Golden Star Wassa Limited intends going for contract mining in 2022 for their Surface mine operation. The simple reason is that cost per ton is much higher when it is owner mining as compared to contract mining. The cause is attributed to the higher maintenance cost of the mobile mining fleet as the critical driver of the price. Perseus mining company in Ayamfuri is already in that system for the past seven years where the pit mining is contracted to AMS and

Rocksure international mining contractors. Some other mining companies not excluding Goldfields Ghana Limited Tarkwa and Daman have followed suit.

This study investigates the sources of higher maintenance costs and finds ways of reducing them, offer technical advice to GSR Wassa so that their Open pit operation will not be outsourced to mining contractors. Pending outsourcing of the open pit mining to contracting firm, partial redundancy has been carried.

1.2 PROBLEM STATEMENT

Many companies in the early days resorted to run-to-failure repairs, this form of repair policy is defined as the reactive maintenance. This restores an equipment back to its old state in the shortest possible time. These companies that employ this form of maintenance have reserved machines in place to cater for spare parts inventories, and reassign workers to tackle unscheduled breakdowns (Sheu & Krajewski, 1994). Failure of an equipment, in many cases, results in hold ups in the completion of a project, which decreases the rate of production. The hourly rate of production of a machine is influenced by many factors. e.g., operator efficiency, weather condition, and the availability of the equipment. The most controllable element among these factors is the equipment availability. (Rapp & George, 1998).

Therefore, top firms undertake regular inspections in order to avert possible breakdowns that are time-consuming. These regular reviews and servicing, which are scheduled by an inspector, are called planned or preventive maintenance. In the 1950s, progressive corporations added preventive maintenance (PM) to reduce unscheduled breakdowns (Sun, 2012). The PM is scheduled upkeep work suggested with the aid of producers to preserve machines in the pleasant running condition (Nunnally, 2000). (Panagiotidou & Tagaras, 2007) stated that preventive upkeep insurance policies help to enhance dependability and to decrease costs associated with maintenance. The Preventive maintenance was a significant leap which gave equipment managers some assurance over breakdown of equipment. Previously equipment failures were taken as acts of God, and there was nothing that could be done about it (Sun, 2012).

There is some other kind of maintenance referred to as total productive maintenance (TPM). TPM was first applied by firms in japan in the 1970s, American companies became acquainted with total productive maintenance in the late 1980s, when Seiichi Nakajima's books, Introduction to TPM (Nakajima, 1988) and TPM Development Program (Nakajima, TPM Development Program: Implementing Total Productive Maintenance, 1989) became accessible in English. Nakajima (1989) said that the two targets of TPM are zero defects and zero breakdowns. To achieve these targets, operators are more attentive to maintenance work which makes them care a great deal about the equipment (Sun, 2012). Machine operators are skilled and turn out to be accountable for some fundamental upkeep work, however still, there is a maintenance branch in the business enterprise to cope with primary repairs and preventive maintenance units, carry out repairs to OEM specification and educate operators (Sun, 2012).

Given the preceding, a regime that looks at sources of higher maintenance costs and ways of cost reduction in heavy mining equipment are very limited in the literature. It is this gap in the literature that this extant study seeks to address.

1.3 RESEARCH QUESTIONS

The following research questions were posed to find answers to the research problems:

1. What are the alternative ways of reducing maintenance cost to acceptable economic levels for Heavy Mobile Mining Equipment?

2. What advice can be proffered to management of mining companies so that the surface mining will not be outsourced to mining contractors?

3. What are the current trends of maintenance cost for different types of heavy mobile mining equipment?

1.4 AIM

The aim of the study was strategies to reduce cost of maintenance on Heavy Mobile Mining Equipment.

1.5 SPECIFIC OBJECTIVES

To achieve the aim of this study, the following objectives were set;

- To examine existing Maintenance Strategies in Golden Star Wassa Limited for Heavy Mobile Mining Equipment;
- To identify cost centers within the existing maintenance of Mobile Equipment maintenance; and
- To propose strategies for reducing cost of Heavy Mobile Mining Equipment.

1.6 SCOPE OF WORK

Even though this study was in the interest of all the participants in the Ghanaian mining industry, attention was concentrated on key personnel in the mining sector. The study was limited to the Golden Star Wassa Limited mines. The study was confined to the ways of exploring strategies for reducing cost on maintenance of Heavy Mobile Mining Equipment at Golden Star Wassa mines as part of project management technique to control project cost. These portable machines are also referred to as heavy construction equipment. The time to conduct this relevant study to the Golden star Wassa mine is a limiting factor.

1.7 RESEARCH METHODOLOGY

The following approach was followed to accomplish the proposed research objective and specific goals: The maintenance operation of Heavy Mobile Mining Equipment will be reviewed from a general perspective as well as from the perspective of Golden Star Wassa. The internal procedure of different types of maintenance work will be analyzed to understand the pros and cons of the current procedure in chapter two. The literature on different maintenance systems of heavy mining equipment, maintenance cost forecasting methods and concepts of different algorithms that could be used for this research work were studied and reviewed. Data was collected and analyzed in chapter three.

1.8 JUSTIFICATION FOR THE STUDY

The mining sector employs a substantial amount of the Ghanaian youth and this translate into the reduction of unemployment rate in the country. Also, payment of royalties helps the government and the chiefs in the mining catchment areas to carry out developmental projects. Again, the performance of corporate social responsibilities helps the mining communities to improve upon their standard of living. The Heavy Mobile Mining Equipment of Golden Star Wassa mines range substantially in size and rely on some factors such as the method of mining, the volumes of production, and strip ratios. An opencast mine of a large-size should have a fleet of mining equipment of a number of dozen machines. Placing the financial burden on floor mining equipment, depends on your view demonstrates that mining businesses generally, replace almost 10% of their floor tools yearly. It is consequently comprehensible that mining agencies expend extensive amounts of money yearly in replacing their heavy equipment. This study aids to discover the choice desire of heavy equipment used in mining. It is a difficulty with a high vast range of risks and variables.

1.9 ORGANIZATION OF THE STUDY

The presentation of the report was grouped into five sections as follows: **Chapter One**: Provides background information leading to the statement of this study. It defines the objectives, the scope of work and limitations and delimitations. **Chapter Two**: The section consisted of a review of relevant literature which will provide useful knowledge with the help of past research publications into the nature of standard equipment replacement theory in the mining sector. Construction equipment replacement models, aged-based equipment replacements, applying theory into practice will also be discussed. The secondary data for the research literature will be sourced from books, newspapers, electronic media and journals.

Chapter Three: Provided information on the research design, population, and sampling, unit of analysis, data collection and analysis, confidentiality, limitation of the study, and ethical issues. **Chapter Four**: Provided findings and the discussion of the results of the study. **Chapter Five**: Provided a summary of the findings, conclusion, and recommendation to the Golden Star Wassa mine management team and suggestions for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Mining is a capital-intensive business requiring large size, expensive equipment, such as 12–40 trucks with over 100 tons' capacity, large excavators, loaders and ancillary equipment fleet. The capital costs of these large fleets can be as high as a few hundred million dollars. To sustain the business in a financially secured and stable condition, all aspects of the mining operation must be managed optimally as much as possible. Equipment maintenance cost is one critical financial aspect of a mining operation. Maintenance cost can constitute around 30–50% of the overall haulage costs of a surface mining operation that uses truck and shovel fleets for overburden and ore removal. As part of the process of maximizing profit and minimizing costs, mining operations are continually striving to obtain maximum equipment productivity. Due to the high operating costs associated with mining projects, even a small increase in mining equipment productivity will often result in savings of millions of dollars. As surface mining operations expand and become more profound, more material will need to be hauled longer distances with a consequent increase in truck cycle times. The maintenance application wants to be embedded for the duration of plant graph and construction. As an outcome of many advancements in upkeep management, the overall performance of environmentally friendly plant can be carried out by means of utilization of these plant and equipment. The decision of the ideal machine and plan of the plant can affect maintenance and maximize productivity.

2.2 BENCHMARKING AND CURRENT STATE EVALUATION

The benchmarking is the commencement to acquire a foremost maintenance application with employees, executing fantastic work, the utilization of authentic gear to conform to manufacturing goals is to discover improvement wants and priorities. Assessing the current country will aid determine the present-day levels of maintenance performance with activities that choose enhancement and these that are being carried out well. When the areas marked for improvement diagnosed and prioritized, these serve as prospects for deducing a solution. Evaluation ought to antecede benchmarking to decide the quintessential enhancement wishes for an enterprise or a processing plant. Subsequently, the target areas to be benchmarked can be recognized alongside with target corporations that are efficaciously performing the equal kinds of functions. A motion graph can be put at the same time to span the space between the cutting-edge and aim states. Educating team of employees and their dedication to presenting information for enhancing protection is a necessary issue in organizational alternate management (Tomlingson, 2008).

