Available Online at http://www.journalajst.com

ISSN: 0976-3376

ASIAN JOURNAL OF
SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 09, Issue, 03, pp.7774-7780, March, 2018

RESEARCH ARTICLE

MODEL ABOUT ENVIRONMENT INFLUENCE TO EQUIPMENT FAILURE BASED ON WEIBULL DISTRIBUTION

[1,2]*Xiaobo Su, [1]Qi Gao, [3]Jia Li, [4]Qingchun, Wu

[1]Shijiazhuang Division of Army Engineering University, Shijiazhuang China
[2]Shijiazhuang Division of PLAA Infantry Academy, Shijiazhuang China
[3]The 4th Hospital of Shijiazhuang, Shijiazhuang China
[4]Equipment Department of PLAA, Beijing China

ARTICLE INFO

Article History:
Received 24th December, 2017
Received in revised form
26th January, 2018
Accepted 10th February, 2018
Published online 30th March, 2018

Key words:
Weibull distribution; Environment factor; Equipment failure.

ABSTRACT

Working environment is one important factor to equipment failure. In order to quantity the environment influence to equipment failure, this paper qualitatively analysed some environment factors' effect to equipment failure and drew the graphs about the relationship between equipment failure and environment factors. Based on bathtub curve principle, progressively increasing curve and Weibull distribution principle which are basic theories in reliability engineering, this paper built a mathematical model about environment influence to equipment failure and put forward a calculating method to the unbeknown parameters in the model.

INTRODUCTION

Every equipment has certain environment conditions fit to work. These conditions include temperature, humidity, pressure and dust content etc. Every equipment has its own regular working conditions too. When these conditions beyond the regular working conditions, the equipment's faults will increase obviously. In some conditions equipment damage result of environment factors is more serious because of the harsh conditions which are difficult to be confirmed in normal conditions. In fact, the problem that equipment must to fit for environment conditions perplex people for a long period of time. There are many example that equipments fail to run due to environment factors. A lot of special investigations carried out by USA DoD in 1960s has revealed that the equipment damage caused by environment factors is over 50%, which is even more serious than damage caused by fight. Some data indicates that plane's fault will increase obviously working over 15 hours in a dust atmosphere. In the Gulf war the multinational force headed by the United States' planes often work wrong because of the dust environment. These failure is rarely happen in usually time [1,2]. Above all, to quantity the influence of environment to equipment failure is a significant issue.

2. Qualitative analysis on equipment failure caused by environment factor

There are two situations about equipment failure caused by environment factor. The first is the situation according to the bathtub curve. Such as equipment failure caused by temperature. The second is the situation according to the progressively increasing curve or progressively decreasing curve. Such as equipment failure caused by sand content in atmosphere.

2.1 Analysis of environment factors according to bathtub curve

Taking temperature as an example for analysis.

2.1.1 Conditions and parameters setting

(1) Only consider the factor of temperature, other environment factors is considered to be ideal.
(2) P : Equipment failure rate.
(3) T : Temperature.

(4) $T_{\min}$: Minimum temperature.

(5) $T_{\max}$: Maximum temperature.

(6) There are temperature points 'T_0, T_1, T_2, T_3'. These temperature points divide the whole temperature area to 5 continuously districts '$T_{\min} < T_0 < T_1 < T_2 < T_3 < T_{\max}$'.

(7) T_0 : The lowest temperature to equipment failure.

For $T < T_0$

Then $P = 1$

(8) T_3 : The highest temperature to equipment failure.

For $T > T_3$.

Then $P = 1$.

(9) The suitable temperature for equipment working is the following temperature range.

$T \in [T_1, \quad T_2]$.

(10) Equipment works in the certain temperature for a period of time.

2.1.2 Equipment failure analysis according to the temperature factor

(1) For $T \in \left[T_{\min}, \quad T_0\right]$. Then $P = 1$.

(2) For $T \in \left(T_0, \quad T_1\right)$. The equipment failure rate will decreases with the temperature increasing.

(3) For $T \in \left[T_1, \quad T_2\right]$. The equipment works in a suitable condition and has a low failure rate.

