Risk-Based Inspection and Maintenance in Asset Management Strategy


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THE oil and gas industry is one of the major industries in the world that regularly appears in the news for the wrong reasons. Catastrophic incidents in a process plant or a serious rupture of a hydrocarbon transmission pipeline that lead to severe damages to the environment or fatalities often grab major headlines. In many of the investigations outcome, human error is widely cited as the probable cause of these incidents. This is generally true, however, the seriousness and extent of the damages could be compounded if the facilities were operating with a fleet of ageing and poorly-maintained assets.

A report published in 1992 to identify the causes of leaks in refineries and hydrocarbon plants around the world had shown that the highest percentage of containment loss incidents was actually due to mechanical failure, which is indirectly influenced by maintenance and inspection activities [9]. If the plants or pipelines' operators diligently utilise their facilities' assets according to the standard operating procedures and apply the highest standard of safety, asset deterioration and integrity loss could still influence the consequences of a disaster. The difference could be as harmless as a short shutdown of equipment in a process unit, for example, or a total wipeout of an entire operating plant to quote the extreme.

Typically, due to its nature in handling hazardous and volatile hydrocarbons, the equipment in oil, gas or petrochemical facilities have to be designed and maintained in a very stringent and regimented way. The facilities are usually designed to widely accepted international codes and standards such as API (American Petroleum Institute), ASME (American Society of Mechanical Engineers) or ISO (International Standards Organization). Based on these, the equipment or physical assets within the facilities are designed to last for between 20 to 25 years.

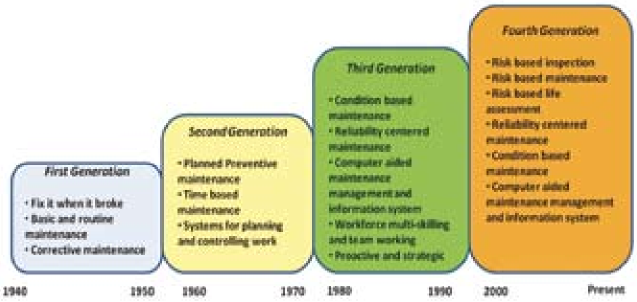

Figure 1: Development in maintenance philosophies [2]

Nonetheless, the design life factor alone will not guarantee that the equipment within the oil, gas or petrochemical facilities will last as intended. If the maintenance activities are poorly planned and executed or the equipment in operation is stressed beyond its safe design parameters, the facility could become a potential time bomb. A systematic asset management and care strategy must be developed even as early as the design stage to ensure that the reliability of the facilities is achieved with the expected requirement to meet the operating company's business plans.

EVOLUTION OF MAINTENANCE STRATEGIES

The old maintenance management strategy of corrective maintenance "fix it only when it breaks" has evolved tremendously since the 20th Century, giving birth to new approaches such as Scheduled Maintenance and Condition-Based Maintenance. Maintenance philosophies such as Total Productive Maintenance (TPM), Reliability-Centred Maintenance (RCM) and Business-Case Maintenance (BCM) were also introduced to complement the maintenance strategy in providing a more economical approach. The latest development in maintenance focuses on Risk-Based Inspection (RBI) and Risk-Based Maintenance (RBM) that aims to further strengthen the existing maintenance practices by focusing on high-risk items in parallel with a practicable maintenance cost reduction.

The type of maintenance for a particular equipment or component in a plant differs depending on its importance and impact on other components. Non-critical equipment could still utilise the corrective maintenance strategy, but for equipment which is dependent on periodic attention, a scheduled maintenance strategy based on the principle that every critical component should be cared and maintained as per prescription must be adopted.

The evolution in the maintenance approaches described earlier was transpired by the need to properly maintain a plant or facility to improve availability and reliability, entail greater safety, enhance product quality, prolong equipment life and be environmentally-friendly with an effective cost utilisation [2]. The evolution of these philosophies and approaches is shown in Figure 1.

Often, the periodic inspection of equipment or component in a plant was seen to impair the plant's safety by diluting inspection resources, induce unnecessary costs and produce a false image of the plant's actual health conditions [3]. These concerns were later addressed by the newer maintenance concepts available such as Condition-Based Monitoring (CBM), RBI and RBM, which decided to move away from time-based maintenance basis.