There are various types of equipment scheduling including random and settled optimal models Pinedo (2008). The total completion time of the job and expected amount of late jobs is the primary focus of equipment problem scheduling in multiple parallel machines. The job with the longest execution time is always scheduled last to increase productivity in a day. In some cases, jobs are scheduled in an exponential manner, in such cases jobs with the most important variance are scheduled and executed first. The models cannot be employed directly onto the mine truck to find a solution to the scheduling program, this is because maintenance costs of trucks in mining do not vary linearly, and the distinct single jobs for each truck cannot be easily ascertained from other trucks and equipment. The mixed integer programming (MIP) model for shifts dependent on a sequence and those devoid of any sequence in machine planning and sequencing problems. Formulated for the lot sizing, the model was designed for single machine, multi-item with shifts or changeover cost pertaining to a unique item during each production period. This paper is not a case study, instead it agrees with the concepts stated in similar applications in dissimilar industries.

For a single vehicle an MIP model was developed for the flexible manufacturing systems scheduling problem (FMSSP) (Caumond et al. 2009). It considered resources with limited capacities for both jobs and equipment scheduling, the maximum number of jobs allowed simultaneously and management of buffer related to inputs and outputs in the system. The proposed model allows for an optimal solution to the demonstrated scheduling of minute and average problems associated with complexity. A new MIP was proposed by Dodin and Elimam (2008) to cater for scheduling projects together with equipment planning. This model looks at multiple activities or events happening at the same time and allocates the available equipment based on cost tradeoffs such as holding, transition costs and holding costs. In order to reduce time spent on CPU, they formulated a model to consider any project with a start time of zero by adopting an optimal schedule with a zero-start time. Furthermore, to make the MIP model more amenable computationally, a general guide has been developed to determine appropriate destinations for each piece of equipment between jobs. The MIP model proposed was tested on eleven projects which involved four network structures, and the generated solutions were delivered.

Available methods for solving the problem of dispatching and analyzing schemes Alarie and Gamache (2002). The attempts to optimize systems for dispatching of trucks do not include the schedule of equipment's utilization to mitigate the cost of maintenance. Burt et al. (2005) developed an MIP model to select the precise correspondence of trucks to the loader fleet. The objective of the model was to denigrate the cost of operating with the correspondence while sticking to the standard requirement for production during operation. Using two decision variables, the model selects the best fit for a fleet of mixed nature within period; one variable identifies the truck type X, the number available and working with a loader Y and the second determines the number of loaders X, working with truck type Y. However, the model does not consider the age of the equipment and the cost to be incurred in maintaining it, it employs an unrealistic plan by using the average cost values for equipment, which does not consider the global optimization of mine life.

2.3 TYPES OF MAINTENANCE

Most equipment is designed and can be extended on condition of periodic maintenance of the equipment. Failure to undertake maintenance activities decreases the lifespan of the equipment Maintenance can be grouped into types, these are; preventive maintenance, corrective/reactive maintenance, reliability-centered maintenance and predictive maintenance (Fig.2. 1)

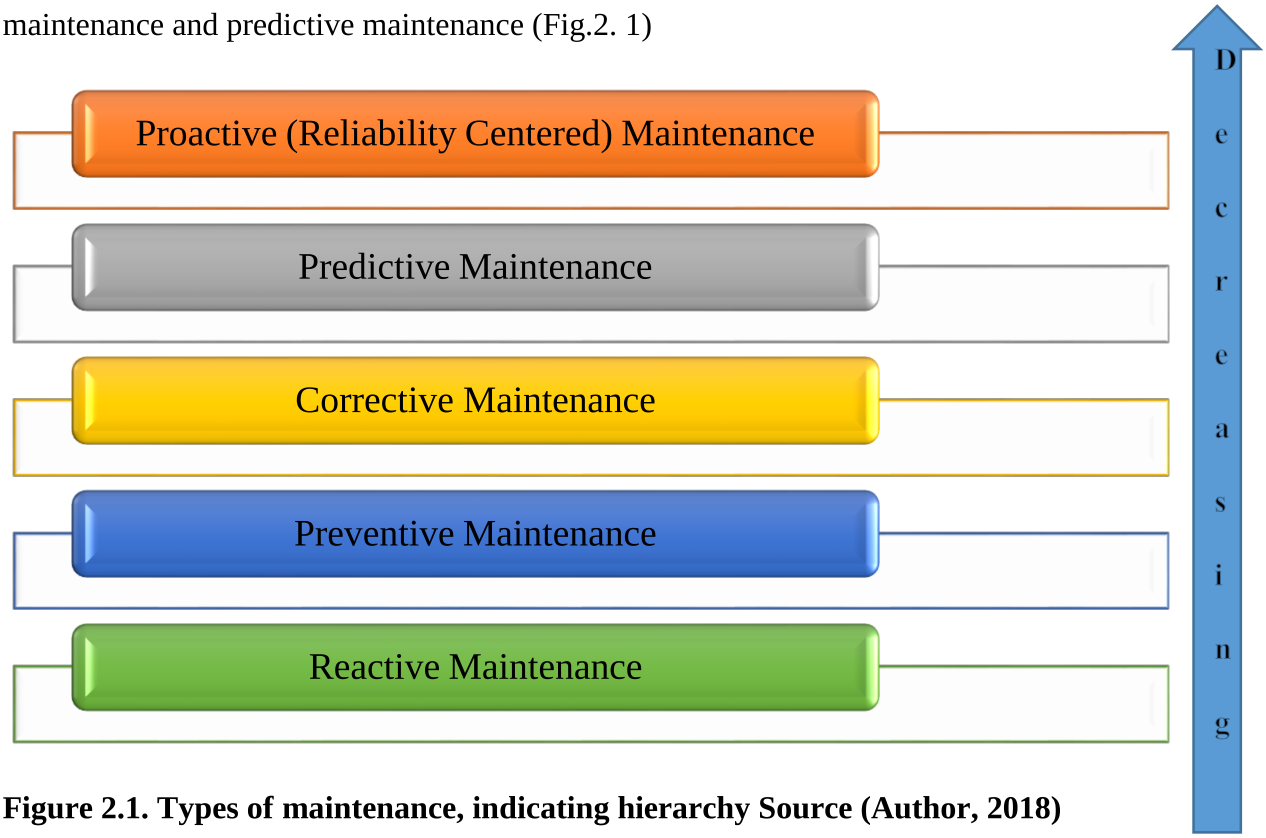

Figure 2.1. Types of maintenance, indicating hierarchy Source (Author, 2018)

2.3.1 Reactive/Corrective Maintenance

The goal of corrective protection is to restore machinery to their preceding state when wished both through scheduled design or observation on the field. The prioritization of such fixes then scheduled maintenance is aborted (Hern, 1995). With this approach, minimum effort is expended to preserve the gear as planned by the designer to extend the existence of the product to its maximum. Studies exhibit that this approach is the dominant approach of maintenance in the United States and other nations (DOE, 2010).

2.3.2 Preventive Maintenance

Compared to reactive maintenance, preventive mainteance is a better method. This type is regularly undertaken based on a schedule (Hern, 1995). Routine checks and replacement of parts based on time of use of the part are undertaken. These periodic checks are mainly determined from the lifespan of similar components previously used. Some components that are far from their expiration are replaced due to preventive maintenance, researchers therefore stated preventive maintenance to be wasteful and inefficient (DOE, 2010). The maintenance intervals can be defined regarding elapsed hours (days, months, years) or operating hours. Key performance indicators (KPIs) for maintenance such as availability (A), mean time between failures (MTBF) and mean time to recovery (MTTR) are greatly influenced by these intervals. Conversely, operational time-based preventive equipment maintenance also requires efficient management of KPIs. The availability of a fleet is a key management parameter to be predicted and controlled. Kothamasu et al. (2006) state that the only way to ensure minimum maintenance costs and a minimal probability of failure is to monitor equipment condition and failures routinely and to make predictions by current conditions and historical equipment maintenance and operations.

2.3.3 Corrective Maintenance

Corrective maintenance is the process of fixing things that are broken or not performing well. Examples are; Emergency Repair, Service Outages, Repair, Performance, and Quality. Depending on the context of its use it may refer to maintenance due to a breakdown, or maintenance identified through a condition monitoring program. Corrective maintenance performed due to a failure could be either planned or unplanned. In this case, planned corrective maintenance is likely to be the result of a run-to-failure maintenance plan, while unscheduled corrective maintenance could be due to an breakdown not stopped by preventative maintenance, or a failure due to a lack of a maintenance plan (this is the same as reactive maintenance. Unplanned, maintenance, like reactive maintenance, is much costlier than planned maintenance. Maintenance performed due to condition-based monitoring software is scheduled maintenance.

