

TPM framework for underground mobile mining equipment; A case study

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In underground mines, mobile mining equipment is critical to the production system. Drill rigs for development and production, vehicles for charging holes, LHDs for loading and transportation, scaling rigs and rigs for reinforcement and cable bolting are all important units in the process to generate a continuous ore flow. For today's mining companies, high equipment availability is essential to reduce operational and capital costs and to maintain high production. High and controllable reliability is also important especially in attempts to automate the production equipment. This paper compares existing maintenance work in a Swedish and a Tanzanian mine. The various maintenance procedures are identified and evaluated based on a TPM framework.

Keywords: TPM, Maintenance, Maintenance strategy, LHD.

1. Introduction

Maintenance is the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform its required function (EN 13 306 2001). The maintenance of mining equipment is both challenging and expensive. Over the years, remarkable progress has been made in maintaining equipment in the field, but factors such as complexity, size, competition, cost and safety continue to challenge maintenance engineers (Unger and Conway 1994). Increased mechanization, automation and amalgamation of processes within mines have further complicated the issue (Kumar 1996). Mining equipment maintenance costs range from 20% to over 35% of total mine operating costs, and they are continuing to increase (Unger and Conway 1994). To control these costs, mining companies have focused on areas such as optimizing scheduled maintenance operations, deferring non essential maintenance, reducing maintenance manpower, controlling inventories of spare parts more effectively and using contract maintenance support (Unger and Conway 1994). They look for better maintenance practices for their mobile

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equipment, especially in underground mining operations where control of maintenance costs requires effective maintenance planning.

It is possible to implement a successful maintenance planning system in a mine as long as systems and procedures provide a logical, disciplined approach to maintenance. Better control of maintenance through team work, proper and timely accomplishment of tasks such as data recording and reporting also play a major role. This paper discusses the concept of Total Productive Maintenance (TPM) and evaluates two case-study mines from a TPM point of view.

1.1 Total Productive Maintenance (TPM)

TPM consists of a range of methods known to improve reliability, quality and production. More specifically, TPM aims to maximize equipment effectiveness by changing the corporate culture to improve a company's personnel and plant. Cultural change at a plant is difficult; it involves personnel working in small groups, machine operators having a role in the maintenance program and the maintenance department providing good support (Willmott and McCarthy 2001). TPM seeks to develop a "maintenance-free" design, asking all employees to help improve maintenance productivity by stimulating their daily awareness (Nakajima 1988).

In any industry, the performance of a company's main priorities needs to be measured by means of key performance indicators. Common parameters include total system/plant effectiveness, system/plant productivity, availability, cost efficiency and quality (Moubray 1997). TPM is in the upper part of the hierarchical asset management pyramid shown below (Figure 1) since it involves both technical and human aspects. TPM is a good concept to use in mining because human factors play a significant role in the operation of a mine. In fact, because operators are quite isolated, management has to handle both technological issues and human factors.

Yeoman and Millington (1997) list the five pillars (Figure 2) of TPM as:

- Increased equipment effectiveness
- Training
- Autonomous maintenance
- Early equipment management
- Planned preventive maintenance.

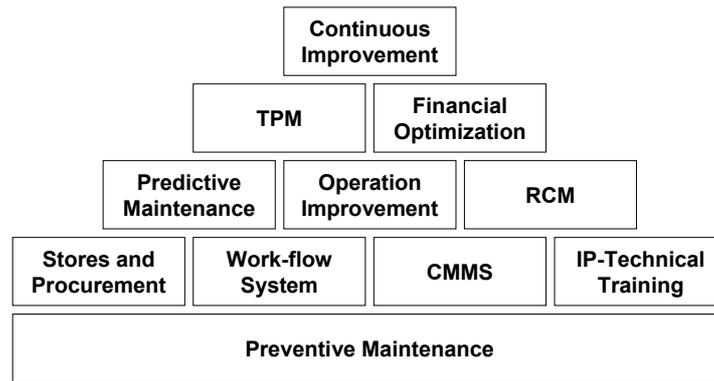


Figure 1 - The Asset Management Pyramid (Wireman, 1998)

