IOP Conference Series: Materials
Science and Engineering

PAPER • **OPEN ACCESS**

Reliability Analysis of Belt Conveyor Based on Fault Data

To cite this article: Meiyan Li *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **692** 012009

Reliability Analysis of Belt Conveyor Based on Fault Data

Meiyan Li[1], Yingqian SUN[1, *] and Chuan Luo[1]

[1]Mining and Safety Engineering College, Shandong University of Science and Technology, Qianwangang Road, Qing Dao Shandong Province, 266590, China

[*]1932001736@qq.com

Abstract. In order to improve the accuracy of the reliable analysis of the belt conveyor, based on the belt conveyor fault data, firstly fit the probability density distribution function of the belt conveyor fault interval time. According to the characteristics of the fault data, it is inferred that it may obey the Weibull three-parameter distribution. The Weibull distribution model is obtained by combining the least squares method with the correlation coefficient method, and the accuracy of the model is verified by d test. Finally, the reliability of the belt conveyor is analysed, and the measures to improve the reliability of the belt conveyor are given, which provides a theoretical basis for the daily maintenance of the belt conveyor.

Keywords. Reliability Analysis; Belt Conveyor; Fault Data; Weibull Three-Parameter Distribution

1. Introduction

As a key equipment in coal mine production and transportation systems, mining belt conveyors will bring significant economic losses when they fail. Therefore, how to carry out reliability analysis on the belt conveyor and master the operation status of the belt conveyor is very important for the mining enterprise. At present, many scholars at home and abroad study the reliability analysis of belt conveyor mainly from the methods of combining qualitative analysis and quantitative analysis and quantitative analysis alone. The research of qualitative and quantitative combination mainly uses fault tree, FMECA and Bayesian network. Ren Zhongquan, Jing Hui, Xie Xin, Han Weihong use the fault tree model to analyze the reliability of the belt conveyor and find out the weak links in equipment maintenance [1-4]. Li Peng [5] uses the FMECA method to obtain the weak links in the maintenance process of the belt conveyor. Zhang Dawei [6] combined the fault tree with the Bayesian network to establish a fault management knowledge model for the belt conveyor, providing a complete set of belt conveyor fault knowledge model for maintenance. Although a combination of qualitative and quantitative analysis is used, errors in qualitative analysis can lead to inaccuracies in subsequent quantitative analysis results. In response to this problem, scholars have separately studied the reliability of belt conveyors from a quantitative perspective, mainly using mathematical statistics. Agnieszka Blokus Roszkowska [7] uses a mathematical approach to reliability analysis of belt conveyor systems by establishing a reliability function. Ovidiu-Bogdan Tomuș [8] uses a two-parameter Weibull statistic method to perform a comprehensive reliability analysis of the belt conveyor system based on the fault data. However, the following problems also exist in the quantitative analysis process:

(1) When scholars conduct quantitative analysis, it is considered that there is a linear relationship

between the fault data, and the two-parameter Weibull distribution model is used for analysis. However, the fault data is often nonlinear, which will cause large errors in parameter estimation. (2) Whether the fault data belongs to the Weibull distribution needs to be verified.

In response to the above problems, this paper analyses reliability from a quantitative perspective. First analyse the fault data, preliminarily estimate the fault data distribution model and solve the model, and then verify whether it conforms to the preliminary estimated distribution model. Finally, the failure rate and reliability analysis are carried out to provide a theoretical basis for belt conveyor maintenance.

2. Fault time probability distribution model

In this paper, the XX enterprise belt conveyor is taken as the research object. By collecting the fault data of the equipment, the probability distribution model of the belt conveyor fault interval is established.

2.1. Fault time probability distribution model

Firstly, the belt conveyor time interval data is analysed, and the number of groups is determined according to the empirical formula (1) proposed by sturges [9].

$$K \geq 1 + 3.322 \times lg(n) \tag{1}$$

Where n is the total number of failures.

Through statistics, there are 61 sets of data. After calculation, K=8 can be obtained. The minimum fault interval of the belt conveyor is 0.5h, the maximum fault interval is 666.2h, and the fault interval time range is [0.85, 666.2]. Divided into 8 groups, as shown in Table 1.

Table 1. Fault interval sample.

Number	Upper limit	Lower limit	Mean	Frequency	Rate of Recurrence	Grand total
1	0.85	83.71	42.11	38	0.6393	0.6393
2	83.71	166.92	125.32	12	0.1967	0.836
3	166.92	250.13	208.53	2	0.0328	0.8688
4	250.13	333.34	291.74	3	0.0492	0.918
5	333.34	416.55	374.95	2	0.0328	0.9508
6	416.55	499.76	458.16	1	0.0164	0.9672
7	499.76	582.98	541.37	1	0.0164	0.9836
8	582.98	666.2	624.59	1	0.0164	1

The mean value of each set of fault intervals is the abscissa, the observed value $f(t)$f of the probability density is the ordinate, and $f(t)$ is calculated as equation (2):

$$f(t) = \frac{n_i}{n\Delta t_i} \tag{2}$$

Where $n_i$is the frequency of failures in each group of fault intervals; n is the number of faults 61, Δt_i is the group distance, and the scatter plot of the probability density can be made as shown in Figure 1.

