2nd IFAC Workshop on Advanced Maintenance Engineering,
Services and Technology
Universidad de Sevilla, Sevilla, Spain. November 22-23, 2012

NHPP APPLIED TO THE REPAIR WARRANTY OF AN INDUSTRIAL ASSET

V. González-Prida*, L. Barberá**,
A. Crespo**, C. Parra***.
* General Dynamics – European Land Systems. Seville, Spain (e-mail: vicente.gonzalezprida@gdels.com).
** Department of Industrial Management, Escuela Superior de Ingenieros de Sevilla (e-mail: lbm@esi.us.es, adolfo@esi.us.es)
*** Ingecon. Ingenieria de Confiabilidad. Venezuela (e-mail: pcarlos@confiabilidadoperacional.com)

Abstract: This paper seeks to address the decision process involved in setting a warranty length for a product after successive repairs are performed. The underlying failure model used is a Poisson process with hazard rate determined by a Weibull distribution, whereby successive repairs do not renew the lifetime distribution. For that purpose, the paper starts describing briefly a reference framework proposal for the warranty management and introducing the relevant literature related to LCCA.. Then, the main aspects of LCCA are defined in order to be applied for the calculation of the warranty period in a product which has been sold and requires a technical assistance for its repair. This work includes as a novelty the calculation of such period of time in relationship with the risk that the company is willing to assume. The result is a procedure that may be crucial for a maintenance company, not only to make better forecasts of future warranty costs but also as an important marketing tool. With this goal, this paper describes important aspects of the stochastic model called Non-Homogeneous Poisson Process (NHPP). The mathematical development will be illustrated with a case study divided in two exercises, where the above mentioned concepts are applied to calculate the proper warranty period for a specific repaired product. Finally, the conclusions are presented summarizing the main contributions of the paper.

Keywords: After-Sales Service; Life Cycle Cost Analysis (LCCA); Non-homogeneous Poisson Process (NHPP); Technical Assistance; Warranty Period.

1. INTRODUCTION

The life cycle cost in a physical asset is determined identifying the applicable functions in each phase of the product life, calculating the cost of these functions and applying the appropriate costs during the whole extension of the life cycle. Therefore, this cost should include all those ones related to design, manufacturing and production (Ahmed N.U. 1995), (Levy H. and Sarnat M. 1990). Part of these costs, in the case of a product launched to the market, has to be faced by the own buyer. Nevertheless, it has been here included all those costs involved in a product life cycle, regardless the actor (manufacturer or user) who has to face such charges. From the financial point of view, the costs generated along the life cycle of the asset can be classified in two types of costs:

CAPEX: Capital costs (design, development, acquisition, installation, staff training, manuals, documentation, tools and facilities for maintenance, replacement parts for assurance, withdrawal).

OPEX: Operational costs (manpower, operations, planned maintenance, storage, recruiting and corrective maintenance - penalizations for failure events / low Reliability).

The aftersales support is frequently offered while the production lines are still open. Therefore, the product engineering and manufacturing can be improved with the feedback of warranty program data, reducing consequently the general costs of the product life cycle. With an adequate reliability and availability assessment, is possible to demonstrate in the first stages of the product, how requirements expressed in initial technical specifications can be incompatible or even impossible to accomplish for determined product configurations (González V. et al. 2009), (Crespo A. and Iung B. 2007). If the product is already launched, this analysis can help to take quickly the necessary measures to correct and/or improve the product, foreseeing also probable claims from the users due to the real lack of reliability on the product, in comparison with the previous reliability, sold a priori. As already commented, the typical life cycle cost analysis includes costs for planning, research and development, production, operation, warranty and disposal (Parra C. et al. 2007). From the consumer's point of view, the life cycle cost will suppose the acquisition costs, purchase price, costs of operation and maintenance, etc. That means, in general terms, the total cost of the item ownership. In any case, the life cycle cost regarding warranty issues, is highly influenced on the values for reliability and failure rate, cost of spares, repair times, and component costs. Normally, a low budget for product engineering leads to high warranty costs in the future. Those customer complaints related to important or costly failures, should be soon attended and the failures fully analysed to identify not only further tasks to proceed with the repair, but also preventive actions which can avoid or at least, decrease future claims due to similar

978-3-902823-17-5/12/$20.00 © 2012 IFAC

10.3182/20121122-2-ES-4026.00003

reasons. Therefore, this consideration involves performing a root cause failure analysis (included in step 1 of the proposed reference framework). An overall review of all the warranty complaints can be helpful to show, for example, repetitive failures and trends related to vendor/buyer problems, quality issues, manufacturing conditions, product design, etc.

