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Reliability Design and Maintenance Formulation for Dumpers used in Mining Industries

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Abstract: **In present day production systems, productivity is dependent on reliability of fewer but more sophisticated equipment and processes, particularly in Manufacturing and Material handling. As a key parameter of this I have found the reliability of the heavy moving machinery such as dumpers in the Singareni Colleries Godavarikani. For this the methodology of Reliability Centered Maintenance is taken as a part of that the Time Between Failures (TBF) and Time To Repair (TTR) for the same have been found and there by plotted the cumulative graphs between the Failure No Vs Cumulative TBF and also TTR. There from did the trend analysis; trend analysis is an aspect of technical analysis that tries to predict the future based on past data. Trend analysis is based on the idea that what has happened in the past gives Engineers an idea of what will happen in the future. There are three main types of trends: positive trend, negative trend and no trend. All the dumpers have been classified in the category of various trend categories so that the suitable maintenance plans have opted to increase the reliability of the heavy earth moving machinery. Hence based on the results obtained from the trend analysis the reliability of the dumpers can be found. That finally enhances the productivity of the system. This is not only limited to the coal mines but also can be applied or useful in all the company's or industries which can use any type of earth moving machinery.**

Index Terms: **Heavy earth moving machinery, Reliability, Time between failures, Time to repair.**

I. INTRODUCTION

The analysis on dumpers operated in Open Cast Project (OCP-III) mine of Singareni Collieries Company Limited (SCCL), Ramagundam are taken up with the following objectives.

1. To check whether the machines have come to their third stage of life cycle (Bathtub curve).
2. To identify the failure distribution and failure patterns of LHD vehicles [1,2,3].
3. To estimate the reliability characteristics of LHD vehicles.
4. To establish reliability oriented maintenance instead of time based preventive maintenance.
5. To optimize the overall maintenance cost.
6. To evaluate group behavior and hence to estimate contribution of each machine to the productivity/loss of production.
7. To evaluate reliability characteristics and failure behaviors of sub units so as to find which components are contributing to higher failures.
8. To establish suitable replacement policy for equipment and sub units.

A. Contribution of this Paper

On the whole this Paper is expected to contribute in the following fashion.

1. The trend tests will help the maintenance and production managers to predict the behavior of machinery. More clearly the trend test indicates in which state the machine stands in its life cycle (Bathtub curve).
2. Maintenance/production managers can thus come to a decision to adopt suitable policy of maintenance such as contractual/preventive/OFCM/CBM etc. hence plan for suitable maintenance policies aimed at utmost reliability[4,5].
3. The TTT plots indicate whether the failures of a machine are increasing or constant or decreasing.
4. The TTT plots can also help in planning and scheduling the reliability oriented preventive maintenance.
5. The reliability growth plots can be used to check whether the machine reliability can be improved by the modifications suggested.
6. The analysis can help to arrive at a decision on replacement policy of the equipment.
7. The analysis of subunits can give an idea for the group replacement of the components or parts.

B. Limitations

Calculation errors: In analysis and calculations wherever accuracy is not significant, figures are rounded off to the

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nearest whole number. It may hence contain or appear as an error and is to be ignored as it is negligible [6,7].

Influencing Factors: Various factors can affect the performance of dumpers.

C. Assumptions

Dumpers unavailability due to the natural disasters or any kind environmental impacts will be assumed as neglected. Hence in that particular case the dumpers are not treated as unavailable.

D. Procedure for RCM modelling

Step 1: Identification and Definition of Problem or Setting the Hypothesis
Step 2: Collection of Relevant Data
Step 3: Removal of Inconsistencies and Errors in Data
Step 4: Trend Analysis and Correlation Tests
Step 5: TTT Plots to Examine Exponential Fit
Step 6: Fitting the Suitable Model
Step 7: Confirmation Tests and Goodness of Fit
Step 8: Reliability Centred Maintenance Planning and Scheduling

