SIE 2015
6th International Symposium on Industrial Engineering
24th-25th September 2015
FACULTY OF MECHANICAL ENGINEERING
STEINBEIS ADVANCED RISK TECHNOLOGIES
INNOVATION CENTER FME

RISK BASED INSPECTION PLANNING AND INSPECTION RESULTS EVALUATION

Emina Džindo[1], Uroš Lukić[2]
[1]Innovation Center of Faculty of Mechanical Engineering in Belgrade, Republic of Serbia
[2]University of Belgrade, Faculty of Mechanical Engineering, Republic of Serbia

Abstract. *Risk based inspection planning (RBI) is an application of the pre-posterior analysis from the Bayesian decision analysis. The analysis is based on the inspection decisions, the inspection outcomes, the repair and mitigation actions, the condition of the structure and the utility (cost or benefit) associated with each set of these variables.*
Key words: *risk reduction, Bayes theorem, inspection planning.*

1. INTRODUCTION

The effectiveness of inspection or monitoring is an important input for risk based maintenance and inspection (RBMI) analysis. Although consequence of failure is not influenced by inspection or monitoring, the assessment of likelihood of failure is.

Even if there is no change in the assessed likelihood of failure as a result of the inspection, uncertainties in the assessment will be reduced (e.g. no degradation predicted, none detected by inspection, increased confidence in predictions). It is important to recognize that inspection and monitoring only change knowledge of the likelihood of failure, and do not change the actual likelihood of failure unless followed up e.g. by remedial action if unacceptable degradation is occurring. Therefore although this report often refers to change in risk, this means change in the assessed risk, not in the actual risk. (It is our knowledge of the component which is changing, not the component itself).

When planning an inspection, or determining change in assessed risk after an inspection, it is therefore important to understand the relationship between inspection/monitoring and predicted likelihood of failure.

For example when using an RBMI approach to priorities plant for inspection and determine inspection intervals, the results of previous inspections or monitoring (and the confidence in these results) will generally have an important bearing on determining what defects are, or may be, present. This impacts directly on calculated likelihood of failure and hence risk of failure.

Similarly after an inspection is performed, or after a period of monitoring, it is important to determine the change in risk of failure. Generally there will be a reduction in the risk of failure, assuming remedial action is taken where appropriate. (If there is no change in risk e.g. no degradation anticipated and none found, there will still be the advantage of increased confidence in the prediction methodology and hence in the calculated risk of failure).

Monitoring the process conditions can also play an important part in checking that the process parameters remain within the envelope for which the RBMI analysis remains valid.

It is therefore necessary to have some metric for inspection/monitoring effectiveness, and to know how to use this metric in RBMI analysis. In this report "effectiveness" means the extent to which inspection or monitoring improves knowledge of a component's integrity.

"Risk assessment integrates reliability with safety and environmental issues and therefore can be used as a decision tool for preventive maintenance planning. Maintenance planning based on risk analysis minimizes the probability of system failure and its consequences (related to safety, economic, and environment). It helps management in making correct decisions concerning investment in maintenance or related field." [1]

Different approaches are described corresponding to different levels of detail. Note that a lower level of detail does not imply a lower quality. "The most appropriate level of detail can depend on a number of factors including:

- the importance of the inspection in reducing risk to an acceptable level;
- the degree of confidence which can be achieved from a given level of analysis;
- the effort required to determine risk change as a function of inspection effectiveness;
- the availability of existing information on inspection effectiveness;
- how detailed the rest of the RMBI analysis is." [3]

Note that since neither inspection nor monitoring can influence the consequence of failure, any change in risk determined after inspection is a result of change in predicted likelihood of failure.

It is also important to recognize that some contributions to likelihood of failure cannot be influenced by inspection or monitoring, such as failures due to human error in operating, inadvertent physical damage, sabotage etc. Even a "perfect" inspection or monitoring system will therefore not reduce risk of failure to zero.

Section above provided examples of measures of inspection effectiveness based on expert judgment. These are generally based on linguistic expressions (highly effective, poorly effective etc.) or a simple scoring system, with expert judgment used to determine which description or score applies to a particular inspection.

