Inventory Management with Reliability Engineering Approach

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Abstract

Management of inventory plays a key role in effectiveness and efficiency of an industry's competitiveness. It contributes to maintaining optimum level of stock of spare parts that could prevent an industry or oganisation from stock outs. To do this, inventory management relies on the forecasting techniques. This paper reports results of developing a novel reliability model to forecast more reliably the level of stock of spare parts by using the covariate analysis.

Keywords
inventory management, reliability engineering, forecasting, spare part management, military defense system

1. Introduction

Inventory management has a prominent place in industrial decision support at which planning stock levels is critical. Acquiring a good prediction of the stock levels can be a difficult task, especially since the future is difficult to be known with precision.

The existence of the correct level of stock related to the demand will enhance responsiveness and efficiency of a firm resulting in high reliability and high productivity. On one hand, excessive stock can result in big losses through damages and stock obsolescence. While stock level is inadequate, huge monetary losses can also occur through a production loss due to stockouts of raw materials or parts. This can be easily explained using a cause-and-effect phenomenon in the root cause analysis methodology (Yuniarto and Pararta, 2016). Therefore, accurate determination of the required stock levels in response to the real demand is notable for efficient inventory management (Aviv, 2001). In this case, forecasting technique plays an important role.

A problem in the inventory management is one of matching supply and demand by efficiently forecasting the supply and the demand. Forecasting has equipped managers with a means of obtaining better and timely information relating to, not only demand, but also lead times and available assets as well as capacity (Kang and Gershwin, 2005). It also enables information to be utilised effectively. As mentioned by Handfield and his colleagues (Handfield et.al, 2009), an important aspect of good inventory management is actually an effective use of the information. Incorporating reliability engineering into forecasting is able to make the information obtained to be processed to predict level of demand since reliability engineering becomes a tool for studying reliability of a system in terms of examining lifetime of sub-systems that form the system. The sub-system in question here can be raw materials or parts. In consequence, if lifetime of - for instance - the parts are able to be established more precisely in advance with reliability engineering so that required stock level of particular spare parts can also be forecast and determined accurately for replenishment. This could conduce to efficient inventory management. In pursuance of this objective, one of statistics' techniques used in the reliability engineering - namely, *covariate analysis* - is applied. *Covariate analysis* takes any external factors into consideration that effect lifetime of the parts (Abbas et.al, 2013). Given this information of shorten lifetime of certain parts, stock level of such particular spare parts can then be predicted accurately.

Hence, this paper concerns development of a reliability model for inventory management of spare parts with forecasting technique using *covariate analysis*. The remainder of the paper is structured as follows: Section 2 presents the method of research. A brief description of covariate analysis is described in Section 3. Section 4 is devoted to the devised reliability model for a spare parts forecast using covariate analysis. The paper ends in Section 5 with concluding remarks along with lines for further developments.

2. The Research Method

Method of running the research is structured systematically around six steps. Step 1 is to study defining characteristics of covariate analysis and forecasting. Step 2 concerns analysis of covariate's characteristics that would be perfect complements to a forecasting technique. Followed by Step 3, concept development of the reliability model is formulated. The reliability model for a spare parts forecast using covariate analysis is developed in Step 4. Once the devised reliability model is successfully developed, Step 5 runs validation of the model with a case study. Conclusions are established in Step 6. Fig. 1 illustrates the steps of the research method.

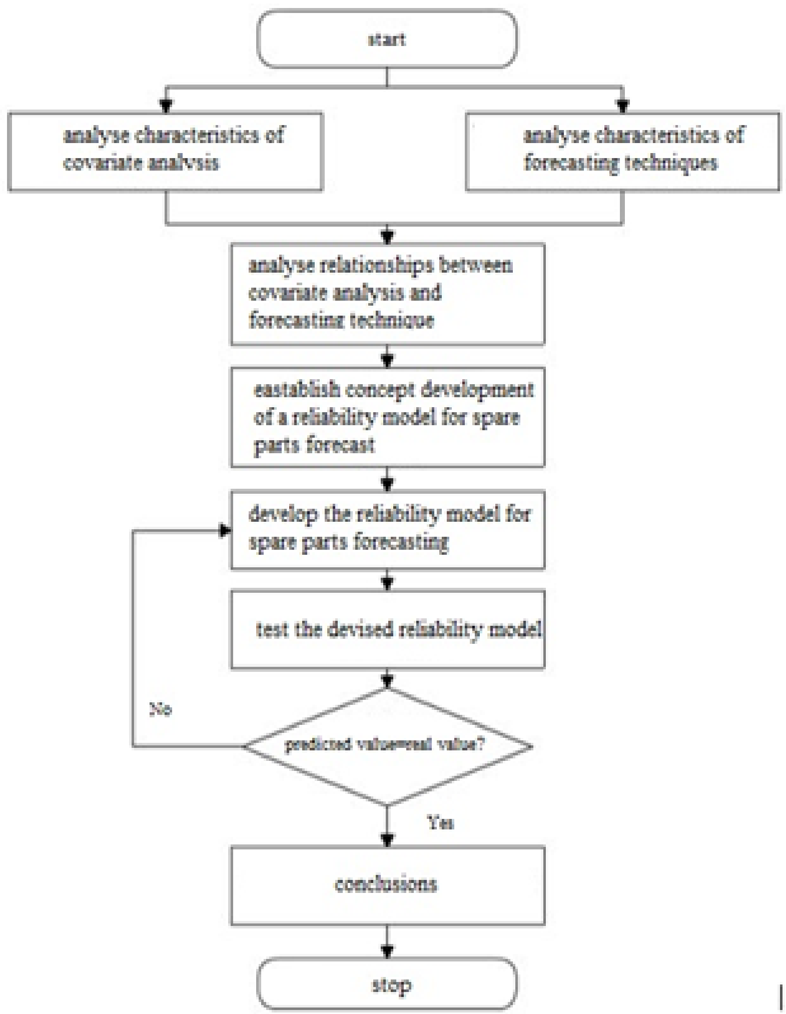

Figure 1. Method of research

Data that has to be collected to conduct this research are as follows: characteristics of the unit of equipment, procedure and process of routine maintenance of the unit of equipment, failure classification of parts of the unit of equipment, type and the number of parts failure of the unit of equipment, type and the number of spare parts of the unit of equipment, lifetime data and details of flying hours of the unit of equipment, list of test flight flying hours of the unit of equipment.

3. The Covariate Analysis

To predict demand of spare parts, not only failure time which has to considered but also risk factors that may cause those failures occurred. Such risk factors are then known as covariate. Hence, covariate analysis is a careful examination with statistical approach to any risk factor that may have caused a failure occurred (Gorjian et.al., 2004). The covariate analysis approach emphasizes studies into external factors that affect the failure, so that spare parts demand can be predicted more precisely.

Basic concept of the covariate analysis is to formulate a failure function which enable it to represent every potential factor causing the failure. Almost any covariate model is built on the basis of *proportional hazard model* (PHM). Kumar and Westberg in 1996 (Kumar and Westberg, 1996) has mentioned that PHM is a multivariate regression analysis which estimates impact of different covariates upon *time-to-failure* (TTF) of a system. They also stress that if weibull distribution is specifically followed by TTF data of a system, hence the covariate model should be built based on *weibull proportional hazard model* (WPHM) at which the formula is as follows:

$$h\big(t; z(t)\big) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \psi\big(yz(t)\big) \tag{1}$$

4. The Reliability Model

Basically, failure of a part or component is caused by lifetime of the part or component itself. Failure occurs as a direct consequence of over-lifetime usage of the part. In addition to the lifetime, external factors can also contribute to failure of the part. For example, air temperature, weather conditions, and low skill of the operator in operating the equipment to name but a view might increase failure rate of the part. Using covariate analysis, the degree of influence of external factors that also cause failure of the part can be examined.

However, covariate analysis lacks capabilities to establish prediction of how many adequate spare parts inventory should be provided in a warehouse to control out of stock of the parts due to failure that prevents the equipment from operating in a safe manner. This is the reason why the covariate analysis needs to be incorporated with the forecasting technique. The covariate analysis is used in the formulation of hazard rates and forecasting technique is used in predicting spare part demand with the hazard rates obtained from those particular parts. Fig. 2 shows the reliability model for a spare parts forecast using covariate analysis.

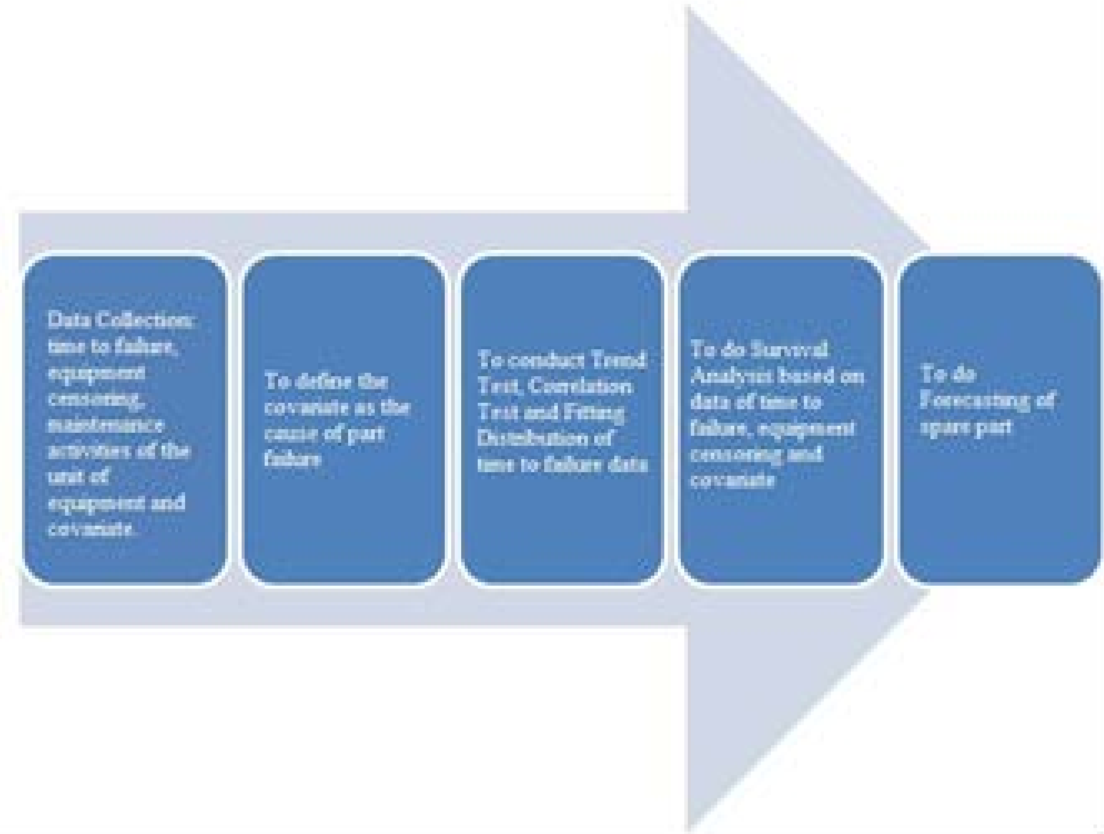

Figure 2. The reliability model

The reliability model for a spare parts forecast using covariate analysis comprises of 5 steps:

1. *Collect time-to-failure data, component censoring, component maintenance activities and covariate*. Time-to-failure data collection is done through data analysis of component failure at particular time range. Time range of each failure is actually failure time of the component. Component censoring process is done in 2 parts at which (a) if the component fails and is replaced with a new one, then the failure is categorized as *exact failure*, and (b) if the component fails and is repaired - not replaced - then the failure is categorized as *right censored*.
   Data is collected from a unit of equipment of an airplane namely *T23B-3 Bronco* as shown Fig. 3 and its component under study is a *high pressure fuel pump* as shown in Fig. 4.

Figure 3. The unit of equipment, T23B-3 Bronco

Figure 4. The component under study, high pressure fuel pump

2. *Define covariate as the cause of component failure*. Process of defining covariates as external factors that influence the component failure is done through a study of maintenance activities performed on the component. Expert judgment is needed in determining the covariate that affects the risk of failure, i.e. through field observation or interviews with officers who perform maintenance of the component.

3. *Conduct Trend Test, Correlation Test and Fitting Distribution Test of time-to-failure data*. Time-to-failure data can only be used in the devised reliability model if result of Trend Test does not indicate any trend occurred and if result of Correlation Test shows that each time-to-failure is independent. Once time-to-failure data is valid, Fitting Distribution Test with maximum likelihood estimation (MLE) is undergone to determine the type of data distribution that matches the time-to failure data. Result of MLE using SYSTAT software is tabulated in Table 1 where it shows that exponential data distribution is ranked highest compared to other data distributions which are also accepted but have lower rank. Therefore, in this case time-to-failure data of component under discussion matches the exponential data distribution so that this particular distribution will be used in the next step of the reliability model.

