The Case for Quantitative Risk Analysis in the Mining Industry

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Introduction

The mining industry commonly uses qualitative risk analysis methods to analyse hazards and business risks, including many classified as catastrophic risks.

Despite the widespread use, qualitative methods suffer from a number of limitations. For instance, the use of language to describe hazards and risks creates inherent subjectiveness. The resultant uncertainty combined with the natural or statistical variability within the often scarce information that is available further complicate scenario predictions and comparisons, particularly around catastrophic failure events that society so often associates with mining. Peoples' inexperience, perceptions and assumptions particularly in times of skill shortage and high staff turnover, are also part of the dilemma.

While other high risk industries have successfully established a range of databases and firmly incorporated quantitative risk assessments (QRA) into their risk management skills repertoire, the mining industry lacks behind in using those tools. Considering the similar or even larger range of hazards, the high risk/cost nature of the industry, adopting a more data focussed management approach would benefit many mine management functions.

Given the ongoing mining boom, lingering skill shortages, the growing number of new employees with little or no mining safety experience and knowledge, QRA will be shown to be a real alternative to qualitative assessments in making better and more objective safety and business decisions in areas such as health, safety and environment, asset and business risk management.

So what is QRA?

Qualitative risk analysis methods such as JSAs, WRAC, FMEA and HAZOP can be readily applied to a variety of risk analysis issues and have found widespread use across the industry. However, being qualitative and reliant on the use of words and language to formulate the issue, they rely heavily on the knowledge of the working team. Resultant human subjectiveness and implicit variability and uncertainty in assumptions mean these methods are often not sufficient to completely and accurately model the critical relationships, dependencies and complexities that bring about system hazards and possible

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catastrophic risks. Semi-quantitative methods allow some relative numerical risk comparisons, but are equally unable to provide complete and detailed assessment of safety or reliability aspects of a system. Also, qualitative and or semi-quantitative methods are not able to model and assess the effects of two or more failure modes at the same time, common cause failures i.e. failures that can affect several parts of the system, or the benefits that redundancy features can bring to a safety system. One of their key shortcomings however is their inability to be used effectively in the modelling and prediction of low-frequency but high-consequence events – i.e. catastrophic risks.

Examples of quantitative risk analysis methods include Fault / Logic Tree Analysis (FTA/LTA), Event Tree Analysis (ETA), Layers of Protection analysis (LOPA), First Order Reliability methods (FORM) and Monte Carlo Simulation (MC Simulation), plus other mathematical approaches. Quantitative assessments overcome many of the above shortfalls and are suited to situations where appropriate data is available and judgements need to be made on system safety and criticality, either during design, operation, maintenance or modification of a system or engineering asset.

Results can also be used in cost benefit studies and demonstrations that risks to employees, plant, society and the environment are 'as low as reasonably practicable' (ALARP), particularly when the assessment concerns catastrophic risks that can be supported defensively only by quantitative analysis.

The further advantage over qualitative methods is that quantitative approaches can be tailored to very specific applications and are able to reflect even fine nuances of the application thereby providing management with less biased decision-making parameters. The use of performance data helps to objectively model, assess and compare often complex technological systems, and test and evaluate its resilience changes in design, operational, maintenance and environment aspects. This approach is well suited to identify system vulnerabilities and mitigation strategies to reduce risk and business exposures. Modelled correctly and effectively, changes can be simulated before settling on a course of action.

Quantitative assessments have their origins in high-risk industries, such as the petrochemical, nuclear or aviation sector, and include many reliability based engineering methods. They are also used in many other methodologies, such as fire and explosion engineering, epidemiological health studies or other areas of science that use mathematical models to study hazards and resultant risk. While primarily aimed at the analysis of engineered systems, some sectors such as the nuclear and aviation sector have also refined the analysis of human reliability and, together with technical reliability and performance data, are able to model the resultant system safety performance of a human-machine system.

Truly probabilistic methods such as 'first order reliability methods' (FORM) are the most complex type for use in quantitative risk analysis. FORM's advantage over any other method is the ability to successfully cope with the statistical uncertainty in the data and use it to advantage. Results from a FORM evaluation provide further information on system vulnerability as a function of the variability of input variables. FORM has the added advantage in that it is able to synthesise failure data (which is usually scarce for catastrophic events) from basic engineering data through the adaptation of design calculations that can then be used to supplement other techniques such as FTA.

Analysis using Monte Carlo (MC) simulation techniques is more commonplace than FORM and because of its intuitive approach and has found broader acceptance in many professions such as engineering and finance. However, MC methods lack some of the direct leverage that FORM provides for engineering solutions

Databases for QRA Applications

While QRA may not provide absolute indicators of safety, the key advantage of quantitative analysis is the relative comparison of two or more risk models with each other. To do this, risk and safety engineers require a combination of event frequencies (or probability of failure, P_F), of say an engineering item, and corresponding consequence outcomes, as inputs into the (safety) system model. Typically two main types of input data are required.

