Failure Analysis on Development Drilling Rigs

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Abstract

Barrick Gold Granny Smith Underground Mine operates a fleet of development drilling rigs. Considering the site condition and the age of the fleet, the current performance is acceptable but may not be at its optimum. The project utilises historical maintenance cost reports and work orders from Granny Smith to analyse the failure behaviour and potential changes to the maintenance strategy on the selected sub-systems of the development drills. Weibull analysis is conducted on both the sub-system and component level to identify the failure modes and the corresponding maintenance strategies. Failure modes are also identified for the sub-systems using the FMEA process. Maintenance tactics addressing those failure modes will be developed using RCM decision diagram in a later stage of the project.

1. Introduction

Face drilling is one of the most important parts of the mining process. The drilling rigs operate in hot, humid, and dusty conditions and are subject to constant vibration as they drill or bolt into hard rock. Because of the harsh operation environment, drills can fail to deliver their required performance. The service targets set for the development drilling fleet must be met to accommodate the expansion of the underground mine and ensure a desirable production profile. The project analyses the failure behaviour of the critical sub-asset groups and seeks opportunities through changes in maintenance tactics to improve the asset availability and reduce the costs associated with the failures.

There are four development drilling rigs in service at the Granny Smith mine. The target monthly drilled metres of each existing drill rig is 22,000, whereas the current performance only reaches 18,000. The availability is 5% below the target. The substantial difference between the two suggests the need to improve the fleet's productivity.

Failure analysis can be a useful tool in identifying failure modes and predicting reliability. The Weibull distribution is a common tool in failure event analysis to determine the mean time between failures of physical assets. It has been used to analyse the failure patterns of the axle bushes on underground loaders by Hastings. The failure pattern information is useful in determining the appropriate replacement policies and a key factor for wear out failure analysis is to be able to detect the onset of wearout. (Hastings, 2003)

Data cleansing and processing is one of the major challenges for the project. Veron and Hodkiewicz (2009) developed a 'Data Decision Criterion' which groups failure modes ensuring they are sufficient to enable distribution analysis. It involves (1) rejection of insignificant data sets, (2) incorporation of similar failure modes into one more broad, (3) accepting the data as is. A similar criteria is used for data processing in this project to improve model accuracy.

Maintenance tactics are to be developed for individual failure modes. Moubray (2007) promoted a reliability-centred maintenance (RCM) decision diagram which integrates all the maintenance processes into a single strategic framework. It categorises failures into three groups based on their consequences and task decision trees will be applied to these groups for maintenance strategy development. The diagram is summarised as *Figure 1.2*.

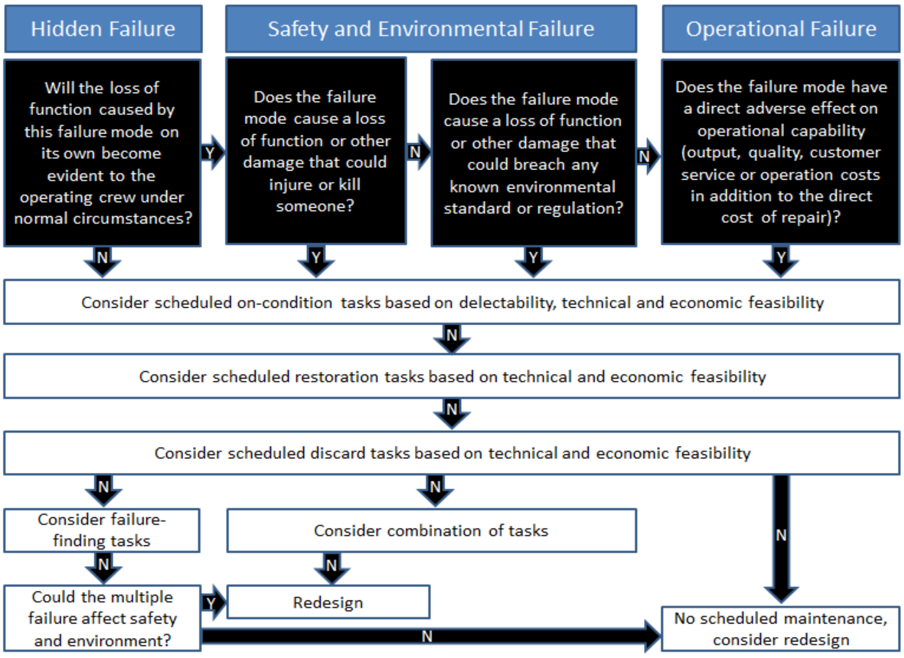

Figure 1.2: RCM Decision Diagram (Moubary, 1997)

2. Methodology

2.1 Data Retrieval and Processing

In the data cleansing process, any failures recorded on the same component within 2 days' time are considered only one as they could be remedial works from the day before. If multiple different failure modes happened within a short time, all the data will be accepted for a sub-system level analysis, as each of them indeed has resulted in the unavailability of the equipment. Weekly service inspects the general condition of the drill. Any preventive and corrective activities occurred in the service are recorded separately in the work orders. Therefore the weekly service is not considered as suspension in the Weibull plot. The first time to failure for all the analysis is unknown so it is taken out from the analysis.

