RELIABILITY CENTERED MAINTENANCE FOR MINING EQUIPMENT

By

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ABSTRACT

The current emphasis within the mining industry to reduce the cost of production has stimulated interest in the field of maintenance and operational reliability of capital intensive mining equipment. The failure consequences of those machines have major safety and economic implications for a mine operator. The reliability centered maintenance (RCM) approach has been found cost effective for equipment maintenance and for achieving high level system performance by many organizations such as airline, military, chemical, process and manufacturing industries. In this paper an attempt has been made to describe in brief the basic concepts of a RCM approach, the methods of RCM analysis and its cost effectiveness for maintenance of equipment. Since this approach is comparatively new for the mining industry, suitable examples are given to illustrate the case.

INTRODUCTION

For a long time maintenance in mining industry was not considered to be a problem requiring a systematic approach. The low degree of equipment utilization in mines made the failure consequences negligible. But during the last few years, the equipment failures have become not only costly but also catastrophic. This is due to deployment of complex and capital intensive equipment to achieve the high level of economy in mines and to reduce the cost of production necessary to withstand the tough market situation.

Under these circumstances, it is becoming more and more important for maintenance engineers to predict the expected life of mining equipment and their critical parts, their availability, the expected maintenance load, in terms of time and resources, and other support systems needed for optimal utilization. Unfortunately, maintenance is an area in which the gap between theory and practice is extremely wide. However, during the last two decades the search for techniques to control the ever increasing operating cost of equipment has led to many research studies. These studies suggested the use of probabilistic models to decide the maintenance tasks and intervals to control the cost of maintenance (Barlow and Hunter, 1960; Jardine, 1969; Barlow and Davis, 1977). Recently considerable attention has been paid to develop and use mechanistic models using actual condition monitoring devices (Lester and Tragelles, 1984). Effective maintenance does not mean merely that a particular maintenance effort is achieved using the least possible resources (Ahmann, 1984). What is of importance is the effect of maintenance effort in the production process to reduce the overall cost of production. It is reported that the reliability engineering techniques are useful for cost control in maintenance (De la Mare, 1978) and also for enhancing the operational reliability of equipment (Cutts and Ford, 1985). Besides, these investigations and techniques are useful in locating inherent design faults present in the equipment, in deciding the optimum replacement intervals, and for developing maintenance strategies for effective control of the unscheduled downtime of an equipment (Kumar and Granholm, 1988a).

AN OVERVIEW OF CONVENTIONAL MAINTENANCE

In conventional maintenance programs, the maintenance plan for a piece of equipment is outlined on the basis of recommendations or instructions obtained from the manufacturers. These recommendations for new equipment are mainly developed on the basis of instructions that have been used for previous models of similar design with or without some modifications. As a consequence, certain preventive maintenance tasks have become standardized, remaining unchanged through many generation of model changes.
even though they have been rendered inadequate or unnecessary by advances in product design technology. At the same time, new maintenance needs are not recognized, and the product and its users have to suffer for this (Nous, 1985). This is also true for the mining industry where the continuous search for achieving a level of economy in the exploitation of mineral and coal has led to the deployment of complex and costly equipment without such changes in old maintenance plans and instructions. This has resulted in many cases of maintenance cost as high as 50-60% of total equipment operating cost (Lindquist, 1987) and sometimes it constitutes 30% of the total production cost (Gotts and Ford, 1985).

CONCEPTUALIZATION OF THE ROM

The traditional approach to scheduled maintenance programmes as discussed above is based on the concepts that every item or equipment have a right age at which complete overhaul or other actions are needed to ensure safety and operating reliability. However, through the years, studies made mainly by airlines have discovered that many types of failures cannot be prevented or effectively reduced by such maintenance activities, no matter how intensively they are performed (Howan and How, 1978). During the early sixties, airlines alarmed by the steeply increasing cost of maintenance and poor availability of their fleet started looking for alternatives to the traditional preventive maintenance approach. Research was initiated to examine various available techniques and methodologies available from the field of operations research and reliability engineering. The main idea behind these studies was to develop maintenance approaches to retain the desired reliability of the equipment through the analysis of the factors that affect operating reliability. The maintenance approach, thus developed is called reliability centred maintenance (RCM). After its success in airlines, the ROM approach to equipment maintenance was adapted by other industries using large and complex equipment such as chemical, process, and manufacturing industries. Presently, the theory and practice of reliability engineering techniques have reached to a level where it can also be applied profitably to the mining industry.

