

**IMPORTANCE OF RISK BASED INTEGRITY MANAGEMENT
IN YOUR SAFETY MANAGEMENT SYSTEM – ADVANCED
METHODOLOGIES AND PRACTICAL EXAMPLES**

Tilman Rasche, MSc, BE, Member AUSIMM
QCL International, Brisbane, Australia

and

Ken Woolley, BSc, CEng, FICE, FIMarE, MIQA
QCL International, Aberdeen, Scotland, UK

Abstract

With the development and introduction of goal setting legislation into many Australian workplaces and the increasing pressures on companies to perform across a variety of areas including Health, Safety and the Environment, Risk Based Integrity Management (RBIM) has evolved as one of the best and most comprehensive techniques available to management, to stay ahead in the development of a proactive Safety Management System (SMS).

RBIM casts its net further than traditional risk management techniques or methodologies by considering all risks within an operation, trying to substantiate them in financial terms and provide meaningful, effective and measurable mitigation strategies in those areas where the risks to the business are greatest. RBIM enhances the existing safety and environmental focus, but also discovers what key drivers (opportunities) and threats exist in an operation.

This holistic approach provides management with the ability to better judge the often competing facets of the business and find an optimum balance between asset care, business safety risks and general vulnerability, thereby maximising the company's returns.

RBIM is now firmly entrenched in the European oil, gas and chemical industry after several large-scale disasters. With the new goal-setting mining legislation being introduced this year in QLD, mine management is faced with a considerable task to provide SMS not dissimilar to those required by the European safety case legislation.

This paper will provide an insight into RBIM and describe why it is a superior risk management tool for either augmenting existing SMS or constructing a new SMS. Examples of successful applications across a range of industries are provided.

Introduction

Risk based integrity management is a complex subject with many facets. This paper takes a global view identifying the need and importance of risk management in the whole process of maintaining asset integrity.

The concept of risk is used to target inspection and maintenance resources at areas of a structure, plant or process where they can have the greatest effect in reducing the level of risk, unplanned failures and unnecessary inspection.

Greatest value is achieved by identifying risk during the design stage as this will have a direct effect on the maintenance cost during the whole life of the asset.

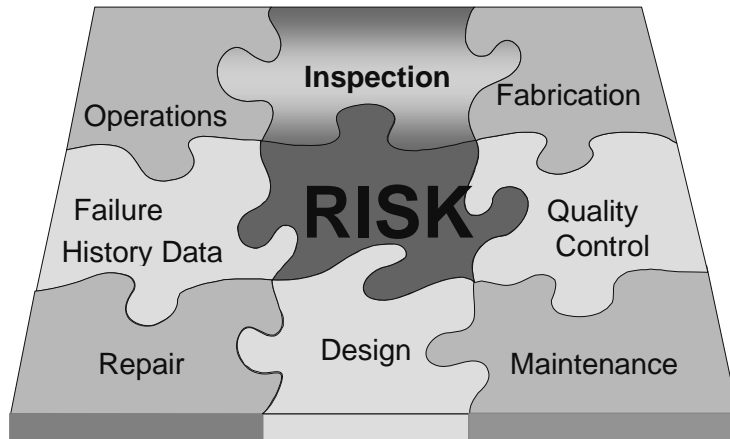


Fig. 1: Overview of Risk Based Asset Integrity Maintenance

As shown in Figure 1 above, 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.

The traditional approach to integrity management has been to carry out inspection, often on an annual basis, to check for deterioration and to confirm fitness for purpose. The requirement for survey was based on prescriptive legislation which resulted in many cases of collecting the same level of information on a regular basis, with little thought given to the increased confidence brought about by these surveys. No account was taken of the relative risks and consequences of failure of the individual components and the effect this may have on the total asset. Also the data collected may be in a different format each time making it very difficult to compare and analyse the results. Consequently, maintenance decisions have often been highly subjective without an overall strategy or a clear understanding of the long term cost implications.

Rigid inspection periods can be unnecessarily frequent and can lead to:

- excessive downtime of the plant which may have to be made safe to inspect it,
- lost production targets due directly to the above,
- unsafe plant due to human error which can occur during the plant shutdown,
- unnecessary costs of carrying out the prescribed inspection and maintenance activity,
- limited life of the asset by insisting on replacement at a set interval, or life reduction by excessive interruption.

