Evaluation of Factors Affecting Availability of Drilling Rigs in Minerals Exploration in Tanzania

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Abstract
Ensuring availability for any engineering equipment is crucial towards achieving the expected results including minerals exploration using drilling rigs. In achieving such goals deploying of effective Engineering Maintenance Management techniques is vital. The researchers assessed four minerals exploration drilling rigs and revealed that they experienced frequent breakdowns which result into low availability. This study aimed to identify and evaluate key factors which affect availability of drilling rigs in Minerals Exploration activities in Tanzania. In achieving the objective the researchers used structured questionnaires, documentary reviews and measuring methods for data collection. The collected data were analyzed using Statistical Package for Social Sciences Software, Microsoft Excel and Relative Importance Index method. The Relative Importance Index technique used to identify key factors which affect availability of the drilling rigs. The identified factors include: skilled personnel (0.79), spare parts (0.77), maintenance tools (0.69) and ineffective communication (0.67). During the study it was revealed that most of Exploration drilling rigs deploys traditional run to failure maintenance approaches. The study provides four (4) strategic recommendations towards improving Availability of drilling rigs in minerals exploration activities which are formulation of the Maintenance Management Policy, developing effective Maintenance Management System, introduction of a Maintenance Management Unit and provision of adequate Maintenance tools, Spare parts, Skilled Staff and Effective communication.

Keywords: Maintenance Management, Availability, Drilling rigs and Minerals Exploration.
1. Introduction
The study managed to assess availability of four drilling rigs operating in minerals exploration activities in Tanzania namely; Long year, Sonmak, Terramac and Multipurpose air rotary rig. All these rigs are used for drilling activities in exploration of mineral resources. The recovered rock cores or chippings are subjected into laboratory analysis to establish quantities and quality of mineral resources available below underneath.

The study assessed performance of the drilling rigs through collecting operational data for the drilling rigs when performed various drilling activities. A key performance indicator for drilling rig performance is meters drilled per shift or meters drilled per day. During the study each drilling rig was found to have a specific target based on several factors including rock hardness and structures, manpower availability and weather conditions.

Hence, this study aims at identification of factors affecting availability of drilling rigs in minerals exploration activities. Specifically, it identifies factors affecting availability of drilling rigs, analyzes factors affecting availability of drilling rigs and proposes strategies for enhancement availability of drilling rigs in minerals exploration activities.

1.2 Theoretical Overview
1.2.1 Drilling Rigs
Drilling rig equipment refers to a machine used to drill earth crust or rocks for the purpose of exploring minerals deposits in the ground. The drilling rigs use mechanical, hydraulic and electrical energies to perform its drilling functions. Drilling rigs in mineral exploration operates based on several drilling techniques including; Auger drilling, rotary percussion drilling and Diamond drilling (Marjoribanks, 2010).

1.2.2 Components of a Drilling Rig
Essential components of a drilling system are the rock drill, feed equipment, drilling rods, bit, supports against the drilling reaction, power source, and cuttings disposal equipment. Different drilling rigs are designed and constructed with various combinations of these elements and other accessories for particular drilling purposes. Figure 1.1 depicts the Key components of the drilling rig (Watanabe, 2011).

Figure 1.1
Drilling Rig components (Watanabe, 2011)
1.2.3 Common Failures of Drilling Rigs
Al-Chalabi et al. (2014) identified frequently failed components of drilling rigs and proposed some solutions to address those problems as follows:

1.2.3.1 Feeder Failures
Due to its movements in different angles and especially when is restricted because of spatial limitations. To overcome this problem, the feeder could be equipped with an iron plate on both sides; the plate should be large enough to prevent hoses from being scratched and to prevent nipples at the necks from being broken.

Another problem in the feeder is the pull rope breaking which happens for two reasons. First, the pull rope relaxes with usage and hence hangs over the edge of the cradle plate when the plate moves forward and back on the slide bar. Secondly, the operator or repair person may put extreme tension on the pull rope when making an adjustment. This excessive tension leads to two undesirable occurrences: first, a reduction in the lifetime of the pull rope; second, a high load on the pulley wheel leading to a reduction of the lifetime of the roller bearing inside it.