In this paper an attempt has been made to describe in brief the maintenance function, the basic concepts associated with the ROM approach, and its possible application for mechanized mining systems. The cost effectiveness of such approach is also discussed. However, the discussions in the paper centre around the research study being pursued to achieve competence in field of maintenance using ROM approach at the Division of Mining Equipment Engineering, Luleå University of Technology, Luleå, Sweden. In this paper, maintenance function refers to the replacement or repair of parts or items of mining equipment.

DEVELOPMENT OF MAINTENANCE PHILOSOPHY

Maintenance is necessitated by a system when an item or component fails to fulfill its function and it involves either replacement or repair of failed items. Maintenance is equally essential for both a simple item or the complex equipment with thousands of items. A complex piece of equipment is composed of a vast number of parts and assemblies. All these items can be expected to fail at one or another time, but some of the failures have more serious consequences than others. Some of the failures directly affect the operating capability and some of them have direct effect on the operating safety. The purpose of the maintenance is to avoid these failures. In short, maintenance function can be defined as the actions and activities required to retaining an item in, or restoring it to, a serviceable condition. Thus, the maintenance function includes servicing, repair, replacement, modification, inspection, calibration, overhaul, and condition monitoring of an equipment or related facilities. The consequences of a particular failure depend on the design of the item and equipment in which it is installed, the driving element in all maintenance decisions is not the failure of a given part, but the consequences of that failure for the equipment as a whole. Thus the effectiveness of the maintenance programme for a piece of equipment depends on the knowledge about the various designed characteristics such as reliability and maintainability characteristics of each components influencing the operational capability of the equipment together with secondary influential factors like logistics and information system characteristics of the operating environment. Further, the influence of the ergonomics considerations in design of equipment and the maintenance facility should also be taken into consideration while developing maintenance programme for an equipment (Kumar and Granholm, 1988b).

BASIC CONCEPTS OF THE ROM

The main objective of the ROM is to maintain the inherent reliability which is designed into the system at reduced cost compared to conventional approaches. The ROM approach is structured to implement the
principle that no preventive maintenance task will be performed unless it can be justified. The criterion for justification are safety, availability, and cost effectiveness in differing or preventing a specific failure mode (Mess, 1985). ROM is applied in the form of two part analysis of the product design. The first part of the analysis identifies potential failure modes, their sources, and their frequency of occurrence. In next step, the decision logic is developed for each of the failure modes in terms of questions and answers to these questions determine the nature of scheduled maintenance tasks to be performed. In brief, it can be said that the ROM approach is useful in making decisions:

- whether a scheduled maintenance is needed or not;
- if needed, whether it will be time based or condition based; and
- what the scheduled maintenance tasks will be.

**ESSENTIALS OF ROM ANALYSIS**

The ROM analysis can be divided into two major steps:
1. Identification of significant maintenance tasks
2. Identification of maintenance tasks interval

