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Failure Rate Prediction of Belt Conveyor Systems using 2-parameter Weibull distribution

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Abstract: The conveyor belt is one of the most operational critical equipment's in the mining industry, they are mostly used in the transportation of crushed materials from the crushing station to where there'll be further processed. Due to the increasing complexity of belt conveyor systems, managing their integrity has become even more difficult, as they are now used across various industries, environments and carry materials of different weight variations, leaving them susceptible to failures (1). This paper provides an industry specific knowledge on how Weibull analysis can be used to predict the failure rate of a conveyor belt system, using parameters such as the time to failure (TTF), installation and failure dates, as determinant parameters for the predictions. Several Weibull failure distributions and functions have been used to establish accuracy of results and to create comparisons on the different ways in which risk, unreliability and availability are quantified, using calculated values such as the Shape and scale parameter. The paper utilizes real world case studies in the area of mining, which sheds light on key component failures and their cut sets within the conveyor belt system (2)
Keywords: TTF, TTR, Threshold parameter, Repair date, Shape parameter, B10, B15, B20, Scale parameter, ECA, CDF, PDF

I. INTRODUCTION

In recent years, the mining industry has experienced various disasters worldwide, due to improper planning and lack of functional reliability improvement programs being put in place. A vivid example of such is the recent dam disaster which occurred in Brazil, in January 2019, which claimed the lives of over 270 people, where the company in question later settled for a compensation of $7 billion, to be paid out to the families of those affected. This shows the direct cost implication of disasters, caused by unanticipated failures and how much disrepute it may bring to operating companies. Equipment failures are never taken likely by regulatory bodies, as it sometimes reflects how good or poorly, a company has prioritized safety and integrity management of her assets. That being said, to better manage assets and minimize disasters caused by equipment related failures, there are several cost and time effective ways of properly anticipating failures in systems, components and their sub-components, one of such techniques is the Weibull analysis, which utilizes the historical failure data of an equipment to predict the behavior and failure trends. Weibull analysis was specifically chosen in this paper due to its relevance and improved accuracy in the domain of reliability and asset risk management. In this paper, the common failure modes of conveyor belts are discussed, their failure parameters are analyzed using failure prediction software tools, and conclusions are drawn from results generated.

II. WEIBULL ANALYSIS FOR FAILURE RATE PREDICTION

The Weibull analysis is a failure prediction tool invented by Gordon Weibull (1887-1979), it is used in reliability engineering to predict the number of failures that would occur in a system over a period of time(9). Weibull analysis has gained more relevance in the mining industry due to its accuracy and its ability to utilize key system operating data in its prediction model. Weibull analysis relies on historical failure data, which is then used to predict future failures, historical data such as , mean time to failure (MTTF), mean time between failure (MTBF), Time to failure (TTF), installation, suspension and repair dates, are important data needed for the analysis(10).

There are two different forms of the Weibull distribution, the 2-parameter and the 3-parameter Weibull distribution. The major difference between them is the threshold parameter. The threshold parameter (τ) is always equal to zero (0) in a 2-parameter Weibull distribution. Another major difference is that the 3-parameter Weibull distribution is able to hold and analyze negative values(11).

$T \geq \tau$ with probability of 1, where T is the cycle time to failure and τ is the threshold parameter.

The 2-parameter Weibull distribution can be represented as follows(11).

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The probability density function (11)

$f(t, \gamma, \alpha) = \frac{\gamma}{t}(\frac{t}{\alpha})^{\gamma} e^{(\frac{t}{\alpha})^{\gamma}}$ (1)

where γ (gamma) or β is the shape parameter

where α is the scale parameter and characteristic life

Cumulative density function (11)

$F(t) = 1 - e^{-(\frac{t}{\alpha})^{\gamma}}$ (2)

Where $\gamma = \beta$ and $\tau = 0$

Reliability (11)

$R(t) = e^{-(\frac{t}{\alpha})^{\gamma}}$ (3)

Where $\gamma = \beta$ and $\tau = 0$

Failure rate (12)

Failure rate is given by,

$H(t) = \frac{\gamma}{\alpha}(\frac{t}{\alpha})^{\gamma - 1}$ (4)

Where $\gamma = \beta$ and $\tau = 0$

Failure rate λ increases with t when β is greater than 1

λ (t) decreases when β is less than 1

$\lambda(t)$ is constant when β is equal to 1

Usually, β is > 1, which signifies wear out (11).