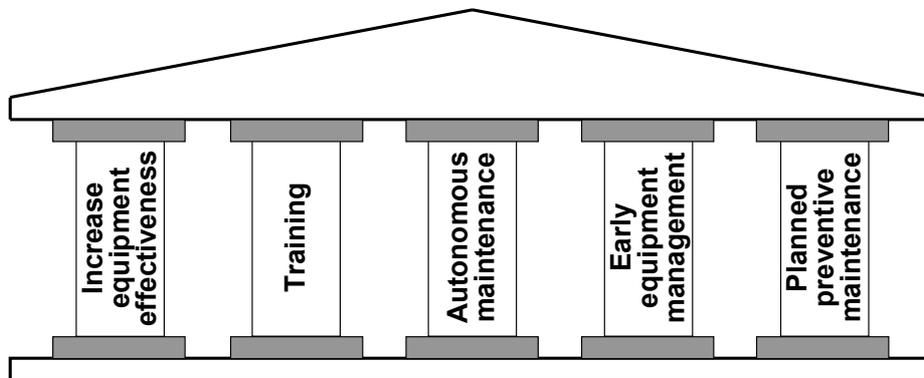


Figure 2 - The 5 Pillars of TPM (Yeomans and Millington, 1997)

In its measurement of overall equipment effectiveness (OEE), TPM goes beyond availability or machine uptime to factor in all issues related to equipment performance. The formula for equipment effectiveness must look at availability, the rate of performance and quality. This allows all departments to be involved in determining equipment effectiveness (Moubray 1997). Training is equally important in TPM; the aim is to develop learning and understanding through real-life experience. TPM also seeks to establish autonomous maintenance which refers to operator asset care. When establishing autonomous maintenance, there are seven steps to consider: these include creating an awareness of the equipment, order, cleanliness and discipline at the workplace. Others are creating and following cleaning and lubrication standards, and undertaking general inspections of the equipment. In TPM, special attention is given to early equipment management or the reduction of the life cycle costs in the early stages of the process. Finally, to improve the planning of preventive maintenance, details vary depending on the industry, but in all cases, it is important not to perform unnecessary

maintenance. The best tool for condition monitoring is the operator who knows his/her equipment and feels responsible for it. (Willmott and McCarthy 2001)

1.2 Maintenance types and strategies

According to EN 13306 (2001) standards (Figure 3), maintenance can be grouped into two major groups, Preventive Maintenance (PM) and Corrective Maintenance (CM). PM can be further subdivided into condition based maintenance and predetermined maintenance which implies that PM can be time based or condition based. CM can be subdivided into two subgroups: deferred and immediate. CM is a reactive maintenance approach; PM is proactive.

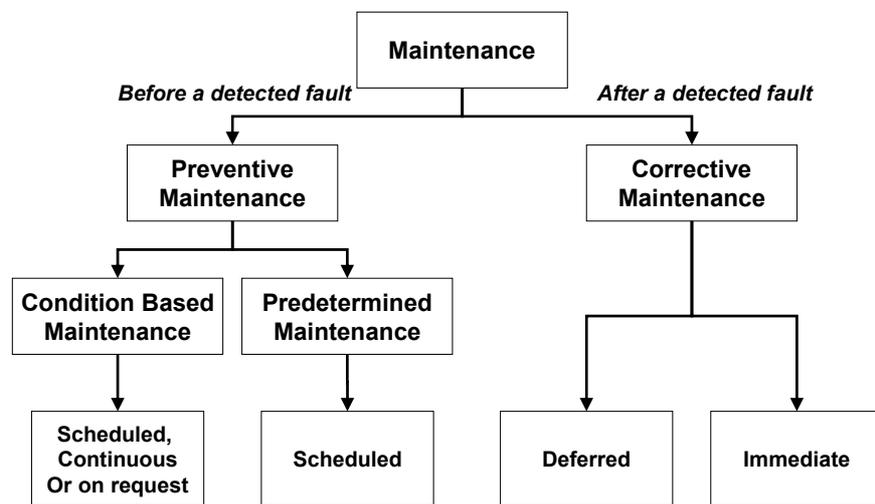


Figure 3 - Maintenance overview chart according to EN 13 306 (2001)