**IDENTIFYING SIGNIFICANT MAINTENANCE TASKS**

The identification of significant maintenance task necessitates the understanding of the failure characteristics, failure types, and related economic, safety and social consequences associated with equipment operation. For example, the economic consequence of an unscheduled stoppage of a large capacity load haul drill (LHD) machine is estimated to be several thousands Swedish crowns for a mechanized mine in Sweden. Safety consequence, for example, in case of an underground mine arises due to the failures such as the brake failure of the winch or ventilation fan stoppages. Social consequences are mostly associated with companies like transport, power supply companies, and similar other public utility companies. Thus, the identification of a significant maintenance tasks is dependent on the identification of significant items in equipment on the basis of their failure consequences. Failures affecting the operational capability of the equipment are identified by failure mode effects and criticality analysis (FMECA) or by fault tree analysis (FTA). FMECA uses inductive logic in a “bottom up” approach starting at the lowest level of the system hierarchy to determine the effect that each failure mode will have on system performance. In FTA, deductive logic is applied in a “top down” approach and the analyst assumes the system failures and traces down through the system hierarchy to determine the event or series of events that could cause such a failure (Sadoc, 1985). For both analysis, the analyst must have full understanding of the design and operating characteristics of the equipment.

In short, FTA applies “how could this happen” and FMECA applies “what happens if” approach in analysis of failure mode (Burton, 1992). Thus for ROM analysis, identification of significant item and development of decision logic to decide the significant maintenance tasks are important.

**Identifying significant items**

This is done by partitioning the equipment into object categories to identify those items that require intensive studies to avoid major economic and safety consequences through suitable maintenance actions. An example of partitioning of a LHD machine is shown in figure 1.

The partitioning procedure provides a conservative approximation of the significant items that should be maintained properly. Once partitioning is done, the consequences of failure of each significant item are evaluated by a set of questions and answers. The analysis itself begins with an evaluation of the failure consequences for each type of failure to which the item is exposed. This part of analysis is based on the principles of decision theory. A simplified example of the decision logic used in such analysis is shown in figure 2 and is commonly known as decision or logic diagram.

**DECISION ABOUT MAINTENANCE TASK INTERVAL**

In ROM analysis, the nature of maintenance tasks are rather easily identified with the help of partitioning and decision logic but the interval of such maintenance are not identified in that process. The maintenance tasks intervals are conceptualized during the design stage of the equipment. The efficiency and success of such maintenance interval depends on the foresight of the designer and the information available about similar equipment in use. As discussed earlier, the interval of the scheduled maintenance tasks will be based either on the basis of time to failure and their distribution (time based policies) or on the basis of information obtained from condition monitoring devices about the physical state of significant items.
Maintenance task intervals based on operating time

Time based maintenance intervals are mostly calculated through the reliability analysis for each significant item. These analyses will identify the mean life of the component or equipment based on the time to failure data collected from the existing equipment or the fleet of equipment. If the equipment is new, an estimate of reliability characteristics of the equipment or component is made through laboratory test under controlled conditions. The reliability analysis will provide a probabilistic estimate of the maintenance interval based on the time to failure of the component or the equipment as a whole. Many test books are available where the techniques for calculation of optimal operating time of an
equipment or the component are discussed at length under various conditions (e.g., Bazovsky, 1961; Barlow and Prochan, 1965; Billinton and Allen, 1983). In such studies, failure rate, mean time to failure and the probability of survival are the important parameters to be investigated and calculated to arrive at the correct estimate of the life distribution. These informations obtained from such analyses can be used effectively to forecast maintenance interval for mine operating systems. Assessment of reliability of a machine is simplified by use of reliability block diagrams for the system under consideration. Once the block diagrams are conceptualized, its structure and configuration known, the reliability or other parameters can be calculated. A simplified reliability block diagram for a diesel operated LHD machine is shown in figure 3.

![Figure 3. Simplified reliability block diagram of a LHD machine](image)

An example is presented in Appendix 1 for the calculation of the optimal maintenance interval for a hydraulic pump of a LHD machine. Through reliability investigations, decision about the optimal replacement interval of a significant item can be arrived at.

Maintenance interval based on condition monitoring

Condition monitoring, manually or through monitoring devices installed in a piece of equipment, provides correct information about the deterioration of items being monitored, and thus, exact decisions can be taken about the maintenance time. Thus, this type of maintenance policy is developed on the basis of physical condition of the significant item monitored manually or through some device. The application of such monitoring devices in mines appears to be economically viable due to the increasing use of the capital intensive and complex mining equipment. Besides, the ever increasing capacity and capability of microprocessors and downward trend in their costs have made it possible to use such devices for the purpose of equipment condition monitoring in mines. Once successfully conceived and implemented, this type of policy is bound to reduce unscheduled downtime of complex and costly mining equipment to a tolerable limit (Morris, 1987).