The traditional approach has been effective in ensuring inspection and maintenance activities have been carried out, but the approach can be haphazard, it does not fully address the engineering needs and is generally not cost effective.

Integrity Management Drivers

There are many reasons for maintaining an asset including:

- Health and Safety - there is a moral, commercial and professional responsibility for ensuring the risk to life is as low as reasonably practicable. (This is the ALARP principle). For example, catastrophic failure of a dam or a bridge (by the post tensioned cables failing) will likely result in

high loss of life. Spalling of a concrete structure or the explosion of a plant may injure, maim or kill individuals working or walking close by.

- Environmental - loss of containment of a pipe, pressure vessel, nuclear reactor or earth embankment can result in significant damage to the local ecology and general environment. This is becoming an increasingly sensitive issue and it can have grave political consequences for the owners, operators, consultants and contractors involved in the project.
- Asset Assurance - the equipment or structure has been designed and built for a specific purpose. It has a job or function and an economic effect. Take, for example, an offshore oil and gas platform. If production has to be suspended due to uncertainty regarding the integrity of a critical system, operation of the installation is essentially uneconomic until the uncertainty has been satisfactorily resolved. Loss of part or all of the installation also has capital cost implications, as well as lost revenue consequences.
- Statutory Compliance - legislation plays an important part. Historically it has been prescriptive, particularly in the offshore oil and gas industry. This has now changed, certainly in the United Kingdom North Sea, as a result of the Piper Alpha platform failure (1988) which resulted in the tragic loss of 165 people and a cost of estimated US\$1200 million. The new UK offshore regulations (1992) require operators of offshore structures to have an effective safety management system which identifies, categorises and mitigates risks to a level which is on low as reasonably practicable. These are effectively goal-setting requirements to maintain the overall integrity of the asset.

The Risk Based Approach

The regulatory environment is now changing in Queensland to a Safety Management System one incorporating a Goal Setting environment. This requires asset owners to conduct a risk assessment for their own particular operating circumstances with the aim of setting an acceptable level of Risk or Likelihood of failure for a piece of equipment.

This regime brings in the introduction of the *ALARP* concept, where no specific level of risk is specified, only that the Risk must be “As Low As Reasonably Practicable”. No definition of “Reasonably Practicable” is normally offered - where such a regulation is in place, the onus falls on the Operator to demonstrate that the Risk has been reduced to such a level that the cost, effort or inconvenience required to further reduce the Risk is not justified.

Under ALARP, it is imperative to identify the safety critical items. However, the Operator or Owner is also concerned about economic consequences and about environment hazard as this can have a strong bearing on reputation and share price. The risk-based approach combines these factors by taking a 'holistic' view of system reliability. Some components may be largely redundant, others will have critical consequences should they fail.

What is Risk?

Risk is defined as the combination of the Likelihood of a failure occurring, or hazard arising, and the Consequence of failure were it to occur, as shown below in Figure 2.

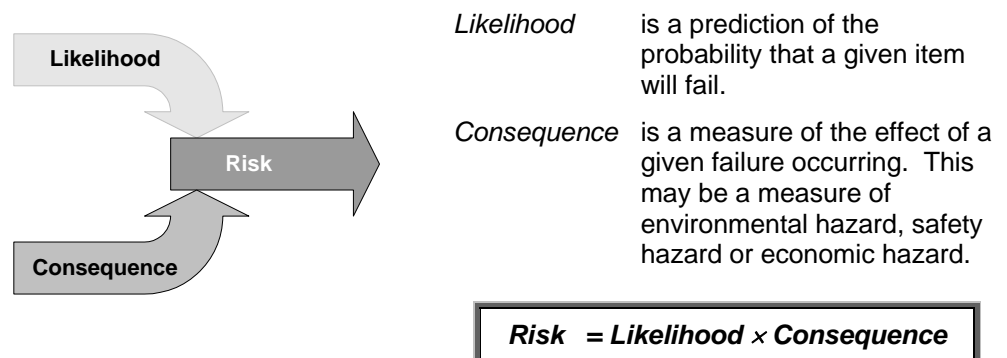


Fig. 2: Components of Risk

Where possible risk should be expressed in dollars. This may involve putting a value on human life as well as quantifying the environmental and economic hazard. However, defining risk in financial terms means that the added value of inspection and maintenance activity can be quantified by the reduction in risk value, thereby helping to determine the optimum asset integrity management strategy.