2.3.4 Predictive Maintenance

Preventive preservation can neglect some problems. However, such issues are detected by way of predictive maintenance. The oncoming deterioration mechanism of an equipment is recognized through predictive maintenance. This makes room for the removal or control of stresses before any massive deterioration in the bodily kingdom of the component. Predictive maintenance constitutes of one-of-a-kind factors including; oil analysis, thermographic analysis, motor meagering and vibration analysis.

2.3.5 Proactive (Reliability-Centered) Maintenance

Reliability-centered/proactive maintenance bears on efficacious decision making taking into consideration merits and demerits as well as limited resources. It caters for the probable failure due to different mechanisms of degradation. It prioritizes actions by considering the limited financial and human resources. This directs focus to essential items to be effectively dealt with (DOE, 2010). Reliability Centered Maintenance (RCM) assesses the modes of failure of a valuable asset and develops a strategy to maintain and extenuate the aftermath for each one. Equipment failures can be classified to track their happenings. Failure codifications include:

- Defect of materials;
- Defects pertaining to design;
- defect of installations;
- Errors in fabrications;
- Inadequate maintenance;
- Bad service conditions; and
- Improper use.

Tracking the price of incidence and the influence of failures can be a useful resource in the location of focal points, whether it be a manufacturer, manner or a particular equipment, (Plucknette, 2014). The cost incurred through using this strategy is very minimal compared to the other prices.

2.4 TECHNOLOGY-ENHANCED MAINTENANCE MANAGEMENT

The maintenance administration system can be heightened with the aid of making use of technology. Computerized maintenance management systems (CMMSs) are employed in quite a number of sectors of the economy. CMMSs have been developed since the late 1980s, and it very exotic that a large association involved in the renovation of equipment would do so barring applying any specialized software program to useful resource in enforcing strategies. Some of the CMMS are CMMS/EAM, TabWare, FIIX (cloud-based) and Bentley Systems. Sometimes CMMSs are tied to incomes and outflows of revenue and expenditure where they can be associated to purchasing, receiving, and also colligating to accounting systems for payables to heighten the efficiency of the workflow and expediting decision making in large organizations. Industries that are more capital-intensive have employed software that integrate CMMS with their software for planning. CMMS is a capital-intensive venture. Furthermore, hosting of such service can add up to the maintenance cost, therefore, size of the firm needs to be considered while adopting such systems. Work orders can be scheduled effectively using CMMS. These systems operate with highly required inputs and enhanced reporting for staff, plant, corporate maintenance leadership and site managers. Initial maintenance assessment is done by spider diagram fig. 2.2.

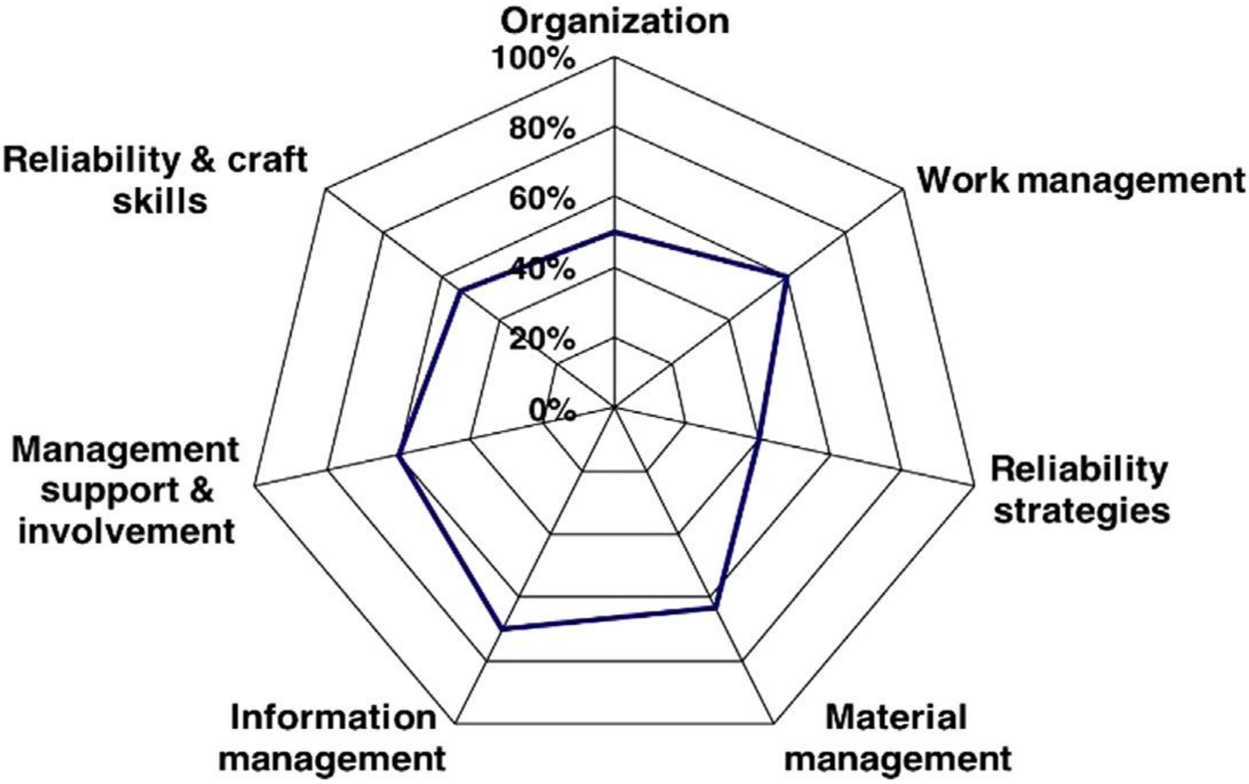

Figure 2.2: Spider diagram indicating initial maintenance assessment.

Source (Kumar 2018).

2.5 CRITICAL SPARE PARTS ORDERING DECISIONS

Decision-making processes are crucial for organizations within a scenario of intense competitiveness. Since companies are frequently required to reduce production costs and increase asset utilization, misguided decisions may lead to over-stress on equipment. An efficient resource ordering is indispensable to achieve significant availability exigencies of equipment-intensive industries, such as Mining, Aeronautic, Nuclear Energy, or Defense. This equipment is supported by spare parts inventories, which are particularly relevant considering the influence of stock-outs on downtime (Louit, 2007). Appropriate spare parts allocation decisions are therefore essential to system performance of these industries. The improvement of key profits on both logistics and maintenance performance can be achieved by inventory management of expensive components, which have extremely criticality on equipment-intensive industries (Braglia & Frosolini, 2013). According to (Wang et al., 2008), few existing ordering and replacement policies are proposed in the context of condition-based maintenance. Spare parts estimation based on reliability and environment-operational conditions is a method to improve supportability. This method can guarantee non-delay in spare parts logistics and to improve production output (Ghodrati et al., 2010).

2.6 CONSTRUCTION AND MINING EQUIPMENT REPLACEMENT MODELS

A tool for determining which equipment owners time the equipment replacement decision is the replacement analysis tool. The cost of owning the present equipment is compared with the cost of owning potential alternatives for replacing the worn-out equipment can be determined through the analysis. The following sections explains the theoretical and practical methods to accomplish the equipment management task

2.6.1 Theoretical Methods

A theoretical method for executing replacement analysis include the minimum cost method, intuitive method, the mathematical modeling method and the maximum profit method. The advantage with these approaches is that each procedure can be applied to a different type of equipment owner.

2.6.2 Intuitive Method

This is the most predominant method among the theoretical methods due to its simple application and understanding. This method primarily depends on individual judgment and requires a little experience to make replacement decisions. Replacement of equipment normally takes place when there is a requirement for a major overhaul or at the beginning of a new equipment-intensive job. The most decisive factor for replacement is the availability of capital. These decisions have no sound economic criteria to be used as a standard to be followed for a planned and orderly replacement program (Douglas, 1978).

2.6.3 Minimum Cost Method

A relevant goal for owners of equipment is the minimization of costs. However, reduction in such costs is dependent on firms or groups that own large and small fleets of construction equipment, as they have no mechanics to generate revenue to cancel out their costs. In attaining this goal, this method focuses not only on operating and maintenance cost of a piece of equipment but also the reduction in the book value of the equipment due to depreciation. This method provides a rational for replacement unlike the intuitive method. The replacement of an equipment is undertaken annual cost of the equipment for the next year exceeds the minimum average annual cumulative cost of replacing it (Douglas, 1978).

2.6.4 Maximum Profit Method

Revenue can be generated by firms, so can profits be generated as well. Defining and isolating the profits associated with a piece of equipment is a very effective practice. The process of isolating annual profit of an equipment from the profit generated by a whole project or a fleet of equipment. The economic life of equipment is the year in which the average annual cumulative profit reaches its maximum. This leads to recordings of high profit margins over a long period. Determining the right time for replacement is a critical factor in this method. the best time for replacement is when the following year's estimated annual profits of the current equipment fall below the average annual cumulative profit of the proposed replacement (Douglas, 1978).