The Mean (12)

$\alpha\tau(1 + \frac{1}{\gamma})$ (5)

Where τ is known as the gamma function

The median(12)

$\alpha(\ln 2)^{\frac{1}{\gamma}}$ (6)

The Variance of T (12)

$\alpha^2\tau\left(1 + \frac{2}{\gamma}\right) - \left[\alpha\tau\left(1 + \frac{1}{\gamma}\right)\right]^2$ (7)

The cumulative distribution function (11)

is used to define the distribution of a random quantity T

where $F(t) = P(T \leq t)$ (8)

Formulars represented in (equation 1- 9) will be used to calculate our results in the later part of this paper. The failure of the system will be predicted by plotting graphs of the cumulative probability, failure rate and the probability density function using statistical software, Isograph.

III. CASE STUDY

This study is based on a belt conveyor system in an underground mine located in Canada. The temperature tolerance of the belt is between -14^{o}c to 42^{o}c. The major use of the belt is to convey crushed rock to the material processing plant. The belt conveyor is regarded as a criticality B equipment, following a recent ECA carried out on all equipment's within the mine. The belt conveyor is made up of over 20 different components which are modeled without any redundancy, thus they are all connected in series, which means that the failure of one component would render the entire system nonfunctional. Data was obtained for 20 safety critical component failures within the system, and is analyzed using Isograph reliability improvement software.

In order to carry out a 2-parameter Weibull analysis to predict the failure tend of the system, several work orders which covers the most frequent failures in a period of 2 years were obtained from the computerized maintenance management system (SAP), to obtain failure data such as, installation date, suspension date, repair date, time to repair (TTR) and the time of failure (TTF) of several components within the system. Table 1 below represents the bulk of the data set used.

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	Failures	Time to repair (hrs)	Time to failure (hrs)
	Picking belt repair & replacement	3	1220
	Picking belt repair & replacement	2	951
	Tail pulley guarding missing	1	988
	Repair tear at picking belt	2	901
	Replacement of brush scraper	5	861
	Failure of rollers	1	812
	Long Belt scraper repair	1	800
	picking belt splice coming apart	1	772
	Skirt board on Picking belt failed	1	740
	Replacement of return rollers	8	712
	Picking belt splice replacement	1	610
	Failure of snub pulley lagging	6	601
	Repair and replacement of Idler	1	552
	Failure of spring tensioners	3	400
	Side travel safety switch repair	2	363
	Missing roller at tail end	2	341
	Repair side travel arm	5	242
Table 1: Failure data for belt conveyor system	Replace tail pully shaft	1	800
	Torn lagging	2	613
	Replace belt tear side travel switch	3	761

Table 1 above contains failure data from the belt conveyor system, with times of failure between 100-1220 hours. The time to repair is also given, on the average, it takes about 3 hours to resolve component failures, which would result to a total downtime cost of about $51,000.

IV. RESULTS

Using the Isograph availability workbench, which is used in modelling system reliability, by making use of failure parameters, such as the time to failure, time to repair, time between failure, installation and repair date. The results generate will include the scale parameter (in hours), the shape parameter, which is the characteristic lifetime, the B10, B15 and B20 life of the equipment. Below are graphs generated for the failure rate prediction.