1.2.1 Corrective Maintenance (CM)

CM is the maintenance carried out after fault recognition and is intended to put an item into a state in which it can perform its required function (EN 13 306 2001). This is the most expensive form of maintenance, especially if it is urgent. Since there is little time for planning and coordination, the start-up cost and the cost of lost production can be large (Kumar et al. 2010). As it does not involve forecasting failure, CM is often applied when it is difficult to predict when an item will fail.

1.2.2 Preventive Maintenance (PM)

PM is carried out at predetermined intervals or according to prescribed criteria; it is intended to reduce the probability of failure or the degradation of an item (EN 13306 2001). All preventive management programs are time driven. The item to be maintained can either be replaced or reconditioned depending on its condition. As noted above, PM can be divided into condition based or predetermined maintenance (Coetzee 2004).

2. Case studies

This paper considers two case studies, a mine in Sweden and one in Tanzania. The work is limited to maintenance of mobile mining equipment with special focus on Load Haul Dump machines (LHDs). The research approach includes questionnaires, oral interviews, discussions with stakeholders and data collection.

2.1 Case study 1: LKAB Malmberget mine, results and analysis

LKAB's Malmberget mine is the second largest iron ore mine in Sweden. The mine is owned by Luossavaara-Kiirunavaara AB (LKAB) and has an annual production capacity of over 12 million tonnes of iron ore. It is located in Gällivare in the north of Sweden and contains about 20 ore bodies spread over an underground area of about 5 by 2.5 km. Seven are currently being exploited. Mining began in 1888, and since then, over 350 Mt of ore have been extracted. LKAB employs about 1,000 people at Malmberget. In 2009, Malmberget produced around 4.3 Mt of pellets out of LKAB's total production of 17.7 Mt of pellets. Magnetite is the principal iron ore mineral, although some areas contain significant amounts of haematite (Net resources international 2011).

As it was not possible to interview all department members, we selected the key personnel responsible for the maintenance department activities; the selection process was based on covering all levels of maintenance department processes. Discussions and interviews took place with maintenance manager, maintenance planner, maintenance supervisor and operator of the LHD machine. The findings of the interviews and discussions are presented below, along with the data analysis.

2.1.1 Maintenance workshop and storage

Currently, the mine has about 50 mobile equipment units, including drill rigs, LHDs, scaling machines, charging trucks, etc. There are three types of workshops in the mine. The first repairs development vehicles (drill rigs, scaling machines, concrete trucks, trucks, etc.). The second maintains LHDs (Figure 4), scaling machines and big boulder trucks. The third deals with maintenance trucks, mining trucks, fire trucks and busses. Maintenance services from major services to small repairs, bearing and brake changing, transmission and motor changing are done in workshop two. The repair work includes boom repair, bucket repair and equipment structural repair. The maintenance team has up to 60 workers. Another 8 employees are at a high managerial level. The department has 3 shifts with 5 persons in each.



Figure 4 - Underground workshop (number 2); to the left is the LHD in maintenance and to the right is the front of the LHD with its bucket being removed for repair

The mine has an underground storage room at level 815m, where most of the materials and spare parts are stored. Various other special underground storerooms contain big materials and spares such as tires and buckets. The mine also has a storage room which is shared with Kiruna mine. Briefly states, the storerooms' management function is to ensure an adequate inventory of parts to meet the mine's needs. Figure 5 shows a storeroom with hydraulic pipes and tubes, as well as other spare parts such as fittings, bolts and nuts.



