Quantitative Risk Analysis (QRA)
Quantitative Risk Analysis

**Service Title:** Safety & Risk Management Services  
**Lead Practice:** GL Safety & Risk (UK)

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Service Description and Values Generated:

Quantitative Risk Assessment (QRA) is a formalised specialist method used by Germanischer Lloyd (GL) for calculating numerical individual, societal, (employee and public) risk level values for comparison with regulatory risk criteria.

Satisfactory demonstration of acceptable risk levels is often a requirement for approval of major hazard plant construction plans, including transmission pipelines, offshore platforms and LNG storage and import sites.

Each demonstration must be reviewed periodically to show that risks are controlled and reduced to an acceptable level according to applicable legislation and internal company governance requirements.

Risk evaluation can also help the decision-making process, in comparing the risks involved in alternative processes or layouts and can help optimise expenditure to improve safety.
a. Performance of Quantified Risk Assessment

An overview of the general approach taken in a risk assessment is shown in Figure 1. GL has developed a number of specific software packages to perform quantified risk assessments. This includes the FROST and ARAMAS packages for the evaluation of risks on gas or oil plant onshore or offshore respectively and the PIPESAFE package for the evaluation of risks from buried natural gas transmission mains. These packages have been used to assess installations worldwide.

The packages can be used to determine the consequences from, and the risks associated with, a range of hazards. Types of hazards that may be assessed include explosions, jet fires, smoke, pool fires and flash fires. The structure and the use of correlation/phenomenological models in the packages allow the effect of many parameter variations to be studied. The large data set obtained from these simulations provides a greater degree of confidence in the conclusions that can be drawn from studies.

In general, the models have been validated against experimental data obtained from large-scale experiments.

More detailed technical information can be provided, if required. However, it can be confirmed that, where relevant, the models take account of:

- Initial release conditions
- Mixture thermodynamics
- Transient release rates
- Heat transfer effects from the surrounding atmosphere
- Gas cloud density relative to air
- Ambient weather conditions (wind speed, air temperature, humidity, atmospheric stability)
- Emission rate from a liquid pool
- Effects of vapour cloud confinement and congestion (explosions)
- Radiant heat predictions
- Smoke modelling – combustion by products & dispersion

The basis of many of these models have been published in peer reviewed journals.

An overview of the methodology used for the assessment is shown in figure 1. Details of each of the steps involved are described in the following sections.

Figure 1: Overview of General Risk Management Methodology
b. Scenario Evaluation

Our approach to scenario analysis has been developed as a result of over 20 years experience in analysing major accident hazard scenarios related to onshore plants. This has included the development of event trees for commonly postulated major accident scenarios and the use of fault tree analysis to determine appropriate failure frequency information in situations in which there is insufficient historical data available. The experience gained in these studies has been encapsulated in the production of ‘knowledge bases’, describing how common scenarios are modelled and the linkage between the various stages in the evolution of each scenario. The consequence and risk models have been encoded within packages in a way that follows these knowledge bases, to ensure that any assessment is carried out in an auditable and repeatable way.

In carrying out the consequence calculations, a range of possible release positions and directions will be considered, as appropriate for each scenario. For pipeline ruptures this will take due account of the direction of the pipework and the predominant direction of the flow within the pipe. Typically, a range of directions is taken to ensure that any risk contours that are produced properly reflect the layout. Equally it is important that a range of wind speeds and direction are accounted for in the calculations.

It is also important to take into account the different delayed ignition times of drifting or accumulating clouds as the consequences of delayed ignition depend on the time at which ignition occurs. The effects of the flash fire depend on the location of the flammable cloud when ignition occurs. The effects on the running pool fire depend on its size and duration. Later ignition times lead to pool fires with a larger area and a shorter duration, with the former effect leading to more severe consequences and the latter effect leading to less severe consequences. These effects depend on the exact nature of the release, and the balance of the effects may be different for instantaneous releases compared to continuous releases. Therefore, a range of different ignition times are considered in the analysis.

The immediate and delayed ignition probabilities used in the analysis for the continuous releases are generally derived from correlations as a function of the initial release rate and duration. Optionally, the delayed ignition probabilities for the larger releases onshore (vessel failures and pipework ruptures) can be predefined or calculated from an assumed ignition source density over the site, such that the probability depends on the flammable cloud extent.

c. Frequency Assessment

The frequency assessment consists of the evaluation of the underlying failure rate for each scenario and also the evaluation of the frequency of the range of possible outcomes from the initial failure, e.g. immediate ignition following failure at a certain location in certain weather conditions.