The work order cost report covering the period from January 2008 to February 2012 categorises the components serving different functions into several sub-asset groups. Due to the complexity of the system, a criticality analysis (CA) is conducted in order to prioritise these sub-systems and decrease data processing time. The sub-systems are prioritised in terms of their functions, maintenance cost and number of failures during the testing period. The ranking for major sub-groups is shown in *Table 2.1*.

Group	No. of failures	Maintenance Cost		Function	Rank
		Preventive	Corrective		
Hydraulic	316	$403,600	$202,550	Force/Power Supply	1
Boom	160	$256,050	$470,990	Positioning	2
Drifter	145	$204,840	$343,080	Drilling	3
Feed Rail	155	$149,250	$194,140	Feeding	4
Electrical and Controls	146	$12,990	$99,310	Control etc.	5
Engine	52	$40,170	$78,600	Mobility	6
Frame	71	$93,720	$120,330	Safety and Support	7

Table 2.1: Sub-asset group prioritisation

The key functions for the development drilling fleet are drilling, scaling and ground support. Therefore the top five sub-asset groups are considered more important to the system availability and are analysed in this project.

2.2 Failure Distribution

A two parameter Weibull distribution is used to analyse the MTBF and determine the failure pattern. The following assumptions are made for the calculation: (1) the development drilling rigs are the same machinery and operate under the same conditions so that the time to failure records for all four drills can be put together for Weibull distribution analysis, (2) all the preventive and corrective activities are recorded in the work order cost report, (3) all the preventive and corrective activities are able to bring the asset back to its as good as new condition.

The work orders are put into different Excel sheets based on their sub-asset group and asset number. The sample time to failure is calculated by subtracting two subsequent dates. For consistency, this number is multiplied by 5 (average drilling hours per day) to get the time in hours. The data is then imported into a Matlab Weibull distribution calculating program (Ho, 2012) to obtain the results. The MTBF calculated using the program is based on Gamma distribution with two parameters β and η.

2.3 Failure Modes and Effects Analysis (FMEA)

The FMEA process started with prioritising the components under the selected sub-system by counting the number of failures and evaluating their criticality to the key functions of the drills. It follows the Standards Australia AS IEC 60812 – 2008 manual to identify the failure modes and potential effects. The information for the analysis is obtained from three sources: (1) work orders cost report, (2) Atlas Copco Maintenance Manual and (3) on-site discussions with the maintenance group.

3. Results and Discussion

3.1 MTBF and Shape Factor

The MTBF and shape factor for the selected sub-systems is listed in *Table 3.1*.As the shape factors for the sub-systems are close to 1, the failure distribution can be considered exponential with a constant hazard rate. Since the combination of multiple failure modes may often result in a constant hazard, this cannot be used for the maintenance decision without further analysis on the failure modes.

Sub-system (number of failures/suspensions)	MTBF μ	Shape Factor β
Hydraulic (316/96)	66.5	1.12
Boom (160/46)	126	0.99
Drifter (145/130)	299	0.92
Feed Rail (155/36)	118.5	0.96
Electrical and Controls (146/20)	121	1.01

Table 3.1: MTBF and Shape Factor

3.2 Weibull Plots for Sub-systems

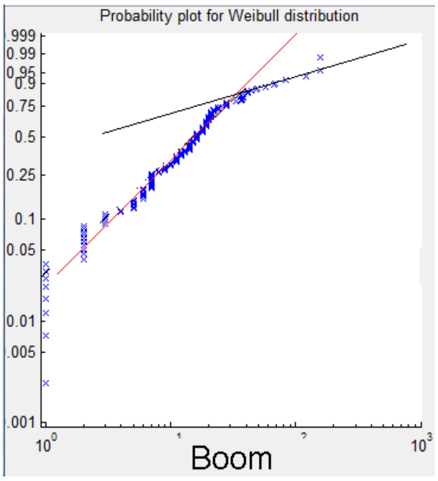

Figure 3.2

The Weibull plots for the selected sub-systems are used for failure modes identification and analysis. Since the work orders description does not always specify a failure mode, the failed component is then investigated instead. The Weibull plot for boom system (*Figure 3.2*) shows two patterns of failure distribution/modes with different MTBF and shape factor. On a sub-system level, the shape factor β decreased after 14 days (70 hours). Different maintenance tactics shall be applied according to the failure modes. The MTBF, shape factor and recommended maintenance for the two failure modes based on the RCM decision diagram is shown in *Table 3.2*. (Note: the parameters are estimated from the plot and may not be the exact value.)