This can be expressed by the following formula:

$$AV = RR - CT$$

where the added value of inspection/maintenance (AV) equals the reduction in risk (RR) minus the cost of completing the task (CT).

What is Risk Based Integrity Management?

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 maximising 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.

RBIM Approaches

The different approaches to risk based integrity management are summarised in Fig. 3. The traditional, prescriptive approach is shown to indicate where it fits in the level of RBIM thinking.

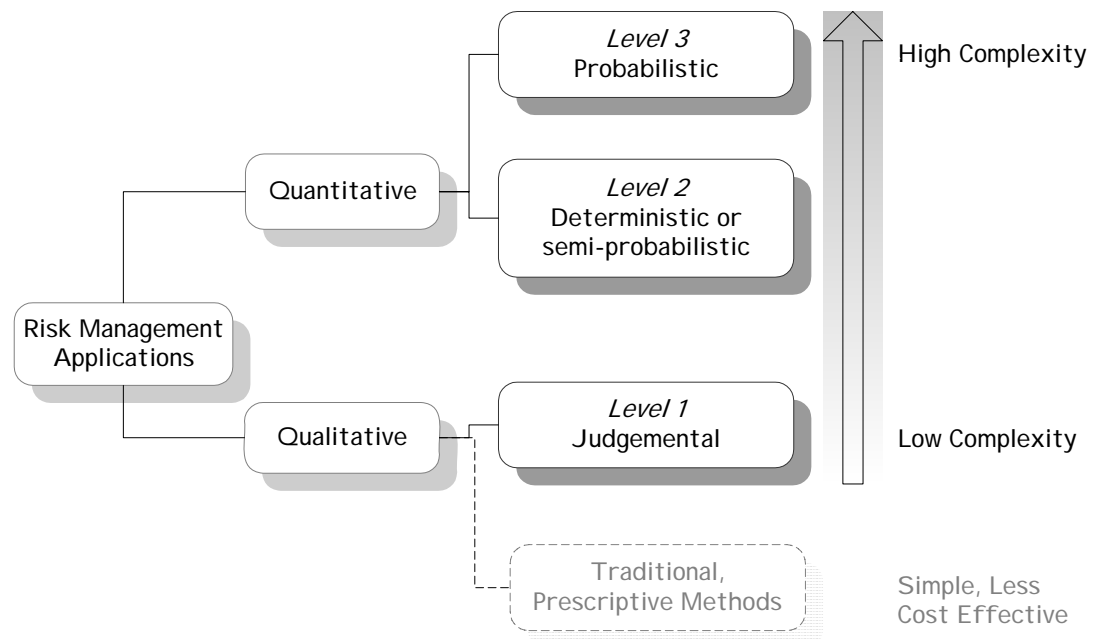


Fig. 3: Different Approaches to RBIM

Qualitative Approach

For the qualitative approach engineering judgement and experience are the main basis of this type of assessment. This means that to a greater degree, the results are dependent on the knowledge and experience of the engineers carrying out the analysis.

The process of qualitative risk assessment can be divided into six main stages:

1. System/component identification, description and history.
2. Identification of failure modes and mechanisms.
3. Identification of consequences.
4. Identification of likelihoods.
5. Estimation of risk levels.
6. Ranking of components for initial inspection and survey.

Likelihood of failure	High	Negligible Risk (1)	High Risk (4)	Very High Risk (5)
	Medium	Negligible Risk (1)	Moderate Risk (3)	High Risk (4)
	Low	Negligible Risk (1)	Negligible Risk (1)	Small Risk (2)
		Low	Medium	High

Severity of Consequences of failure

Fig. 4: Qualitative Risk Matrix

The results may be plotted on a risk matrix (Fig. 4) which in turn identifies the respective action, as described, by example, in Fig. 5.