It can be seen from Figure 1 that the distribution of the belt conveyor fault interval does not conform to the normal distribution characteristics, and may obey the exponential distribution or the Weibull distribution.

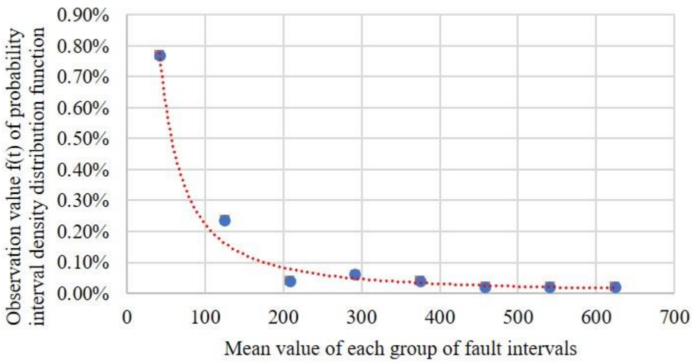

Figure 1. Probability density scatter plot.

3. Determination of the time interval distribution model

According to the distribution law of the empirical model, the shape of the Weibull distribution curve is different depending on the corresponding shape parameters. The exponential distribution can be seen as a special Weibull distribution. In general, the concave curve obeys the three-parameter Weibull model, so it is assumed that the belt conveyor's fault interval is subject to a three-parameter Weibull distribution. The parameter estimation is performed by the least squares method, and the result is checked to determine whether the time interval of the belt conveyor obeys the Weibull distribution.

The probability density function of the Weibull distribution is:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\lambda}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \tag{3}$$

The failure probability function is:

$$\lambda(t) = \frac{\beta}{\eta} \times \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \tag{4}$$

The reliability function is:

$$R(t) = exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \tag{5}$$

Where t is time, $\gamma$is a positional parameter; $\eta$is a scale parameter andβ is a shape parameter.

3.1. Parameter estimation method

The logarithm of the formula (5) can be converted to:

$$ln\{-ln[R(t)]\} = \beta\, ln(t-\gamma) - \beta\, ln(\eta) \tag{6}$$

A set of fault intervals with a capacity of n, arranged in ascending order and defined as t. In order to reduce the error, its reliability is estimated by the median rank method:

$$R(t_i) = \frac{(i-0.3)}{(n+0.4)} \tag{7}$$

Let $y_i = ln\{-ln[R(t_i)]\}$,$x_i = ln\, t_i$. The regression equation that needs to be fitted is:

$$y = ax + b \tag{8}$$

According to the principle of least squares, the regression coefficient a, b and the correlation coefficient R_{xy} are:

$$b = \frac{l_{xy}}{l_{xx}} = \frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sum_{i=1}^{n}(x_i-\overline{x})^2} \tag{9}$$

$$a = \overline{y} - b\overline{x} \tag{10}$$

$$R_{xy} = \frac{l_{xy}}{\sqrt{l_{xx}l_{yy}}} \tag{11}$$

The numerical iterative method is used to determine the estimated value of the position parameter γ, and the positional parameter $\gamma_{01} = min\{t_i\}$ is assumed to be the initial value of γ, and the corresponding correlation coefficient R_{01} is calculated. Similarly, R_{0n} is calculated in turn, and when $\gamma$is estimated correctly, there is a maximum correlation coefficient between x,y, thereby determining the value of the position parameter γ.

The fault interval time data of the belt conveyor can be rearranged and calculated by the parameter estimation method. The results are shown in Table 2.

Table 2. Recalculated fault interval time.