2.6.5 Mathematical Modeling Method

Computer software for construction management problems has provided a simple and precise means to figure out complex problems related to connected systems containing lots of input. Utilizing a computer model to determine all the essential times for replacing the equipment and selection decision makes room for more accurate solutions to be attained. A mathematical model to aid in equipment decision making should include the following factors (Douglas, 1978):

- Time value of money;
- Technological advances in equipment (obsolescence);
- Effect of taxes (depreciation techniques, etc.);
- Influence of inflation, investment credit, gain on sale;
- Increased cost of borrowing money;
- Continuing replacements in the future;
- Increased cost of future machines; and
- Effect of periodic overhaul costs and reduced availability

2.6.6 Payback Period Method

(Peurifoy & Schexnayder, 2002) described the payback period as the time required for the value of an equipment to return to its initial investment by generating returns. This method provides a measure based in time instead of money and allows for the comparison of options depending on the time taken for each possible piece of equipment to recover its investment. This method is helpful when it is difficult to auspicate equipment cash flow due to market, inherent uncertainty, technological changes and instability. This method developed from classical engineering economic theory and thus does not seek to determine the economic effects after the payback period. It is therefore recommended that, it is used together with other methods for analysis to provide a wider view in optimizing equipment replacement decision.

2.7 COST CENTERS

Costs are categorized into two main streams, the first category are the costs incurred by owning a machine (Vorster 2003, p.63). important aspect of possesing an equipment, the costs per hour is the fact that such costs reduces with the increased use of the machine. The next category is the operating costs, these are costs incurred while using the machine. (Tomlingson, 2015) referred to that ideal program for maintenance can result in a soar ability for manufacturing and high profitability. The following are targets for maintenance management:

- Minimize whole maintenance fee;
- Minimize the equipment idle time;
- Maximize the lifespan of the capital asset;
- Minimize energy utilization and accidents;
- Optimize maintenance resources;
- Better utilization of preservation tools and personnel (Kumar, 2018).

2.8 LIFE CYCLE COST

Life Cycle Cost Analysis (LCC) is a mature business discipline that was once developed to enhance the cost effectiveness of equipment procurement by way of estimating the full fee of ownership of a precise asset or undertaking for its entire economic life. The method offers important benefits, including:

- It identifies all costs associated with a project or investment, from concept to retirement;
- It allows managers to consider possible trade-offs between capital and operating expenses, especially in terms of up-front costs which may result in long term advantages; and

- It offers a framework with which to design and assess the actual operating strategy for the asset (Dwaikat and Ali, 2018).

The methodology was introduced into settings where the operation and maintenance of assets clearly represent the majority of total expenditure, thus justifying extra effort at the outset to identify which combination or alternative represented the most attractive total cost option. LCC consists of the price of acquisition, operation, maintenance and disposal for the existence of an asset.

Life Cycle Cost = Capital Cost + Operating + Maintenance – Disposal

Where;

- Capital Cost = sum of all net prices related with obtaining and assembling the gear on site. This includes the rate of the laptop (net of trade-in), freight, assembly, commissioning costs such as testing to meet nearby regulations, and training. It should also include costs of changes or additions to other assets in order to service or accommodate the new vehicles, such as new shop bays, tools, or road modifications.
- Operating = cost of operating the equipment, primarily fuel, tires, and wear items. In some cases, the cost of an operator is included in the analysis if one alternative enjoys such a significant productivity advantage that fewer machines (and operators) are required.
- Maintenance = consists of ordinary preventive maintenance, lubrication, repairs, and major factor overhauls.
- Disposal = internet proceeds from disposal, along with sale charge and demobilization fees (freight is normally the buyer's responsibility). There is a rule of thumb that the residual value of a mining machine seldom exceeds the cost of demobilization and should therefore always be

assumed as zero: however, this is not always correct, depending on location and market conditions.

LCC has been employed in support of mobile equipment for many years, primarily as a tool for assessing equipment purchases and as a framework for developing maintenance plans (every mobile equipment planner has a spreadsheet that constitutes an LCC model). It has other uses, however; its zero-based structure makes it ideal for budgeting, evaluating specific maintenance tactics at the component level, and as the driver for determining required physical and human resources to support mobile equipment fleets. LCC is a discipline that is understood and accepted in the mobile equipment user community, but has not been universally adopted. Commercial real estate investors, for example, utilize common LCC standards to assess competing projects and gauge operating performance (Dwaikat and Ali, 2018).

2.9 MAINTENANCE COST

Maintenance costs are the direct prices associated with servicing the truck in order to make sure its mechanical integrity, permitting it to produce. Mine personnel are generally responsible for day-to-day preservation activities, while the supplier handles guarantee repairs and duties requiring great off-site assets or proprietary technical skills. These offerings are managed by means of the mine's Maintenance and Purchasing Departments. Maintenance charges are controllable and predictable. Haul trucks have a formal equipment plan, which describes the upkeep approach for the automobile inclusive of carrier intervals, anticipated minor and main components' service lives, sources of supply, an on-hand inventory plan, and a condition-monitoring strategy to aid maintenance and reliability engineers. The key to managing renovation costs is to maximize the level of planned, preventive endeavor and to carefully file and determine results via disciplined use of work orders associated to precise pieces of tools and sub-assemblies. From the equipment plan, Life Cycle Cost Analysis requires a realistic estimate of the annual preservation expenditure for each truck, including parts, materials, labor (both inside and external), freight, extraordinary education and tools. These estimates commonly categorize fees as:

- Running repairs - minor leaks and breakage, inspections, alarm investigation, welding; commonly undertaken in the subject and executed in much less than one shift;
- Scheduled preventive preservation (PM's) - lubricant and filter changes, adjustments, scheduled inspections, and minor section replacements, deliberate and coordinated to be performed for the duration of scheduled store visit; Box overhauls - re-plate, repair any structural problems, modifications. Wear rate depends on payload material, though 15,000 hours is a typical interval; and
- Major components - planned major repairs to components and systems. Scheduled to occur concurrently wherever possible in order to minimize downtime, and often managed using exchange components rebuilt offsite

2.10 MAINTENANCE MANAGEMENT SYSTEM

A plant/equipment used for mining activities need to be nicely maintained it is the underlying shape of a rich management system (MMS). The reason of the MMS is to grant a sturdy basis for value reduction, renovation work, and to set desires for uninterrupted advancement. A firm's success is structured on repeatable and continuous production that outcomes from proactive and ordinary maintenance. MMS is a perfect concordance of machine, methods and man (the 3M framework).

2.10.1 Man

The best should always be recruited and a standard must be set to enforce it. The consistent depreciation in the people interested in maintenance of equipment has led to a reduction in the skill level of the workforce, this conjugated with the competition from the various industries has caused a reduction in the pool of people available for recruitment. Automated methods can be put in place to these issues. Therefore, mining companies are straining to be more safe, cost-efficient and reliable.

2.10.2 Machine

Several mine plants use outdated equipment. Overhauls require substantial capital to begin the process. The use of the right equipment can reduce drastically, the maintenance costs. Due to advances in technology, many pieces of equipment are not requirements for higher rates of production leading to reduced cost of maintenance. Effective design of plant plays a vital role to this effect (DeHart, 2007). Revenue generated reduces with an increase in activities that lengthen the maintenance cycle in firms. Steps involved in maintenance have become more automated with the current advancement in technology. The use of standard methods will simplify maintenance. (Hern, 1995) stated that mistakes in rebuild and installation can be reduced by fixing standard vibration screen drives.

2.10.3 Methods

The organizational subculture of a firm is indispensable in the willpower of the profitable nature of preservation schedules. A flaw in the renovation application of an association is the failure of an equipment. In this study, the lowest-cost profitable oil refineries had the least demand for repairs (Ricketts, 1994). Clear definition of roles and obligations is pivotal in accomplishing higher results.

2.11 ROOT CAUSE ANALYSIS

This analysis is very important to realize the cause of any failure and to prevent it from repeating itself. What may seem like the problem might end up being a symptom instead. Practical tools, such as 5- why analysis, material failure analysis, flowcharting, and fishbone analysis can simplify the process and aid in getting required results.

2.12 PROCEDURE-BASED MAINTENANCE

Maintenance is required based on the real or approaching failure. A function based on time have to be used to aid in appreciation the efficient walking of a gear for its diagram life. Fig. 2.3 plots the fee of failure of aspects over time. The traditional bathtub curve characterizes the initial infant mortality phase as a high charge of failure accompanied by way of a period of the place the charge of failure decreases. Many of the failures accorded with this phase are as a result of bad installation or misapplication and poor design. During this stage, the practicable existence of the element has an almost non-stop rate of failure.