(4) For $T \in \left(T_2, \quad T_3\right)$. The equipment failure rate is increasing with the temperature increasing.

(5) For $T \in [T_3, \quad T_{\max})$. Then $P = 1$.

According to analysis above, A simple graph as figure 1 can be drew.

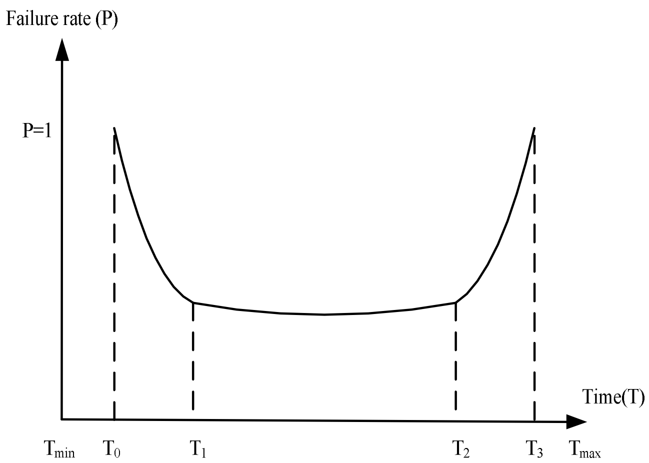

Figure 1. Equipment failure rate according to temperature

2.1.3 Preliminary conclusions

Figure 1 is a typical bathtub curve. From the curve we can draw conclusions that under the premise that other conditions is ideal, in a certain temperature district such as '$\left[T_1, T_2\right]$' equipment can work stably and the equipment failure rate is low. When temperature deviates the district to left or right such as '$\left[T_0, T_1\right]$' or '$\left[T_2, T_3\right]$', the equipment failure rate will increase too.

2.2 Analysis of environment factors according to progressively increasing or decreasing curve

Taking dust content, rain and snow content and pressure as examples for analysis.

2.2.1 Conditions and Assumptions

(1) The dust evenly distributes in atmosphere and the unit of dust content is g/m^3.

(2) The rain and snow evenly distributes in atmosphere and the unit of rain or snow content is g/m^3.

(3) There is the same pressure in the same area. The pressure is expressed as P_a.

(4) When one environment factor is analysed, other factors are supposed in ideal state which can be ignored.
(5) Equipment run for a period of time in certain conditions.

2.2.2 Intuitive analysis

It can be determined that equipment failure rate will increases when the content of dust or rain or snow is increasing. And equipment failure rate will increases with the pressure drop. The detail can be describe as following.

(1) The influence of dust content

When the dust content is lower, the equipment failure rate will be lower. As the dust content increasing, the equipment failure rate will increase. When the dust content increases to one certain degree, the equipment will breakdown. From above, a progressive increasing curve can be got as figure 2. The trend of equipment failure rate changing with dust content changing is that the rate increasing slowly at beginning, then increasing faster progressively until the equipment breakdown.

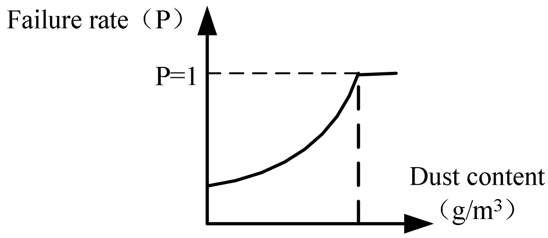

Figure 2. Equipment failure rate according to dust content

(2) The influence of rain and snow content

The influence of rain and snow content to equipment failure rate is alike as dust content's influence. As the content of rain and snow in atmosphere is increasing, the equipment failure rate is increasing. When the content is lower, the influence is less. When the content is higher, the influence is larger. When the content is to one certain degree, the equipment will breakdown. From the changing trend figure 3 can be got.