No	t_i	$R_n(t_i)$	x_i	y_i	No	t_i	$R_n(t_i)$	x_i	y_i
1	0.5	0.011401	-0.69315	-4.46836	27	57.12	0.434853	4.066117	-0.56094
2	0.85	0.027687	0.405465	-3.57278	28	58.33	0.45114	4.069027	-0.51097
3	1.5	0.043974	0.774727	-3.10176	29	58.5	0.467427	4.110874	-0.46198
4	2.17	0.060261	0.845868	-2.77816	30	61	0.483713	4.113657	-0.41386
5	2.33	0.076547	1.054312	-2.53029	41	98.92	0.662866	4.405499	-0.04926
6	2.87	0.092834	1.108563	-2.32862	42	104.42	0.679153	4.51086	-0.00497
7	3.03	0.109121	1.991976	-2.15809	43	104.77	0.69544	4.594311	0.039315
8	7.33	0.125407	2.413232	-2.00994	44	109.33	0.711726	4.648421	0.083676
9	11.17	0.141694	2.449279	-1.87866	45	120.8	0.728013	4.651767	0.12821
10	11.58	0.15798	2.70805	-1.76054	46	122.05	0.7443	4.694371	0.173017
11	15	0.174267	2.833213	-1.65295	47	125.75	0.760586	4.794136	0.218208
12	17	0.190554	3.223664	-1.55398	48	132.5	0.776873	4.804431	0.263902
13	25.12	0.20684	3.241811	-1.46218	49	150.67	0.79316	4.834296	0.310238
14	25.58	0.223127	3.330417	-1.37643	50	161.97	0.809446	4.886583	0.357368
15	27.95	0.239414	3.398527	-1.29585	51	162.42	0.825733	5.015092	0.405474
16	29.92	0.2557	3.519869	-1.21972	52	178.83	0.84202	5.087411	0.454768
17	33.78	0.271987	3.541539	-1.14748	53	197.58	0.858306	5.090186	0.505504
18	34.52	0.288274	3.725693	-1.07863	54	259	0.874593	5.186436	0.557995
19	41.5	0.30456	3.769999	-1.01277	55	295	0.890879	5.286144	0.612633
20	43.38	0.320847	3.805106	-0.94957	56	330.28	0.907166	5.556828	0.669923
21	44.93	0.337134	3.824939	-0.88872	57	360.17	0.923453	5.686975	0.730534
22	45.83	0.35342	3.827118	-0.82998	58	412.6	0.939739	5.799941	0.795389
23	45.93	0.369707	3.83579	-0.77312	59	456.5	0.956026	5.886576	0.865815
24	46.33	0.385993	3.839452	-0.71795	60	582.02	0.972313	6.022479	0.943846
25	46.5	0.40228	3.989539	-0.6643	61	666.2	0.988599	6.50169	1.498302
26	54.03	0.418567	4.045154	-0.61201					

From equations (9) and (10), $\beta = b$ =0.81848, a =-3.76548, then $\eta = e^{\left(-\frac{a}{b}\right)}$ =109.508. According to the numerical iteration method, γ = 0.4 can be obtained.

3.2. *d test*

The d test is a difference between the distribution function $F_0(t)$ corresponding to the belt conveyor interval time data and the calculated value $F_n(t)$ corresponding to each fault interval time, and the largest absolute value of the difference is the observed value D_n. Then compare the value of D_n and the critical value $D_{n,\alpha}$. If $D_n \le D_{n,\alpha}$, the fault data of the belt conveyor conforms to the Weibull three-parameter distribution model. On the contrary, it does not match. After calculation,$D_n = 0.0907902$. In the d test, according to the experience $\mathrm{D_{n,\alpha}} = \frac{1.22}{\sqrt{\mathrm{n}}} = 0.156 > \mathrm{D_n}$, the original hypothesis is established, and the fault interval of the belt conveyor conforms to the three-parameter Weibull distribution model.

The probability density function is:

$$f(t) = 0.0075 \times \left(\frac{t\text{-}0.4}{109.508}\right)^{-0.8} exp\left[-\left(\frac{t\text{-}0.4}{109.508}\right)^{0.818}\right] \tag{12}$$

The failure probability function is:

$$\lambda(t) = 0.075 \times \left(\frac{t-0.4}{109.508}\right)^{-0.812} \tag{13}$$

The reliability function is:

$$R(t) = exp\left[-\left(\frac{t-0.4}{109.508}\right)^{0.818}\right] \tag{14}$$

4. Reliability analysis

4.1. Failure probability

The failure rate curve of the belt conveyor can be obtained from the failure probability function. As shown in Figure 2. Analysis of belt conveyor failures found that most of the faults are concentrated on belts, rollers, and motors. Therefore, through quantitative analysis of reliability, it is possible to take preventive maintenance or replace originals, and increase the frequency of regular inspections to reduce the failure rate.

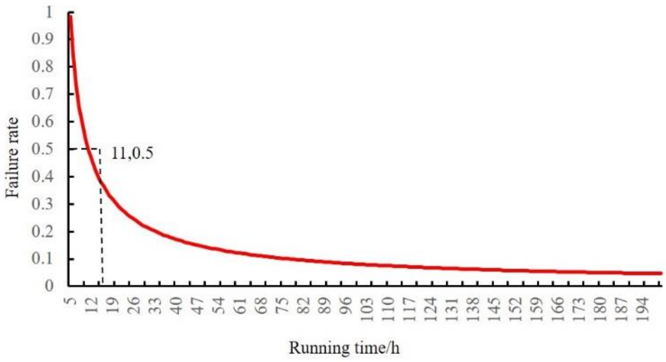

Figure 2. Failure rate curve

4.2. Reliability

Figure 3 shows the reliability distribution curve. It can be seen that as time increases, the reliability gradually decreases, indicating that the longer the time, the less likely the belt conveyor will work properly. Therefore, proper maintenance is required to ensure that the belt conveyor maintains high reliability.