The RBI/RBM strategy originated from equipment safety efforts in nuclear power plants and from the refinery industry in Canada in the 1980s. RBI/RBM has been implemented mainly in the oil, gas and petrochemical sector even before the release of the API RP 580 (Risk-Based Inspection) recommended practice in 1995. Since then, this recommended practice has served as a guideline for the practical applications and implementations of RBI/RBM, specifically for mechanical static equipment such as tanks, heat exchangers and pressure vessels. RBI/RBM was also believed to be used during the development of RCM in the aircraft industry to counter problems posed by the increased complexity of modern aircraft systems. However, the initial phase was merely for inspection and maintenance scheduling.

Outstanding results were shown by the process industries since the inception of RBI/RBM thereon. From that stage onwards, turbomachinery equipment such as steam or gas turbines had also started to use RBI/RBM leading to its implementation in the railway system and power distribution system in improving reliability performance [2].

In Europe, Risk-Based Life Management (RBLM) has been developed from RBI, initiated by the European RIMAP (RIsk based and MAintenance Procedures) project [5]. The RBLM shows how the risk-based approach and prioritisation of tasks serve as input to the final plant life management, as shown in Figure 2. It is starting to gain recognition for use in the safety implications to the United Kingdom HSE regulations.

DEFINITIONS

In order to fully appreciate the RBI/RBM strategy, a full understanding of what 'risk' is needs to be discussed. 'Risk' is defined as the combined effect of the probability

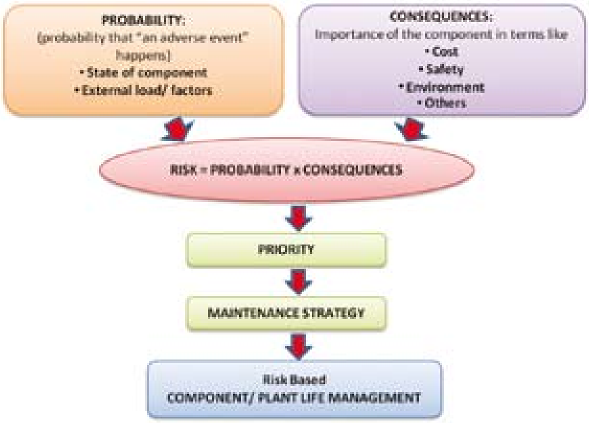

Figure 2: Risks and priority in RBLM flow chart [5]

(likelihood) of a failure and the consequence of a failure to personnel safety, quality of product, environmental damage and economic loss [1].

Risk = Probability of Failure x Consequence of Failure

Risk-Based Inspection (RBI) is a systematic methodology to measure the risk of specific equipment by evaluating its current operating parameters and its mechanical condition. The risk ranking process will optimise the inspection programs to enhance process safety, improve operability and reduce maintenance and inspection costs.

Risk-Based Maintenance (RBM) is a total maintenance approach which includes the equipment or process risk in improving the maintenance management systems and practices. By considering the risk factor, work and resources prioritisation can be easily identified to assist the maintenance decision-making.

RISK BASED INSPECTION (RBI)

The often-used guideline for RBI in the oil, gas or petrochemical industry in Malaysia is the API RP 580. It was developed by API as the recommended practice in undertaking a RBI program. It summarises the objectives of a risk-based inspection program as follows:

- Review operating units within a plant to point out high-risk area
- Estimate a risk value associated with the failure modes for equipment in a refinery or a chemical process plant based on a consistent methodology
- Prioritise equipment based on measured risk to optimise the inspection program
- Employ systematic risk management on the risks associated with equipment failure

The RBI concepts and methodologies are summarised as follows:

- Equipment/process risks are evaluated in detail – the risk analysis process uses the probability of an event occuring and the consequences related to it
- Requires detail equipment information for the analysis
- Risk analysis can be either qualitative or quantitative
- Requires knowledge on common equipment failure mode(s) and its failure rate(s)
- The risk analysis process has a feedback loop to re-evaluate the risk and decision/action made; which also serves as a continuous improvement practice
- Feedback loop also serves as a 'gatekeeper' where evaluated risks are used to formulate the maintenance strategy to suit changed operating conditions

The RBI concept is applied on critical equipment or system by analysing the data and information gathered in regard to risk in terms of the consequence of failure and probability of failure. From the assessment, a specific

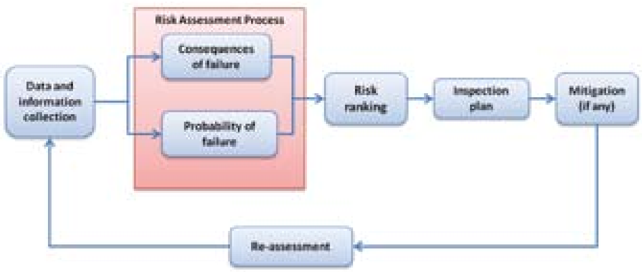

Figure 3: Risk-based inspection planning process [4]

inspection plan is drawn up for the equipment or system based on its risk ranking as shown in Figure 3.

The fundamentals of RBI execution depends on the people and organisation in terms of the competencies and capabilities of the designers, operators, maintainers and the RBI team in evaluating the risk of a plant or equipment or system failure to formulate a viable RBI program as shown in the example in Figure 4.

ASSESSMENT APPROACH

API RP 580 also presents the approaches of RBI assessments. These are broken down into three components:

- **Qualitative** – requires descriptive data inputs based on engineering judgment and experience as basis. Results are given in qualitative terms (*e.g.* high, medium and low) with associated numerical values. It enables the completion of risk assessment without detailed quantitative data. The accuracy of this assessment is dependent on the capability of the analysts.
- **Semi-quantitative** – a combination of qualitative and quantitative approaches to take advantage of the speed of the qualitative and the rigour of the quantitative. Results are given in consequence and the probability categories are represented by numerical values.
- **Quantitative** – integrates information about facility design, operating practices and history, human actions, the physical progression of accidents and potential environmental and health effects. It uses logic models, *i.e.* event trees and fault trees to estimate accident sequence. Results are presented as risk numbers (*e.g.* cost/year).

Each approach provides a systematic way to screen for risk, identify areas of potential concern and develop a prioritised list for more in-depth inspection or analysis [4]. Risk-ranking measures are used to evaluate the probability of failure and the potential consequence of a failure to produce the estimated risk for the respective equipment or component or system.

The continuum of the RBI approaches is illustrated in Figure 5, whereby qualitative and quantitative approaches being the extremes of the continuum and everything in between are semi-qualitative approaches [4].

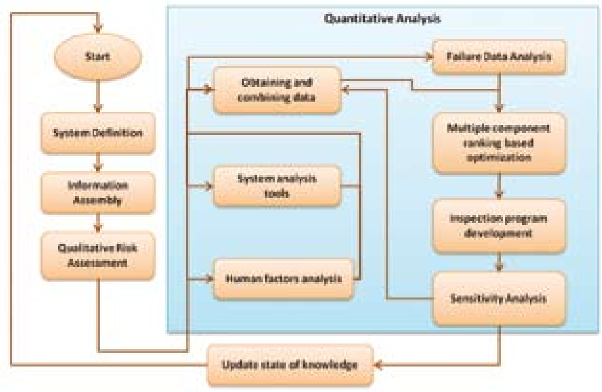

Figure 4: RBI process based on ASME code [6]

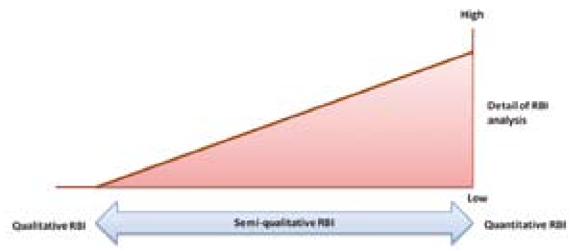

Figure 5: Continuum of RBI approaches [4]

The quantitative RBI is an equipment-level risk assessment tool that calculates the risk associated with the equipment, which is then used to rank the equipment according to its criticality, for example, high-risk, medium-risk and low-risk in order to prioritise the inspection planning and maintenance works by list of importance.

RISK PRESENTATION

As outlined in API RP 580 also, there are two ways of presenting the risk calculated from the risk assessments either by using the Criticality Risk Matrix in Figure 6 or the Risk Plot in Figure 7.

The 5 x 5 Risk Matrix with designated risk numbers is commonly used as it is effective, with a clear color representation and risk definitions, in communicating the information to the general workforce. On the Risk Matrix, the Probability of Failure (PoF) is on the vertical axis with numerical factors starting from a small value and increasing upwards (more critical) depicting the likelihood

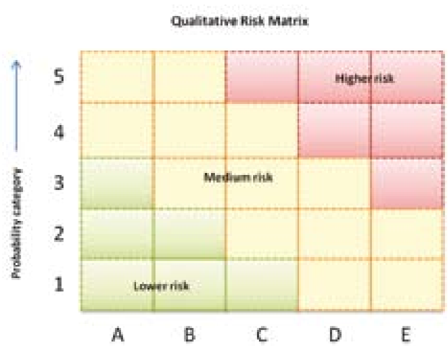

Figure 6: Example of a risk matrix [4]

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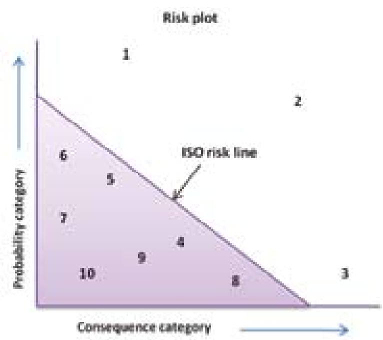

Figure 7: Example of a risk plot [4]

of a failure to occur while the Consequence of Failure (CoF), in terms of health and damage, is on the horizontal axis with assigned letters representing the most damaging effects on the outermost fifth column.

On the other hand, the Risk Plot uses a log scale and is used when numeric risk values are important to stakeholders. The item with the highest risk is plotted towards the upper-right-hand corner. From both risk presentations, the items residing at the upper-right-hand corner of the Matrix or Plot are likely to be prioritised for inspection planning as they are of high risk. Similarly, items at the lower-left-hand corner will have lower priority as they have the lowest risk.

Since the RBI assessment is sometimes subjective and difficult to quantify, some typical considerations for RBI analysts to come up with the most reasonable risk rating could be based on the description given in Figure 8.

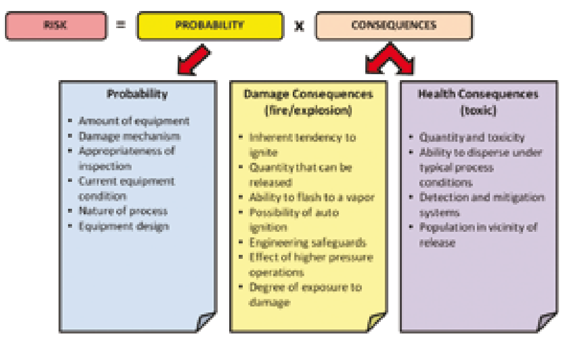

Figure 8: Factors that affect PoF and CoF

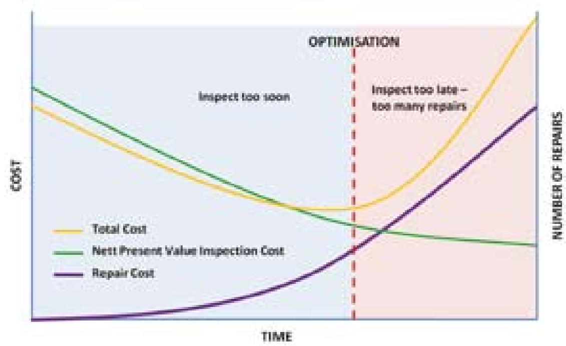

Figure 9: Cost optimisation of repair plan and re-inspection interval [7]

When all the equipment or system risks and its associated factors have been evaluated and the items are ranked accordingly, the next step is the optimisation process that takes into consideration the value of money spent for the work. This includes the possibility of delaying the maintenance decision to another time without incurring production loss, or the plant or unit breakdown, and without compromising safety within that duration. In making this decision, the accurate value of money with regards to resources and materials must be measured by its Net Present Value (NPV). Figure 9 illustrates the relationship between inspection costs and repair costs. The optimisation line gives the best value for money which complements the opportune time to repair or inspect with respect to the total costs. From this, the maintenance planning can derive the maximum inspection interval feasible without compromising production, quality and safety.

RISK-BASED MAINTENANCE (RBM)

RBM is a holistic approach which comprises RBI being built into a workable maintenance strategy. It is based on integrating a reliability approach and a risk assessment strategy to obtain an optimum maintenance schedule. The RBM methodology comprises these four modules [1]:

- Identification of the scope
- Risk estimation: consists of risk identification and estimation calculations
- Risk evaluation: consists of risk aversion and risk acceptance analysis
- Maintenance planning: a maintenance plan built-in with risk factors

In summary, RBM first formulates the likely equipment failure scenarios with the most probable one to be further analysed with detailed consequences. Subsequently, a fault tree analysis is used to determine the failure scenario probabilities. Finally, the risk is calculated as the product of

