



Maintenance analysis: a case in ore handling plant

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ABSTRACT

The Mechanical ore handling plant in Goa, India comprises of receiving and shipping section. Receiving section deals with the unloading of ore from barge. This is accomplished by wire rope operated grab un-loader. Since the unloading is being done round the clock, frequent failure of wire rope is observed. The unloading process gets disrupted when the wire rope fails. This results in significant loss in unloading hours. Detailed investigation is carried out to reduce the down time and recommendations regarding maintenance are made in this paper. Details of the maintenance policy model and results and discussions carried out are presented in this paper.

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Introduction

The unloading of ore at Ore handling plant (OHP) in Goa, India is done with wire rope operated grab un-loader. The grab used for barge unloading is Smag /Scissor type. This grab weighs around 8tons with shell assembly and saddle with chain links. It is operated with the help of hold/close wire ropes 2 nos. each. There are winch drums for hold/close and wire ropes are separately powered by 250 KW gearboxes. Goa is enriched with iron ore which places Goa in the rank list among other states of India resulting in higher per capita income. This mining has been the second large profession in the state besides, tourism evidently seen since 1912. Iron ores and processed ores in the form of pellets are being exported to the Middle East countries. The grab bucket is found suitable for handling or unloading from barges and storage areas, bulk iron ore, ore fines, caked or frozen lumps or pellets.

Operation

Principally the unloading operation carried out in the following way: Lower the open grab on to the cargo. Tighten the closing ropes, whereby the pivoted arms are closed along with the shells until the shell lips meet. The grab is then full and closed. The Holding ropes may be slack during the closing operation. As soon as the grab is closed, the closing movement changes into a lifting movement. The holding rope may remain slack as the grab is raised. The grab is then taken over to the dump yard. Lower the grab. Keep the holding ropes tight. Slacken the closing ropes. The shells open under its own dead weight, weight of the arms and the cargo weight. The grab is now emptied. Slacken the holding ropes to allow the grab to lower. The closing rope follows the descent and remains slack. Lower the grab in this open condition onto the cargo. Thus the cycle continues.

Specifications & Dimensions

Volume Capacity at 40° Angle of Repose	: 6.1m ³
Payload	: 13500 kg
Self Weight of Grab	: 8900kg
Spread of Lips in open condition	: 5600mm

Overall height in open condition	: 55330mm
Overall Width	: 2650mm
Rope Size IWRC Steel	: 28 mm
Rope Sheave PCD	: 660 mm
Closing Rope Stroke	: 6150mm
Length of Rope withdrawn for closing	: 14400 mm
Speed of Rope	: 160M/min
Grab lifting / lowering speed	: 93M/min
Time required for closing the grab – Minimum	: 5 sec

Problem on Hand

Since the unloading is round the clock, frequent failure of wire rope is observed/reported. The common practice prevailing at the plant is shortening wire rope 3-4 times giving approximate life of 1 month and provision has been made to provide extra wire ropes on hold/close winch drum. However, the required length is around 67m is necessarily to be maintained. The unloading process cannot be done if the wire rope fails. Moreover, it was observed that frequent shortening of close wire ropes will lead into major failure. Failure of scissor main axle assembly could lead to a major problem. Replacement of single sheave/double sheave with bearings is difficult task due to improper access which causes loss of unloading hours. Hence a detailed study of wire rope and its failure needs to be done to find ways and means to address this problem.

Literature Review

In [1], Vaurio develops unavailability and cost models for periodically inspected and maintained units to minimize the cost rate by proper selection of optimal inspection interval using bisection procedure. [2] analyzes a policy for optimal scheduling replacement intervals of technical systems on the basis of maintenance cost parameter. The author validates the policies proposed using Raileigh and Maxwell distributions. [3] proposes a method to obtain optimal replacement time of a complex system based on the lifetime distribution function and repair cost of the components. [4] surveys literatures from 1976 to 1990 and presented an overview of optimal maintenance and replacement models. Hjorth proposed a three-parameter distribution with

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increasing, decreasing, constant or bathtub – shaped failure rate function [5]. This paper mainly attempts description of hazard rate function piecewise. Xie and Lai presented additive model involving four parameters to describe the bathtub profile [6]. The parameters of this model were estimated using Weibull probability plot (WPP). Jha discussed the problem of determining optimal burn-in time under general failure modes [7]. The author provided bounds for optimal burn-in considering bathtub shaped failure rate function as a special case.

[8] proposed a decision diagram to prefer PM schedule over BDM based on the model discussed by Kay. The authors used two –parameter Weibull distribution whose parameters are estimated by Weibull Probability Plot (WPP).

In reliability engineering, determination of burn-in plays a key role in provisions of warranty. As pointed out by [9], fitting probability distributions, like Weibull distribution to data related to electronic components, is an essential activity in warranty forecasting model and lifetime analysis.

Latest maintenance systems like reliability centered maintenance (RCM) demands rather closer estimation of the parameters pertaining to the failure process of maintenance significant items. As commented by [10] that traditional tool life models do not take into account the variation inherent in metal cutting processes.

As a consequence, the real tool life rarely matches with the predicted values. [11] remarked that Weibull distributions play important role in reliability studies and they have many applications in engineering.

According to the authors, estimating parameters of three-parameter Weibull distribution is quite difficult, and to that effect the authors developed an approach that takes the advantage of artificial neural networks (ANN) exploiting the concept of the moment method to estimate Weibull parameters.

Notation

A	: Availability in case of BDM
A _s	: availability in case of PM
ANN	: Artificial Neural Network
BDM	: Breakdown maintenance
β	: Shape parameter of two-parameter Weibull distribution
C	: Maintenance cost per unit time for BDM
c _s	: Maintenance cost per unit time for PM
C	: Average effective maintenance cost rate for BDM
C _s	: Average effective maintenance cost rate for PM
c _p	: cost of scheduled replacement
c _f	: Replacement cost on failure
f(t)	: probability density function (pdf) of time to failure
F(t)	: Distribution function of time to failure
h(t)	: Hazard rate function
m	: Mean Time To Repair (MTTR) or Mean maintenance time, in case of BDM
m _s	: MTTR, Mean maintenance time of PM
MTBF	: Mean Time Between Failures (MTBF)
PM	: Preventive maintenance
OHP	: Ore handling plant
R(t)	: Reliability function
RCM	: Reliability Centered Maintenance
T*	: Optimal schedule
\bar{T}	: Mean time between preventive maintenances
θ	: Scale parameter of Weibull distribution
WPP	: Weibull Probability Plot

Models

There are two models proposed to resolve the issue of wire rope failure in the ore handling plant at Goa. Brief descriptions of the models are taken in this section while the applicability and the results fall in the subsequent sections of the paper.

Kay's Model

The model developed by [12] offers considerable scope to derive collaborative maintenance decisions. The schedule maintenance is to mitigate the failure of machinery, during its assigned operating time by means of scheduled maintenance. It has long been accepted that a reasonable criterion by which the effectiveness of PM can be addressed via availability and maintenance cost. This is so because the relative increase in availability that can be obtained by PM compared to BDM is rather limited. Equations for availability and maintenance cost rate have been derived in respect of PM and BDM. Availability under BDM is

$$A = M/(M+m) = 1/(1+\mu) \quad (1)$$

and under PM is

$$A_s = \frac{\bar{T}}{\bar{T} + m_s R(T) + m[1 - R(T)]}$$

Maintenance cost rate under BDM is

$$C = \frac{c \cdot m}{M + m}$$

And under PM is

$$C_s = \frac{[1 - R(T)]mc + R(T)m_s C_s}{\bar{T} + m_s R(T) + m[1 - R(T)]} \quad (4)$$

Hence the criteria for preventive maintenance to be attractive are: A_s-A > 0 or C_s-C < 0 The following conditions have been derived using the above criteria, to ensure that the preventive maintenance scheduled in time T offers maximum benefit than the corrective maintenance.

$$\alpha = \frac{1}{M} \int_0^T R(t) dt$$

$$\alpha > 1 - kR(T) \quad (8)$$

where k = k₁=1-γ for maximizing availability and k = k₂ ≈ (1-δγ) for minimizing maintenance cost. As failure processes can be safely modeled as Weibull distribution, Equation (7) can be evaluated after carrying out Weibull analysis. The integrand in Equation (7) is transcendental but real valued analytic function. Therefore, a graphical approach would be more feasible. Equation (8) resolves into α-curve and a straight line [1-k.R(T)]. It is proposed to obtain optimal schedule corresponding to the max gap between α-curve and criterion line under consideration as shown in Fig. 2.

Unit Replacement

Using the first principles of replacement policies, an optimal period for age replacement policy is derived for two-parameter Weibull distribution as applied by Mariappan et.al. (2008)

$$T^* = \theta \left[\frac{c_m}{(c_f - c_m)(\beta - 1)} \right]^{1/\beta} \quad (9)$$

Results and Discussion

Required cost data were collected from the field, which are as given under:

Total tons unloaded per day per un-loader = 5,555 tons
 Cost per ton unloaded = Rs. 30/-
 No. of working hours per day = 20hrs
 Mean time for replacement on failure m = 12 hours
 Mean time required for replacement on PM, ms = 10 hours
 Cost on maintenance crew = 3625 INR
 Cost of wire rope = 10000INR
 Cost due to loss in unloading due to down-time = 83325 INR
 The associated costs were calculated as shown below:
 Thus the cost associated with replacement on breakdown is calculated and comes to