Risk Level	Maximum Period Between Surveys
Very high (5)	1 year
High (4)	2 years
Moderate (3)	3-5 years
Small (2)	6-10 years
Negligible (1)	Inspection not necessary

Fig. 5: Inspection Frequency

Deterministic Approach

The next stage up from the qualitative assessment is to use deterministic or semi-probabilistic methods to plan inspection or maintenance. This increases the objectiveness and decreases the subjectiveness of the evaluation, making it less sensitive to the individual expertise and experience of the engineer applying the method.

The deterministic risk-based approach is a fully auditable, quantified approach, involving statistical data and computations to define the level of risk. On offshore structures, a semi-probabilistic ranking tree approach is used (Figure 6). This ranking tree approach equates the consequences of failure (e.g. production loss, personnel safety, environmental damage) against the likelihood of failure (e.g. vessel collision, dropped objects, in-service defects, corrosion). Note that some of the likelihoods are time dependent (in-service degradation, corrosion) whilst others are instantaneous (collision and dropped objects). All these risks are assessed but only the time dependent (progressive defects) may

be inspected or checked for. Other safeguards have to be put in place to prevent critical, instantaneous events from occurring; typical measures may include the training of personnel.

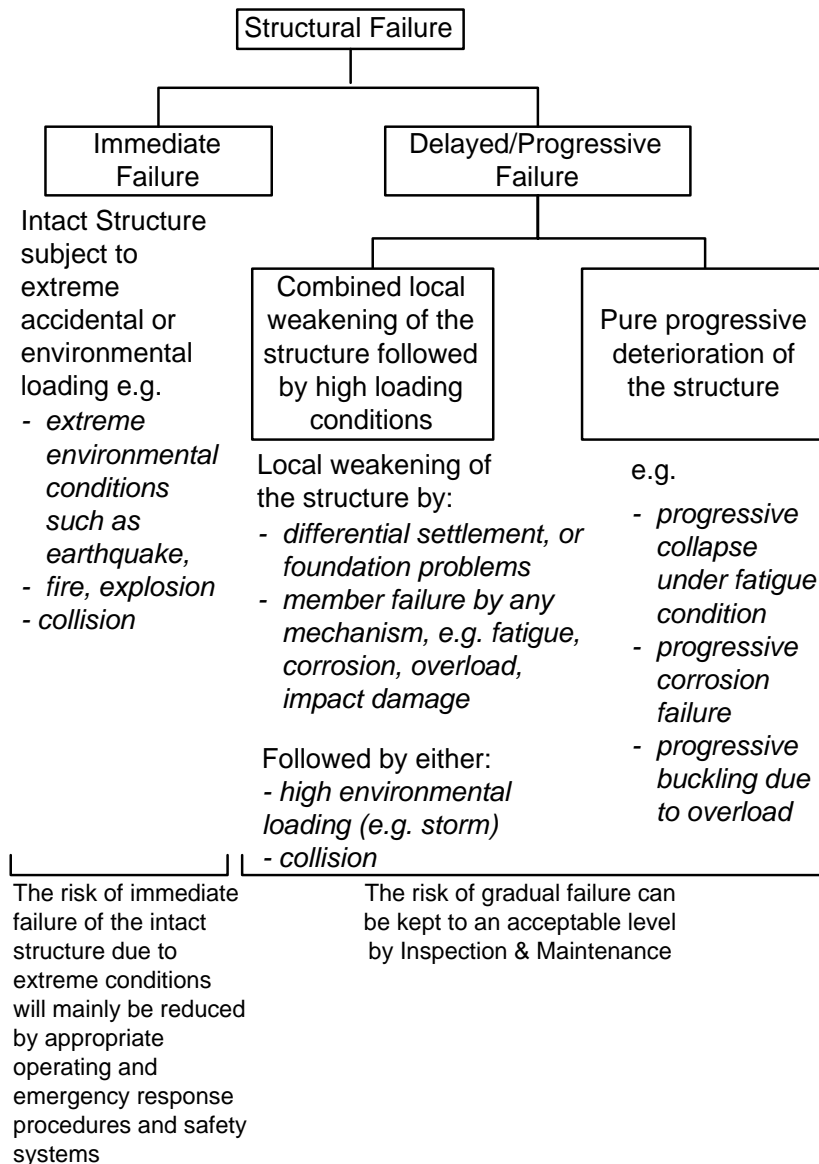


Fig. 6: Ranking Tree - Structural Failure

On mining equipment, system failure modelling using fault trees (see Fig. 7) or reliability block diagram methods can be used to assess the likelihood of failure allowing subsequent estimation of risk to safety and operations.