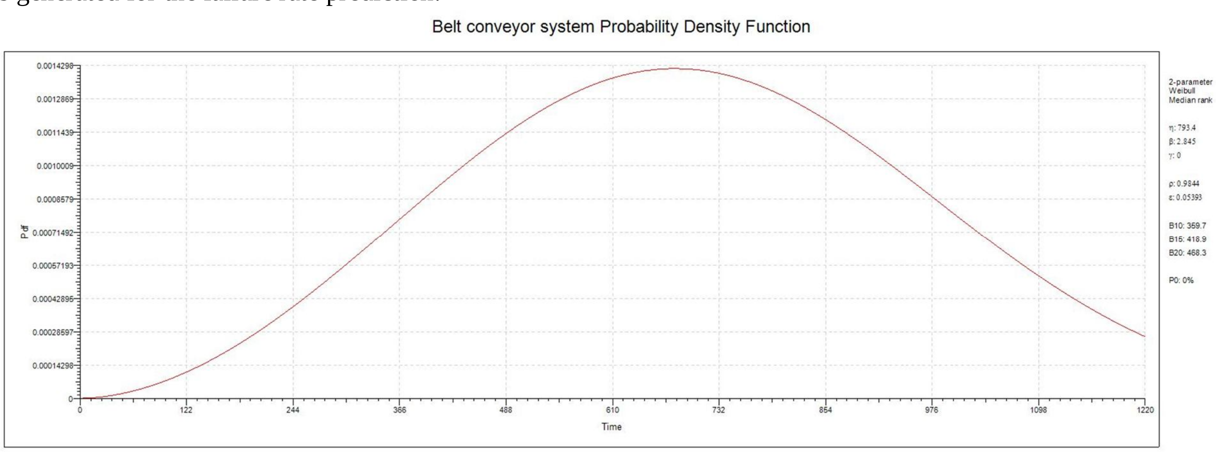

Fig. 6 Representing failure behavior using PDF

Figure 6 above represents the probability of failure per unit time, using the probability density function, which illustrates the distribution of component failures with respect to time. Looking at figure 6 above, there is a 0.0015 probability of the belt conveyor failing at about 700 hours, using a threshold parameter of zero (0) and a confidence level of 50%, baring in mind that the analysis can also be done using a higher confidence level.

The graph of failure rate with respect to time (t), is another function used in representing failures, using the 2-parameter Weibull distribution. The failure behavior of most systems, follow the bathtub failure rate life distribution model, where β being less than 1, represents infantile failures in the early life of the equipment. In a situation where β is equal to 1, it means that failure rate is constant and is regarded as the normal useful life of the equipment, however , when β is greater than 1, then it means that system is wearing out, as is on the right side of the bathtub shape curve(10).

Below is the graph representing the failure rate function (λ) of the Weibull distribution.

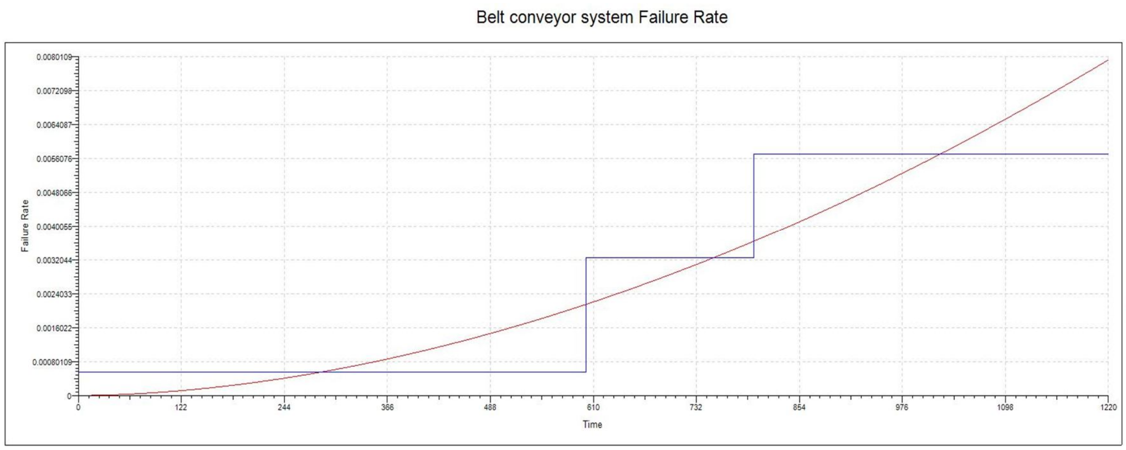

Figure 7: Representing the instantaneous failure rate of the Weibull distribution.

From the results generated, the scale parameter is 793.4 hours, while the shape parameter (β) is 2.84, which signifies wear out of the belt conveyor system. In a case where the β parameter is above 10, it will be regarded as an extreme value distribution which signifies that the equipment is reaching the concluding stages of its product life; in other words, the end of its useful life(10).