- 'Event' frequencies, or an equivalent numerical descriptor such as mean time to failure (MTTF), probability of failure P_F or failure rate, and
- Consequence estimates that describe credible outcomes linked to the event, or failure of the item, or system.

Given the importance of human involvement in most systems, estimates of human error should also be available and used in the modelling process. Despite its size, the mining industry lacks such data, which in part has limited the application of QRA methods in the industry.

Event and Consequence Frequency Databases Taxonomy

Because even simple systems can comprise many thousands of items, all databases use a hierarchical system, usually referred to as taxonomy, to create order and reference logic amongst the listed items. Taxonomy is intended to facilitate data collection, analysis and subsequent storage of the data. It follows that the quality of data will determine the quality of the risk analysis study.

One of the key elements of the taxonomy is a clear boundary definition around the piece of equipment, or the system. This means all interfaces with its surroundings must be identified. If this is achieved, failures and consequences within the boundary can be accounted for. The intent here is one of resolution, ranging from a 'piece part' representing the most basic level of component, e.g. a spring, tyre or O-ring, to an entire system which is an engineered collection of many components arranged to fulfil a specified function, such as a ventilation system, vehicle breaking system, a dragline or fuel storage and pumping system.

It needs to be noted that the effort and ongoing cost required maintaining a detailed database can generate considerable demands and ongoing costs requiring careful decisions to maximise paybacks.

Database Challenges

Generic databases can provide a lot of information but they are less than ideal for applications outside their initial scope. Difficulties lie in the direct application of the data to 'foreign' scenarios (e.g. nuclear to mining) as failure data is likely to be conditional to environmental factors, duty conditions, basic engineering and functional characteristics, (preventative) maintenance and housekeeping regimes etc., which are rarely identified in the parent database. The latter are important, as they will have direct beneficial or detrimental effects on failure rates of the equipment. Considerable issues also lie in the uncertainties and variability associated with the available data. Unless all raw data suppliers apply the same strict taxonomy and same rigor, uncertainties will propagate into the resultant pooled database which will then adversely bias the safety or reliability study.

OREDA – a best practise database model for the Offshore industry

Reliability assessment and considerable work in the areas of QRA for the offshore sector often relies on the OREDA database (offshore reliability database) (Sintef, 1997). This is a large offshore equipment failure database populated with reliability data from offshore operations in the North and Adriatic Sea regions and widely accepted as the standard information source for quantitative risk analysis (Jensen, Stian, and Ostby 1993). Data from OREDA is used in many quantitative risk studies for safety case submission (Kroger and Fischer, 2000).

The particular success of this database is based on the long-term contribution of offshore failure data into a single database facilitated through an industry joint project by over 10 major oil and gas producing companies.

At a detail level, ORDEA provides the safety and risk engineer with a comprehensive catalogue of offshore equipment. It includes their failure modes and corresponding failure rates and repair information which form the key input into risk and reliability calculations of quantitative risk analysis tools, such as fault tree or event tree analysis.

Individual savings in the order of tens of millions of dollars have been attributed to the use of databases such as OREDA and QRA, and management and the regulatory bodies now accept the use of databases for safety and reliability studies in the oil and gas industry as industry practice

(Sandtorv and Hokstad, 1996). Databases containing human error data originated from studies carried out in the nuclear industry and are used, in conjunction with equipment failure models, to assess overall levels of safety to an operation.

Unlike the offshore and nuclear industry, the minerals industry generally does not have specific equipment failure databases or data sources that are readily available for use in quantitative risk analysis applications. Also personal observations suggested that, while a considerable amount of data is collected, availability, quality and accuracy of good useable data were seen as wanting

Creating a Mining Industry Safety and Reliability Database

Currently there is no publically available or industry owned event database that can be used for a mining QRA with any confidence. To carry out a quantitative risk assessment at a mine site, staff would typically use plant or OEM (original equipment manufacturer) data where available to establish a realistic model of plant reliability or safety (OECD, N.E.A, 1989).

This data may be stored in the maintenance management and equipment scheduling systems, but unless a strict taxonomy has been used the data is likely to require some processing before it can be analysed and used in a QRA application. For instance, ‘time to failure’ statistics are best analysed using Weibull statistics; the process is simple, efficient and provides the much needed ‘time to failure’ behaviour of engineering items, however the same process also lends itself to create better statistical measures across other metrics.

Other mine site data sources are the incident /accident reporting system, and where it exists the ‘Hazard Register’ implemented by many mines, and importantly the HR system that tracks work hours. In conjunction these might be able to provide some frequency information, but are probably best used to determine likely consequences of an event.