Fault Tree models show how individual events or equipment failures need to interact to cause functional failure of the assembly and hence disruption to the process. Effects of parallel (redundant) or standby equipment can be modelled providing an accurate representation of the real application.

Typical output from such models provides individual likelihood of failure for events and components as well as likelihood of subassembly and system failure. By use of mean time to failure or mean time to repair information, equipment and plant availabilities can also be calculated providing estimates of downtime for the respective models and sections. Ranked listings of critical items and the automated generation of 'cut sets' provide the user with groups of events or components that together will cause functional failure hence allowing the operator to optimise the maintenance and inspections strategy for the particular unit.

If carried out for a number of functional units across the operation, quantitative establishment of failure risk and ranking is possible, enabling the planning of optimum maintenance and operating strategies based on risk exposure and derived failure statistics with long-term gains in operations integrity and success.

Results from Fault Tree analysis can also be used in the creation of Event Trees. As the name suggests, Event Trees study mixed failure sequences and escalation of progressive failure of the component with time. The particular strength of Event Tree analysis is the quantification of risk by considering all credible outcomes and consequences thereby providing the most safety, cost and engineering critical component listing for inspection, maintenance and other intervention.

Probabilistic Approach

This is the most advanced and most complex of the three proposed methods for risk based integrity management. A probabilistic approach utilises similar data needed for a deterministic assessment but considers mainly the inherent variability of the inputs and its effect on system failure thereby providing the most realistic assessment.

Fault and Event Trees may be used to create a range of sensitivity scenarios but only the creation of Safety Margin Equations and the use of First Order Reliability Methods (FORM) and Monte Carlo simulation techniques are able to make best use from failure distributions.

This is a high level method not suited for the majority of engineering assets due to the lack of statistical information and reliability data. The method has been fully researched for offshore structures and reported elsewhere. ⁽¹⁾

Practical Examples

Offshore Structure, UK North Sea

Single 8-leg open space frame, steel jacket structure standing in 138m water depth in the North Sea. Weight 17,000 tonnes. Installed in 1978 and nearing the end of its operational life.

Historically, under a prescriptive regime, the underwater inspection comprised an annual general visual inspection by a Remote Operated Vehicle (ROV), with cameras and lights, plus a comprehensive diving programme every 5 years. The overall cost of the 5-year programme was around A\$3M.

Structural models existed and the plethora of inspection data proved invaluable. A rigorous level 1, 2 and 3 RBIM assessment was carried out and a new inspection plan developed which eliminated all manned intervention (use of divers) and limited the ROV inspection to every second year.

The resultant 5-year risk based programme cost A\$0.5M, freeing up A\$2.5M which could be diverted to other budgets or to increase profitability.

Similar results have been achieved in the Bass Strait, Australia ⁽²⁾.

Pipelines and Process Plant, NW Shelf, Australia

Ten separate facilities, two substantial gas processing plants and 450 km of pipelines.

Inspection strategy was prescriptive-based. An integrated RBIM system was subsequently developed. This comprised procedures and risk based inspection plans for the pressure vessels and protective devices and corrosion control for the pipelines. The pipelines were covered by both external and internal inspection and monitoring. This required corrosion risk assessment and inspection methods to conform to Australian practices but also enabled the development and implementation of probabilistic methods.

Particular to the development of management procedures was the need to integrate with the existing client organisation. Work was initiated in 1997 and is ongoing ^(3,4).

Hard Rock Mine, Scotland

Mining is undertaken by typical open cut methods, bench drilling, blasting, truck haulage followed by crushing, screening and either sale of the aggregate or manufacture of bitumen products.

