plant life management with respect to RBI and RBM

Dr. S. R. Allahkaram, A. M. Zahraie, A. Ohadizadeh, A. A. Shokrollahi
1-Associate professor of Tehran University
2-M.Sc. Corrosion and Protection of Materials
3-R&T center Petrochemical Researcher

- Abstract
Corrosion can limit the safe and useful life of process equipment. Thus, the effects of corrosion must be incorporated into component remaining life assessment and aging management programs. Taking a risk based approach for the overall asset brings together the jigsaw of maintaining integrity for most industrial assets. Risk assessment can be applied to all aspects of an operation, from design, through fabrication, operations, maintenance, repair, inspection, assessing failure history data and at all times meeting quality requirements. Managing equipment integrity is essential to the safe, reliable operation of process plant equipment. Risk based integrity management is rapidly becoming the best and most appropriate technique for determining inspection and maintenance strategies for industry assets. In this paper we describe plant life management as a facet of integrity management and its relation to RBI and RBM.

Keyword: integrated management, plant life management, risk assessment, RBI, RBM

- Introduction
Corrosion is major problem in petroleum refineries and chemical process plants. Key equipment, such as piping, valves, tanks, pumps, vessels, vessel internals, condensers, boilers, turbines and heat exchangers, can be degraded by corrosion attack. Such attack can reduce equipment performance and reliability and, in extreme cases, lead to unexpected failures and shutdowns. Typically, indications of corrosion are found by means of inspections conducted during planned shutdowns and proper maintenance. If corrosion has been unexpectedly severe or if inspections have been infrequent, equipment damage can occur. Corrosion monitoring during operation can help minimize such damage by indicating when corrosion initiated and by measuring the rate of corrosion damage. This information then can be used to alter operating conditions to reduce corrosion or to plan maintenance and repair work.
Managing equipment integrity is essential to the safe, reliable operation of process plant equipment. The current condition of equipment and remaining life must be evaluated to perform the risk assessment. Results of the inspection are used to assess the current condition, whereas stress analysis and materials degradation models are used to assess remaining life. Equipment condition depends on the type of material damage, such as corrosion, fatigue, or creep. Inspection is used to quantify this damage. The type of inspection employed must be tailored to the type of material damage that is expected in service. Thus, selection of the inspection technique(s) is based on analysis of the equipment operating conditions and past experience. Also, the remaining life evaluation depends on the material damage mechanism expected in future service.
Risk based integrity management is rapidly becoming the best and most appropriate technique for determining inspection and maintenance strategies for industry assets. Risk based integrity management allows you to find an optimal balance between asset care and business risk hence maximizing your return. Risk based integrity management, in contrast to other methodologies, focuses on quantifying total business exposure to equipment failure risks. It provides a rational decision making logic to apply corrosion prevention, inspection and maintenance resources to those assets that are vital to your business survival, providing the greatest return for your asset management dollar. Significant savings are possible for both new build projects and existing brown-field assets. Risk based integrity management is a complex subject with many facets that one of these is plant life management.

![Figure 1. overview of risk based asset integrity management](image)

Plant life management is a vast subject and will be limited to some general principles of the possibility of utilizing explicitly risk based methods to manage the structural integrity of a plant, in particular the in-service inspections. With the concept risk is usually meant the

![Figure 2. example frame work for an integrity management program](image)
probability that some undesired event occur. Such an event may be called the end event. It is in general preceded and caused by other events, so called initiating events. Clearly, the end event could in turn be viewed as an initiating event for further event with undesired consequences.

A general concept risk-based plant life management could then be that the plant has to be managed so that the total risk of undesired consequences is kept below acceptable levels. in a certain sense risk based management has always been a guiding principle of plant design and maintenance. Presently more effective utilization of resources has become a main concern and thus more carefully planned systems for maintaining safety at reasonable cost levels are under development in several countries.

1- Risk & Consideration:

prediction, quantification and management of technical risks through appropriate maintenance strategies also has a large bearing in the mitigation of risks within an operation. Risk is the product of ‘likelihood of an unwanted event $P_E$’ and the ‘consequences C of that unwanted event’, or in shorthand form given as $R = P_E * C(\text{units})$.

In a maintenance context, event probabilities $P_e$ such as equipment or component failure rates can either be estimated using subjective expert opinion or can be calculated using objective historical data from maintenance information systems or suitable databases. The consequences C that arise out of those failures are established through consequence analysis.