It can also be deduced from the B10 life estimation of the Weibull distribution in Figure 7, that the system will reach 10% unreliability at 359.7 operating hours, at this point, some preventive maintenance should have been carried out. The system will be more failure prone at B15 and B20, where the system would only have a reliability of 85% and 80% respectively, with predicted times of failure at 418.9 and 468.3 operating hours respectively. Looking at the cost implication of these failures, according to work orders reviewed, it would take an average of 3 hours to carry out repairs on the system, which can result to 91% production loss and a cost implication of about $17,000 per hour.

The last but not the least, is the cumulative distribution function, which is used to predict the unreliability of a system. Below is the CDF graph, predicting the unreliably of the conveyor belt system, as shown in figure 8.

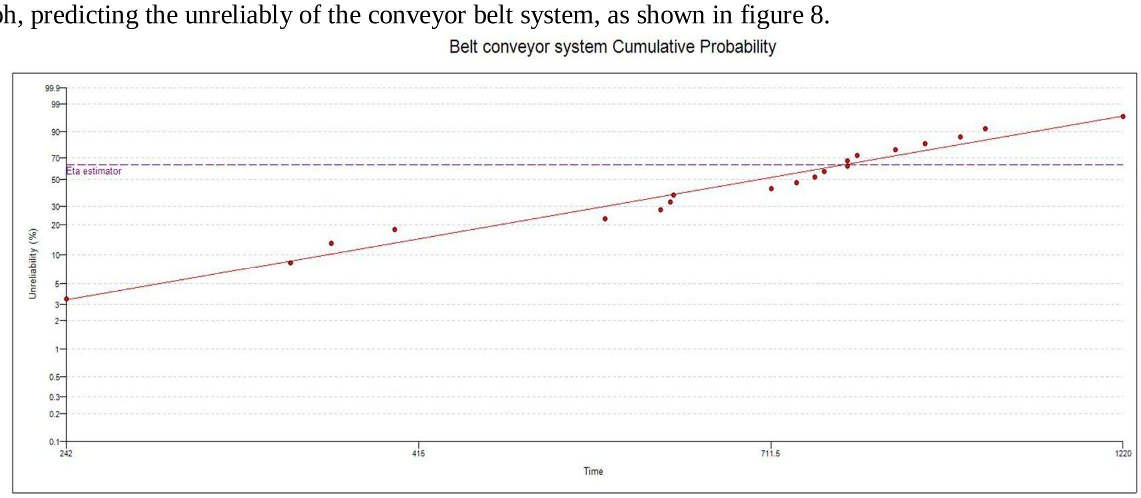

Figure 8: Showing the unreliability vs time plot using the CDF function.

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Figure 8 below represents the unreliability prediction of the system per unit time. According to the prediction, the system will reach an unreliability of 96.57% at about 1220 operating hours, at this point, the system is only regarded as being 3.43 % reliable. It is crucial that, duty holders pay close attention to preventive maintenance tasks and that areas of concern are addressed before a system reaches its end of life, further significance of this findings is discussed in the final chapter.

V. CONCLUSION

The belt conveyor system remains a critical equipment in open pit and underground mining. In this paper, failure rate prediction has been carried out using real life data obtained from several mining companies and individual subject matter expertise, and results have been used to draw useful conclusion. Regardless of the maintenance strategy put in place by mining companies, addressing unexpected failures has remained a concern, which makes current effort insufficient. Priority must be placed on identifying bad actors and organizing a total review of current preventive, predictive and corrective maintenance plans, with early failure detection being the main determinant factor for improvement. Predictive maintenance technology is certainly the way forward, as the technology is capable of identifying failure contributors such as, temperature, pressure and vibration changes in fixed and rotating assets before failure occurs.

It is imperative that more concern is directed towards improving maintenance task for key components, such as the rollers, the picking belts, Idlers and the pulleys, which are failure prone components within the belt conveyor system. Duty holders must also take into consideration that the overall system reliability of the conveyor belt can be compromised if only one component fails, this is due to their series arrangement, which makes every individual component of equal importance.