Failure rate data is generally derived from generic sources, if insufficient case specific data is available. It is important for the estimation of the frequency of releases of various sizes (and the consequence assessment) to take account of the full range of pipework sizes and equipment that will be actually present. Component counts, based on the P&IDs supplied by the client, can be used for this purpose. Alternatively, we can propose to include an estimation of the amount and distribution of smaller diameter pipework based on previous experience if the project does not have such data available at this time (for example, at a concept stage).

Specific analysis may be carried out for important, high consequence items, such as transmission pipelines or storage vessels, depending on the details that are available.
d. Consequence Assessment

GL has a range of experimentally validated models that will be used in the assessment of the consequences of accidental releases. These models address different aspects of a release scenario, including:

- Outflow – transient release rate for each release size considered.
- Liquid spread
- Dispersion – both gas, dense gas and two phase jets
- Fires – pool and jet
- BLEVEs (Boiling Liquid Expanding Vapour Explosion)
- Explosions
- Toxic dispersion and smoke movement

The consequence modelling will take account of the potential harm to people using defined criteria. These criteria are used to determine vulnerability values for personnel at defined locations for each of the scenarios considered in the assessment.

The individual models have been incorporated within a risk assessment package in order to ensure that assessments are performed in a controlled manner.

The operation of ESD (Emergency Shut Down) and/or blowdown can be included within the analysis by assuming that the ESD is activated in a fixed percentage of cases. The subsequent transient nature of the flow is allowed for in the analysis.

One of the important factors affecting both the dispersion and the explosion analysis concerns the amount of obstruction on the plant or offshore module. GL can analyse site layout drawings and visualisations of the various units to derive representative parameters describing the degree of congestion in each unit. The offshore package ARAMAS has its own database descriptions for the obstructions on offshore modules. It may be possible to examine CAD system output or undertake a site visit, depending on the circumstances to help determine the required parameters.

The resulting values are used as input to our phenomenological jet dispersion, gas accumulation and explosion models. The dispersion behaviour and the explosion source overpressures will depend on the layout as well as the physical properties of the fuels and release conditions. The use of ‘lumped parameters’ for each region is in some ways analogous to the use of sub-grid modelling within computational fluid dynamic (CFD) models. However, it is important to bear in mind that, just as in CFD studies, use of such approximations introduces uncertainty into the analysis.

The explosion model for onshore plant has been configured so that the interactions between different congested regions are included in the analysis. The model takes account of the predicted decay of flame speed on leaving one congested region before entering another region. The output from the dispersion model will be used to predict the extent of the overlap of the flammable part of the gas cloud with the different congested regions.
e. Risk Assessment

The frequency and consequence information are combined to allow risks to personnel to be calculated. If relevant, this stage also considers the frequency with which explosions in the confined and congested regions on the facility occur.

The location specific risk (LSR) and individual risk (IR) values will be calculated using the vulnerability values obtained from the consequence calculations. The term location specific risk is used to refer to the risk to a person positioned at a specific location 100% of the time. The term ‘individual risk’ is used to refer to the risk to which an individual person is exposed as a result of their pattern of work or residency at various locations. For a worker on a site it is important to take account of the time spent in different locations on the facility.

The risk to individuals in different representative worker groups, taking account of their occupancy of different indoor and outdoor locations, is also evaluated. It is assumed that information concerning the typical location of the workers and the time they spent in each location is provided by the client.

If required, the societal risks can be developed by producing individual F-N curves for each scenario. These curves plot the occurrence of N or more casualties against their frequency F. These can be combined to produce an overall F-N curve for the facility. A number of different measures of societal risk can be inferred from the F-N curves. This includes the Potential Loss of Life (PLL), which provides the average number of fatalities resultant from the release scenarios considered and the risk integral as defined by the UK Health & Safety Executive. The latter is a measure that is weighted to reflect a greater aversion to incidents that cause many fatalities.

f. Comparison with Criteria

The results of the risk assessment can be compared with relevant risk criteria. Both individual and societal risks can be compared. In addition, GL has experience of comparing results of the assessment with criteria in use in a number of different companies and countries and with the UK requirements for land use planning associated with new and existing facilities.

g. Mitigation Plan

GL has produced software to estimate the financial impact of the major accident hazard scenarios, based on output of consequence calculations and input information on the value of various facility components. This can be used in performing cost benefit analysis to help to determine the requirements for risk reduction measures. Such calculations are often required as part of a demonstration that risks are ‘ALARP’ (as low as reasonably practicable). Allowance can be made in these calculations process for business interruption losses and other financial losses related to major incidents, such as loss of reputation.

Given that the evaluated risks may be within the ‘Cost Benefit Region’, a range of appropriate risk reduction measures can be suggested or discussed. Possible options can be identified based on the aspects of the facility that contribute the highest levels of risk and, after discussion with the client, a number of these measures will be evaluated as part of the ALARP demonstration.