While the above equation suggests a single value, we know that an event can have many outcomes and risk is better described as the combination of an event with potentially several adverse consequences. To be effective, risk based decision-making must focus in the area of highest risk and mitigation must address the reduction in the event likelihood as well as the consequences. Key drivers that must be considered in setting up a risk based decision making approach in a maintenance operations include:

a- Industry Fatalities

For a sustainable industry to remain, risk based efforts must focus on the reduction of fatalities throughout the sector.

b- Duty of Care

Application of ‘duty of care’ principles is mandatory and requires operations management to comply to avoid loss of license or risk personal prosecution. Maintenance management therefore needs to consider a wide area and adequately address these hazards in assisting legal compliance.

c- Environmental Protection

There are strict statutes and numerical targets governing environmental performance. Mine maintenance must adequately provide effective mitigation strategies. A holistic approach needs to be firmly incorporated into the planning, design, operating, maintenance strategies and emergency preparedness for a site.

d- Asset Integrity

Threats to the integrity of the actual engineering asset, will bring with it potential safety and health issues for employees that work in that working environment but will also result in costly downtime of the asset.

A risk-based approach can also be used in establishing an optimal spare parts program, maintenance routine (allocation of resources) or capital expenditure program.

e- Company Reputation
Many incidents over the last few years have cast a shadow over the reputation of some companies, their management and entire industry sectors. Clearly all operations incidents and their possible effects need to be considered in the decision making process.

**f- Cost of Downtime**

Incidents, accidents or unnecessary downtime will always result in a temporary upset to the operations flow and output. The cumulative unavailability and beneficiation process and the added cost can quickly affect the financial performance of a operation.

**g- New Technologies**

Commercial pressure often requires the implementation of new ‘state of the art’ technologies. While in isolation, hazards arising from new technology may be manageable, but maintenance must be able to deal with the hazards arising through the combination and interrelation of often software driven equipment in a system safety context. Adopting a risk based approach, rather than a purely reliability centered approach allows a more focused allocation of maintenance resources to those areas that are critical to the operation.

**h- Human Unreliability**

Human unreliability is routinely considered by many other high-risk industries where considerable emphasis is put into the design of safe work procedure design, particularly for safety critical, high stress and emergency tasks.

**2- Assessing the risks and their potential**

There are several tools available to the maintenance engineer and techniques that can help a maintenance team to better estimate the level of risk. These may be either ‘subjective – qualitative’ or ‘objective – quantitative’, as shown in Figure 2, and both streams have been used effectively in establishing a risk based safety and maintenance strategies in many industries.
Risk analyzing is a technique for identifying, characterizing, quantifying, and evaluating the loss from an event. Risk analyzing approach integrates probability and consequence analysis at various stage of analysis. The procedures for RBI have been based on semi-quantitative methods.

The growing interest in risk based management is driven by the need of developing strategies that lead to optimal safety versus cost balance. It is formally shown that the core damage frequency can be factored into a system part and component failure frequency part.

A very idealized model is estimate of component failure probabilities for optimizing the plant maintenance with respect to safety and cost consideration. The total system safety is composed of a sum of component reliability multiplied by system –dependent factors.
In order to calculate the component failure frequency the following is needed:
First the possible damage mechanisms have to be identified, e.g. stress corrosion cracking, fatigue cracking, erosion, etc. when this is done the analysis can be pursued for each mechanism that can occur at the considered location. The procedure may then consist of some or all of the following elements below:

- A model for the initiation of considered damage statistical data to quantify the probability of initiation. In the former case probability distributions for variables that inter the model are needed.
- A model for the growth of the damage and probability distributions for the material variables that inter the chosen model. In the case of stress corrosion or fatigue cracking this models of supplied from fracture mechanics theory.
- Probability distributions for the load variables
- A model for the flow rate calculations with necessary probabilistic information
- A probabilistic model for the in-service inspection efficiency
- A model for leakage measurement with necessary probabilistic information
- A mathematical statistics framework to handle the probability data in the models

3- RBI
An inspection strategy consists of specifying for any locations in the plant:

- Where to inspect? Which systems and locations shall be inspected?
- How to inspect? Which inspections method should be used and which are the requirements of accuracy and efficiency?
- When to inspect? What is the appropriate inspection interval at a particular location?

Risk-Based Inspection (RBI) is a method for using risk as a basis for prioritizing and managing the efforts of an inspection program. In a typical operating plant, a relatively large percentage of the risk is associated with a small percentage of the equipment items. RBI permits the shift of inspection resources to provide a higher level of coverage on the high-risk items and an appropriate effort on lower risk equipment. A potential benefit of a RBI program is to increase operating times and run lengths of process facilities while improving, or at least maintaining, the same level of risk. RBI planning places a larger emphasis on inspections with shorter intervals and higher quality inspection types where they will have the greatest benefit in reducing both planned and unplanned shutdowns.

Benefits will accrue from one or more of the following:
- improved availability and reliability,
- reduced cost exposure to failure,
- reduced maintenance expenditure,
- life extension,
- extended period between inspections.