Finally, effort must be put into minimizing repair times, as every minute lost during downtime would cost thousands of dollars, which affects revenue generation and the overall reputation of the company.

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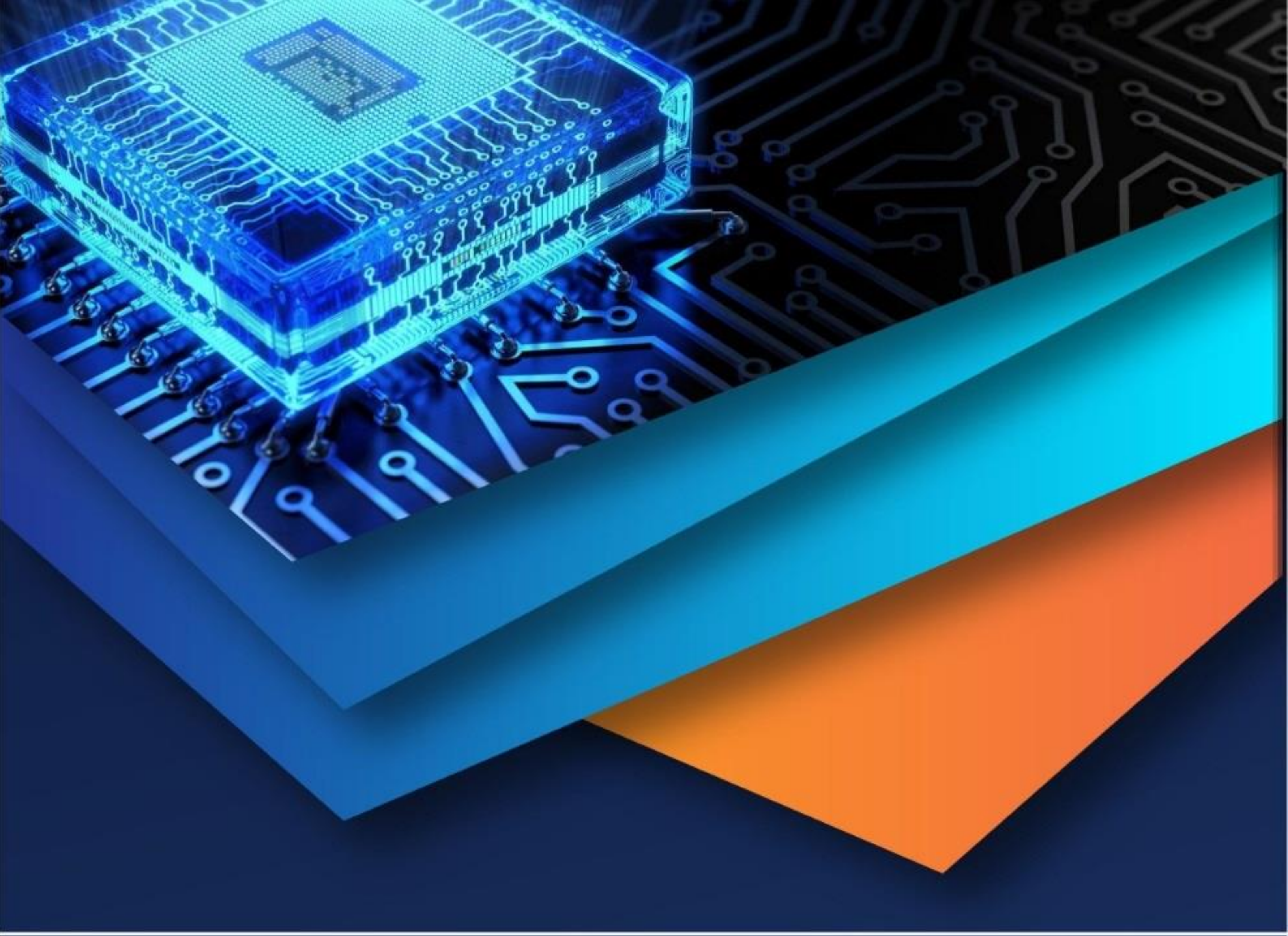

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