1.2.3.2 Rock Drill Failures
Frequent failures in rock drill found to cause damages to the third and fourth cup seals located inside front head (nose) of this component. A possible cause is the high water pressure inside the nose. Water is used to cool the front head and flush it during the drilling process. However, damaging the cup seals will cause water and oil to mix, leading to the adhesion of the valves used in the hydraulic system. To solve this problem, it was suggested that water pressure inside the front head should be reduced by increasing the number of holes, especially in the area between the third and the forth cup seals.

Figure 1.2
Cup seals (Al-Chalabi et al., 2014)

1.2.4 Maintenance Management Concepts
Filho, (2006) describes Maintenance Management as an integral part of the organization and aims to manage the maintenance in the broadest sense of the word. The maintenance management is a set of actions, rules and procedures of a maintenance system that assigns targets to the maintenance team and the organization it serves. The Maintenance Management establishes goals and objectives through standards and work procedures in order to obtain a better utilization of available resources, which are staff, equipment and materials. Kardec and Lafraia, (2002) states that modern management must be underpinned by a vision and governed by processes management where the full satisfaction of its customers is a result of the quality of its products and services. In accordance with this line of thought, the maintenance management is considered strategic when it is the results driven business organization. This implies that, besides having to assure the functional availability of
equipment and facilities of a production process or service, safety and environmental factors as well as cost have to be considered.

1.2.5 Elements of Effective Maintenance Management System

Dhillon, (2002) mentions eight key elements of effective maintenance management system whose effectiveness is the key to the overall success of the maintenance activities as discussed below:

1.2.5.1 Maintenance Policy

A maintenance policy is one of the most important elements of effective maintenance management. It is essential for continuity of operations and a clear understanding of the maintenance management programme, regardless of the size of a maintenance organization. Usually, maintenance organizations have manuals containing items such as policies, programmes, objectives, responsibilities, and authorities for all levels of supervision, reporting requirements, useful methods and techniques, and performance measurement indices. Lacking such documentation, i.e., a policy manual, a policy document must be developed containing all essential policy information.

1.2.5.2 Material Control

Past experience indicates that, on average, material costs account for approximately 30 to 40% of total direct maintenance costs. Efficient utilization of personnel depends largely on effectiveness in material coordination. Material problems can lead to false starts, excess travel time, delays and unmet due dates. Steps such as job planning, coordinating with purchasing, coordinating with stores, coordination of issuance of materials, and reviewing the completed job can help to reduce material related problems. Deciding whether to keep spares in storage is one of the most important problems of material control.

1.2.5.3 Work Order System

A work order authorizes and directs an individual or a group to perform a given task. A well-defined work order system should cover all the maintenance jobs requested and accomplished, whether repetitive or one-time jobs. The work order system is useful for management in controlling costs and evaluating job performance. Although the type and size of the work order can vary from one maintenance organization to another, a work order should at least contain information such as requested and planned completion dates, work description and its reasons, planned start date, labour and material costs, item or items to be affected, work category (preventive maintenance, repair, installation, etc.), and appropriate approval signatures.

1.2.5.4 Equipment Records

Equipment records play a critical role in effectiveness and efficiency of the maintenance organization. Usually, equipment records are grouped under four classifications: maintenance work performed, maintenance cost, inventory, and files. The maintenance work performed category contains chronological documentation of all repairs and preventive maintenance (PM) performed during the item’s service life to date. The maintenance cost category contains historical profiles and accumulations of labour and material costs by item. Usually, information on inventory is provided by the stores or accounting department. The inventory category contains information such as property number, size and type, procurement cost; date manufactured or acquired, manufacturer, and location of the equipment/item. The files
category includes operating and service manuals, warranties, drawings, and so on. Equipment records are useful when procuring new items/equipment to determine operating performance trends, troubleshooting breakdowns, making replacement or modification decisions, investigating incidents, identifying areas of concern, performing reliability and maintainability studies, and conducting life cycle cost and design studies.