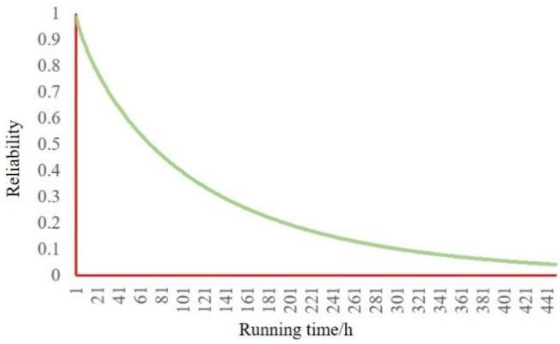

Figure 3. Belt conveyor reliability function

Table 3 shows the operating cycle of the belt conveyor under different reliability. It can be seen that the reliability of the belt conveyor decreases very rapidly with the non-stop operation, and the reliability will be lower than 0.75 in continuous operation for 24 hours. Therefore, if you want to ensure the reliability of the belt conveyor, you need to develop a daily maintenance plan, and carry out equipment maintenance activities every day.

Table 3. Reliability of belt conveyors at different running time

Reliability	0.95	0.9	0.85	0.8	0.75
Running time(hour)	3	7	12	17	24

5. Conclusion
In this paper, for the problem of inaccurate reliability analysis of belt conveyor, the distribution function is fitted based on the belt conveyor fault data. According to the fitting result, the fault interval time may be consistent with the Weibull distribution, and the least square method and correlation coefficient method are used to solve the problem. Finally, the d test is used to prove that the belt conveyor fault interval is in accordance with the Weibull distribution, and the reliability study is carried out. The main conclusions are as follows:

(1) Based on the fault data characteristics, it is concluded that the belt conveyor fault data conforms to the Weibull three-parameter distribution model and is verified. The results show that the belt conveyor fault data conforms to the Weibull three-parameter distribution model and lays a foundation for the reliability analysis of the belt conveyor.

(2) The Weibull three-parameter distribution model is used to analyse the reliability of the belt conveyor. The analysis results show that the belt conveyor will have a reliability of less than 0.75 during continuous operation for 24 hours, which provides a reference for the development of the maintenance cycle.

Acknowledge
This work also financially supported by the Shandong Higher Education Teaching Reform Research Project of China(2015M138), Qingdao Social Science Planning Project of China (QDSKL1801117), Shandong Natural Science Foundation of China (ZR2009HM003) and Ministry of Education, Higher Education Department, Industry, Education and Research Collaborative Education Project of China (201802197019).

References
[1] JING Hui, HAN Gang, Belt Conveyor System Fault Analysis Based on Fuzzy Set. 2015. J. *Coal Mine Machinery*.**36(05)**:305-307
[2] REN Zhongquan, SHEN Xuerong, ZOU Lili,The reliability analysis for the belt conveyor based on FTA. 2009. J. *Mining & Processing Equipment.* **37(17)**:53-55.
[3] Xie Xin, Zhang Liangyou, Reliability analysis for mechanical structure of transmission device of belt conveyer. 2016.J. *Hoisting and Conveying Machinery*. **(09)**:23-26
[4] Weihong Han,Xingshu Li,Yongqing Lv and Haichuan Liang, Application of Fault Tree Analysis to Reliability Analysis of Belt Conveyor. 2011.J. *Colliery Mechanical & Electrical Technology*. **(04)**:79-81+85
[5] Peng Li, *Research on Reliability Analysis and Fault Diagnosis Expert System of Belt Conveyor*. 2016.D(China University of Mining and Technology)
[6] ZHANG Dawei, MA Hongwei, CAO Xian'gang, DU Kang and DONG Ming, Study on fault diagnosis of belt conveyor based on Bayesian network. 2016. J. *Mining & Processing Equipment.* **44(05)**:31-33
[7] Blokus-Roszkowska A, Kolowrocki K, Failure dependency analysis of series system with example of conveyor belt. 2014 (The Slovak Republic :10th International Conference on Digital Technologies) P290
[8] Tomuș, Ovidiu-Bogdan, Andraș and Andrei, Magyari M, Study on the reliability of the underground conveyor belt system installed at Vulcan Mine the Jiu Valley Basin in Romania. 2017(Singapore: MATEC Web of Conferences) P121
[9] Dong Du, Qinghua Pang, *Modern comprehensive evaluation method and case selection*. 2005.M(Beijing: TSINGHUA UNIVERSITY PRESS)