II. Methodology

The field data is collected for the equipment categorized under repaired items in the form of Time between Failures (TBFs) and Time To Repair (TTRs). The data inconsistencies and errors are removed and the refined data is analyzed by both types of models viz. graphical and analytical models. However, more importance is given to graphical methods since it provides better simple understanding and can be easily reproduced. The graphical tests such as eye-ball analysis, cumulative plot test and serial correlation determine the presence of trend. The machines, which exhibit presence of strong trend, are further analyzed and fitted into non-homogeneous Poisson process (NHPP) models. Power law process (PLP) model, one of the most popular and commonly used NHPP models can be used for such study. If there is no trend, it confirms the independently and identically distributed (IID) assumption. The values obtained can be checked with some analytical tests such as Laplace test [8,9]. The machines free from trend are further graphically analyzed through total time on test (TTT) plots. The exponential fit that confirms homogeneous Poisson process (HPP) models can be known from this analysis, otherwise can be categorized as renewable process (RP) model which is in accordance with Weibull pattern. The goodness of fit (analytical) tests can confirm this. Thus, reliability characteristics and maintenance schedules can be estimated. Further, their reliability growth plots can also be drawn to estimate the improvements [10,11,12]. The reliability analysis and maintenance formulation are the key areas for enhancement of the dumpers performance. Further it is also to be understood that reliability is the key indicator of the dumper performance and also it has the influence over the other facets of the machine life cycle (MLC). Rahimdel, M et al have made an interesting research towards the betterment of the machines by analyzing the machine position in the MLC and also the cause and effects were found. Wang, R et al have used the failure mode effects and criticality analysis for understanding the failure criteria and their prioritization.

TABLE I.
Cumulative Plot Test Table-C-379

Failure no	TTR	CTTR	CAUSE	TBF	CTBF
1	160	160	oil leakage	120	120
2	138	298	Hoist	192	312
3	2250	2548	Differential	1128	1440
4	12	2560	Brakes	96	1536
5	8	2568	Hose	1056	2592
6	72	2640	Body	696	3288
7	348	2988	Brakes	24	3312
8	36	3024	Brakes	48	3360
9	42	3066	Brakes	48	3408
10	12	3078	Brakes	24	3432

Similarly, the remaining tables for C-379, C-362, C-378, C-306, C-304, C-314.

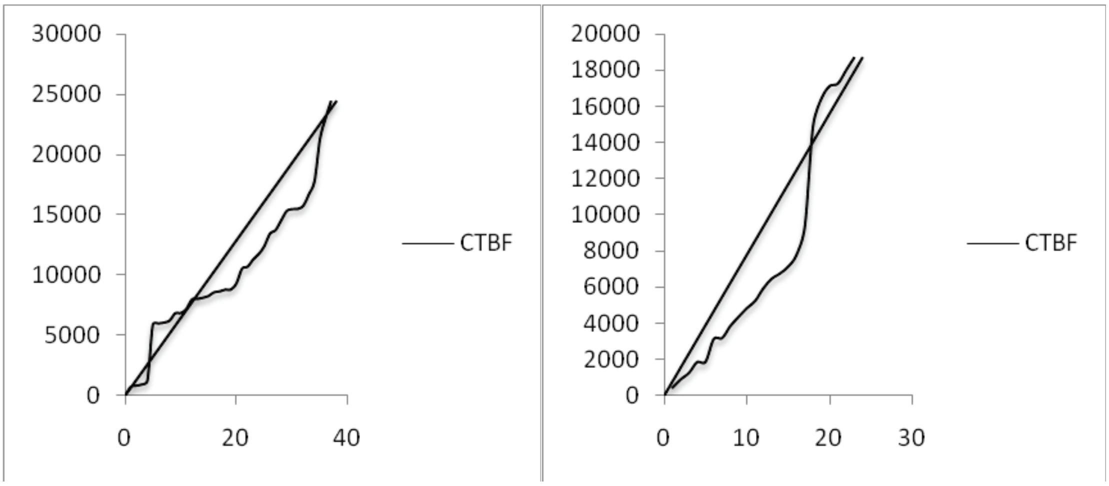

Figure 1. Cumulative Plot Test for C-379 and C-362 Dumpers

Similarly the remaining graphs for C-379, C-362, C-378, C-306, C-304, C-314, C-312, C-310, C-371, C-370, C-313, C-301, C-303, C-309, C-366, C-381, C-307, C-354, C-305, C-384, C-374, C-353, C-377, C-302, C-352, C-357, C-368, C-383, C-363, C-308