No maintenance program other than breakdown and repair was in place prior to the study and any operations budgeting was entirely ad hoc thereby not exploiting the full capacity of the mine or any of its assets. Maintenance information was gathered, analysed and Fault Tree models were established which showed the link between equipment and plant failure and disruption to the mining operation. Results of these models were combined with consequence cost estimates for safety, environmental and operational losses thereby fully quantifying the range of failure risks to the operation.

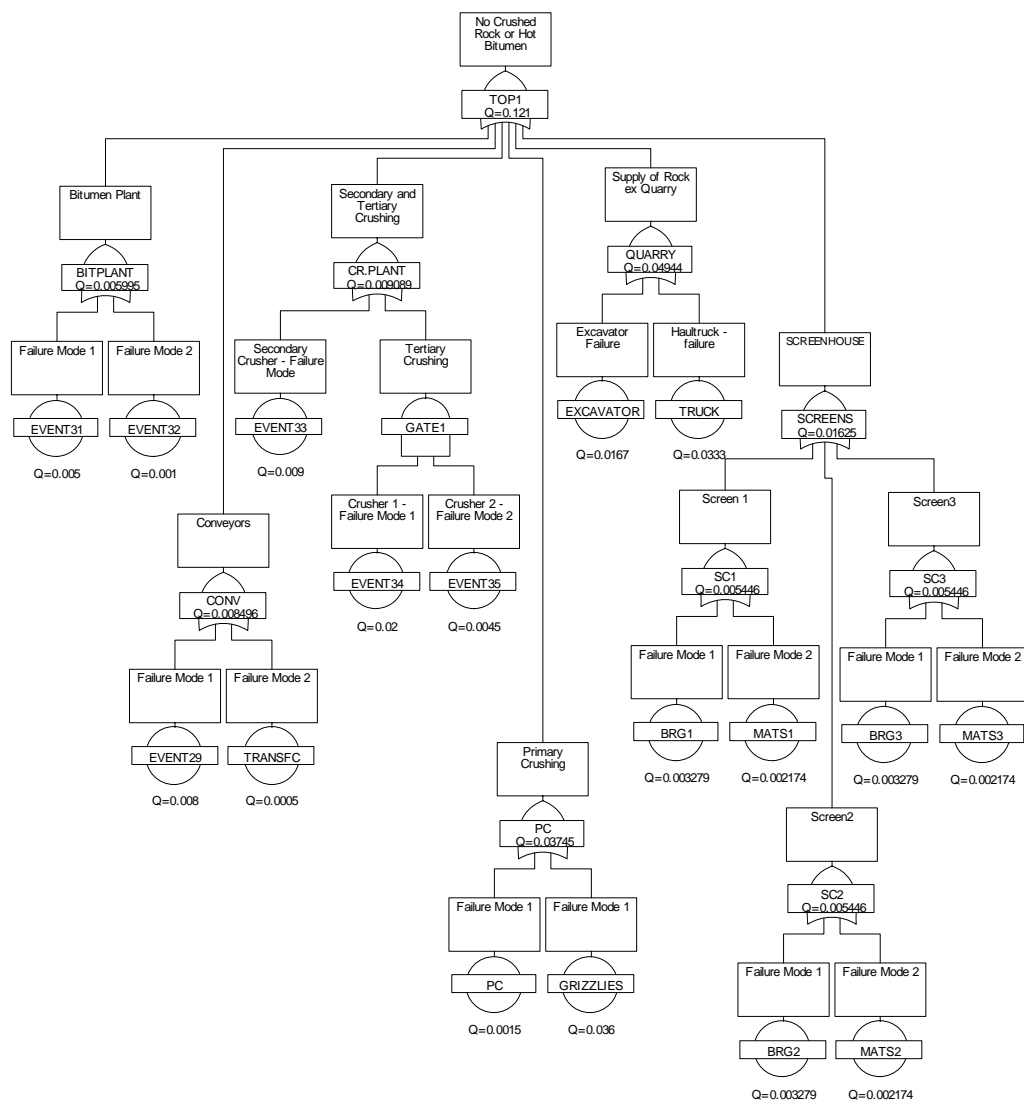


Fig. 7: – Simplified Fault Tree – Quarrying Operation

A maintenance strategy was then established for the mining and processing equipment carrying higher risk levels towards overall operations risk thereby enabling effective and more cost conscious planning and budgeting while also improving operator safety, environmental and bottom-line performance.