To create a reliable and encompassing system for carrying out QRA in the minerals industry a similar approach to that taken by the petrochemical industry is recommended. This database system should fulfil the following requirements:

- Be the first port of call for equipment reliability and human reliability information for the minerals industry
- Provide a reliable source of independently generated quantified equipment failure, incident and consequence data including data on safety (critical) systems for any mining applications.
- Be a repository of all incident and accident investigations, as a valuable source of data as well as providing models of incident and accidents causation as both an investigation and risk management education tool.

- Provide a library of benchmark applications and reliability models representing best practice
- Have a flexible data supply structure which utilises the built-in functionality of current safety information and maintenance scheduling systems
- Provide a medium of information exchange, technology development and research
- Be largely computerised or automated to generate little if any extra on-site work for mine employees.

The key to the data collection is a flexible taxonomy that can be implemented at any mine site irrespective of the local systems being used. A flowchart of the proposed system, its inputs, processes and deliverables is shown in Figure 1.

Design Templates

Well engineered systems, processes and equipment offer higher levels of safety and reliability than other systems.

The creation of a mining industry safety and reliability database also offers the opportunity to create a set of best practise design principle templates to facilitate a more rapid adoption of quantitative risk analysis and system design. These templates would also assist OEMs achieve more effective designs in a shorter period of time.

The consistent application of these templates utilising failure or performance data would provide the opportunity for transparent and explicit analysis and comparison of two or more designs.

Minerals Industry Human Error Databases

Quantitative risk analysis should also consider human error information at the machine equipment interface as another source of engineering design information to yield an optimal design solution. Because of the relatively large percentage of human error related mishaps, proper consideration of human acts and behaviours may yield the largest improvements in terms of safety and asset performance. Given its ability to model dependencies effectively (man-machine interface) this may be best achieved through QRA.

Education

The introduction of quantitative analysis, creation of databases, design templates etc. must also include the provision of suitable education and ongoing development to industry champions to participate and lead in this exciting new branch of risk analysis and operations management. Education must cover both the engineering and human error aspects, including some statistical training. Failure to support educational requirements will delay the introduction of QRA and lead at best to little or no performance, cost and environmental improvement. At worst, it will lead to unsafe designs that are potentially hazardous.

Conclusion and Opportunity for the Mining Industry

While considerable improvements have been made in terms of mine safety through risk based legislation and the proactive analysis of hazards and resultant risks, the mining industry has not truly engaged in quantitative risk analysis as is practised by other high risk industries. Using quantitative risk analysis these industries have successfully improved their safety performance through a better understanding of their engineering assets, and safety and reliability improvement of those assets.

Consistently applied quantitative analysis, compared to a qualitative approach, offers the unique advantage in that the system safety or operational performance of engineering systems can be objectively and explicitly evaluated.

The mining industry's reluctance to adopt quantitative analysis is surprising for two reasons.

Firstly, the mining industry, by its dynamic nature, has an equal or greater number of hazards and risks than comparable industries. A number of these are addressed in current legislation as 'principle hazards' and by their nature lend themselves to more rigorous hazard and risk analysis, and investigation of control effectiveness. Similar rigorous approaches could be applied to many other hazards.

Also, many manufacturers' recommendations on equipment usage and maintenance are based on generic user characteristics. Using actual site data as the basis for driving improvement in the performance of say high costs items would be highly beneficial. The opportunity is that a quantitative approach to risk analysis based around capture of data and analysis would provide the industry with better 'near real time' performance indicators and prediction tools than the qualitative means used now.

Secondly, the industry relies heavily on complex technologies throughout its production processes – large fixed plant installations and large mobile equipment fleets, and support services – often in remote locations and hostile environments. These offer a unique opportunity for the collection of maintenance data that, in turn, could be analysed and used to proactively improve the performance of the equipment being observed. The realisation is that appropriate data, collected in an appropriate way using a taxonomic approach, provides a direct image of the health and performance of an engineering asset. This knowledge can be used to the organisation's advantage.

It becomes obvious that the above insights can equally be applied across a much wider spectrum than safety. The mining industry operates a large number of highly complex electro-mechanical equipment which by their nature are prone to a spread of failure mechanisms which, after analysis would provide the right input data into quantitative risk analysis.

Capturing equipment performance and failure data and implementing quantitative risk analysis as a business resilience strategy and converting the data into hard management actions is an inspirational concept but one that would significantly improve safety, environmental and operational performance of the industry.