TABLE II.
TREND ANALYSIS TABLE

Sl. No	Dumper No	Cumulative Trend Test	EyeBall Trend Test	Trend
1	C-361	Weak +Ve Trend	No Trend	No Trend
2	C-369	+Ve Trend	+Ve Trend	+Ve Trend
3	C-375	No Trend	No Trend	No Trend
4	C-357	No Trend	No Trend	No Trend
5	C-353	Strong +Ve Trend	Strong +Ve Trend	+Ve Trend
6	C-374	Weak +Ve Trend	No Trend	No Trend

Trend Analysis

1. 20 Dumpers out of 36are not possessing any trend.
2. 10 Dumpers are showing a positive trend.
3. 06 Dumpers are showing a negative trend.

III. TTT PLOTS BY MLE METHOD

TABLE III.
MLE METHOD FOR C-361

F.NO	TBF	CTBF	OTBF	SI	I/N	PHI	SLOPE
1	696	696	8	288	0.027027	0.011784	0.050595
2	120	816	24	848	0.054054	0.034697	0.123448
3	96	912	48	1664	0.081081	0.068085	0.217251
4	288	1200	72	2456	0.108108	0.100491	0.30909
5	4704	5904	72	2456	0.135135	0.100491	0.336117
6	72	5976	72	2456	0.162162	0.100491	0.363144
7	72	6048	96	3176	0.189189	0.129951	0.449091
8	168	6216	96	3176	0.216216	0.129951	0.476118
9	600	6816	120	3848	0.243243	0.157447	0.558137
10	17568	24384	144	4496	0.27027	0.183961	0.638192

Similarly, the remaining tables for C-379, C-362, C-378, C-306, C-304, C-314

IV. TTT Plots by KME Method

TABLE IV.
KME method for C-361

F. NO	OTBF	LN(OTBF)	Ti(Beeta)	PRODUCT	CDF	PHI	SLOPE
1	8	2.07944154	42.22425	87.80287	3E-05	4.1E-06	4E-05
2	24	3.17805383	305.0565	969.4859	0.00022	5.4E-05	0.0003
3	48	3.87120101	1062.268	4112.254	0.00075	0.00026	0.0013
4	72	4.27666612	2203.934	9425.488	0.00156	0.00057	0.0027
5	72	4.27666612	2203.934	9425.488	0.00156	0.00057	0.0027
6	72	4.27666612	2203.934	9425.488	0.00156	0.00057	0.0027
7	96	4.56434819	3699.033	16883.68	0.00261	0.00093	0.0045
8	96	4.56434819	3699.033	16883.68	0.00261	0.00093	0.0045
9	120	4.78749174	5527.468	26462.71	0.0039	0.00134	0.0066
10	144	4.9698133	7674.542	38141.04	0.00541	0.00181	0.009

Similarly the remaining tables for C-379, C-362, C-378, C-306, C-304, C-314, C-312, C-310, C-371, C-370, C-313, C-301, C-303, C-309, C-366, C-381, C-307, C-354, C-305, C-384, C-374, C-353, C-377, C-302, C-352, C-357, C-368, C-383, C-363, C-308

V. Results of TTT Plotting by MLE and KME Methods

TABLE V.
List of Results

Sl. No	Dumper No	MLE METHOD	KME METHOD	RESULT
1	C-361	Deteriorating	Deteriorating	Deteriorating
2	C-375	Deteriorating	Deteriorating	Deteriorating
3	C-357	Deteriorating	Deteriorating	Deteriorating
4	C-372	Deteriorating	Deteriorating	Deteriorating
5	C-383	Deteriorating	Deteriorating	Deteriorating
6	C-352	Improving	Improving	Improving

Characteristics of reliability designing and planning

The following characteristics have been chosen for reliability designing and planning for maintenance of repairable equipment as these are found more suitable and meaningful [13,14,15].