Evaluation of H+S Risk and Mitigation Strategies

The above RBIM methods can also be applied successfully in evaluating risk levels and the quality of mitigation strategies for projects concerned with the Health and Safety in a mining operation.

Most mining activities still retain elements of risk and often involve the use of sometimes large and hazardous equipment or processes. It is possible to create Fault Tree models of safety, protection or other equipment that has been designed to reduce these workplace hazards thereby quantifying actual likelihood of failure and adequateness of such safety systems. Together with 'softer' measures such as risk mitigation through procedures as well as contingency actions, a 'Hierarchy of Control' matrix can be mapped in its entirety considering equipment, procedures and competencies, as shown in Figure 8. A column for legislative requirements is included also as an indicator and check for compliance and minimum mitigation. Hazard reduction is achieved ideally through either elimination or substitution by choice of the correct and reliable equipment but is also achieved, less reliably, through administrative controls. Hazard mitigation that purely relies on contingency capability (e.g. fire fighting or PPE) should be avoided. This mapping process will highlight particular strengths of the mitigation strategy but will also show improvement opportunities for all elements.

As failure of some or all identified mitigation mechanisms is likely to result in an incident or accident, the non-performance of individual prevention mechanisms can be modelled using Fault Trees and at least a qualitative interpretation for the whole mitigation strategy can be carried out. It should be pointed out even a basic diagrammatic representation using Fault Tree diagrams aids in the identification of weaknesses of a mitigation strategy. Should actual numerical figures exist, a quantitative estimate can be obtained.

Figure 8 – Hierarchy of Control Matrix

	Elimination	Substitution	Eng. Controls	Admin. Controls - Maintenance	Admin. Controls - Operations	Contingency Capability	Legislative Requirement
Equipment	Preferred Mitigation						
Procedures							
Competency						Least preferred Mitigation	

Conclusions

Risk based integrity management is a technique to increase safety and reliability and minimise the losses and consequences of failure. It involves the identification, evaluation and control of risks.

RBIM should ideally be applied during the design stage for new facilities, but can be applied part way through asset life for existing facilities. Historically structures and plant were designed and built with little regard to whole life costs.

RBIM is now an important aspect of safety and engineering process. It requires a thorough understanding of the risk issues and substantial, sound, engineering experience. There are various approaches that increase in complexity but have the effect of reducing the cost of inspection and maintenance. The correct balance is achieved by converting the risk value to a financial number and comparing the added value of inspection with risk reduction.

A successful combination of RBIM 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 maximising plant output and life, minimising downtime and life of asset costs, whilst maximising safety, reliability and total life integrity.

The overall goal of a Risk Based Integrity Management system is to achieve a level of protection against failure that meets:

1. Statutory and legal obligations,
2. Corporate objectives, standards and self-regulation,
3. The expectations of the company's shareholders,

in the most efficient and cost effective manner possible. In order to achieve these objectives the frequency of maintenance interventions should be set to ensure that deterioration is detected sufficiently in advance of failure, such that corrective or remedial action may be taken prior to unsatisfactory performance or failure.

References

1. Descamps, B., Woolley, K., Baker, M.J.: "Targeted Subsea Inspection of Offshore Structures Based on Risk and Criticality". Proceedings of the Offshore Technology Conference, Houston (1996).
2. Barton, A.D. (Esso Australia), Descamps, B (QCLI): "Risk-Based Inspection Planning Applied to 14 Steel Jacket Structures in Bass Strait, Australia – Case Study." Proceedings of the International Offshore and Polar Engineering Conference, Seattle, (2000)
3. Nielsen, M. (QCLI), Bingham, S. (Apache Energy): "Increased Availability – The benefits of Introducing an Integrated Corrosion Management System. SPE Conference, Perth, W. Australia. (1998).
4. Nielsen, M.F. (QCLI), Beckford, P. (Apache Energy): "Successful Implementation of a Corrosion Management System. 39th Annual Conference of the Australasian Corrosion Association, Sydney. (1999).