1.2.5.5 Preventive and Corrective Maintenance
The basic purpose of performing PM is to keep facility/equipment in satisfactory condition through inspection and correction of early stage deficiencies. Three principle factors shape the requirement and scope of the PM effort: process reliability, economics, and standards compliance. A major proportion of a maintenance organization’s effort is spent on Corrective Maintenance (CM). Thus, CM is an important factor in the effectiveness of maintenance organization.

1.2.5.6 Job Planning and Scheduling
Job planning is an essential element of the effective maintenance management. A number of tasks may have to be performed prior to commencement of a maintenance job; for example, procurement of parts, tools, and materials, coordination and delivery of parts, tools, and materials, identification of methods and sequencing, coordination with other departments, and securing safety permits. Although the degree of planning required may vary with the craft involved and methods used, past experience indicates that on average one planner is required for every twenty craft persons. Strictly speaking, formal planning should cover 100% of the maintenance workload but emergency jobs and straightforward work assignments are performed in a less formal environment. Thus, in most maintenance organizations 80 to 85% planning coverage is attainable. Maintenance scheduling is as important as job planning. Schedule effectiveness is based on the reliability of the planning function. For large jobs, in particular those requiring multi-craft coordination, serious consideration must be given in using methods such as Programme Evaluation and Review Technique (PERT) and Critical Path Method (CPM) to assure effective overall control.

1.2.5.7 Backlog Control and Priority System
The amount of backlog within a maintenance organization is one of the determining factors of maintenance management effectiveness. Identification of backlogs is important to balance manpower and workload requirements. Furthermore, decisions concerning overtime, hiring, subcontracting, shop assignments, etc., are largely based on backlog information. Management makes use of various indices to make backlog related decisions. Furthermore, determination of job priority in a maintenance organization is necessary since it is not possible to start every job the day it is requested. In assigning job priorities, it is important to consider factors such as importance of the item or system, the type of maintenance, required due dates, and the length of time the job awaiting scheduling will take.

1.2.5.8 Performance Measurement
Successful maintenance organizations regularly measure their performance through various means. Performance analysis contribute to maintenance department efficiency and are essential in revealing the downtime of equipment, peculiarities in operational behaviour of the concerned organization, developing plans for future maintenance works.
1.2.6 Equipment Availability

Dhillon (2002) describes availability as the probability that a piece of equipment is functioning satisfactorily at a specified time, when used according to specified conditions, where the total time includes operating time, logistical time, active repair time, and administrative time. Therefore, the equipment availability is simply the proportion of time the equipment is able to be used for its intended purpose. Availability reflects the part of the scheduled hours that the machine is mechanically and electrically ready to be operated. Barringer, (1997) expresses availability as the duration of up-time for operations and is a measure of how often the system is alive and well. It is often expressed as ratio of up-time to total time i.e. (up-time plus downtime). Up-time and downtime refer to dichotomized conditions. Up-time refers to a capability to perform the task and downtime refers to not being able to perform the task.

\[
Availability = \frac{T_{up}}{T_{TOT}} \times 100\% 
\]  

Where:

\[ T_{up} = \text{Up time} \]
\[ T_{TOT} = \text{Total time} \]

Also equipment Availability can be computed as per the formula below;

\[
A = \frac{MTBF}{MTBF+MDT} \times 100\% 
\]  

Where;

\[ MTBF = \text{Mean Time between Failure} \]
\[ MDT = \text{Mean Downtime} = f (a, b, c, and d) \]

Where;

\[ a = \text{Skilled staff} \]
\[ b = \text{Available Tools} \]
\[ c = \text{Available spare parts} \]
\[ d = \text{Communication} \]

Davidson (1988) describes availability as a driver for:

i. Increasing time to failure,
ii. Decreasing downtime due to repairs or scheduled maintenance, and
iii. Accomplishing items (i) and (ii) in a cost effective manner.

The above-mentioned statement depicts that as availability grows the capacity for collecting more revenues increases because the equipment is in service for larger percent of time. In general Availability can be described as the probability that an item, under the combined influence of its reliability, maintainability and maintenance support, will be able to fulfil its required function over a stated-period of time, or at a given point in time.

Mjema and Mongomongo(2010)identified several factors which affect Availability performance of equipment including: Skilled Staff, Training, Spare parts and Tools, Operators actions, material Availability, Schedule requirements, Maintenance Practices, Communication, Maintenance records and working Condition.

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According to Johnson and LeBreton (2004), Relative Importance Index (RII) aids in finding the contribution a particular variable makes to the prediction of a criterion variable both by itself and in combination with other predictor variables. Therefore, the researchers use this technique to evaluate influences of factors which affect availability of drilling rigs in minerals exploration works. The method used to rank the identified factors by authors in the literature review in which the four point scale ranged from 1 (not important) to 4 (extremely important) was adopted and hence transformed to relative importance indices based on responses of respondents.

\[
RII = \frac{\sum W}{A \times N} \quad (1.3)
\]

Where
- W: weighting given to each factor by respondents (ranging from 1 to 4)
- A: Highest weight
- N: Total Number of respondents

2. Methodology

2.1 Research Design

Saunders et al (2012) point out that the case study has considerable ability to generate answers to the questions; why, what and how. Furthermore, Yin(2009) states that research design is an action plan for getting from here to there, where ‘here’ may be defined as the initial set of questions to be answered and ‘there’ is some set of (conclusions) answers”. Further, Peersman (2014) describes research design as the process that involves the overall assumptions of the research including methods of data collection and analysis. The choice of research design depends on the objectives of the research in order to address each research question effectively. Based on the above factors, the researchers carried this study as an exploratory case study. This design was used because it allows the use of different data collection techniques at different stages such as questionnaires, structured and unstructured interviews, observation etc. The design was found to be appropriate due to the nature of the study and the research questionnaires were designed in such a way that they addressed all key issues in regard with the development of effective maintenance management system for minerals exploration drilling rigs.

2.2 Study Areas

The study areas were selected drilling rigs which are operational in Tanzania and particularly around Victoria areas. The choice of these areas of the study is based on the reason that, these areas are very active in minerals exploration and exploitation activities through both large and small scale miners.

2.3 Sampling Technique and Sample Size

Judgmental or Purposive sampling was employed to select the sample. The response rate for the study was 74.3% where 52 out of 70 responded to questionnaires. The characteristics of respondents taken into consideration during this study are; age, gender, type of employment, education level of the respondents and working experience of the respondents.
2.4 Methods of Data Collection
Both primary and secondary data were used in this study. Primary data include both quantitative and qualitative data where observation was among the methods used. Structured interview questions, questionnaire and personal interviews were concurrently used to collect data from primary sources. Questionnaires were administered such that, either be completed by the respondents themselves or filled in by the researchers during personal interviews.

2.5 Data Analysis
The data analysis was carried out using Statistical Package for the Social Sciences (SPSS) and Microsoft office excel. The results were presented in column chart graphs. Furthermore, collected data were evaluated in order to determine factors affecting availability of exploration drilling rigs towards developing Effective Maintenance Management System for better performance of drilling rigs using relative importance index (RII) techniques. In assessing significance of the abovementioned factors, researchers used relative importance index (RII) techniques to establish the main factors which affect Availability of exploration drilling rigs in Tanzania.

3. Data Analysis, Results and Discussion
The researchers analyzed technical parameters affecting exploration drilling rigs Availability based on the respondents scores and hence ranked the factors as per their corresponding relative importance index (RII) as per equation 1.3; the value of each factor has been calculated and presented on table 3.1.