T (Mode)

It is the most frequent probable Time Between Failure in a sample space of time domain.

$$T(mode) = \alpha * (1 - 1/\beta)^{1/\beta}$$

T (Median)

It is the median Time Between Failure of an equipment among the sample space of time domain about a Weibull Distribution at Reliability (R) = 0.5

$$T(median) = \alpha * (-\ln 0.5)^{1/\beta}$$

T (Optimal)

It is an optimal Preventive Maintenance interval for a machine to be observed at a certain reliability value.

$$T(optimal) = \alpha*(1/(\beta - 1))^{1/\beta}$$

T (Characteristic)

The life (period) of equipment in which 63.2 % of Weibull failures will occur. It is independent of shape parameter and reliability.

$T(Char) = \alpha$ [It's value is equal to alpha (α)].

B1 Life

It is the time at which 1 percent of the population will have failed at a reliability of 0.99.

$$B1\ life = \alpha * (-\ln 0.99)^{1/\beta}$$

B.1 Life

It is the time at which 0.1 percent of the population will have failed at a reliability of 0.999.

$$B.1\ life = \alpha * (-\ln 0.999)^{1/\beta}$$

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VI. Summary of Results

TABLE VI.
Summary of Results

Sl. No	D. No	α	β	T (Mode)	T (Median)	T (Optimal)	T (Char)	B1 Life	B.1 Life
1	C-361	2613.05	1.8	1665.58	2131.657	3475.86	2613.05	202.88	56.31
2	C-375	454.733	1.05	26.079	320.959	755.88	454.733	5.73	0.64
3	C-357	1237.11	1.62	683.79	987.17	2153.9	1237.11	72.81	17.58
4	C-352	1847.66	2.26	667.58	783.78	936.62	1847.66	95.24	30.2
5	C-374	1288.85	1.68	752.3	1036.23	1621.43	1288.85	83.37	21.11
6	C-383	609.6	1.3	198.09	459.97	1532.14	609.6	17.71	3.01

VII. Scheduling

The number of working hours after which the dumper should be taken for minor and major overhauling for increased efficiency of the dumper are given below.

TABLE VII.
Scheduling of Dumpers

Sl. No	Dumper. No	Major Overhauling	Minor Overhauling
1	C-361	3475.86	2613.05
2	C-375	755.88	454.733
3	C-357	2153.9	1237.11
4	C-352	936.62	940.67
5	C-374	2321.43	1288.85
6	C-383	1532.14	609.6

The available hours as well as utilized hours for dump trucks are less.

The availability of dumpers for production / the dumpers on roll at any point of time is 28 to 30 out of 36 (85T dumpers), at Ramagundam open cast project. This should be improved.

It is observed that about 35 – 40 % of the time is lost in attending machine breakdowns. A critical analysis of machine failures were taken into consideration, to locate the areas that require additional attention in maintenance, ordering spares and other requirements. Out of these the Spare Parts management area should be concentrated to strengthen the maintenance activity.

At the Ramagundam OC-III project, the reporting system is so poor, it was found difficult to analyze typical types of faults. Sometimes the reported failure could not be ascertained for want of confirmation from workshops. Hence with available data only reliability/availability analysis was carried out on 36 nos. of 85T trucks. The record keeping should be made perfect in directly usable form.

At last, it is advised that the company must emphasize Research and Development particularly, to perform research in reliability studies pertaining to the maintenance department.

It is better to establish a separate cell to evaluate reliability, schedule maintenance intervals, costing maintenance planning, study inventory policies, logistic studies etc. Such a department may be established with highly experienced, qualified and intellectual engineers and managers. If required this department may be centralized to oversee all the machines operated in various units/quarries/OCPs/UG mines of SCCL so that the transferability, interchangeability can be increased in the interest of enhancing the overall productivity. Further, the company should adopt by sponsoring some research scholars and make tie up with academicians such as professors to help in studying in this direction.

VIII. Results and Discussions

The purpose of this study is to collect data relating to transporting equipment operating in a group of coal mines, analyze data and evaluate the performance of dump trucks using the techniques of reliability engineering. Further the study is aimed at locating areas that need special attention, so that the availability and utilization of transport equipment can be improved in addition to enhancing the machine life.