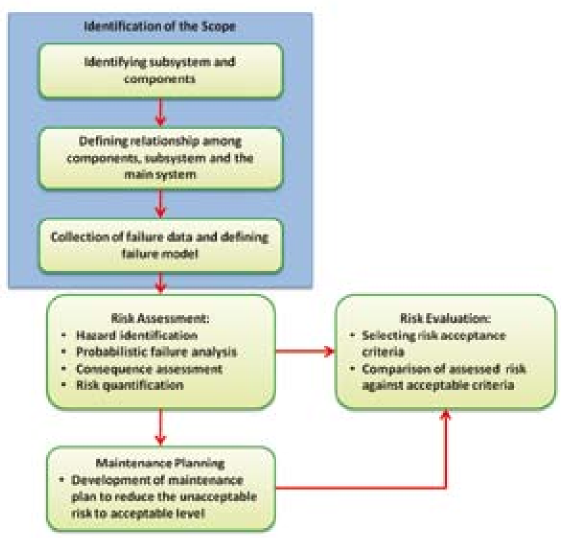

Figure 10: Simplified architecture of RBM methodology [1]

the failure consequences and the failure probabilities which have been analysed earlier. For the risk acceptance criteria, the calculated risks are compared against known acceptable criteria. The maintenance or inspection intervals are then derived by minimising the estimated risk.

The architecture of the RBM methodology is presented in Figure 10 for a clearer representation of the four modules.

IMPLEMENTATION

With the right support from the management on the maintenance management policy and the correct RBI/RBM implementation, an operating hydrocarbon plant will benefit from the many advantages of the maintenance strategy. Decision-making on maintenance and inspection works will be improved when the integrated risk information is made available. Furthermore, reduction in maintenance costs could be realised by the optimised plant's planned maintenance activities, optimised inspection frequency and rationalised warehouse spares inventory. Resources could be optimised to only undertake corrective maintenance on high-risk and critical equipment. The comprehensive equipment inspection and maintenance schedule will improve a plant's turnaround planning for equipment inspections as there will be longer inspection intervals, shorter turnaround duration and less field work required.

No single asset maintenance strategy is fault-free and the RBI/RBM method also has its limitations due to the qualitative risk assessment approach that it utilises. Quite often, the risk-ranking results are conservative and highly dependent on the RBI assessors' skills, experiences and knowledge in analysing the data. The criterion for the risk ranking is also judgmental and difficult to be documented. There are also areas where there are difficulties with RBI/RBM implementation such as the need to have a substantial and accurate existing equipment or plant data and information. In addition, the risk matrix is time consuming to prepare since many aspects have to be considered and entails more resources for its continuous implementation.

Nevertheless, with the right implementation and continuous improvement to the maintenance approach, the RBI/RBM strategy has shown significant benefits to the operators. In one case, a chemical plant recorded an economic potential of 5 million Euros (RM20 million) per year by extending the turnaround interval, reducing unplanned outages and improving prime production time when the RBI/RBM was applied. Similarly, a petrochemical plant showed a 5% increase in production and a 10% reduction in maintenance cost without any increase in HSE risks with a similar RBI/RBM strategy [9]. Many of the hydrocarbon plants in Malaysia are also undertaking RBI/RBM activities but the economic impacts have not been widely shared within the industry or not available for public consumption.

CONCLUSION

An unfortunate disaster resulting from an equipment failure in a hydrocarbon plant or facility will affect the operating company's business and market share, not forgetting the legal actions that may be initiated upon it. The impact of this failure can be in terms of monetary loss since the higher the impact, the more money it will cost the operator. This will distort the operating company's cash flow and Returns-on-Investment (ROI) as well as denting its products market share. It could also tarnish the company's reputation for a long time such that it may take years for it to regain its business stature prior to the disaster, if that ever materialises again.

Besides investing in safeguarding mechanism and the continuous training of the company's personnel, investment in a systematic physical infrastructure assets management is critical to prevent any untoward accidents from happening due to a plant's equipment failure. RBI/RBM has proven to provide major impacts on the oil, gas and petrochemical industry by introducing a strategy that is based on equipment prioritisation and integrating the maintenance decision-making with the calculated risk involved. It has resulted in an optimised maintenance planning and scheduling, an optimised inspection planning and scheduling, and has rationalised equipment spares inventory without compromising the plant's operational safety.

Cost savings are gained by not spending the capital at hand earlier than necessary. Although there are limitations and difficulties in RBI/RBM implementation, continuous developments are being made to enhance the risk assessment approach so as to make it less rigorous. There is no single clear and hassle-free strategy to guarantee that an accident would never happen but a systematic and structured method will definitely minimise the risk to the lowest state possible. ■

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