A Bayesian approach to reliability prediction for one-shot devices

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ABSTRACT

Projectile such as rocket and missiles is one of most important object for military and space industry. In order to measure its reliability accurately, general method which uses binomial distribution often require more than 3,000 sample to evaluate the reliability which can be problematic for further research and development. There have been many researches and studies to predict reliability with small sample size. Many studies suggest Bayesian approach with precise prior distribution as effective method to measure reliability of one shot device. In this research, we suggest application of proportional hazard model with Bayesian approach to estimate reliability of one shot device with small sample size.

1. BACKGROUND

One shot device is one of essential tools in many industries including military and space aircraft. Due to its importance of mission, measuring its reliability is necessary. However reliability testing of one shot device requires destructive test and sample cannot be recycled for another use. Also Most of one shot device is not used instantly after production, but kept in storage for future use. So measuring the storage reliability also becomes another issue for one shot device. To measure the storage reliability, one shot device has go through the accelerate life test to escalate the degradation. Despite the accelerated life test to degrade its performance, one shot device often have low failure rate due to its high reliability and it makes more difficult to obtain the failure data to measure the life of one shot devices. Therefore alternative method is required to measure the storage reliability with small sample size.

2. ACCELERATED LIFE TESTING

One shot device takes long time for failure with normal condition. It became inevitable to apply the accelerated life test to degrade performance of one shot device to make induced failures of object. Nelson (1990) classified the accelerated life testing into three different types which are constant-stress test, step-stress test and progressive-stress test.

1) Constant-stress test: Each test sample is subjected to constant level, but each item may have different stress level.
2) Step-stress test: each test sample goes through a pattern of increasing stress levels for certain amount of time. First, test item start with pre-specified constant stress level for certain amount of time, and then stress level increased and stays for a while. Stress level constantly increased by steps until designated level.
3) Progressive-stress test: stress level is increasing continuously over time.

3. PROPORTIONAL HAZARD MODEL

To measure the storage reliability of our subject, we plan to apply the Proportional Hazard Model (PHM) to measure the reliability. Proportional hazard model composed of two parts which is known as baseline hazard rate and a positive functional term is independent of time variable.

$$\lambda(t|X) = \lambda_0(t)\psi(X, \beta)$$

From the above equation, $\lambda_0(t)$ that depends on time and known as baseline hazard rate. X is row vector consisting of the covariates and β is unknown parameter of model, defining the effects of the covariates. Many different parameterization form of $\psi(X,\beta)$ can be applied for proportional hazard function such as exponential, logistic, and inverse linear etc.

4. DATA EXPLANATION

Due to delay of time and uncertainty of variable selection for one shot device, we refer data set used by Ling (2012) which is shown in Table 1.

Table 1. Number of failures recorded under ALT

Condition	Inspection time	Numbers of devices	Numbers of failure	Stress factor Temp (℃)
1	10	10	3	35
2	20	10	3	35
3	30	10	7	35
4	10	10	1	45
5	20	10	5	45
6	30	10	7	45
7	10	10	6	55
8	20	10	7	55
9	30	10	9	55

5. BAYESIAN APPROACH

By application of Bayesian approach, we may measure the storage reliability with small sample. Proportional hazard model will be used and prior distribution and actual test data set as posterior data set to measure the storage reliability. Following function is likelihood function for parameter α_0 and α_1 with exponential form.

$$L(\alpha_0,\alpha_1) = \prod_{i=1}^{I} p_i^{K-n_i}(1-p_i)^{n_i}$$
$$= \prod_{i=1}^{J} \exp\left(-\alpha_0(K-n_i)e^{a_1 x_i}(IT_i)\right)\{1 - \exp\left(-\alpha_0(K-n_i)e^{a_1 x_i}(IT_i)\right)\}^{n_i}$$

6. CONCLUSION

Application of proportional hazard model and Bayesian approach can be effective method of estimation of one shot device for storage reliability. Yet, sample size is still critical issue for accurate design of proportional hazard model and prediction of Bayesian approach. In this thesis, we only achieve small result and still require more verification about proposed method. As further research, we plan to use the data achieved from delayed the accelerated life testing of one shot device with proportional hazard model and comparing with other statistical models.

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Reference

Alexandre C. Mendes. (2014), Proportional hazard model applications in reliability, *Northeastern University*

Man Ho Ling, B. sc. & M Phil. (2012), Inference for one-shot device testing data. , *McMaster University*

Narayananswamy Balakrishnan & Man Ho Ling . (2013), Expectation Maximization Algorithm for One Shot Device Accelerated Life Testing with Weibull Lifetimes, and Variable Parameters over Stress, *IEEE TRANSACTIONS ON RELIABILITY*, 62(2), pp 537-551, DOI: 10.1109/TR.2013.2257054

Narayananswamy Balakrishnan & Man Ho Ling . Gamma lifetimes and one-shot device testing analysis, *Reliability Engineering & System Safety*,126, pp54-64, DOI: https://doi.org/10.1016/j.ress.2014.01.009

Man Ho Ling, Hon Yiu So & Narayananswamy Balakrishnan. (2016), Likelihood Inference under Proportional hazard model for one-shot device testing. *IEEE transactions on reliability*, 65(1), pp 446-458, DOI: 10.1016/j.patcog.2003.06.005

Nelson. (1990), Accelerated Testing, Statistical models, Test plans and Data analysis, John Wiley &Sons, New York

S. Bobrowski, M. Doring, U. Jensen & W. Schinkothe. (2011). Reliability prediction using the cox proportional hazards model, *56th International scientific colloquium, Ilmenau university of technology*

Tsai-Hung Fan, N. Balakrishnam & Chi-Chen Chang. (2009), The Bayesian approach for high reliable electro-explosive devices using one shot device testing, *Journal of Statistical Computation and Simulation*, 79(9), pp1143-1154, DOI: 10.1080/00949650802142592