The maintenance intervals are decided either on the basis of actual data available from the field or from the laboratory test about the failure characteristics of the equipment or the significant component. The maintenance intervals, thus decided are more effective and realistic. Since the ROM is completely new to the mining industry, no cost data are available to support the facts. However, substantial cost savings have been reported from other fields through such applications (North and Heap, 1978; Jardine and Jardine, 1986). Optimal component replacement intervals, preventive maintenance intervals, and optimum maintenance crew deployments can also be achieved through the application of the ROM approach to maximize both safety and productivity in a mine. Once successfully implemented, the improved cost-effectiveness of the maintenance program based on the ROM approach will reflect in the form of shorter and fewer production shutdowns resulting in increased utilization and productivity of mining equipment. The major benefit in applying ROM approach to mining equipment is that it facilitates the identification of significant items, their life distribution and the consequences of their failures and suggest suitable maintenance task and the optimal maintenance intervals on the basis of the actual operating characteristics of equipment under different operating conditions.

CONCLUSION

In this paper a brief description of the ROM approach is presented together with a short overview of the conventional maintenance system. Simplified examples are given to illustrate the methods of ROM analysis. Application of reliability techniques to calculate the optimal maintenance interval is also presented. As the ROM approach for equipment maintenance in airlines and other organizations has resulted...
in considerable cost savings, experiences from these industries should be used to adapt this approach for maintenance of capital intensive and complex mining equipment with major economic consequences. For the mining industry, the real challenges lie in the successful conceptualization and implementation of the RCM approach to optimize the maintenance functions and related activities.

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REFERENCES


Barlow, R. E. and Davis, B. 1977. Analysis of time between failures for repairable components, Int. Conf. on Nuclear system reliability engineering and risk analysis, SIAM, Pennsylvania.


APPENDIX 1

CALCULATION FOR OPTIMAL MAINTENANCE INTERVAL

Given below is a calculation for deciding maintenance interval for a hydraulic pump of an EHD machine based on the reliability characteristics of the pump. This interval is decided by calculating the optimal operating time based on the time to failure data recorded and the degree of the ratio desired. The following 30 time to failure data is recorded for a particular pump in hours:

325, 443, 160.9, 85.3, 123.4, 148.8, 99.0, 168.8, 127.0, 55.0, 19.9, 176.9, 57.3, 41.2, 21.4, 4.3, 97.9, 164.1, 7.4, 123.3, 113.5, 127.9, 67.7, 1.3, 161.8, 77.3, 14.4, 30.6.

Assuming that the times to failure are identically and independently distributed, the statistical test shows that these are exponentially distributed with a mean time to failure (MTTF) of 87 hours. Now, the maintenance intervals are calculated for 90%, 85% and 80% of operational reliability for the pump.
The reliability function of exponentially distributed time to failure is given by (Billinton and Allan, 1983):

\[ R(t) = \exp(-\lambda t) \quad t \geq 0 \]

or\[ t = \ln(R(t)/\lambda) \quad -- (1) \]

Where \( R(t) \) is the reliability of operation, \( \lambda \) is the failure rate and \( t \) is the optimum time of operation. In this case, \( R(t) = 0.9, 0.85, 0.8 \); \( \lambda = 1/\text{MTTF} = 1/87 \). The value of 't' for 90%, 85% and 80% operational reliability from equation (1) are 9.1, 14.1, and 19.5 hours respectively. Thus, for example, to achieve 80% of operational reliability the pump is to be operated approximately for 20 hours and then preventive maintenance, replacement or required repairs should be performed. This simple calculation may be helpful in deciding the maintenance schedule of the system and assessing the failure risks during operation for different operation times.