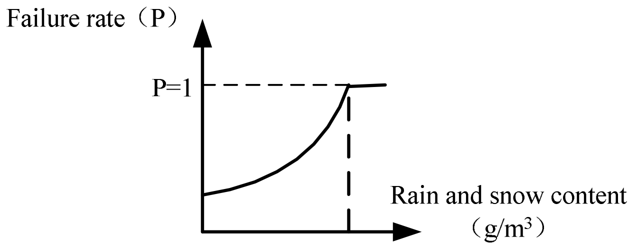

Figure 3. Equipment failure rate according to rain and snow content

(3) The influence of pressure

Equipment can stably work in certain pressure range. In plateau area as pressure declining, equipment failure rate will increase progressively. When the pressure decline to certain degree, equipment will breakdown. From the trend figure 4 can be got.

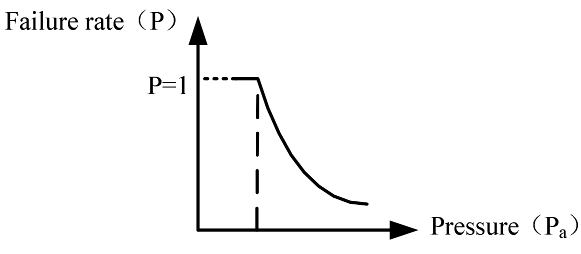

Figure 3. Equipment failure rate according to pressure

2.2.3 Preliminary conclusions

The intuitive analysis and figure 1-4 above shows the influence of dust content, rain and snow content to equipment failure rate is according to progressively increasing curve, and the influence of pressure to equipment failure rate is according to progressively decreasing curve.

3. Model of environment influence to equipment failure based on Weibull distribution

3.1 Analysis about the applicability of Weibull distribution

3.1.1 Basic graphs of Weibull distribution

In reliability theory there are graphs of failure rate function, failure density function, and failure probability function [3,4]. And there are 3 parameters in Weibull distribution function. They are β, η and γ. The shape of the functions depend on the parameter 'β'. In order to draw the graph conveniently, in this paper the value of η and γ is set as following.

$\eta = 1$

$\gamma = 0$

Then the value of β is given respectively as following.

$\beta = 1$

$\beta > 1$

$\beta < 1$

Set the value of the parameters, give a serious of values to the environment factor, use the software of Matlab, figures 5-7 can be got.

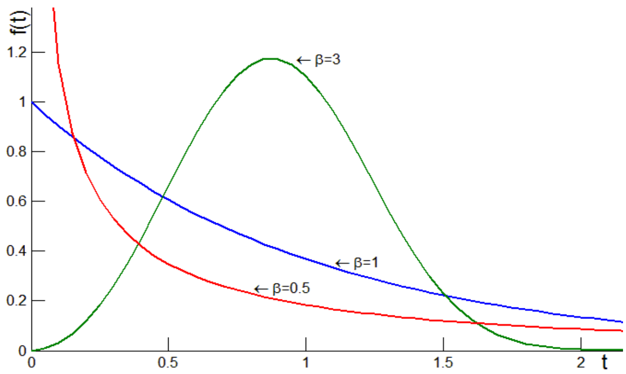

Figure 5. Failure density function

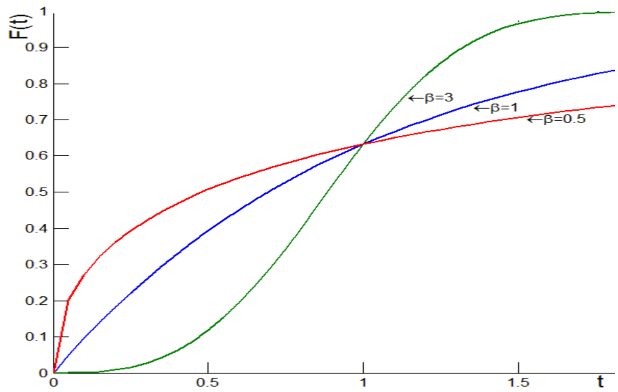

Figure 6. Failure probability function

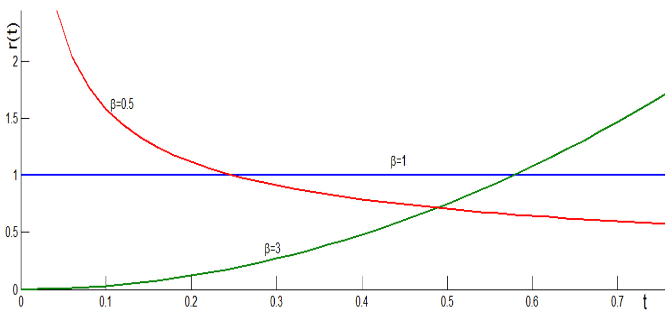

Figure 6. Failure rate function

3.1.2 Applicability analysis of Weibull distribution

Following conclusions can be drew according to Figure 5-7.