Figure 5 - Underground storeroom with hydraulic pipes and other spare parts and materials

The purchasing department buys all spare parts and materials. The ordering of materials/spare parts and purchase procedures are the following. First, the work order is written using Movex, a resource planning, scheduling and inventory control software. A service person or maintenance planner is responsible for the work order. The manager approves the order and sends it to the purchase department who completes the order. If the spare part or material requirement is urgent, it is ordered immediately, and the paper work comes later. The maintenance planner can also order materials that are not available in the storeroom or that are running short.

2.1.2 Maintenance work programs

The flow of maintenance work can be categorized into PM servicing and failure fixing/repair. Inspection is done by the operator at the start of each shift. PM servicing is done every 250, 500, 1000, 2000 machine engine hours; an overall inspection takes place after initial cleaning of the machine to identify other necessary maintenance tasks. Servicing of the engine, converter, gearbox, hydraulic pump and transmission system is done after a predetermined amount of machine hours. In addition to the workshop, a field service team fixes failures immediately when that is possible. The work order for each job is written by a service person or by the maintenance planner. Breakdowns, especially major ones, greatly affect the maintenance planning budget, and this is

normally shown in increased maintenance cost/ton. Major causes of LHD breakdown are faulty hydraulic systems, electrical systems, engines and tires.

2.1.3 Maintenance strategy

The maintenance strategy of the department follows the standard EN 13306, (2001). For a better understanding of the maintenance process, CM and PM data were analyzed for the LHDs were analyzed. We found that the amount of time spent for CM was on average 70 percent more than the time spent for PM during all years of analysis, 2006 to 2010. This means that attention must be paid to the CM time.

2.1.4 Maintenance performance indicators

The main goal of the production and maintenance department is to achieve optimum production with minimal or no obstructions. With the maintenance planner's input, the production manager and repair crew attempt to keep 9 out of 13 LHDs available at all times. The key performance indicators of the department are cost per ton (SEK/ton), mean time to failure (MTTF) and equipment downtime. The person responsible for measuring these indicators is the maintenance planner or maintenance engineer.

2.1.5 Improvement groups

The department's PM improvement plans include collecting suggestions from the workers in the department with a view to making improvements and providing savings. The ideas are reviewed by a committee; with the help of the maintenance planner, the committee calculates the savings potential, and an award is given to the person who makes the best suggestion.

2.1.6 Education and training

There is some training for the maintenance crew and the LHD operators, but it could be more effective and properly planned. There is a need to establish effective training schedules and programs for the maintenance staff. LHD operators receive on-the-job training during normal working operations under the supervision of an experienced operator (trainer); this takes two to three weeks depending how quickly the trainee

learns the work. When the new operator manages to run the machine, he/she is given the same work as the more experienced operators.

2.1.7 Health and safety issues

Risk analysis is normally performed in the mine and to ensure proper safety management, risks, incidents and accidents are continually reported and worked out. The plan is to improve safety through the immediate reporting of risks, incidents and accidents in the mine. Safety rounds are currently being made as well; every person has to visit 2 internal workplaces per year; high ranking employees (managerial level) have to visit 15 workplaces per year. They investigate how regulations are being followed and how workers use safety gears and equipment, escape routes and assembly points, and they conduct talks on other worker safety issues.

2.1.8 Continuous reliability improvement and feedback

The continuous reliability improvement system at the department is reactive, meaning that improvement groups are formed when a problem arises. Feedback is an important tool in any organizational department, but in this case, the feedback is not effective, especially to operators.