Expert opinion can also be used to judge the degree of risk reduction (or increase in confidence with which risk is determined) which results from performing the inspection. For example application of a highly effective inspection has the potential to reduce likelihood of failure from high to low (for a prescribed period of operation). It is important to recognize that the actual reduction in assessed risk will depend on other factors, with inspection being only one of a number of factors.

For example application of a highly effective inspection method is unlikely to result in a further significant reduction in likelihood of failure if there was already high confidence from knowledge of the process conditions, material, generic data etc. that there were no potential degradation mechanisms active.

On the other hand a medium effectiveness inspection method might result in a significant reduction in assessed risk (assuming no defects found) if there was little other information available on which to predict whether degradation was occurring.

Thus while there will be a tendency for the most effective inspection methods to result in the greatest reduction in assessed risk (and increased confidence in "knowing" the risk"), expert judgment is required to decide what weighting should be applied to the inspection effectiveness and results, taking into account all other factors which determine likelihood of failure.

Note that although this approach may be particularly appropriate for high level screening using a qualitative RBMI approach, it can also be used in conjunction with more quantitative elements of the RBMI process in accordance the overall RIMAP approach, by providing an input to the expert's qualitative modification factor applied to he calculated basic quantitative failure frequency.

2. APPROACHES BASED ON STATISTICAL METHODS

If the probability of detection (POD) for the defects of concern is known for the inspection procedure applied, then the probability of a given subset of these defects remaining (as a function of e.g. size) can be determined and the revised probability (and hence risk) of failure calculated. A weighting factor may need to be applied to allow for any additional uncertainties due to sampling.

"Bayes' theorem provides a logical way of updating incomplete knowledge (e.g. 75% confident no degradation present) based on a test or observation which may not be 100% reliable (e.g. inspection method detects degradation 90% of the time).

Bayes' theorem states that given that event B has occurred, the probability that it was due to cause Aj is equal to the probability that A_j should produce that event times the probability that A_j should occur in the first place, all divided by a scaling factor which is the sum of such terms over all causes." [2]

A_s an example let us assume that before inspection of a particular plant item we are 75% confident that no gradation is present.

Imagine that we now inspect using a method which detects degradation 90% of the time with no false calls, and it does not report any degradation.

We want to know the revised probability that no degradation is present, given that none was reported. In this case the event "B" is that no degradation is reported, and the "cause" A_j is no degradation present.

However another possible cause is that degradation is present (but missed). The notation p(A | B) means "the probability of A, given B". According to Bayes' theorem (probability no degradation present given that none reported).

$$\frac{(\text{prob. none reported} \mid \text{none present}) \times (\text{prob. none present})}{(\text{prob. none reported} \mid \text{none present} \times \text{prob. none present}) + (\text{prob. none reported} \mid \text{present} \times \text{prob. present})} = \frac{1 \times 0.75}{(1 \times 0.75) + (0.1 \times 0.25)} = 0.968 \quad \ldots(1)$$

The confidence that no degradation is present has therefore increased from 75% to around 97%.

Note that Bayes' theorem can be used to support decisions based on expert judgement even if there is not precise quantitative data on inspection effectiveness or likelihood of degradation. For example expert judgement could be used to assign a category to inspection effectiveness such as "very high", "medium high", "medium" etc. where each category is taken to represent a band such as "better than 90%", "between 75% and 90%" etc. A similar approach could be adopted to describe initial

likelihood of degradation (or degradation rate). The average within each band (e.g. 95% for very high) could then be used to apply Bayes' theorem. Depending on the band within which the "answer" lay, the revised likelihood of degradation (or degradation rate) could then be interpreted in the original linguistic terms (very high, high etc.).

Note that care should be taken when using probability of detection (POD) data in Bayes' theorem in cases where a number of discrete defects (e.g. cracks) may be present. A technique with a POD of 90% will have a 90% probability of detecting each individual defect, but a much lower probability of detecting all of the defects. A disadvantage of detailed statistical methods for determining risk reduction after inspection is that they generally require information on the probability of detection of the inspection procedure. As explained above, suitable POD data might not exist and can require a major exercise to generate it.

3. DECISION LOGIC APPROACH

Condition Monitoring is used to reduce risk by detecting damage at an early stage before the damage has caused a large consequence event. The condition monitoring equipment should be selected based on the consequence related to the event that should be prevented and the cost of installing and maintaining the equipment. In addition aspects like false calls and the probability of detecting the damage should be considered.