2. CALCULATION OF THE WARRANTY PERIOD

In order to calculate the appropriate warranty period, is needed to apply suitable measures which should be defined during the strategy phase of the warranty program. The measures must enable the comparison of reliability data and the inclusion of the life cycle cost assessment. The company should therefore establish and use a standard and repeatable method for collecting and analysing data and interpreting results, which may be based on corporate or industry factors. The results should be used to support and justify enhancements. This section reviews the mathematics of non-homogeneous Poisson processes with a Weibull hazard rate.

2.1 NHPP Model proposed for the warranty period assessment

This subsection presents an algorithmic breakdown of the previous one, with the addition of the warranty period choice. That means that, in a similar way as the paragraph above, here below are described those steps to estimate the minimal time for the warranty period (t_{MTW}) according to NHPP. As starting data, it is here necessary to know the intervals of time t_i ($i = 1,\ldots, n$), when failure and repair events have taken place. With these data, it is possible to follow the following steps:

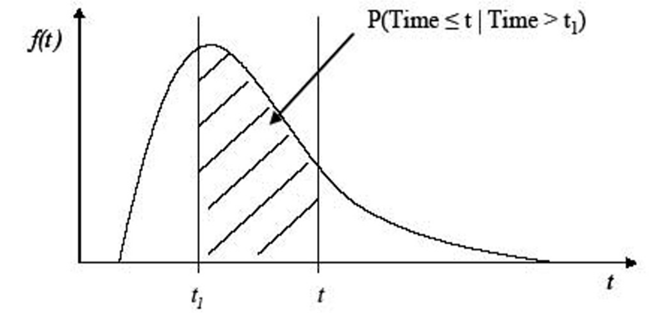

Fig. 1. Conditional probability of occurrence of failure

a) Calculation of parameters:

Considering T_n as the total accumulated time:

$$T_n = \sum_{i=1}^{n} t_i \tag{1}$$

The parameters α and β of the Weibull distribution in the (n)th event will be then:

$$\hat{\alpha}_n = \frac{T_n}{n^{\frac{1}{\beta}}} \tag{2}$$

$$\hat{\beta}_n = \frac{n}{\sum_{i=1}^{n} \ln\left(\frac{T_n}{T_i}\right)} \tag{3}$$

Where T_i is the time at which the (i)th failure occurs, T_n is the total time where the last failure occurred, and n is the total number of failures.

b) Calculation of expected time till next failure (TNF):

The expected time till next failure, taking into account the Weibull parameters and the total accumulated time, will be given by the following expression:

$$TNF_n = \{[\frac{1}{\alpha} + (T_n)^{\beta}]^{(1/\beta)}\} - T_n \tag{4}$$

c) Calculation of minimal time for the warranty period (t_{MTW}):

With all the above calculations, it is possible to obtain now the minimal time for the warranty period after the (n)th repair (see Figure 2) with the following expression (considering 20% of TNF as minimum time of warranty):

$$t_{MTW_n} = TNF_n \times 20\% \tag{5}$$

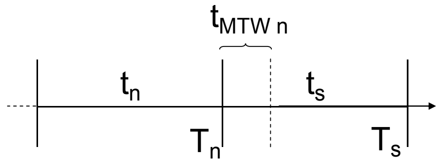

Fig. 2. Time line of failures events

d) Calculation of expected number of failures for t_{MTW}:

The total expected number of failures in the time interval [T_n, $T_n + t_{MTWn}$] according to the Weibull cumulative intensity function is (Modarres M. et al. 1999):

$$\Lambda(T_n, T_n + t_{MTWn}) = \frac{1}{\alpha^{\beta}}\left[(T_n + t_{MTWn})^{\beta} - (T_n)^{\beta}\right] \tag{6}$$

Where, as already commented, t_{MTWn} is the minimal time for warranty after the last failure and repair took place, and ($T_n + t_{MTWn}$) is equivalent to (T_{MTWn}).

e) Calculation of system reliability for the recommended warranty period ($T_n + t_{MTW\,n}$):

Assuming a Weibull distribution, the reliability function will be according to the following expression:

$$R(T_{MTWn}) = \exp\{-\alpha \times [(T_{MTWn})^{\beta} - (T_n)^{\beta}]\} \tag{7}$$

f) Calculation of failure probability for the recommended warranty period ($T_n + t_{MTW\,n}$):

Therefore, the failure probability in a system will be consequently:

$$F(T_{MTWn}) = 1 - R(T_{MTWn}) \tag{8}$$

As we can see in the above described process, a risk balance has been applied for the calculation of the recommended warranty period, and not an objective function. Basically, that percentage considered as minimal reliability within the warranty period, is a parameter to be estimated during the