(1) When $\beta < 1$, the failure rate is decreasing progressively. This is according to the early failure time of bathtub curve.
(2) When $\beta = 1$, the failure rate is certain. This is according to the occasional failure time of bathtub curve.
(3) When $\beta > 1$, the failure rate is increasing progressively. This is according to the tired failure time of bathtub curve.
From above, Weibull distribution can fitting curves of failure rate increasing, failure rate decreasing and failure rate stable through change the value of β. So failure rate according to the regular of increasing progressively or decreasing progressively or stably can be forecast through Weibull distribution [5].

3.2 Mathematical model based on Weibull distribution

3.2.1 Assumptions

(1) Equipment failure caused by environment factor meets bathtub curve.
(2) Every environment factor is independent.
(3) In traditional failure graphs, the data of the horizontal axis is time. When replace time with one environment factor such as temperature, pressure or dust content, one distribution about equipment failure caused by the environment factor can be got. Simultaneously in the model of Weibull distribution function the variable parameter of time is replaced by the environment factor data. So based on Weibull distribution theory one model to quantify the influence of equipment failure caused by environment factor can be got.

3.2.2 Equipment failure function

Because the Weibull distribution model with 3 parameters have better adaptability and easy to solve [6], this paper set up Weibull distribution model with 3 parameters.

Function 1 is the function of equipment failure density.

$$f(x) = \frac{\beta}{\eta}\left(\frac{x-\gamma}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{x-\gamma}{\eta}\right)^{\beta}\right] \quad \text{.......................................(1)}$$

In function 1 ‘ β ’ is parameter about shape. ‘ γ ’ is parameter about place. ‘ η ’ is parameter about scale [7].

3.2.3 Method to parameter estimation

Use maximum likelihood estimation method to calculate the parameters in function 1.

Setting ‘ $\theta = (\beta,\ \eta,\ \gamma)$ ’.

Set up likelihood function.

$$\begin{aligned} L(\theta;\ x_1,\ x_2,\ \ldots,\ x_n) &= L(\beta,\ \eta,\ \gamma,\ x_1,\ x_2,\ \ldots,\ x_n) \\ &= \prod_{i=1}^{n} f(\beta,\ \eta,\ \gamma,\ x_1,\ x_2,\ \ldots,\ x_n) \\ &= \prod_{i=1}^{n} \frac{\beta}{\eta}\left(\frac{x_i-\gamma}{\eta}\right)^{\beta-1} \exp\left[-\left(\frac{x_i-\gamma}{\eta}\right)^{\beta}\right] \end{aligned} \quad \text{.......................................(2)}$$

Find the function logarithm.

$$\begin{aligned} \ln L(\beta,\ \eta,\ \gamma,\ x_i) &= n\ln\frac{\beta}{\eta} + (\beta-1)\sum_{i=1}^{n}\ln\frac{x_i-\gamma}{\eta} - \sum_{i=1}^{n}\left(\frac{x_i-\gamma}{\eta}\right)^{\beta} \\ &= n\ln\beta - n\beta\ln\eta + (\beta-1)\sum_{i=1}^{n}\ln(x_i-\gamma) - \sum_{i=1}^{n}\left(\frac{x_i-\gamma}{\eta}\right)^{\beta} \end{aligned} \quad \text{...(3)}$$

Derive the partial derivative of the function to set up equation set 4.

$$\begin{cases} \dfrac{\partial \ln L(\beta, \quad \eta, \quad \gamma, \quad x_i)}{\partial \beta} = 0 \\ \dfrac{\partial \ln L(\beta, \quad \eta, \quad \gamma, \quad x_i)}{\partial \eta} = 0 \\ \dfrac{\partial \ln L(\beta, \quad \eta, \quad \gamma, \quad x_i)}{\partial \gamma} = 0 \end{cases} \quad \text{...(4)}$$