One of the main benefits when a condition monitoring system is installed is that the repair time is reduced. The reason is that the monitoring equipment reduces the diagnostic time, and the preparation for repair can then be done well in advance.

The decision logic or workflow related to the selection of condition monitoring as a maintenance method is shown in Figure 1.

The risk can be assessed, and if the risk is above a predefined limit, or if the cost associated with the failure is large, condition monitoring is one alternative solution to reducing the risk. The figure below sketches the decision path to derive to a strategy for risk reduction The prerequisite for condition monitoring is that the damage development can be detected by means of condition monitoring methods. This is obvious, but not always considered when condition monitoring equipment is selected.

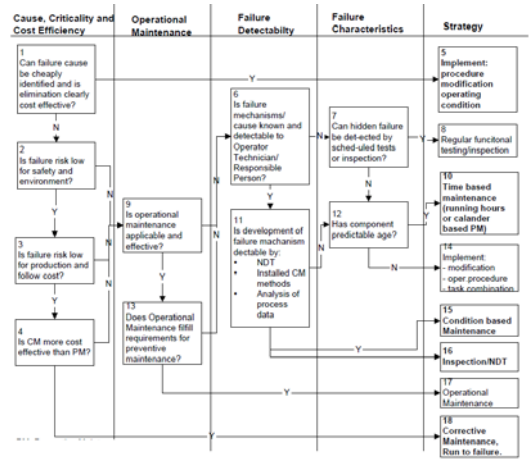

Figure 1. Decision logic for maintenance strategy

4. NUMERICAL MODELING APPROACH

This approach described above it is possible to define quantitative measures for the effectiveness of monitoring. The risk can be determined as the intersection of the Load and Resistance distributions. This is shown on figures 2 and 3.

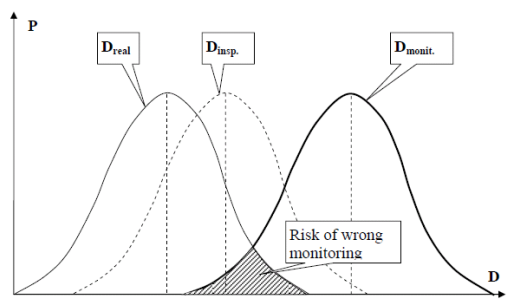

Figure 2. Failure risk due to monitoring

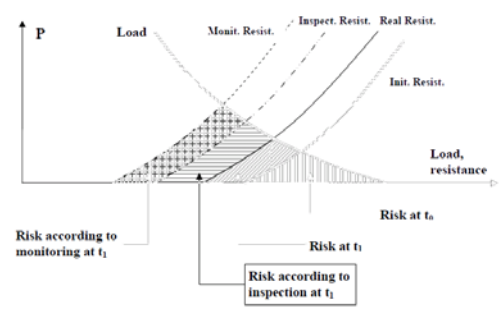

Figure 3. Explanation of different risks

It means that, assuming:

$$D_{real} \approx D_{inspection} \qquad \ldots(2)$$

$$D_{real} = D_{inspection} = D_{monit} \cdot E \qquad \ldots(3)$$

one can assess the probability distribution of D_{real} (or at least of $D_{inspection}$).

5. CONCLUSIONS

The proposed risk-based maintenance strategy aims at reducing the overall risk of failure of the operating facilities. In areas of high and medium risk, a focused maintenance effort is required, whereas in areas of low risk, the effort is minimized to reduce the total scope of work and cost of the maintenance program in a structured and justifiable way. The quantitative value of the risk is used to prioritize inspection and maintenance activities.

Risk-based maintenance strategies can be used to improve the existing maintenance policies through optimal decision procedures in different phases of the life cycle of a system.

REFERENCES

[1] [RIMAP] (2004) D3.1 *Risk Assessment Methods for use in RBIM (with appendices*). Ref. No. 3-31-F-2004-01-1, RIMAP Consortium 2004.

[2] Daniel Straub, *Generic Approaches to Risk Based Inspection Planning for Steel Structures*, IBK, Zurich.

[3] ASME 1991, *Research task force on risk based inspection guidelines, risk based inspection development of guidelines*, General document CRTD 20-1 American Society of Mechanical Engineers, Washington DC, 1991.