C_f = Charges of working group + Cost of wire rope + Cost due to loss due to down-time

$$= 3625 + 10,000 + 99,990 = 1,13,615 \text{ INR}$$

C_m = Charges of working group + Cost of wire rope + Cost due to loss due to down-time

$$= 3625 + 10,000 + 83,325 = 96,950 \text{ INR}$$

Carrying out Weibull analysis as mentioned in Table 1 and Fig. 1, gave shape parameter, $\beta = 1.985$ and scale parameter $\theta = 181$ hrs

Applying Models

$$ms/m = \gamma = 0.3$$

$$K_1 = 1 - \gamma = 0.7$$

$$F(T) = 0.4 \text{ yields } T^* = 173 \text{ hrs}$$

$$K_2 = 1 - \delta\gamma$$

$$\delta = c_s / c = 0.853$$

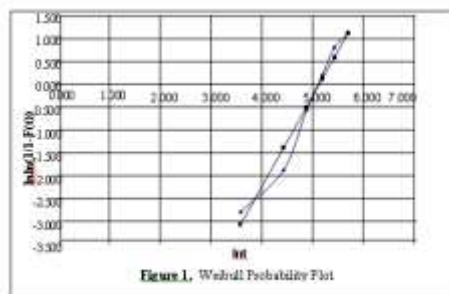
$$\therefore k_2 = 1 - 0.853(0.3) = 0.744$$

$$\text{Hence } 1 - k_2 = 0.256$$

Both the cases the optimal T^* is 173 hrs.

As Kay's model is more effective as it is evolved on the comparison between BDM and PM and moreover as per the criteria of improvement in availability and maintenance cost are almost closer, $T^* = 173$ hrs for the wire rope replacement is considered to be optimum. Applying on Equation of unit replacement gave finally the optimal schedule for wire rope replacement

$$T^* = 181.272 \left[\frac{96,950}{(1,13,615 - 96,950) \cdot (1.985 - 1)} \right]^{1/1.985} = 440.53 \text{ hrs}$$



First of all, both the models agree on one thing that PM is preferable for the mere fact of the shape parameter being greater than 1.

But these two models offer two different optimum schedule periods for wire rope replacement.

As the underlying principles in Kay's model is on preference of PM over BDM, that too with two different criteria. So, the schedule period for replacement obtained from Kay's model is preferred over unit replacement model. It is important to note that the schedule obtained is almost close for both the criteria: improving availability and minimizing maintenance cost, usually conflict to be the case.

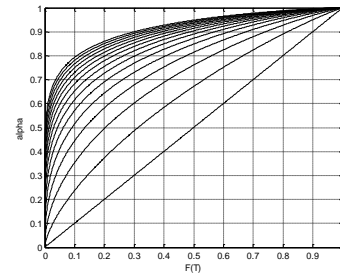


Figure 2. Kay's maintenance policy decision

Conclusions

As failure of wire rope in material handling plant under study is found to be quite crucial and the unloading of barges carrying iron ore to be exported to Middle-East from Goa from various mines is round the clock. It is also found from the cause and effect diagram that ignoring or misdoing of maintenance of wire rope will lead into other undesirable consequences. To this effect two models are identified and applied. The application of these models comes out with an optimal schedule for replacing wire rope as 173 hrs. This schedule period of replacement is expected to award enhanced availability and minimized maintenance cost. Therefore the present maintenance practice of BDM must be discontinued.

However, the replacement schedule recommended needs to be applied and compared for the actual gain in availability and maintenance cost. For effective operation at material handling plant, based on the failure analysis, the following recommendations are also offered in addition to the optimal schedule for replacement.

- Prevent the contact of wire rope and saddle material by introducing a material having lesser hardness.
- Place proper lubrication mechanism for lubrication of the bearing on which pulley is mounted.
- Provide some surface coating for the wire ropes.

A hydraulic system in place of wire rope will be an advanced thinking and the need of the hour too for the plant in order to pace with technological advancement and modernization which are omnipresent in industrial scenario and in fact they are global phenomena.

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Table 1. Transformation for Weibull Probability Plot

Interval	Mid-point	Frequency	P(t)	F(t)	$\ln \ln [1/1-F(t)]$	$\ln (t)$
$12 \leq t \leq 60$	36	5	0.059	0.059	-2.803	3.584
$60 \leq t \leq 108$	84	7	0.082	0.141	-1.883	4.431
$108 \leq t \leq 156$	132	25	0.294	0.435	-0.560	4.883
$156 \leq t \leq 204$	180	23	0.271	0.706	0.202	5.193
$204 \leq t \leq 252$	228	16	0.188	0.894	0.809	5.429
$252 \leq t \leq 348$	300	5	0.059	0.953	1.117	5.704
$348 \leq t \leq 516$	432	4	0.047	1.000	∞	6.068