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In today's economic climate, it is extremely important to minimize both capital and operating costs in any mining project. In an open cast project loading and hauling are the expense areas, the later costing as good as 30 to 50% of total mining cost. There is a concentrated effort to reduce haulage costs as well as limiting the haulage fleet size so that overall capital and operating costs are minimized.

The results of the trend analysis have given the nature and direction of the dumpers performance and also it has the laid arena for the total time on test. The complete analysis over the time horizon has also yielded the dumpers ability for the work to be performed.

A. Summary of Results

Trend Analysis

1. 20 Dumpers out of 36 do not possess any trend.
2. 10 Dumpers are showing a positive trend.
3. 06 Dumpers are showing a negative trend.

The performance of dump trucks in opencast coal mines are evaluated using the conventional statistical techniques and the performance when compared to the set norms of CMPDI with respect to available hours and utilized hours were found to be not up to the mark expected. The mines chosen for evaluation of transport equipment are working in a harsh environment with gradients of 1 in 10, with limited workshop facilities and trained personnel, the mining technology is different (old), in the sense open cast mining of already developed mines in a bored and pillar system. Further, it is found that the maintenance department is giving less importance to reliability orientation than production orientation.

B. TTT Plotting

1. 16 numbers of Dumpers out of 20 no trend are deteriorating.
2. 04 numbers of Dumpers out of 20 no trend are Improving.

IX. Conclusions

The conclusions drawn from the aforesaid discussion of results after thorough analysis and scrutiny are summarized in the paragraphs to follow.

A. Investigation on Machine Condition

The fundamental objective with which this research work has been started is to find the machine condition. The Dumpers are chosen for this purpose as they are assumed to have high a failure rate. The failure periods are time independent and not contradicting IID assumption. They are found to have increasing failure rates even though there is no evidence of Trend. Thus the assumption with which it started has been found true and hence it can be concluded that they are on the thresholds of the third stage (Old age/Worn out failures) of Machine Life Cycle i.e. BathTub Curve.

C. Reliability Characteristics

Various Reliability Characteristics such as $T_{(mode)}$, $T_{(average)}$, $T_{(optimal)}$, $T_{(median)}$, B1 life, B.1 life, Scale Parameter (α) and Shape Parameter (β) of Weibull MLEs are estimated. These characteristics will be highly useful guidelines for scheduling the maintenance activity and to deriving the suitable maintenance policy.

D. Maintenance Schedule

The present Preventive Maintenance is modified with reliability orientation. The existing Yearly, Half Yearly, Quarterly and Monthly Maintenance are substituted by Complete overhauling (C), Major Overhauling (M), minor overhauling (m) and Inspection (I). The frequency of dumper maintenance is arranged based on the machine conditions and MTBF or Failure Rate (and other Reliability Characteristics). The detailed proposed schedule chart is provided for quick reference. However, a little flexibility is taken in preparing the schedule in view of accommodating the complete and uniform overhauling of the dumpers and distributing the maintenance force evenly. This could be altered according to the practical demands and availability.

E. Further Scope

The present study is confined to a small no. of equipment i.e. 36, 85T trucks. Collection of data is not only a time consuming task but it is also challenging because proper collection of data is possible only when failure and repair logs are maintained accurately. Equipment performance depends among other things than its age also. Failure/repair data, properly collected, analysed and stored can be used by the management for a(a) maintenance planning, (b) spare parts provision and (c) ordering new equipment depending upon the life of the project. Right now, cost of maintenance, equipment wise is not readily available for evaluation of effectiveness of maintenance. There is a need to provide a PC at the mine workshops to log the information and store for retrieval. The log sheets should properly be planned and the reporting system has to be perfected. It is observed that there is vast scope for improving machine utilized hours in case of 85T dumpers by reducing the idle hours by properly reorganizing the interfacing activities and maintenance plans.

Performance of mine not only depends upon production equipment like shovels/dumpers but very much affected by availability and utilization of service equipment like dozers, scrapers, graders and other equipment. An integrated study of availability of all the equipment in a mine can only be improved by the enhanced utilization of the production equipment in spite of their availability.

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