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An Approach to Risk Quantification Based on Pseudo-Random Failure Rates

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Abstract: The risk quantification is one of the most critical areas in asset management (AM). The relevant information from the traditional models can be shown in risk matrices that represent a static picture of the risk levels and are according to its frequency and its impact (consequences). These models are used in a wide spectrum of knowledge domains. In this paper, we describe a quantitative model using the reliability and failure probability (as frequency in our risk model), and the preventive and corrective costs (as consequences in our risk model). The challenge here will be the treatment of reliability based on failure rate values with different e random distributions (normal, triangular etc.) according to the available data. These possible values will enable the simulation of the behavior of the system in terms of reliability and, consequently, to use this information for making a risk based analysis. The traditional risk-cost-benefit models applied to maintenance usually provides an optimum for the time to apply a preventive task. But in this case, a time window is obtained showing minimum and maximum thresholds for the best time to apply the preventive maintenance task, together with other interesting statistics useful for the improvement of complex industrial asset management.

Keywords: Reliability, Statistical Approaches; Asset and maintenance management; Maintenance Models and Engineering.

1. INTRODUCTION

System reliability is usually modelled by using the mean time to repair (MTTR) registered in historical databases. This parameter is connected to the failure rate providing information related to the system probability to fail, F(t), or not to fail, R(t) = 1-F(t), which are the reliability, both within a period of time. Failure databases generally provide information about the minimum, mean, maximum failure rates, as well as their standard deviation. These values depend mainly on the systems design and installation quality. Normally, the use of mean failure rates gives an insight into the physical asset behaviour, under controlled environments. The common definition of risk (associated with failure) is the probability that a failure will occur and the negative consequences of that failure. According to ISO 31000:2010, it is basically expressed as follows (i referred to event i):

$$Risk = \sum_{i=1} P_{f_i} * C_{f_i} \qquad (1)$$

Where:

- R is the risk,
- Pfi is the probability of failure
- Cfi is the consequences of the unwanted event.

The objective of this study is to express risks in terms of maintenance costs (consequences) linked to parameter values given for the system reliability. In order to illustrate this goal, an example is shown considering a Weibull distribution for modelling system reliability, and how considering different values for its failure rate (minimal, mean, maximal and pseudo-random), it is possible to analyse appropriately the subsequent risk, achieving a greater sensitivity of risk assessment in order to obtain relevant information about the potential costs to maintain the system at a specific time. In order to simplify the analysis, in this paper we consider an item from the Offshore Reliability Database (OREDA) with a specific failure mode. With the available data for failure rate and assuming specific costs for planned and unplanned maintenance, the result will aid in the decisions on preventive maintenance tasks. In other word, this methodology allows maintenance managers to better follow their risk appetite. With that purpose, this paper will start with a brief review of general risk indicators for maintenance and a proposed methodology for risk assessment. Then, with the support of a simple example, the study will approach the reliability uncertainty considering different alternatives for failure rate (with analytical and simulated values). The obtained results are shown and discussed in the following sections, providing different points of view for the analysis. Finally, the paper concludes with a summary of the main findings from the research.

2. RISK MANAGEMENT IN AM: RISK INDICATOR TO OPTIMIZE MAINTENANCE PERIODS

Risk management is one of the main aspects in the AM approach. ISO 55002:2013 introduces how the organizations

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should determine the actions needed for addressing risks for its AM System. While addressing risks, the organization should determine the risk assessment criteria within the asset management decision making process. Given the contextual importance, of maintenance management in Asset management, it is interesting to present an example of risk-based maintenance decision making. According to Kaplan and Garrick, 1981, risk consists of three components; (1) the scenario, (2) the probability of the scenario and (3) the consequences of the scenario. They also suggest that one has to take all hazards into account and risk picture should be accomplished by summing up all possible scenarios with their consequences for a certain activity. Particularly for the calculation of probability, we refer to the failure occurrence and the reliability of the equipment, which depend directly on the parameters of life (MTTF) of its distribution function. The changes and evolution of life parameters impacts directly on the reliability and failure probability and, consequently, in the risk assumed for such a failure (Gonzalez-Prida et Al. 2014). The Risk Indicator (Ri) is applied in maintenance management processes with the objective of preserving the asset operation, maximizing operational performance and economic profitability. All this is achieved by applying the best maintenance strategies, inspections, and inventory control, in order to minimize the risks generated by different failure modes within the operational context (Woodhouse, 1993). Risk is a term which is probabilistic in nature and is commonly expressed in monetary units per time (e.g., EUR / year). In mathematical terms, the risk can be calculated from the following equation (Parra and Lopez, 2002):