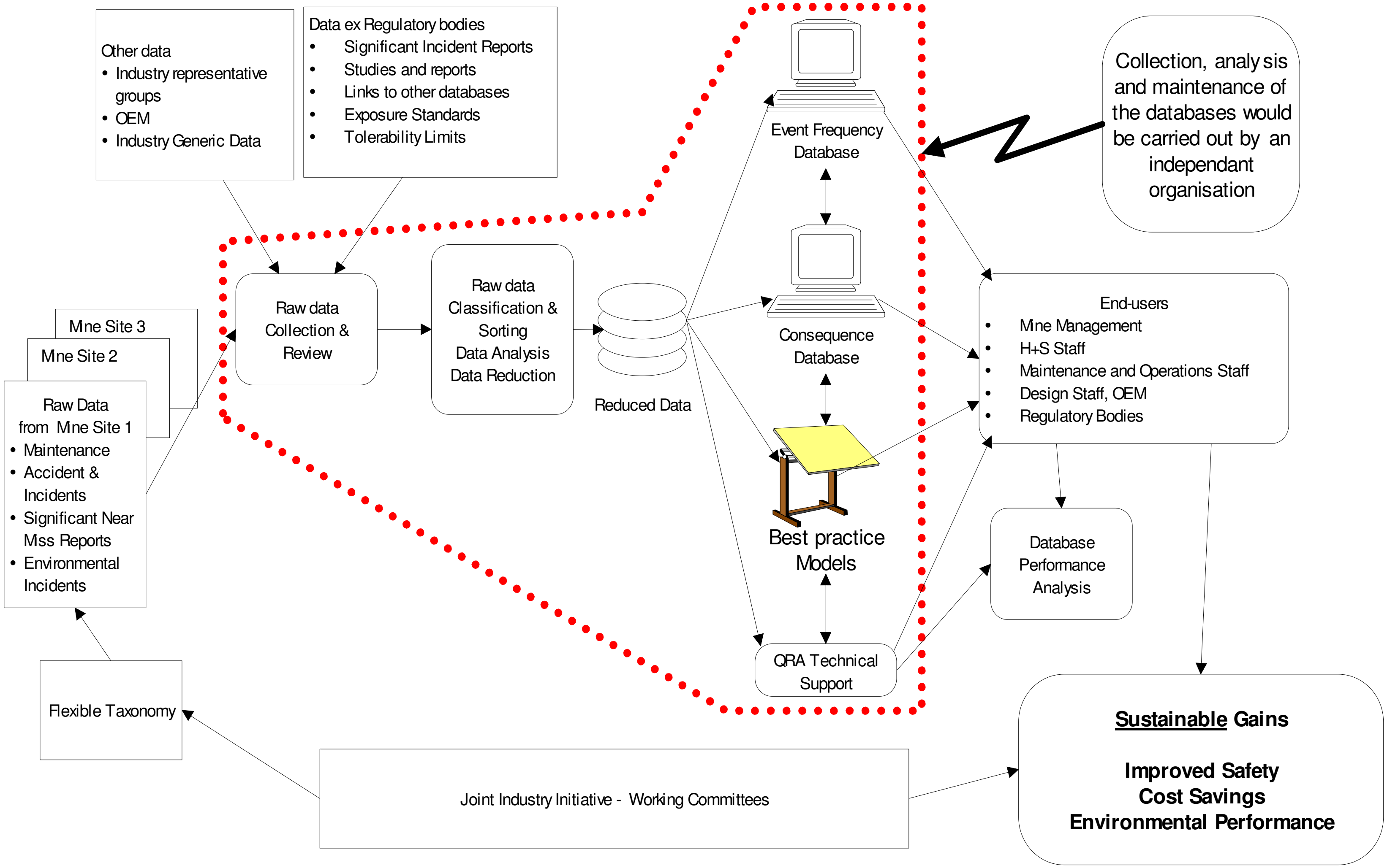

Figure 1 - Conceptual Image of a Mining Industry Engineering Asset and Equipment Safety and Failure Database

Bibliography

Jensen, S, Stian, R and Ostby, E. 1993. OREDA: A software tool and database for offshore systems reliability In *12th International Conference on Offshore Mechanics and Arctic Engineering*, (20-24 June,1993, Glasgow, UK).

Kroger, W and Fischer, P U, 2000. Balancing safety and economics, *Nuclear Engineering and Design,* 195(1): 101-108.

OECD, N. E. A., 1989. Probabilistic Safety Assessment in Nuclear Power Plant Management *: a report by a group of experts of the NEA Committee on the Safety of Nuclear Installations, June 1989,* 112, (OECD, Paris)

Sandtorv, H., Hokstad, P. and Thompson, D W, 1996. Practical Experiences with a data collection project: the OREDA project, *Reliability Engineering and System Safety,* 51: 159-167.

Sintef 1997.Oreda offshore reliability data handbook,3rd ed., 535, (Hovik, Norway).