Form function 3 and equation set 4 to get equation set 5

$$\begin{cases} \sum_{i=1}^{n}\left[\dfrac{1}{\beta} - \ln\eta + \ln(x_i - \gamma) - \left(\dfrac{x_i - \gamma}{\eta}\right)^{\beta} \ln\dfrac{x_i - \gamma}{\eta}\right] = 0 \\ \sum_{i=1}^{n}\left[\dfrac{\beta}{\eta}\left(\dfrac{x_i - \gamma}{\eta}\right)^{\beta} - \dfrac{\beta}{\eta}\right] = 0 \\ \sum_{i=1}^{n}\left[\dfrac{\beta}{\eta}\left(\dfrac{x_i - \gamma}{\eta}\right)^{\beta-1} - \dfrac{\beta - 1}{x_i - \gamma}\right] = 0 \end{cases} \quad \text{...(5)}$$

Equation set 5 include 3 equations and 3 parameters. It can be solve with computer. And the estimated value can be expressed as $\hat{\theta} = (\hat{\beta}, \quad \hat{\eta}, \quad \hat{\gamma})$

3.3 Discussion on the estimated parameters

(1) Discussion on $\hat{\beta}$

When $\hat{\beta} < 1$, the influence to equipment failure is decreasing progressively. For example when equipment works in a lower temperature than normal condition, the failure rate will increase with temperature decreasing.

When $\hat{\beta} = 1$, the influence of environment factor to equipment failure is stable. In this condition equipment failure rate is lower. For example when equipment works in the normal condition.

When $\hat{\beta} > 1$, the influence of environment factor to equipment failure is increasing progressively. For example when equipment is working in the condition of dust, snow, rain or high temperature.

(2) Discussion on $\hat{\eta}$

In Weibull distribution as scale parameter, the parameter η decides the changing velocity of the graph. In the model of environment factor influence equipment failure, the estimated parameter $\hat{\eta}$ decides the sensitivity about equipment failure to environment factor.

(3) Discussion on $\hat{\gamma}$

As place parameter, $\hat{\gamma}$ decides the parameter index about the equipment breakdown.

4. Conclusion

Start from the qualitative analysis on the environment influence to equipment failure, in terms of the principle that Weibull distribution can be used to forecast typical distribution failure rate, this paper replace the time dimension with environment factor and built one model to quantify the influence that equipment failure caused by environment factors. The model is fit for increasing progressively curve, decreasing progressively curve and bathtub curve.

REFERENCES

Qi Gao. Management on Ordnance Maintenance Equipment [M]. 2012, pp. 27-31.

Wen Cao. Study on Environment Adaptability of Logistic Equipment [D]. Master thesis of Logistic Command College, 2010.
G.W.Cran.Graphical. Estimation Model for Weibull Distributions. Microelectronics & Reliability, 1976.
Seki T, Tokoyama S. Simple and Robust Estimation of the Weibull Parameters. Microelectron Reliability, 1993
Yanjun Shao. Weapon Equipment Preventive Maintenance Strategy Research Based on Fault Prediction [D]. Doctor thesis of North University of China, 2013.
Nenghuan Wang, Zuxing Yao, Honglu Hu. An Analysis Method of Passenger Car Free Repairing Data Based on Weibull Distribution [J]. Machinery Design & Manufacture, 2016, 9 pp. 57-59.
Yingwei Wu, Xinglin Qi, Liang Cui. Calculation and Application of Environment Conversion Factors for Weibull Distribution [J]. Equipment Environment Engineering, 2016, 13(4), pp. 88-90.

Brief introduction of the authors

Xiaobo Su, PhD student of Army Engineering University of PLA and lecture of Army Infantry Academy of PLA.
Qi Gao, Professor of Army Engineering University of PLA and Tutor of PhD student.

Address

The 14th team the 13th building Hepingxi road 97 Shijiazhuang Hebei province China, 050003.
Tel: 13722791570

****