Failure Mode	μ	β	Recommended Maintenance Strategy
1	55hrs	1.2	Scheduled Restoration Maintenance
2	350hrs	0.8	TBA

Table 3.2: Failure Mode and Recommended Maintenance Strategy for Boom System

The shape factor for failure mode 1 indicates a wear-out failure pattern, whereas that for failure mode 2 suggests a wear-in pattern. The failure modes for the boom system will result in a loss of production but are very unlikely to cause safety and environmental hazards. It is assumed that under most circumstances the failures are evident to the operators. Therefore the failures are considered as operational failure. Since condition monitoring is not suitable for the boom system, scheduled restoration maintenance is recommended for failure mode 1 at this level of analysis. For failure mode 2, the maintenance strategy is to be determined by RCM decision process and a age-based replacement interval can be worked out through a cost analysis using Glasser's graphs (Jardine & Tsang, 2006).

3.3 Component Level Analysis

Weibull analysis also is conducted for the major components under the sub-systems to provide a more comprehensive base for maintenance strategy decision. *Figure 3.3* shows the failure distribution for the centraliser. 5 failure modes are identified from the plot. Scheduled on-condition inspection tasks based on the human senses (e.g., checking for visible physical damages) is recommended for failure mode 1 as restoration tasks may not be economically feasible for a short MTBF of 50 hours. For the failure modes with an increasing hazard rate, a

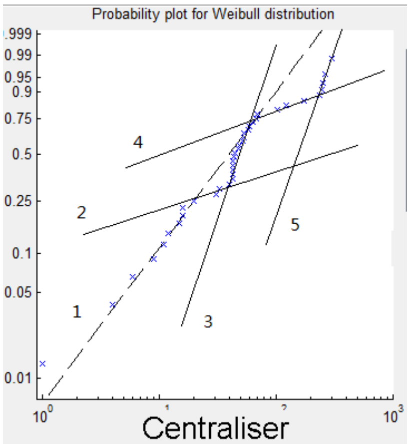

Figure 3.3

scheduled restoration strategy should be considered to prevent it from failing, or at least to reduce the consequences of the failure before it enters the wear-out zone. If the failure modes show a wear-in pattern, further investigation will be conducted to discover the causes. Operate to fail and scheduled restoration are the two possible choices. Again, no conclusion can be drawn without the cost analysis at this stage.

Similar analysis following the RCM decision process is done for major components under the boom system and feed rail system. The result is summarised in *Table 3.3*.

Component	**Failure Mode**										**Maintenance Strategy**
	1		**2**		**3**		**4**		**5**		
	μ	**β**	**μ**	**β**	**μ**	**β**	**μ**	**β**	**μ**	**β**	
Centraliser	50	1	100	0.8	350	2.5	500	0.7	1500	1.3	**Failure mode 1**: Scheduled on-condition task **Failure mode 2**: TBA **Failure mode 3**: Scheduled restoration task **Failure mode 4**: TBA **Failure mode 5**: Scheduled restoration task
Feed Rope	360	1.4	-		-		-		-		**Failure mode 1**: Scheduled restoration task
Rollover Unit	615	0.9	-		-		-		-		**Failure mode 1**: Scheduled restoration task
Zoom	50	1.1	250	2	500	0.9	-		-		**Failure mode 1**: Scheduled on-condition task **Failure mode 2**: Scheduled restoration task **Failure mode 3**: TBA
Knuckle	55	1.2	120	1.4	-		-		-		**Failure mode 1**: Scheduled on-condition task **Failure mode 2**: Scheduled restoration task

Table 3.3: Failure Modes for Components and Recommended Maintenance Strategy

3.4 Analysis Limitations

Some of the limitations in the analysis include: (1) incorrect failure or information entry (failure is recorded against the wrong asset-group), (2) the grouping of multiple failure modes and (3) failure to record the work order descriptions. Further investigation on the failure modes under each sub-system will be conducted to justify the assumptions and eliminate the errors caused by these assumptions.

4. Conclusions and Future Work

The constant hazard rate found for most of the sub-asset groups might result from a combination of multiple failure modes. Therefore further investigations are made on a component level for failure modes identification and maintenance strategy decision. Recommendations for the boom system and major components under the boom system and the feed rail system are made based on the RCM decision diagram.

Failure analysis conducted on a lower level of each sub-system, (i.e. key component or failure mode level) will be conducted for all the sub-systems and major components using the RCM decision diagram. Future work can also include cost analysis using Glasser's graphs to find the most appropriate time interval and potential changes to the maintenance tactics. Conclusions and recommendations will be formulated once the analysis mentioned above has been completed.

5. Acknowledgements

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6. References

Hastings, N. A (2003), *'Component Reliability, Replacement, and Cost Analysis with Incomplete Failure Data'*. Case Studies in Reliability and Maintenance, John Wiley & Sons, New Jersey.

Veron, B. & Hodkiewicz, M. 2009, 'Rapid availability model development using delay accounting data', ICOMS Asset Management Conference Sydney 2009, Australia

Moubray, J. (1997), Reliability-centred Maintenance, 2nd ed, Butterworth-Heinemann, Oxford.

Ho, M. (2012), Weibull Probability Plot – markcopy, the University of Western Australia.

Standards Australia. (2008) *AS IEC 60812 – 2008 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*. Sydney: AS.

Jardine, A. K. & Tsang, A. H. (2006), *Maintenance, Replacement, and Reliability - Theory and Applications,* Taylor & Francis Group