Modeling of uncertainties in reliability centered maintenance — a probabilistic approach

S. Eisinger[a,*], U.K. Rakowsky[b]

[a]*Det Norske Veritas, Veritasveien 1, N-1322 Høvik, Norway*
[b]*University of Wuppertal, Department of Safety Engineering, D-42097 Wuppertal, Germany*

Abstract

Uncertainties in the decision making of reliability centered maintenance (RCM) are discussed. These uncertainties might be unacceptable in many practical applications, leading to non-optimum maintenance strategies. An alternative approach, opening for specified uncertainties is shown to correct this defect. Exemplifying the approach, a simple fire detection system is discussed. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Reliability centered maintenance; Decision making; Probabilistic approach

1. Introduction

First introduced in the aircraft industry, reliability centered maintenance (RCM) has been used with considerable success in the recent decades in many industrial branches. A brief introduction to the method is given in Section 2. A simple fire detection and extinguishing system is also introduced. This system is used as an illustration throughout the paper.

The choice of the "best maintenance strategy" is one of the main points of RCM. Decision making might, however, be difficult because of questions without a certain answer. For example, the question whether or not a component is critical might not be easy to answer with "YES" or "NO". This is discussed in Section 3, where an alternative approach also is developed. Analysis on how the initial decision uncertainties are propagated to the strategy uncertainties is presented, indicating in which cases the uncertainty effects become important. In Section 4, the new approach is applied to the fire detection and extinguishing system introduced in Section 2.

2. The RCM method

The Electric Power Research Institute (EPRI) defines RCM as a systematic consideration of system functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective preventive maintenance (PM) tasks.

An RCM analysis may be subdivided into four main parts. The subdivision and introduction to RCM given here is rather coarse-grained. For a more detailed guide see Refs. [1,4,6].

Preparation. A study group is established and the system documentation is made available. The collection of important system and component data should be initiated.

System analysis. This is the most work-intensive part of the whole analysis. The system functions are broken down into sub-functions to the desired component level. The components are then analyzed by a modified failure mode, effects, and criticality analysis (FMECA) — a method adopted from reliability and risk analysis. All relevant component information should be collected in these forms by the study (expert) group.

Decision making. The main modification of the FMECA analysis consists of the inclusion of information facilitating the choice of the optimum maintenance strategy. This is normally performed with a decision diagram. Many different decision diagrams are proposed for use in RCM analysis. To illustrate the probabilistic approach, a decision diagram (Fig. 1), which is very similar to the ones used by both DNV and MARINTEK [3,7], was selected. Note that the chosen diagram is not necessarily complete nor always applicable.

Decisions on the following questions should be made.

---

* Corresponding author.
  E-mail addresses: siegfried.eisinger@dnv.com (S. Eisinger),
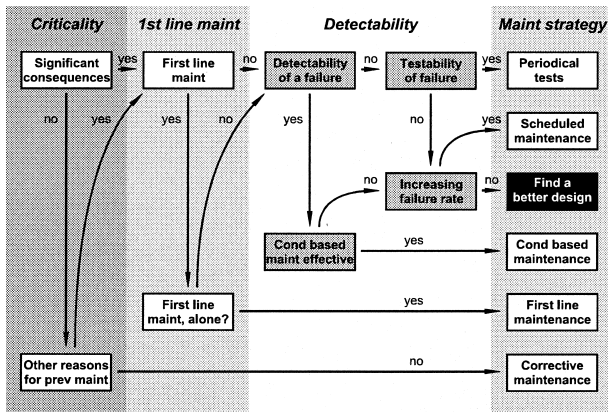ry@verkehr.uni-wuppertal.de (U.K. Rakowsky).

Fig. 1. RCM decision diagram [3,7] used as example throughout this article.

Significant consequences: does component breakdown imply significantly reduced system function? *Other reasons for preventive maintenance:* in most cases preventive maintenance strategies are more expensive than corrective maintenance. Are there other reasons for rendering preventive maintenance cost-effective? *First line maintenance:* is the operator able to do online supervision and maintenance? *First line maintenance alone:* is first line maintenance effective and sufficient? *Condition-based maintenance effective:* do there exist methods for effective condition monitoring, so that component failure can be avoided? *Increasing failure rate:* is there an aging mechanism (YES) or a tendency that new components exhibit more failures than older ones?

Note that the maintenance strategy "find a better design" should be interpreted as an indication that a meaningful maintenance strategy cannot be found. For example, many preventive maintenance strategies only make sense if a wear-out failure mechanism is present in the component. If the component is found critical, but no wear-out failure mechanism is present, this represents an inconsistency and the problem can only be solved through better design. The maintenance strategy resulting from the answering of the questions of the decision logic is often called the "proposed strategy" to indicate that it is not always identical to the finally implemented strategy.

For the choice of maintenance strategy, the finding of the right answer to the questions is clearly crucial. As discussed below, this might be a difficult task.

Implementation and feedback. Finally, the maintenance program should be implemented and feedback from operation experience and new data should be used to regularly improve the program.

The illustration that we will use throughout this paper is a simple fire detection and extinguishing system. A system block diagram is shown in Fig. 2.

A fire incident is normally detected by four *smoke detectors* sending a signal to the *voter*. Persons working in this area might also detect the fire and actuate the *manual detection* facility. The *voter* sends an alarm signal whenever two-out-of-four detectors or the manual actuation send a detection signal. An alarm signal is processed through an *alarm bell* (mainly for personnel safety), through an alarm *transmitter* to the local fire brigade and through *activation* of the main valve of the *sprinkler system*. If the main valve is activated the sprinkler system is filled with water, but the individual *sprinkler* is only activated if the temperature of the area rises above a critical point so that the internal fuse breaks (preaction system). The functions of the system that are mainly considered are "detection of fire" and "non-false alarm".

In Fig. 2 the gray and white rectangles illustrate the system functions and sub-functions. The components (the detectors, the activation valve,…) should be analyzed by an FMECA. Some of the details of this analysis will be postponed to Section 4.

3. Probabilistic RCM

As stated above, the decision making process is crucial for the resulting maintenance program to be effective. Here, however, the problem arises that it is often not appropriate to state "YES/NO"-answers in practical cases. Consider, for example, the question whether one of the detectors is critical within a two-out-of-four system. Criticality assessment for use in RCM analysis may be performed, for example, by subjective expert judgement or by estimating the location of the function according to a predefined risk matrix [2]. In any case there is no clear distinction between "critical" and "non-critical" functions. Likewise, the question whether a failure rate of some function (e.g. activation valve is opening when required) may be called "increasing" is partially subjective. If significant doubt exists as to whether "YES" or "NO" is the right decision it might be better to "quantify the doubt" and find an approach that results in weighted recommendations on which maintenance strategy to choose. Moreover, it may be felt to be more satisfying for an expert to give a
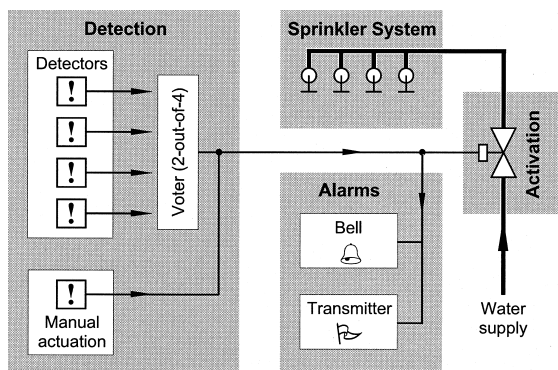

Fig. 2. Fire detection and extinguishing system.