2.2 Case study 2: Barrick Gold Corporation Tulawaka mine, results and analysis

The Tulawaka mine is located in northwest Tanzania, in the Biharamulo District of the Kagera Region. It is an open-pit mine with an underground access ramp located at the bottom of the pit. Tulawaka is a joint venture between African Barrick Gold and Northern Mining Explorations Ltd. Barrick holds 70 percent interest and is the operator. In 2009, Barrick's share of production was 66,000 ounces of gold at \$413 per ounce, with Barrick's share of proven and probable gold reserves estimated at 93,000 ounces of gold. Tulawaka's life as of December 31, 2009, was estimated to be approximately two years based on proven and probable reserves. According to a Tulawaka responsibility report (2010) an updated mine plan based on the current successful underground mining is being prepared; this may result in the extension of the mine life. Current operating capacity of the mill operations is approximately 1,320 tonnes per day. Total production in 2009 was approximately 94,000 ounces of gold at an overall recovery rate of 94.1 per

cent. A study of the operation and feasibility of mining the ore body below the pit with underground methods is being done as well.

At the Tulawaka mine, we interviewed maintenance personnel at different hierarchical levels.

2.2.1 Maintenance workshops and storage

Currently, the mine is not deep enough to accommodate an underground maintenance workshop and storeroom, although there are plans to construct one for minor repair and services. Maintenance is performed in a central surface workshop supported by the purchasing and warehouse units for materials and spare parts; the department also outsources maintenance. The workshop uses a team specialized in both surface and underground mining equipment. The department deals with the service of the following mobile underground mining fleet: 3 LHDs, 3 drill rigs and 3 tele-handlers. The maintenance work is done in three shifts and according to a Tulawaka responsibility report (2010) the maintenance department has about 25 employees. The maintenance department ensures continuous equipment availability and maintenance. The supply chain starts with the materials required by the department; the warehouse is contacted to check their availability. If spare parts or materials are not available, a quotation/proforma invoice for them is sent to the selected supplier, using a purchase requisition from the system. The major causes of LHD breakdowns in the mine are hydraulic system or electrical system, wear and tear caused by friction and expansion and contraction of materials.

2.2.2 Maintenance strategy

The department categorizes maintenance as planned maintenance, unplanned maintenance, corrective maintenance and condition monitoring. Preventive maintenance as a planned maintenance activity has been a key in the successful implementation of maintenance practices at the mine. But to ensure continuous availability and reliability, the department has designed the following improvement plan:

- Prepare maintenance schedule based on hours interval
- Put in place the maintenance kits
- Conduct condition monitoring and oil analysis

- Perform pre and post PM inspection
- Put in place all proper tooling for maintenance activities
- Introduce a service report system

Future plans of the department to reduce downtime include the following:

- Complete backlogs in a timely manner during planning downtimes
- Educate operators to report all defects they see during operations, and plan for execution as fast as possible
- Educate mechanics in inspection methods
- Introduce condition monitoring

2.2.3 Maintenance performance indicators

The main maintenance performance indicator at the mine is availability; this is the first priority in assessing maintenance effectiveness.

2.2.4 Education and training

The maintenance crew is trained in two ways. The first is classroom training; during training, the crew is removed from the work site to attend the session. Classroom training normally involves theories and discussions of the particular maintenance subject. The second is on-the-job training with the aid of an experienced maintenance worker.

2.2.5 Health and safety issues

The maintenance department follows the company philosophy which says that every person should go home safely and healthily every day. The mine is committed to achieving a zero-incident work environment with a safety culture based on teamwork and safety leadership. The company's safety and health policy states that "nothing is more important than the safety, health and well-being of workers and their families". Therefore, the department has implemented key safety programs and activities, including systems and policies, training for all crews, performance measurement, risk assessment processes, recognition programs for safety achievement, and a steady flow of information that keeps people focused on continuous safety improvement.

2.2.6 Continuous reliability improvement and feedback

To ensure continuous improvement of the maintenance process, the department provides feedback on the work and receives feedback from the production crew in daily meetings at the mine site.

3. Discussion

From a TPM perspective, the two mines have both similarities and differences.

Increased equipment effectiveness: From a maintenance perspective, neither mine uses the full concept of OEE; each has developed its own key performance indicators to control and manage maintenance and operation.