Table 3.1
Assessment of factors affecting availability of drilling rigs in minerals exploration

<table>
<thead>
<tr>
<th>S/N</th>
<th>Availability Factors</th>
<th>Respondents Score</th>
<th>Weight (W)</th>
<th>RII</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>1.</td>
<td>Spare parts</td>
<td>1</td>
<td>5</td>
<td>34</td>
<td>12</td>
</tr>
<tr>
<td>2.</td>
<td>Maintenance Tools</td>
<td>2</td>
<td>17</td>
<td>24</td>
<td>9</td>
</tr>
<tr>
<td>3.</td>
<td>Skilled personnel</td>
<td>1</td>
<td>10</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>4.</td>
<td>Poor Working Condition</td>
<td>21</td>
<td>30</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5.</td>
<td>In effective communication</td>
<td>2</td>
<td>19</td>
<td>23</td>
<td>8</td>
</tr>
<tr>
<td>6.</td>
<td>Limited Training</td>
<td>20</td>
<td>15</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>7.</td>
<td>Lack of historical data</td>
<td>20</td>
<td>31</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>8.</td>
<td>Poor Maintenance Schedule</td>
<td>19</td>
<td>32</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

3.1 Analysis of Factors Affecting Availability of Exploration Drilling Rigs
In regard with current maintenance practices for minerals exploration drilling rigs, the findings in Table 3.1 shows that lack of skilled personnel ranked first followed by Spare parts.
which is the second and limited maintenance tools and Ineffective communication ranked third and fourth respectively. Other factors having RII values less than 0.5; including limited training, Maintenance planning and Schedule as well as Working condition ranked lower and this implies that these factors have less impacts to Availability of minerals exploration drilling rigs compared to the first four factors.

3.2 Strategies for Enhancement Availability of Drilling Rigs in Minerals Exploration
In improving Availability of drilling rigs in minerals exploration, the studies suggest the owners to integrate the entire maintenance requirements through an Effective Maintenance Management System which incorporate both planned and unplanned Maintenance activities to be carried in parallel based on priorities and available resources. In addition the owners are required to ensure that all maintenance records are well kept and maintained for future uses.

3.3 Effective Maintenance Management System Flow Chart
Figure 3.2 indicates the developed Maintenance Management System flow chart based on both Preventive Maintenance (PM) strategy and also Breakdown Maintenance (BM) strategy for some cases, especially, when drilling rigs fail (in rare cases). The development of this flow Chart provides sequence of activities; the findings obtained in this study and all key Maintenance components, for the smoother operation. This maintenance management flow system covers the key maintenance steps identified by users, which are work reporting, work order generation, execution of the work, job suspension, inventory control, maintenance database, reporting and model processing. All these were aimed to ensure systematic tracking, analysis and planning of maintenance management activities for improving availability of drilling rigs in minerals exploration works.
Figure 3.2

Effective Maintenance Management System Implementation Framework

1. **Work Identification**
   - Maintenance Management Unit

2. **Preventive Maintenance**
   - Schedule Works
   - Work Order generation
   - Work Execution
   - Inventory

3. **Breakdown Maintenance**
   - Faults Reporting
   - Work Order generation
   - Work Execution

4. **Material required for job completion?**
   - Yes: Job Executed
   - No: Go back to Schedule Works

5. **Job Completed?**
   - Yes: Completed
   - No: Pending Work Orders

6. **Rigs Maintenance Database**
   - Maintenance Management Model
   - Improved Drilling Rigs Availability Performance
4. Conclusion and Recommendations

4.1 Conclusion
Based on the assessment made to the four drilling rigs, the findings reveals that availability of drilling rigs is highly affected by lack of skilled personnel, inadequate Spare parts, limited maintenance tools and Ineffective maintenance communication which scored 0.79, 0.77, 0.69 and 0.67 RII respectively. Other factors which scored RII values less than 0.5 were found to have less impact to the overall Availability of minerals exploration drilling rigs and hence were considered insignificant. Then the Maintenance Management System flow chart based on both Preventive Maintenance (PM) strategy and also Breakdown Maintenance (BM) strategy to improve maintenance activities for the drilling rigs was developed.

4.2 Recommendations
In achieving the expected Availability for the drilling rigs, the paper recommends the owners to develop an effective maintenance management policy to provide clear guideline on how to address all maintenance issues including drilling rigs maintenance. It has to consider establishment of the effective maintenance management system in order to handle all maintenance activities efficiently. Further, it has to establish a specific Maintenance management Units to manage all Maintenance activities and plans. Also it has to ensure availability of skilled staff, Maintenance tools, Spare parts and Effective maintenance communication for effective operations.

References