$$Ri\ (xi) = F\ (xi) \cdot Co\ /\ xi \qquad (2)$$

Where:

- xi: TTFi time to failure (hours, days, months, years, etc.)
- F(xi): probability of failure (%)
- Co: economic consequences of failure (in monetary units: Euros, etc.)

Therefore, this risk indicator integrates technical and economic factors, because, it combines failure probabilities (frequencies) with economic consequences (costs).

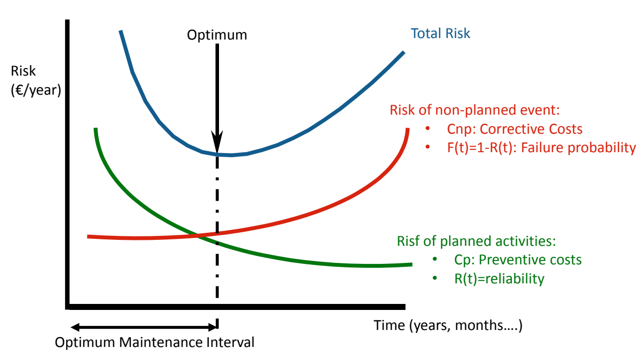

Fig. 1. Example of curves and the minimum expected cost per unit time.

The risk indicator quantifies the influence of both magnitudes (figure 1): failure probability and consequence of the failure, useful for maintenance optimization (Woodhouse, 1998). Risk indicator is useful to quantify the time for a preventive replacement at a lowest cost per unit of time (Campbell and Jardine, 2001) The mathematical expressions for calculating the time period that generates the minimum cost of a preventive maintenance replacement can be expressed as follows (Hastings, 2005):

$$Risk\ (t) = Cnp \cdot (F(t)\ /\ t) + Cp \cdot (R(t)\ /\ t) \qquad (3)$$

Where:

- t: TTF time to failure (hours, days, months, years, etc.)
- Cnp: Corrective maintenance costs (or non-planned costs). It includes material, labour, lost profits, safety, environment, etc.
- F(t): probability of failure (%)
- Cp: Preventive maintenance costs (or planned costs). It includes materials, labour, lost prof-its, safety, environment, etc.
- R(t) = 1 – F(t): Reliability (%).

3. MODEL APPLICATION WITH ANALITICAL VALUES

3.1 Procedure

The value of failure rate (λ) is obtained in OREDA by an estimator, using data from multiple installations. Minimum and maximum values are also given with an uncertainty range of 90%. Considering this, assumptions are used in the calculations for different analysis in order to observe the system behaviour in reference to its reliability. In this case study, a Control and Safety Equipment, among the Fire & Gas Detectors has been selected with the following values from OREDA: (i) Lower Failure Rate: 1,32 (failures per million hours); (ii) Mean Failure Rate: 6,53 (failures per million hours); (iii) Upper Failure Rate: 15 (failures per million hours). The failure probability distribution for the example will be the Weibull distribution:

$$R(T) = \exp\{-(\frac{T}{MTTF})^{\beta}\} \qquad (4)$$

$$MTTF = \frac{1}{\lambda} \qquad (5)$$

This case assumes Weibull distribution and equations refer to an exponential case (beta = 1 in Weibull). The scale parameter (MTTF) will be calculated applying the analytical values for failure rates given by OREDA. On the other hand, for the shape parameter (β) as well as for Corrective and Preventive maintenance costs (Cnp and Cp), specific values are given:

- Cp = 5000 EUR
- Cnp = 367200 EUR