Training: Training is a very important issue for the development of multi-skilled persons. In mining workshops, the number of maintenance personnel is small. This reduces the reliability of the personnel, as training is oriented towards teaching specific tasks to specialists rather than training all workers to multi task. However, personnel can still be trained in basic tasks, so that a majority can perform them. Regardless of the amount of training in either mine, both could develop this further. Training needs to be continuous, well planned and documented. An evaluation of the current maintenance work in the LKAB mine maintenance department indicates the lack of an effective training program for staff members; this should be remedied. The department has to think of timely training so that the workforce can better maintain equipment. In Tulawaka, meanwhile, the reporting of downtime and repair has been a problem for the maintenance department; accordingly, the department should think of establishing standard reporting procedures. In addition, occasional training should be provided to the staff and the crew on how to report downtime.

Autonomous maintenance: The way to inspect and clean the machines is presently satisfactory in both mines but could be developed to improve maintenance and increase the workers' sense of responsibility for the equipment and shop floor. Developing cleaning and lubrication standards would be a good first step. The policy of forming improvement groups or conducting discussions with the supplier when problems have already occurred needs to be reviewed. Feedback was identified as a problem in the LKAB mine: the shop floor workers do not receive feedback on the work they perform, and the planners do not get feedback on the performance indication measured data. If

workers receive feedback on their daily activities, they will perform better. Although there is some feedback in the Tulawaka mine, it could be better utilized and further improved.

Early equipment management: There is little information on this for either mine; however, it is our opinion that more could be done to reduce the life cycle costs of the equipment (LHDs).

Planned preventive maintenance: A mine maintenance workshop has to follow a strict PM plan because of agreements with the manufacturers and also because of environmental factors. Even so, improvements in proactive maintenance can improve the overall preventive maintenance. Maintenance departments should seek an optimal balance between a strict PM and improvements of PM. It is necessary to find the optimal PM improvement plan for each mine so the PM can be optimized. High CM is a problem, as it means a department frequently faces unplanned and immediate maintenance in its day-to-day activities. Proper PM planning and scheduling can reduce the high frequency of CM.

4. Conclusion

TPM is used in mining to eliminate waste by reducing or eliminating production time lost to machine failures. The goal of a TPM program is to ensure that fleets of mobile equipment and process lines are always available. By minimizing slow running equipment and downtime, maximum value is added at minimum cost

However, successful TPM is a group effort where the entire organization works together to maintain and improve the equipment. New concepts such as autonomous maintenance and tools like OEE are worth considering but traditional methods continue to dominate; there is little desire to implement new techniques that directly involve workers.

The principal difficulties lie in the area of organizational change. When the organizational structure is flattened, teams can address issues with the greatest impact. As maintenance issues are addressed and total productive maintenance programs implemented, the true value of TPM begins to emerge. Employees join TPM teams, and operators are trained to perform routine maintenance items and assume an ownership role. This blurs the distinction between the roles of production and maintenance by

empowering operators to help maintain their equipment. The implementation of a TPM program creates a shared responsibility for equipment that encourages the greater involvement of all workers. In the right environment, this can be very effective in improving productivity.

A common misunderstanding is that the TPM method requires production employees to work more, thus reducing the number of maintenance personnel. This issue should be addressed to ensure that all employees cooperate with the implementation of TPM.

There are no strict rules for TPM application; rather, a tenable method for gradual and smooth application must be found. Workers from any level in the mine have to be gradually but constantly involved in the implementation of TPM. For good application of TPM, “top-down” involvement is fundamental, especially to change ways of thinking. For this reason, it is necessary to continue training and education, in both theoretical sessions and practical simulations, before on-site implementation takes place. In fact, after a simulation, the TPM approach should be tested in a pilot area.

In the starting phase, it is necessary to compile technical and economic information related to the performance parameters and to the costs of a maintenance system. An analysis of the starting situation allows a company to identify criticalities and to find possible solutions so that the next steps can be taken. Management procedures must be aligned with TPM, based on autonomous maintenance, work groups and increased worker competence.

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Biographies



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