Table 1. Results of fitting distribution test

HPFP_SFP : Auto::Fit

Auto::Fit Distributions

distribution	rank	acceptance
Exponential[24, 1.67e+03]	100	accept
Erlang[24, 1, 1.67e+03]	100	accept
Weibull[24, 1.09, 1.92e+03]	79.1	accept
Pearson 6[24, 4.28e+03, 1.35, 3.81]	73.3	accept
Lognormal[24, 7.01, 1.21]	71.1	accept
Gamma[24, 1.35, 1.24e+03]	67.1	accept
Beta[24, 6.15e+03, 0.784, 1.59]	60.1	accept
Pearson 5[24, 0.738, 362]	54.7	accept
Triangular[23, 6.2e+03, 23]	41.7	accept
Inverse Gaussian[24, 693, 1.67e+03]	31.7	accept
Pareto[24, 0.287]	6.66	accept
Uniform[24, 5.4e+03]	0.917	accept
Log-Logistic[24, 1e-06, 1.18e+03]	0	reject

4. *Conduct Survival Analysis based on data of time-to-failure, component censoring and covariate*. Survival Analysis is done as follows:
   a. To determine data of time-to-failure, component censoring and covariate.
   b. To calculate t-ratio and p-value of each of each covariate iteratively until p-value < 0.15.
   c. To formulate hazard rate of each component by using covariates upon iteration.
   Table 2 tabulates results of Survival Analysis with SYSTAT software on *high pressure fuel pump* component.

Table 2. Results of survival analysis

Step 0			
incoming covariate	t-ratio	p-value	outgoing covariate
OS	-0.910	0.363	
CC	-1.678	0.094	
MCS	0.760	[illegible]447	
AFC	1.444	0.149	
HOQ	0.324	0.746	
Step 1			
OS	-0.875	0.382	HOQ
CC	-1.627	0.104	
MCS	0.788	0.431	
AFC	1.455	0.146	
Step 2			
OS	-0.457	0.648	HOQ
CC	-1.913	0.056	MCS
AFC	1.978	0.048	
Step 3			
CC	-2.089	0.037	HOQ
AFC	2.007	0.045	MCS
			OS
Final Model			
Covariate	Estimate	Standard Error	t-ratio
CC	-0.829	0.397	-2.089
AFC	0.754	0.375	2.007

4. *Conduct Forecasting.* Once hazard rate is eventually determined in Survival Analysis, forecasting to predict stock level of spare part of the component - high pressure fuel pump - is conducted. The forecasting technique used is *process renewal* where the steps are as follows:
   a. To perform calculation of *real mean time-to-failure* ($\bar{T}$) and *standard deviation of time-to-failure* ($\sigma(T)$). Equation 2 and equation 3 underneath performs ($\bar{T}$) and ($\sigma(T)$) respectively.
   b. To predict level of stock of spare part under discussion (N_t) upon a specified time frame.

$$\bar{T} = \eta\Gamma\left(1 + \frac{1}{\beta}\right) \tag{2}$$

$$\sigma(T) = \eta\sqrt{\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)} \tag{3}$$

Changing scale parameter as well as *shape parameter* can be determined using equation 4 and equation 5 below consecutively.

$$\eta = \eta_o c^{-\left(\frac{1}{\beta}\right)} \tag{4}$$

$$\beta = \beta_0 \tag{5}$$

Finally, a number of stock level of the component to be predicted can be determined with equation 6.

$$N_t = \frac{t}{\bar{T}} + \frac{V^2 - 1}{2} + V\sqrt{\frac{t}{\bar{T}}}\ \phi^{-1}(p) \tag{6}$$

5. Conclusions

This research has successfully developed a reliability model to exhibit a link between the use of reliability engineering with covariate analysis and the application of forecasting techniques to predict the stock level of spare parts of components. This finding needs to be further validated with a case study to confirm wide-ranging applicability of the devised reliability model. A case study of inventory management for components of military aircrafts (military defense system) using the reliability model developed is being run these days and the results will be published in a reputable international journal soon.

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Biographies

Ir. Hari Agung Yuniarto, ST, MSc, PhD, IPU received his first degree in Mechanical Engineering from Universitas Gadjah Mada (UGM) Indonesia and then completed his MSc and PhD in Industrial Engineering - specialising in the area of Industrial Manufacturing Engineering and Management - from UMIST (University of Manchester Institute of Science and Technology) UK. He pursued a career in 3 world-class industries, i.e. SCHLUMBERGER Oil Field Services, TOYOTA Manufacturing Corp and FREEPORT-McMoRan Inc, before he has eventually served as a senior lecturer of Industrial Engineering in Faculty of Engineering UGM since 2002. His expertise and research interests have been Reliability Engineering, Quality Engineering and Risk Assessment applied to maintenance & operation management, energy efficiency, supply chain management, product design development and safety engineering. He conducts close collaboration researches with universities as well as industries around the world and has published considerable amount of papers in the reputable journals and proceedings.

Jansen Dapit Sipayung, ST did his First Degree in Industrial Engineering at UGM in 2014. He develops a passionate interest in Reliability Engineering since then. There is plentiful experience in accomplishing reliability projects he gained involving great companies in Indonesia. He is now appointed to an engineering analyst manager at a state owned banking industry in Indonesia.