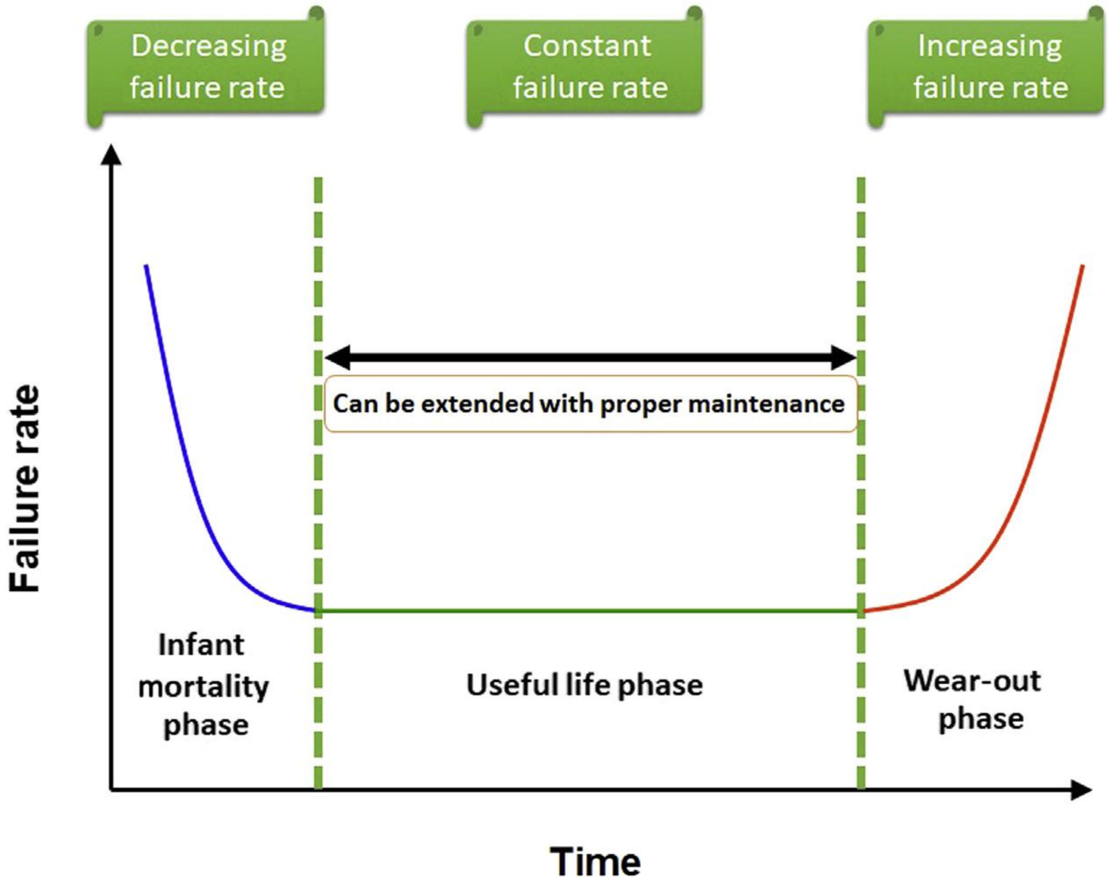

Figure 2.3: Bathtub curve, component failure pattern over lifecycle

(Source: Kumar 2018)

2.13 BASIC DESRIPTION OF GOLDEN STAR WASSA MINES

Wassa is in south-western Ghana, approximately 40 km from the Prestea Gold Mine. Golden Star commenced production from the surface operation at Wassa in 2005, and commercial production was achieved at Wassa Underground on January 1, 2017. In early 2018 Wassa transitioned into an underground-focused operation. Wassa Underground has exploration upside through extension drilling of B Shoot North, step out drilling on B Shoot South, step out drilling on the 242 Trend and the extension of the F Shoot. This work is expected to increase the mine life of Wassa Underground in the short, medium and long-term. Wassa mine is expected to produce 137,000-142,000 ounces of gold in 2018 at a cash operating cost per ounce of $600-650.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In the previous chapter, the relevant literature on the topic was reviewed to place the research in a sound theoretical context. This chapter deals with approach and methodological decisions taken to carry out the objectives of the research. It explains the context of the study, sample design, measurement tool, data collection procedure, and analysis techniques used and how they are appropriate to address the objectives of this research.

3.2 RESEARCH DESIGN

The study adopted a descriptive survey design. A descriptive survey design allows for an in-depth analysis and understanding of a particular phenomenon as it exists in the present condition (Cooper and Schindler, 2008). In a descriptive survey design, objectives are predetermined allowing data collection relevant and sufficient to the study problem (Kothari, 2004). By combining both quantitative and qualitative data collection procedures, descriptive survey design allowed a researcher to gather exhaustive information in a way that reduces the cost of the data collection. A research study that raises questions that require interviewing and questionnaires for data collection should use a survey design. The same Author further explained and quoted Orodho (2003) as defining a representative survey as a method of collecting information by interviewing or administering questionnaires to a sample of individuals. Indeed, this is what the questions of my study require and therefore will guide my choice of the design. The secondary data was collected using desk research. That is to say, internet, magazines, journals, reports, and textbooks as attributed to the literature review.

3.3 RESEARCH APPROACH

Two main approaches have been identified and named as the Deductive and Inductive research approach. The Deductive approach deals with what is already known as existing theories or ideas about a subject by identifying the theory and testing through observation to confirm the theory (Creswell, 2013). This approach involves a top-down approach in the formulation of the theory and testing of hypothesis while maintaining the independence of the researcher. That is to say that, the process starts from the identification of the relevant theories and the use of scientific study through observations to confirm these theories. The research is therefore used to test specific propositions, hence deductive approach adopted for this study.

3.4 RESEARCH METHOD

This research is based on deductive approach as it involves the use of already existing theories together with quantitative methods to make inference into maintenance cost reduction strategies. That is the study first reviews literature as a theoretical guide, and then collects data from participants. Hereafter, statistical techniques will be used to draw diverse meanings and interpreted within the context of the already existing theoretical framework. The results of this deductive method will be observations and findings unlike the inductive, which will be theories.

3.5 RESEARCH STRATEGY

In order to achieve this, a case study of the maintenance activities of Golden Star Wassa Mine was adopted. Case study research strategy involving a survey was adopted. To attain the general overview of issues on high cost of maintenance of heavy mobile mining equipment, employees of Golden Star Wassa mines, and other ancillary mining companies were interviewed. Questionnaires were also administered to seek answers from the various research variables. Heavy mobile mining equipment, engineering managers, project managements and others personnel from the mining industries were the target population for the study.

3.6 TARGET POPULATION

This represents an acknowledgeable group of elements (people) that are of activity to a researcher and opposite to a particular data associated problem. According to Salkind (2008), population is the entirety of a group of people. Sekaran and Bougie (2010) supported the notion, they mentioned that populace is described as the entire team of people the researchers desire to seem to be into. The population of this study about comprised the Mobile Mining Equipment professionals employed at the Golden Star Wassa Mines and Rocksure International Contract Mining, and the good-sized Mobile Mining Equipment companies contracted to function at the surfaces of these mines, also the original gear manufacturer (OEMs) had been involved in the study. The experts protected the engineering managers, area engineers, mine managers, website online managers, sales managers, regularly occurring managers and different humans worried in decision making concerning the substitute of cellular mining equipment. The authorities involved in this study are well vexed in the discipline of equipment maintenance. The population for this study was 95 personnel involved in mining activities.

3.6.1 Sample Size and Sample Technique

A sample of about 10% of a population can often give a reliable data Kothari (2014), sampling is very vital in research because an entire population is almost impossible to examine (Fellows & Liu, 2003). The unit for sampling in the study was exploring strategies for reducing cost on mobile mining equipment at Golden Star Wassa Mines and Rocksure international Contract Mining, contractor companies and equipment suppliers. Engineering managers, mine managers, sectional engineers, sales managers, general managers and other persons involved in the replacement and maintenance decision of Mobile Mining equipment were the target. However, according to Israel (1992) if a population is less than 200, the total population should be considered for the sample size. Hence, in this study the sample size is almost equal to the population. In addition, Israel (1992) advice that in such cases census sampling technique should be adopted. Thus, this study again adopted the census sampling technique in the data collection.

3.7 DATA COLLECTION

The researcher used questionnaires, interview courses and focal point team discussions for collecting secondary data. The questionnaires were used because they are effortless to administer and at the identical time, they generate a massive design of wished data. Questionnaires are economical, make sure anonymity, and allow use of standardized questions, shop time specifically the self-administered as the 76 respondents have an adequate time to suppose and fill the questionnaires at ease, as a result minimizing error. An interview guide was additionally used to elicit data from the senior management from the two mining companies. Document evaluation is a method of information series from documented sources. The researcher also used file evaluation to accumulate statistics that is now not captured in the responses in the questionnaires and others used. The Information used to be amassed from paper files as well as computer databases and coverage files from Ghana Chamber of Mines. Document analysis has benefits over other data series techniques because the files are predicted to be complete, detailed, and steady and well structured. They also saved on time when you consider that they are conveniently available.

3.8 DATA ANALYSIS

This is the process of collecting, modeling and transforming data to highlight useful information, suggesting conclusions and supporting decision making (Sharma, 2005). The Researcher collected the data, using questionnaires, interview guides, focus group discussion and document analysis. The data that was collected was examined and checked for completeness and clarity. Quantitative data that was analyzed using descriptive statistics while qualitative data was also analyzed using content analysis. However, Qualitative data was also transformed into quantitative data and analyzed by the helped of Statistical Package for Social Scientist and ANSWERMINER by the primary objectives of the study. The data was then presented using frequency tables, percentages and mean.

3.9 Ethical Consideration

The involvement of human participants creates ethical issues that need to be considered to ensure the ethical and moral compliance of the study (Farrell, 2011). The research was carefully designed to avoid creating any physical or psychological damage. Additionally, the respondents were informed about the aim of the research and how their data were going to be used, as well as full consent was. Furthermore, the option of withdrawing until the deadline of the survey was also available and clearly stated in the covering letter. All data collected were treated with respect and confidentiality, while the questionnaire was hosted in a reliable and secure platform that was chosen.

3.10 Limitation of Research

In this specific research, the chief limitation was the duration for this study. The topic is vast enough to be covered as a whole. Moreover, every project has their possible limitation and stringency as well. Thus, Project Management style can also differ. Participants were chosen by selecting earth hauling professionals associated to equipment from companies who were willing to participate in the study. Generalizing the results from this study will not apply to other mines with different settings.

CHAPTER FOUR

DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 INTRODUCTION

This section presents data analysis, results, response rate, and demographic characteristics of the respondents and discussions of the study in reference to the research objective and research methodology.

4.2 RESPONSE RATE

A total of 76 questionnaires were issued. Out of these questionnaires, 73 were returned duly completed. This represents a 96.1% response rate. This was considered a representative sample for further studies according to Mugenda and Mugenda (2003) who report that a rate of 50% and above is acceptable.

4.3 DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

This section sought to identify the demographic characteristics of the respondents. The demographic characteristics considered in the study were level of education, years of experience, involvement in mining projects, and job title.

4.3.1 Highest Level of Education

The researcher sought to establish the level of education of the respondents. The level of education encompasses knowledge and skills which enabled the researcher to understand the perception levels of the respondents. Table 4.1 shows the results.

Table 4.1 Highest Level of Education

Highest Level of Education	Frequency	Percentage
Doctorate	1	1.4%
Masters	7	9.6%
Degree	25	34.2%
Diploma	38	52.1%
Other	2	2.7%
Total	**73**	**100**

From the findings 52.1% of the respondents had a diploma; 34.2% had a degree; 9.6% had masters; 1.4% had a doctorate degree, and 2.7% had other educational qualification. It was concluded that a majority of the respondents had degrees and diplomas. Hence, they are in a better position to give good responses.

4.3.2 Years of experience

The study sought to determine the number of years of service of the respondents to establish whether they had attained adequate expertise to provide accurate and reliable information. Table 4.2 outlines the results.

Table 4.2 Years of experience

Years worked	Frequency	Percentage
Less than 5 years	11	15.1%
5-10 years	31	42.5%
10-15 years	15	20.5%
15-20 years	12	16.4%
Above 20 years	4	5.5%
Total	**73**	**100%**

The results show that 15.1% of the respondents had worked in the mining sector for less than 5 years; 42.5% of the respondents had worked in the mining industry for between 5 – 10 years. 20.5% of the respondents had worked for 10 – 15 years; 16.4% of the respondents between 15 -20 years and 5.5% had worked for more than 20 years.

4.3.3 Job Title

The study sought to establish the job title of the respondents at the workplace. This can help develop a relationship between the role of the respondents and levels of cost-cutting strategies. Table 4.3 shows the results.

Table 4.3.3 Job Title of Respondents

Job Title	Frequency	Percentage
Consultant	3	4.1%
Project Management	4	5.5%
Engineering Manager	3	4.1%
Planning Engineer	5	6.8%
Engineering Superintendent	5	6.8%
Maintenance Supervisor	10	13.7%
Other	43	59%
Total	**73**	**100%**

From the results in Table 4.3, 4.1% were consultant; 5.5% were project management; 6.8% were planning engineers of various engineering disciplines; 6.8% were engineering superintendent; 13.7% were maintenance supervisor and 59.1% in another level. This is in line with the population distribution of the study which showed that the majority of the population is in the engineering cadre.

4.4 TYPES OF MAINTENANCE PRACTICE ON HEAVY MOBILE MINING EQUIPMENT

The first objective of the study was to examine the types of maintenance practice on heavy mobile equipment. Respondents were requested to respond to a number of maintenance practices techniques by indicating the level of significant using a five-point Likert scale of 1=Not significant; 2=Less significant; 3=Moderately Significant; 4= Significant; 5=Very significant as shown in Table 4.4. The responses are summarized in the table 4.4 below:

Table 4.4: Types of Maintenance Practice on Heavy Mobile Equipment

No	Maintenance Type	Mean	Rank
1	Preventive	**4.8**	**1st**
2	Proactive	**4.5**	**3rd**
3	Reactive	**4.1**	**5th**
4	Corrective	**4.6**	**2nd**
5	Predictive	**4.4**	**4th**

Source: Field Survey (2018)

To analyze the findings, respondents who responded not significant and less significant were combined into one category of who opposed maintenance practice. In addition, respondents who responded moderately significant and significant were merged into another category of those who ―concurred with the maintenance practice. Another category was that of those respondents who responded very significant. Thus, the three categories of respondents were compared. The interpretation was then drawn from the comparisons of the three categories as shown in the following paragraph. The study findings in Table 4.4 show that the maintenance practices at Golden Star Wassa Mine are very positive (aggregate mean=4.5). From these comparisons, it can be seen that the respondents are in tune with the maintenance practices at the various mines. Thus, from this analysis, the following is the interpretation. The study respondents noted that preventive, corrective and proactive maintenance practices were very significant in the mining section with means 4.8, 4.6 and 4.5 respectively.

4.5 COST CENTERS WITHIN THE EXISTING MAINTENANCE OF HEAVY MOBILE MINING EQUIPMENT

In line with objective number two, respondents were asked to respond to the various cost centers in the mining industry. Owing cost, operating cost and other miscellaneous cost were identified. The respondents noted that equipment replacement, major components change out, and fuel, lubricants, and corporate social responsibility form the major cost components in the maintenance of heavy mobile mining equipment. Table 4.5 depicts the analysis of the various cost centers. The operating cost was found to be predominant among the various mining companies. Abbreviations in the table 4.5 and 4.6 denotes the following;

[Not significant; Less significant; Moderately Significant; Significant; Very significant].

Table 4.5 Cost centers cost

Cost Type	Mean	1	2	3	4	5
1. Owing Cost		**NS**	**LS**	**MS**	**S**	**VS**
a. Equipment replacement	4.5	2(2.7%)	3(4.1%)	1(1.4%)	15(20.5%)	52(71.2%)
b. Depreciation	3.5	7(9.6%)	9(12.3%)	12(16.4%)	28(38.4%)	17(23.3%)
c. Insurance	2.6	22(30.1%)	13(17.8%)	20(27.4%)	11(15.1%)	7(9.6%)
d. Storage	3.4	10(13.7%)	7(9.6%)	15(20.5%)	29(39.7%)	12(16.4%)
e. Transportation	3.5	11(15.1%)	2(2.7%)	6(8.2%)	41(56.2%)	13(17.8%)
f. Major components change out	4.3	3(4.1%)	1(1.4%)	2(2.7%)	33(45.2%)	34(46.6%)
g. Mid-life overhauls	3.5	10(13.7%)	8(10.9%)	11(15.1%)	22(30.1%)	22(30.1%)
h. Major overhauls	3.8	2(2.7%)	5(6.8%)	24(32.9%)	16(21.9%)	26(35.6%)
2. Operating Cost	**Mean**	**1**	**2**	**3**	**4**	**5**
		NS	**LS**	**MS**	**S**	**VS**
a. Fuel	4.2	1(1.4%)	3(4.1%)	14(19.2%)	17(23.3%)	38(52.1%)
b. Lubricants	4.5	4(5.5%)	2(2.7%)	3(4.1%)	12(16.4%)	52(71.2%)
c. Tyres	3.6	3(4.1%)	11(15.1%)	22(30.1%)	14(19.2%)	23(31.5%)
d. Outside repairs	3.3	9(12.3%)	14(19.2%)	13(17.8%)	18(24.7%)	19(26.0%)
e. Staff salaries	4.4	3(4.1%)	1(1.4%)	1(1.4%)	27(36.9%)	41(56.2%)
f. Service kit	4.4	3(4.1%)	2(2.7%)	4(5.5%)	15(20.5%)	49(67.1%)
g. Parts replacement	4.3	6(8.2%)	3(4.1%)	5(6.8%)	7(9.6%)	52(71.2%)
h. Minor components	4.0	4(5.5%)	9(12.3%)	3(4.1%)	21(28.8%)	36(49.3%)