RBI programs address risks due to structural or equipment deterioration from a safety, environment and economic perspective. Implementation of RBI plans can provide and document the overall reduction in risk for the facilities assessed. RBI programs may identify risks of such low level that require little or no inspection as a means of mitigation, and consequently, improving management of inspection activities by directing resources to higher risk areas.

4- Type of Maintenance
What is maintenance and why is it performed? Past and current maintenance practices in both the private and Government sectors would imply that maintenance is the actions associated
with equipment repair after it is broken. Maintenance is the actions taken to prevent a device or component from failing or to repair normal equipment degradation experienced with the operation of the device to keep it in proper working order. Unfortunately, most private and Government facilities do not expend the necessary resources to maintain equipment in proper working order. Rather, they wait for equipment failure to occur and then take whatever actions are necessary to repair or replace the equipment. The design life of most equipment requires periodic maintenance. Anytime we fail to perform maintenance activities intended by the equipment’s designer, we shorten the operating life of the equipment. But what options do we have? Over the last 30 years, different approaches to how maintenance can be performed to ensure equipment reaches or exceeds its design life have been developed in the world. In addition to waiting for a piece of equipment to fail (reactive maintenance), we can utilize preventive maintenance, predictive maintenance, or reliability centered maintenance. Maintenance plays a pivotal role in managing risks at a mine site and it is important that the right risk assessment tools are applied to capture and evaluate the hazards at hand to allow a functional risk based approach.

4.1. Reactive Maintenance

Reactive maintenance is basically the “run it till it breaks” maintenance mode. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached. Studies as recent as the winter of 2000 indicate this is still the predominant mode of maintenance in the United States. The referenced study breaks down the average maintenance program as follows:

- >55% Reactive
- 31% Preventive
- 12% Predictive
- 2% Other.

Advantages to reactive maintenance can be viewed as a double-edged sword. If our maintenance program is purely reactive, we will not expend manpower dollars or incur capitol cost until something breaks.

we could view this period as saving money infact we are really spending more dollars than we would have under a different maintenance approach because, we are shortening the life of the equipment. This is an increased cost we would not have experienced if our maintenance program was more proactive.

Advantages
- Low cost.
- Less staff.

Disadvantages
- Increased cost due to unplanned downtime of equipment.
- Increased labor cost, especially if overtime is needed.
- Cost involved with repair or replacement of equipment.
- Possible secondary equipment or process damage from equipment failure.
- Inefficient use of staff resources.

4.2. Preventive Maintenance

Preventive maintenance can be defined as follows: Actions performed on a time- or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.
In addition to an increase in reliability, dollars are saved over that of a program just using reactive maintenance. Studies indicate that this savings can amount to as much as 12% to 18% on the average.

**Advantages**
- Cost effective in many capital intensive processes.
- Flexibility allows for the adjustment of maintenance periodicity.
- Energy savings.
- Reduced equipment or process failure.
- Estimated 12% to 18% cost savings over reactive maintenance program.

**Disadvantages**
- Catastrophic failures still likely to occur.
- Labor intensive.
- Includes performance of unneeded maintenance.
- Potential for incidental damage to components in conducting unneeded maintenance.

While preventive maintenance is not the optimum maintenance program, it does have several advantages over that of a purely reactive program. In this way we will extend the life of the equipment closer to design. Preventive maintenance (lubrication, filter change, etc.) will generally run the equipment more efficiently resulting in dollar savings. While we will not prevent equipment catastrophic failures, we will decrease the number of failures.

### 4.3. Predictive Maintenance

Predictive maintenance can be defined as follows: Measurements that detect the onset of a degradation mechanism, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state. This maintenance need the actual condition of the machine rather than on some preset schedule but preventive maintenance is time-based. predictive maintenance is used to define needed maintenance task based on quantified material/equipment condition.

**Advantages**
- Increased component operational life/availability.
- Allows for preemptive corrective actions.
- Decrease in equipment or process downtime.
- Decrease in costs for parts and labor.
- Better product quality.
- Improved worker and environmental safety.
- Improved worker moral.
- Energy savings.
- Estimated 8% to 12% cost savings over preventive maintenance program.

**Disadvantages**
- Increased investment in diagnostic equipment.
- Increased investment in staff training.
- Savings potential not readily seen by management.

The following industrial average savings resultant from initiation of a functional predictive maintenance program:
- Return on investment: 10 times
- Reduction in maintenance costs: 25% to 30%
- Elimination of breakdowns: 70% to 75%
- Reduction in downtime: 35% to 45%
- Increase in production: 20% to 25%.
On the down side, to initially start into the predictive maintenance world is not inexpensive.
Training of in-plant personnel to effectively utilize predictive maintenance technologies will require considerable funding.