For example, the reduction in risk due to changes in the emergency shutdown system shutdown time for loading operations can be evaluated.
CASE STUDIES

a. Steel Distribution Main QRA

Date: 2006
Customer: Middle East Company
Savings: Improved safety compared to building to standards

Issue:

A QRA was required at the FEED stage of a project to construct a steel distribution main in a built up area. The aim of the QRA was to inform pipeline design and routing decisions.

Methodology & Results:

The pipeline risk assessment package, PIPESAFE was used in order to quantify the risks from the pipeline. Initially, a design complying with the relevant pipeline design code was assessed and, following this, the effect of changing a number of design parameters was investigated, including variations in pipeline wall thickness, physical protection and proximity to buildings. Optimisation of the pipeline design using cost benefit analysis led to recommendations which, for the most highly populated areas, were more stringent than the design code and therefore produced higher standards of safety.

Savings:

By considering safety aspects at the FEED stage, a pipeline design that would comply with internal risk criteria and reduce risks to ALARP was produced.
b. Quantitative Risk Assessment of Two Potential LNG Plant Designs

Date: 2005/6
Customer: International Joint-Venture
Savings: Comparison with internal risk criteria and aid in decision-making

Issue:

To assess the risks associated with two competing LNG export terminal designs by performing separate quantitative risk assessments in isolation, providing an unbiased comparison of the two proposed layouts and processes.

Methodology & Results:

Two entirely separate quantitative risk assessments (QRAs) of competing LNG export terminal designs were carried out. The detailed process was able to take into account variations in the proposed layouts, processes and export strategies. This allowed the scenarios contributing high levels of risk to be identified and targeted for risk mitigation activities. The predicted individual and societal risks, and the risk of damage to the equipment, were compared with project-specific criteria. Additional studies were carried out to examine the effect of expansion of the terminal as well as growth in the nearby populated areas. A QRA of a series of pipelines associated with the site was also carried out.

Savings:

The results of the QRA were fed into the decision-making process that determined which plant design to take forward into the next design phase, and ultimately through to construction. Detailed technical reports were provided and the results presented to the committee responsible for making the decision, enabling an informed choice concerning a major investment to be made.
c. Risk Assessment of Proposed Pipeline Uprating

Date: 2003/2004
Customer: Major Oil & Gas Company
Savings: Improved safety

Issue:
A study was conducted for a major oil & gas company in which the requirements for pipeline uprating based on prescriptive codes were compared to the need for risk mitigation measures as determined by using a goal setting risk-based assessment process.

Methodology & Results:
This risk assessment process utilised GL's integrated risk assessment package FROST to determine the potential for loss of containment and the resulting risk. This assessment involved the full spectrum of events from the initial failure conditions through to the emergency response. The assessment allowed the effectiveness of practicable mitigation measures to be understood, and to identify the most cost-effective risk reduction options. The study considered pipelines of sizes up to 56" diameter carrying fluids comprising: sweet (or sales) gas, sour gas (up to 10% H2S), natural Gas Liquids (NGL), sweet (or stabilised) crude oil and sour crude oil (up to 0.77% H2S).

Savings:
The risks from the example pipelines that were examined were generally within the band between ‘intolerable’ and ‘acceptable’ and as such, risk reduction measures would be implemented if they were shown to be as low as reasonably practicable. Some pipelines represented a low risk to personnel, and in those cases, the compliance measures did not represent justifiable expenditure.
d. QRA for FEED Stage of LNG Port Expansion Project

Date: 2006/07
Customer: Major Oil & Gas Company
Savings: Support risk based decision making

Issue:
A port was to be developed further, with the provision of additional berth and jetty facilities for LNG, Liquid Product and Dry Cargo export. One part of the requirements for this FEED was to conduct a detailed Quantitative Risk Assessment (QRA) of the additional developments in order to support risk based decision making within the development process.

Methodology & Results:
The QRA assessed the additional risk of the proposed port expansion on personnel, marine operations and adjacent facilities. Risk to personnel was assessed with respect to Individual Risk and Potential Loss of Life, while risk to assets and operations was assessed with respect to Potential Loss of Asset and Potential Loss of Revenue. The risk was estimated for all major construction activities planned while normal operations were carried out at the port, which were combined with existing values to generate absolute risk for each phase of development. The risk values were derived logically in a ‘step-wise’ fashion, taking into account construction activities planned at each stage of development from year 1, to year 8. The absolute risk was compared with Risk Acceptance Criteria in order that an ‘informed decision’ could be made for each stage of development and following completion of all development.

Savings:
The results of the QRA provided a basis for decisions related to the development of the port. By conducting the study at FEED stage it was possible to identify issues at a time when design could still be changed without significant cost or timescale implications.