change out						
3. **Other Miscellaneous Costs**	**Mean**	1	2	3	4	5
		NS	**LS**	**MS**	**S**	**VS**
a. Health and safety	3.9	5(6.8%)	3(4.1%)	11(15.1%)	29(39.7%)	25(34.3%)
b. Environmental	4.0	2(2.7%)	1(1.4%)	14(19.2%)	31(42.5%)	25(34.2%)
c. Social responsibility	4.0	4(5.5%)	2(2.7%)	15(20.5%)	21(28.8%)	31(42.5%)
d. Training	4.4	1(1.4%)	3(4.1%)	1(1.4%)	24(32.9%)	44(60.3%)

Source: Field Survey, 2018

From the findings, respondents indicated that Equipment replacement is significant in terms of existing cost in mobile mining equipment with a mean score of 4.5. Mine equipment has a finite economic life. The unit cost of production for the equipment is minimized and at this point, replacement with new unit should occur. Equipment replacement can therefore be considered as very significant existing cost center, in terms of owning cost. Major component change out as a result of components achieving their useful life was identified by respondents as equally significant with a mean score of 4.3. All major components of equipment have stipulated hours that can run in equipment. At the end of that useful hours, the component has to be replaced.

Major Overhaul conducted as a result of a lot of parts due for replacement in a unit component was rated with 3.8 mean score by respondents. Mid-Life overhaul carried out to ensure the integrity and reliability of equipment availability was considered moderately significant in maintenance cost by respondent with 3.5 mean score.

In reference to Operating cost within the cost centers, Lubricants, Service kit and Fuel, had mean scores of 4.5, 4.4 and 4.3 respectively in terms of cost significance.

They are key elements in equipment maintenance which are used daily for normal servicing. They are normally classified as consumables. Respondents considered parts replacement and minor components which form part of the day to day maintenance activities. They form part of existing costs within heavy mining mobile equipment maintenance.

Other Miscellaneous Costs were considered by respondents in order of high cost, comprising; Training, Environment, Social responsibility, Health and Safety. Cost involved in training comprises how much is spent on training staff in the mine equipment maintenance sector. The environment within which the maintenance activities are carried out need to be protected. Soil contamination, disposal of waste materials. Scraps components and others waste materials require expenditure for their management. Another area identified by respondents as cost center is the Health and safety. Personal Protective Equipment are provided to staff for equipment maintenance activities, in order to minimize incidence.

4.6 STRATEGIES TO REDUCE COST OF MAINTENANCE ON HEAVY MOBILE MINING EQUIPMENT

The third objective of this study was to propose strategies for reducing the cost of Maintenance on Heavy Mobile Mining Equipment. The respondents were asked to respond to a number of statements regarding strategy for cost reduction. The findings are summarized in Table 4.6 below.

Table 4.6 Strategies for reducing cost

No	Strategies	Mean	NS	LS	MS	S	VS
1	Manpower recruitment (Skills)	**3.8**	1 (1.4%)	4 (5.5%)	16 (21.9%)	43 (58.9%)	9 (12.3%)
2	Standardization of equipment	**3.8**	3 (4.1%)	6 (8.2%)	15 (21%)	30 (40.1%)	19 (26.02%)
3	Use of maintenance management systems. E.g. Pronto, SAP, Maximo, etc.	**4.3**	1 (1.4%)	1 (1.4%)	9 (12.3%)	23 (31.5%)	39 (53.4)
4	Root Cause Analysis of failure	**3.9**	7 (9.6%)	3 (4.1%)	10 (13.7%)	18 (24.7%)	35 (47.9%)
5	Material failure analysis	**3.1**	17 (23.3%)	13 (17.8%)	3 (4.1%)	28 (38.4%)	12 (16.4%)
6	Equipment monitoring	**4.6**	2 (2.7%)	3 (4.1%)	1 (1.4%)	10 (13.7%)	57 (78.1%)
7	Quality control and assurance	**3.6**	6 (8.2%)	2 (2.7%)	9 (12.3%)	29 (39.7%)	27 (36.9%)

Source: Field Survey (2018)

From the findings, the respondents responded that manpower recruitment is significant when it comes to maintenance of heavy mobile equipment (mean = 3.8). They also responded favorably to standardization of equipment in the mining sector. Again, they responded that the use of maintenance management software is very significant when it comes to strategic techniques of cost reduction in heavy mobile mining equipment. Equipment monitoring to ascertain its integrity was rated very significant by the respondents with (Mean = 4.6). This analysis implies that the strategies for cost reduction in maintenance of heavy mobile equipment can be achieved by the use of maintenance management software and equipment monitoring. Material failure analysis which always look for the cause of failure of a component was considered as a key in maintenance cost reduction. Ascertaining the cause of failure and ensuring the root cause of the failure is eliminated in order to prevent future occurrence. Quality control and assurance was also recommended. That is where final checks and inspections are carried out after maintenance before equipment is finally released for operation. This exercise reveals any uncompleted jobs or defects that escaped the maintenance team which could have resulted a damage to a component which could lead to expensive maintenance and repairs.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter gives a summary of the findings in terms of the research objectives, conclusion, and recommendations of the study. It also highlights suggestions for future research.

5.2 REVIEWING OF OBJECTIVES

5.2.1 Objective One: To examine existing Maintenance Strategies in Golden Star Wassa Limited for Heavy Mobile Mining Equipment

An essential aspect of sustaining production at Golden Star Wassa mine operations is reducing cost of maintenance on heavy mobile mining equipment. Some managers of equipment are of the notion that equipment should be repaired as long as they are repairable, disregarding the costs involved in the process. These crew of people are frequently biased by means of the capital-intensive nature of acquiring a new machine, and they do no longer reflect on consideration on the advantages of minimal operating prices and elevated overall performance in the long run.

Equipment used for surface mining, has a defined life span that expires right before the concluding part of the equipment's lifespan. The unit cost of production for the machine is minimized at the end of the economic lifespan, replacement of the worn-out machine is undertaken at this point. The tradeoff between capital and operating cost is considered. The extended use of the equipment past the economic lifespan, it results in high costs for operating it. The shareholder value for the equipment is destroyed if the equipment is replaced before the expiry of its lifespan as the money should have been utilized efficiently on other jobs.

Inaccurate decisions on replacement can significantly affect operating costs and the performance of the equipment. This in turn, helps in ascertaining the achievement of results and costs stated in the budget.

5.2.2 Objective Two: To identify cost centers within the existing maintenance of Mobile Equipment maintenance

The various cost centers identified in the study enables the engineering manager and the Equipment professionals at Golden Star Wassa mine to adopt cost-cutting strategies for heavy mobile mining equipment. Fuel and major components change out were identified as the two most effective cost in the maintenance of heavy mobile mining equipment. Replacement of heavy mobile mining equipment due to ageing reasons is additionally a less than optimal answer to the substitute problem. A stable environmental situation is required to correctly reap this. However, the operating stipulations and the protection environment at the Golden Star Wassa mines are generally not constant and not the best condition to apply this rule. The life cycle of the equipment is affected by these changes and causes the adopted method to become sub-optimal. The Golden Star Wassa Mines does not employ the optimal replacement decision making process.

Usually, managers carry out review of cost and performance of previous. The resale value of secondary products are considered.

5.2.3. Objective Three: To propose strategies for reducing cost of Heavy Mobile Mining Equipment

Strategies for cost reduction identified in the study include root cause analysis of failure, equipment monitoring, use of maintenance management systems (SAP, Pronto, etc.) Again, it was revealed during the interview session that professionals well vexed in the management of equipment can take a decision based on intuitive notions critiquing the constituents that affect the decision to replace. Despite the fact that method can be accurate, it is not proven scientifically and cannot be applied consistently. The review of literature indicated that heavy mobile mining equipment maintenance should be based on sound financial principles. The major maintenance techniques, i.e. preventive and proactive if regularly practiced, can save the mining company millions of dollars annually. Golden Star Wassa mines employs economic analysis aimed at minimizing cost when ascertaining replacement options, as a part of a chain of large multinational firms with laid out plans and procedures for maintenance and asset management.

Practically, it is unmanageable to rationalize like -for-like decisions of replacements using the model for minimization of costs.

5.3 CONCLUSION

Responses gathered from interviewees indicated that, there is no universal method used for replacement of heavy mobile mining equipment in the mining sector. Of the companies studied, two of them follow similar methods emphasizing the important role of economic indicators, whereas the other two followed less quantifiable strategy via applying intuition, collectively with analysis of other elements. The life cycle costing approach was endorsed by all three equipment supplying firms.

5.4 RECOMMENDATIONS

In order to maximize their potententials and profits, some advise are offered that can improve reducing cost of maintenance on mobile mining equipment and replacement of heavy mobile mining tools in mining and contracting firms. The tips are as follows;

- Introduction and firm adherence of a formal policy for types of maintenance to be practiced by Goden Star Wassa Limited and other mining companies. Types of maintenance practices noted to be effective for reducing cost of maintenance are; Preventive, Corrective and Proactive Maintenance.
- The equivalent annual cost (EAC) model which seeks to calculate the cost per year for owning or maintaining an asset over its lifetime is the most suitable model for the replacement of heavy mobile mining equipment. The replacement policy should further be communicated and entrenched as standard practice in the companies.
- Forecasting of maintenance costs should be based on life cycle costing principles and through detailed analysis of real maintenance data. The methods and systems for capture, reporting, and analysis of sub-assembly and component performance data are important. A relatively simple database will be sufficient to capture the required maintenance data and to build a statistical database on sub-assembly and other components.
- Set up a maintenance policy/program on findings of maintenance strategies comprising Equipment monitoring, the use of Technology Enhanced Maintenance Management Systems and Root Cause Analysis of failure.

5.5 SUGGESTIONS FOR FUTURE RESEARCH

Other studies can take a look at the line of benchmarking, to determine the average optimal ages for replacement for popular equipment models in the mining sector.

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APPENDIX 1

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ART AND BUILT ENVIRONMENT

DEPARTMENT OF BUILDING TECHNOLOGY

SURVEY QUESTIONNAIRE

"EXPLORING STRATEGIES FOR REDUCING COST OF MAINTENANCE ON HEAVY MOBILE MINING EQUIPMENT"

Dear Sir/ Madam

I am an MSc. student at Kwame Nkrumah University of Science and Technology, Department of Building Technology currently undertaking a **"Study into exploring strategies for reducing cost of maintenance on heavy mobile mining equipment".** The research is ongoing under the supervision of Dr. Ernest Kissi and requires a questionnaire survey to be undertaken to collect data from professionals in the mining industry. Your experience and knowledge in the area of the research is very important and much appreciated. Information on existing Maintenance Strategies for Heavy Mobile Mining Equipment, cost centers within the existing maintenance of Mobile Equipment maintenance and strategies for reducing cost of Heavy Mobile Mining Equipment maintenance will be obtained from the research. The information you shall provide shall be STRICTLY CONFIDENTIAL and for academic purposes only and findings from this research will be made available to you on request.

I know you have a very busy schedule and this will take some time off you, I will plead that you help me with your knowledge as it means so much to the achievement of this research. I appreciate your effort and time very much in advance, please feel free to contact me on 0540276456 for any clarifications. Thank you.

Yours Sincerely,

Kingsley Oware Bredu, MSc Student, KNUST

Dr. Ernest Kissi, Project Supervisor

SECTION A: DEMOGRAPHIC BACKGROUND OF RESPONDENTS

Please, kindly respond to the questions by ticking (√) the appropriate box for each item.

1. Highest level of education: [ ] HND [ ] BSc [ ] MSc [ ] PhD [ ] other ………………….

2. Years of experience: [ ] Less than 5 years [ ] 5-10 years [ ] 10-15 years [ ] 15-20 years

[ ] Above 20 years

3. Involvement in mining maintenance projects: [ ] Yes [ ] No

4. If yes, which type of project: [ ] Surface mining [ ] Underground mining [ ] other………

5. Job Title: [ ] Consultant [ ] Project Management [ ] Engineering Manager [ ] Planning Engineer [ ] Engineering Superintendent [ ] Maintenance Supervisor [ ] Others……

SECTION B: TYPES OF MAINTENANCE PRACICE ON HEAVY MOBILE MINING EQUIPMENT

Kindly, indicate the level of significance of each of the following maintenance practice on heavy mobile mining equipment in the mining industry.

[1=Not significant; 2=Less significant; 3=Moderately Significant; 4= Significant; 5=Very significant]. Please tick (√) in the space provided.

Maintenance Type	1	2	3	4	5
1. Preventive					
2. Proactive					
3. Reactive					
4. Corrective					
5. Predictive					
Others (please identify any not in list)					

SECTION C: IDENTIFICATION OF COST CENTERS WITHIN THE EXISTING MAINTENANCE OF HEAVY MOBILE MINING EQUIPMENT.

Kindly, indicate the level of significance of the effect of the following cost centers on maintenance of mobile mining equipment.

[1=Not significant; 2=Less significant; 3=Moderately Significant; 4= Significant; 5=Very significant]. Please tick (√) in the space provided.

Cost Type	1	2	3	4	5
4. Owing Cost					
i. Equipment replacement					
j. Depreciation					
k. Insurance					
l. Storage					
m. Transportation					
n. Major components change out					
o. Mid-life overhauls					
p. Major overhauls					
Cost Type	**1**	**2**	**3**	**4**	**5**
5. Operating Cost					
i. Fuel					
j. Lubricants					

k. Tyres					
l. Outside repairs					
m. Staff salaries					
n. Service kit					
o. Parts replacement					
p. Minor components change out					
6. Other Miscellaneous Costs					
e. Health and safety					
f. Environmental					
g. Social responsibility					
h. Training					
Others (please identify any not in list)					

SECTION D: STRATEGIES FOR REDUCING COST OF HEAVY MOBILE MINING EQUIPMENT MAINTENANCE

Kindly, indicate the level of significance of the effect of following on maintenance strategies.

[1=Not significant; 2=Less significant; 3=Moderately Significant; 4= Significant; 5=Very significant]. Please tick (√) in the space provided.

Strategies	**1**	**2**	**3**	**4**	**5**
1. Manpower recruitment (Skills)					
2. Standardization of equipment					
3. Use of maintenance management systems. Eg. Pronto, SAP, Maximo, etc.					
4. Root Cause Analysis of failure					
5. Material failure analysis					
6. Equipment monitoring					
7. Quality control and assurance					
Others (please identify any not in list)					

SECTION E: STRATEGIES FOR REDUCING COST OF HEAVY MOBILE MINING EQUIPMENT MAINTENANCE

1. Have you heard about cost reduction/cost cutting: [ ] Yes [ ] No

2. If yes, indicate where: [ ] On Mining projects [ ] Engineering Projects [ ] Professionals [ ] other (please specify) ...…………………

3. Do you practice cost reduction at your mine? [ ] Yes [ ] No

4. If yes, how does it happen on the project ……………………………………………..………………………………………...

a. In your opinion what do you think management should do to reduce cost of maintenance on heavy mobile mining equipment?

   ………………………………………………………………………………….…

APPENDIX 2

Dear Sir/Madam

EXPLORING STRATEGIES FOR REDUCING COST OF MAINTENANCE ON HEAVY MOBILE MINING EQUIPMENT

I write to humbly elicit your participation for Mr. Kingsley Oware Bredu, an MSc. Project Management student to have access to data and other relevant information that will be useful for his research work. The data and information is part of a research project aimed at meeting the requirements for the award of Master of Science (Project Management) at the Kwame Nkrumah University of Science and Technology-Kumasi.

The study seeks to draw on your experience from your involvement as an active member of the Ghanaian mining industry. The study aims to explore strategies for reducing the maintenance cost of Heavy Mobile Mining Equipment. Various cost centers within the existing maintenance of Mobile Mining Equipment will be studied. The expected outcome of the research is to propose strategies for reducing the cost of Heavy Mobile Mining Equipment maintenance in the mining sector.

Please, be assured that face-to-face interview with key staff of your company will be treated confidentially and information provided will be used solely for academic purposes. Your participation will be an immense contribution to the success of the study and its further outcome to the overall reduction of maintenance cost of Heavy Mobile Mining Equipment. We are also willing to share the result of the research with your company. Should you have any queries, please do not hesitate to contact Mr. Kingsley Oware Bredu on 0540276456 or per email: kingoware@yahoo.com

Thank you in anticipation of your cooperation.

Candidate Name: **Mr. Kingsley Oware Bredu**

Supervisor: **Dr. Ernest Kissi**

Yours faithfully,

Mr. Kingsley Oware Bredu

Golden Star Wassa Mines