4.4. Reliability Centered Maintenance
Reliability centered maintenance “a process used to determine the maintenance requirements of any physical asset in its operating context.”
It recognizes that equipment design and operation differs and that different equipment will have a higher probability to undergo failures from different degradation mechanisms than others. It also approaches the structuring of a maintenance program recognizing that a facility does not have unlimited financial and personnel resources and that the use of both need to be prioritized and optimized. RCM is a systematic approach to evaluate a facility’s equipment and resources to best mate the two and result in a high degree of facility reliability and cost-effectiveness.

Advantages
- Can be the most efficient maintenance program.
- Lower costs by eliminating unnecessary maintenance or overhauls.
- Minimize frequency of overhauls.
- Reduced probability of sudden equipment failures.
- Able to focus maintenance activities on critical components.
- Increased component reliability.
- Incorporates root cause analysis.

Disadvantages
- Can have significant startup cost, training, equipment, etc.
- Savings potential not readily seen by management.

4.4.1. How to Initiate Reliability Centered Maintenance
The road from a purely reactive program to a RCM program is not an easy one. The following is a list of some basic steps that will help to get moving down this path.
1. Develop a Master equipment list identifying the equipment in your facility.
2. Prioritize the listed components based on importance to process.
3. Assign components into logical groupings.
4. Determine the type and number of maintenance activities required and periodicity using:
   a. Manufacturer technical manuals
   b. Machinery history
   c. Root cause analysis findings - Why did it fail?
   d. Good engineering judgment
5. Assess the size of maintenance staff.
6. Identify tasks that may be performed by operations maintenance personnel.
7. Analyze equipment failure modes and effects.
8. Identify effective maintenance tasks or mitigation strategies.

5- Concept of risk and its relevance in maintenance:
One of the main objectives of a sound maintenance strategy is the minimization of hazards, both to human and to the environment caused by the unexpected failure of the equipment, in addition the strategy has to be cost effective.
The overall objective of the maintenance process is to increase the profitability of the operation and optimize the total life cycle cost without compromising safety or environmental issues. Risk assessment integrates reliability with safety and environmental issues and therefore can be used as a decision tool for 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. This will in turn result in better asset and capital utilization.

**6- RBM**

RBM is a decision-making tool to prolong the life of aged equipment. It is also, of course, an effective method in planning the operation for new designs. The proposed risk-based maintenance (RBM) strategy aims at reducing the overall risk of failure or operating facilities. In areas of high and medium risk a focused maintenance effort is required, whereas in areas of low risk, effort is minimized to reduce the total scope of work and cost of the maintenance program in a structure and justifiable way. RBM suggests a set of recommendations on how many preventing task (including the type, means and timing) are to be performed. The implementation of RBM will reduce the likelihood of an unexpected failure. Using this RBM, it is possible to formulate optimized maintenance strategy such as when and how to conduct repairs and replacements.

The Risk based maintenance methodology is broken down into three main modules:

1- risk determination, which consists of risk identification and estimation
2- risk evaluation, which consists of risk aversion and risk acceptance analysis, and
3- maintenance planning considering risk factors.

The maintenance strategy consists of plans for inspections, repair, refurbishment and replacement based on the risk assessment. As with the results of RBM assessment, many advantages were found in the maintenance planning as follows.

1- covering all location of a unit concerning potential damage by inventory
2- through RBM assessment, effective information about the plant handed down from expert engineers with much experience
3- improvement of the safety assessment with global standards and knowledge of damage mechanisms
4- by using the unified standard of RBM assessment, maintenance priority and details decided under optimum conditions
5- clarifying the reasons of inspections and repair for reaching a consensus among the maintenance department, the investment department in the plant customer, public inspection organizations and others
6- omitting the current inspections at locations assessed as low-risk categories
7- smooth transition of inspection records stored on paper to the software system

**7- Conclusion**

Risk based integrity management is rapidly becoming the best and most appropriate technique for determining inspection and maintenance strategies for industry assets. Computing estimates of remaining life requires a model of the material damage mechanism. For an in-service component, the current condition of a component must be determined before remaining life can be estimated. The current condition can be determined by computing the current material condition using damage accumulation models and past operating conditions or by means of nondestructive examination (NDE).
RBI planning places a larger emphasis on inspections with shorter intervals and higher quality inspection types where they will have the greatest benefit in reducing both planned and unplanned shutdowns. Risk based inspection focuses on mechanical integrity issues for the avoidance of catastrophic failure of plant equipment. It does not incorporate factors such as human, design and outside influences.

A successful combination of RBM and competent maintenance planning should result in a scheme that embodies maintenance frequency and methods and proposes appropriate mitigation measures. This maintenance scheme is aimed at maximizing plant output and life, minimizing downtime and life of asset costs, whilst maximizing safety, reliability and total life integrity.

References: