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A "Triple Bottom Line" approach to QRA

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Generally speaking, good safety means good business, but demonstrating this to senior management is not always straight forward. By combining traditional QRA techniques with 3BL concepts, where the drivers are environmental and economic performance as well as social, QRA can be applied to more than the management of safety. The "Q" of QRA need not be fatalities, but could equally be effects on the environment, down-time or financial loss. By quantifying impacts on people, assets and the environment in financial terms, analysts are better able to estimate the impact of incidents on the business as a whole.
Accidents like Buncefield have put the risk from hazardous installations high on the agenda of regulators, operators and the public at large. Regulatory regimes for ensuring the safety of those in and around major accident hazard sites are becoming more demanding. The need for accuracy and transparency has increased and stakeholders are interested in more than compliance – they want to ensure best possible performance in terms of minimising societal, environmental and economic risk. The so-called triple bottom line captures an expanded spectrum of values and criteria for measuring organisational success in economic, environmental and social terms. A commitment to corporate social responsibility implies a commitment to some form of 3BL reporting. So why not extend this to risk reporting?
This paper describes use of the Phast Risk QRA tool (Cavanagh et al, 2009; Cavanagh, 2010) to assess the financial risks associated with hazardous installations. The software model allows a library of asset types to be created from which individual assets, such as buildings or process equipment, can be placed on your GIS map. Each asset has a set of associated vulnerability parameters, from which the financial impact of damage through exposure to hazardous outcomes (e.g. radiation or explosion overpressure) can be assessed. Typical outputs from the model include F-Cost curves, analogous with F-N curves used in assessment of societal risk, but where N is financial loss rather number of fatalities. A case study is used to illustrate the concepts and describe how they can add value to the broader business risk assessment activities.

1. Introduction

Over the last 30 years, the management of risks from the operation of major accident hazard facilities has come into increasing focus. This has been driven by a number of major accidents including Flixborough (1974), Bhopal (1984), Piper-Alpha (1988) and, more recently, Toulouse (2001), Fluxys (2004), Texas City (2005) and Deepwater Horizon, Macondo (2010). All these, and more, have resulted in significant fatalities and injuries; this has influenced legislation such as Seveso, which has focused on reducing the risk of fatalities and injuries, and rightly so.
In this same period there have been many high profile accidents which have resulted in few, or even zero, fatalities and injuries, but enormous cost to business. Significant financial losses have been incurred from single incidents involving relatively small direct asset loss and sometimes no fatalities.

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An example is “Seveso” itself, where a dioxin release, although causing no fatalities, required the evacuation and decontamination of a wide area north of Milan. There are many further such incidents in the literature from the Exxon Valdez oil spill on 24th March 1989, up to Buncefield in 2005, many of which resulted in significant financial losses. For this reason companies are now looking beyond safety and are more active in exploring improvements which can be shown to deliver benefits directly to their bottom line. In today’s competitive business environment key drivers are improved financial performance, maximised up-time, reduced insurance costs or reduced risk of interruption to business resulting from an accident.
Recent advances to the “vulnerability” modelling capabilities of Phast Risk enable individual definition of asset types and associated levels of vulnerability. In traditional QRA, vulnerability is considered to be the relationship between effect level (e.g. radiation intensity or explosion overpressure) and probability of death. So, different asset types will have different vulnerability characteristics associated with them, for different types of harmful effect. But these asset type/vulnerability relationships need not be related to fatality. They may just as easily relate to level of environmental or financial losses. In addition, GIS facilities allowing analysts to locate assets in various locations help ensure overall risks can be minimised, or location specific risks for particular buildings can be assessed.

2. Methodology

When performing a “traditional” fatality QRA, there are three distinct steps to the analysis:
Step 1 - Predict the behaviour of a release of flammable or toxic material. This requires assessment of the phases of any releases, model the behaviour of those phases (e.g. does the release contain liquid, does that liquid form a pool, if so how does that pool interact with the dispersing vapour cloud), then, based on the initial vapour cloud released and pool characteristics, predict the behaviour of the vapour cloud in terms of its extent, concentration and variation with time.
Step 2 - Predict the possible consequences of that release. For example, considering flammable releases

- What are the overpressures generated if the cloud is ignited whilst moving through a congested or confined region?
- If there is a flammable outcome such as jet-fire, what levels of radiation intensity will result and how far will they extend

Step 3 - Predict the effects of the overpressure, impulse or radiation on people and/or assets in the vicinity of the explosion or fire.
Steps 1 and 2 have been well documented elsewhere – see for example (Cavanagh, 2001; Worthington and Witlox, 2002). This paper focuses on Step 3, with particular focus on the “Q” of QRA when it is not number of fatalities, but some other generic measure of risk.
Vulnerability is a measure of the relationship between an effect level (e.g. radiation intensity or explosion overpressure) and probability of “loss”. The loss probability is generically referred to as the vulnerability of the asset. This concept for fatality risk is described in more detail in the literature (Cavanagh 2011), but is less well documented for other types of risk e.g. financial, environmental, etc. But in principle there is no reason why the quantification in QRA should be associated with fatality; it could equally be associated with financial loss. By defining different vulnerability relationships for social, environmental and business losses, risk metrics can be quantified for each of these aspects of an operation.
In this paper we extend the vulnerability concept to explore the risk associated with social, environmental and business aspects of a facility – a so-called “3BL” or “Triple-Bottom-Line” approach to QRA.

3. Damage Level and Vulnerability Factor Concept

In Phast Risk, there are a number of methods for defining the vulnerability of an asset to an effect level (Cavanagh, 2011). One of the simplest methods for assessing the impact of each consequence on a receptor is to define a threshold value for each above which the receptor suffers 100 % damage and below which it suffers no damage. This method is used in Phast Risk when selecting the discrete method for overpressure vulnerability, or the intensity method for radiation vulnerability so this will be familiar to Phast Risk users. Historically 2 threshold values have been used for each outcome type, although multiple levels and discrete or continuous relationships between effect and damage level can be used if desired.

Using 2 threshold values, and considering flammable effects, upper and lower damage levels could be defined, with a vulnerability factor between zero and 1 associated with each level. For flash fires, a fraction of LFL could be defined below which no damage occurs and above which maximum damage occurs, on the basis the asset is either inside or outside the flame envelope.

A similar approach is taken for the effects on population and this is already well documented (Worthington and Witlox, 2002). From the effect zone size and location determined using the consequence models available in Phast, the damage levels described above, the associated vulnerability factor and the overlap between assets and effect zones, the level of damage can be calculated, and converted to a total risk or cost for each risk category. For the purposes of the the example below, in order to aggregate risks across the three categories (social, environmental, business) it is assumed that a loss of one asset unit represents a loss of $1M. This requires that a notional value must be placed on a life when looking at Social risks in order to compare these with the Environmental and Business risks that form the other components of the 3BL. This is a highly sensitive topic since the statistical value of a life is considered differently in different parts of the world. However, this concept has already been widely applied when calculating levels of insurance premium and deductions (Bardy et al, 2008).

In Figure 1, the bold inner and outer footprints represent typical upper and lower threshold damage levels respectively for a single release scenario and weather state. Also shown are typical point and area “assets”. Any asset outside the lower threshold value indicated by the bold outer line will be undamaged. Any asset between the inner and outer threshold boundaries will be damaged to the degree indicated by the appropriate vulnerability factor for the lower threshold. Any asset within the inner threshold boundary will be damaged to the degree indicated by the appropriate vulnerability factor shown for the upper threshold.

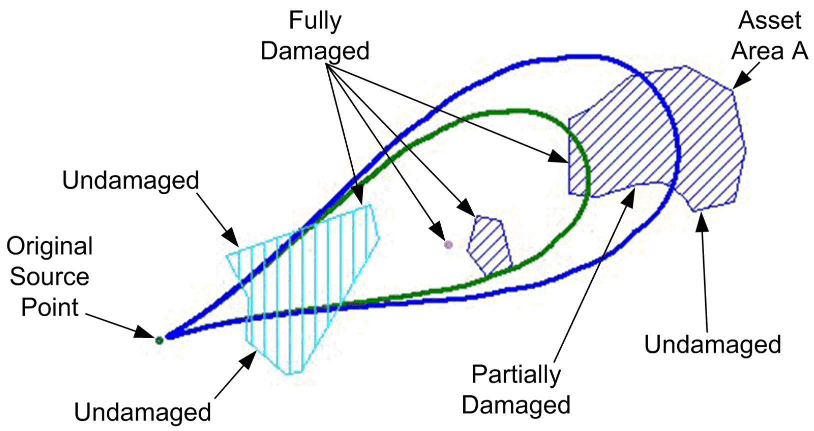
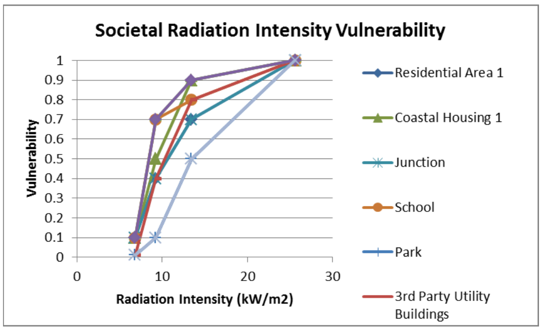


Figure 1: Definition sketch for asset damage when upper and lower damage levels are reached or exceeded

4. Vulnerability Modelling

As mentioned above, vulnerability modelling is used to assess the relationship between effect level and probability of “loss” and there are a number of published vulnerability models for converting toxic, flammable and explosion effects into probability of death (Bevi Reference Manual, 2009; Cavanagh et al., 2009). Also, sources of literature describing other types of vulnerability are becoming increasingly

available. Typical data sources used when creating the vulnerability curves illustrated below include the International Association of Oil and Gas Producers data Directory (OGP, 2010) and the Health & Safety Authority of Ireland Risk-based Land-use Planning Guidelines (HSA, 2010).
In practice the vulnerability of an asset type to an undesirable effect is a function of the asset properties and the type of effect. So, for example, the vulnerability of a person in a strengthened control room is likely to be lower than the vulnerability of the same person in an office building. When considering other assets like equipment, historically important buildings or environmentally sensitive sites (woodland which is the habitat of endangered species for example), appropriate vulnerability models must be used. Further, in order to be able to compare and aggregate the three risk categories (social, environmental and business) the units of measure used when locating these assets within the model must be consistent. Since number of people, area of land or items of equipment can all be represented by their financial value, then the spatial model created is based on "asset" value, unlike more traditional QRA where the spatial unit is typically number of people. Where the statistical value of a life used is $1 M it is relatively straightforward to convert a more traditional F/N representation of Societal risk to an equivalent F/Cost representation.
So what does this mean in terms of the vulnerability to societal, business or environmental assets (i.e. people, property and the environment)? By creating a library of asset types with appropriate vulnerability data, you can build a risk model that provides risk metrics appropriate to specific requirements. In this case study we are interested in social, environmental and business risk metrics, so we have created a library of asset types in each of these categories. Based on the references above, some typical vulnerability curves have been developed and built into the Phast Risk model used in the case study. Figure 2 illustrates typical societal vulnerability for radiation and explosion effects for a range of land use and building type categories. A similar approach is applied in the case study below for social and environmental assets.



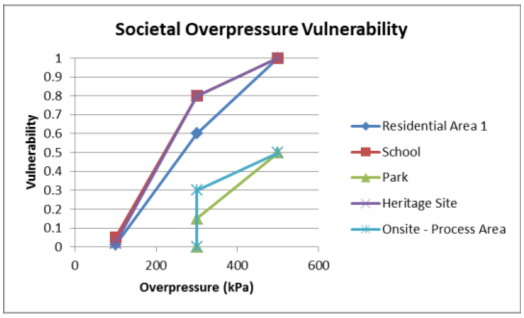


Figure 2: Radiation and Explosion overpressure vulnerability curves for societal risk

5. Case Study

In this case study we shall identify the risk exposure to societal, business and environmental items on a financial basis. The example consists of a single pressurised propane vessel from which we can postulate a range of losses of containment. Assuming a flammable material allows us to see the societal, business and environmental risk exposure to flammable effects, though additionally, the study could easily be extended to take account of toxic and polluting effects. Representative vulnerability values to various effect levels have been entered in a generic manner as described above.

5.1 Societal, Business and Environmental Assets

Population information has been modelled as illustrated in Figure 3, using $1 M as the statistical cost of a single fatality. For simplicity in this example no account has been taken of indoor/outdoor presence of population and the corresponding vulnerability difference. A similar approach is used for the inclusion of environmental (Figure 4) and business assets. Values can be determined for various asset types. For example, business assets may have inventory value, business interruption value and more.

Environmental costs may include but are not limited to clean-up costs, fines and brand damage (brand damage could alternatively be classed as a business cost).

Figure 3: Societal Asset Areas

Figure 4: Environmental Asset Areas

5.2 Financial Risk

The range of postulated Propane vessel releases produce effect zones of various overpressure and radiation effect levels. These effect zones impact the societal, business and environmental assets at intensities which are assessed against the assets' specific vulnerabilities. Taking the traditional FN curve approach, but replacing N with financial loss, it is possible to view an F-Cost for impact on each asset type (Fogire 5).

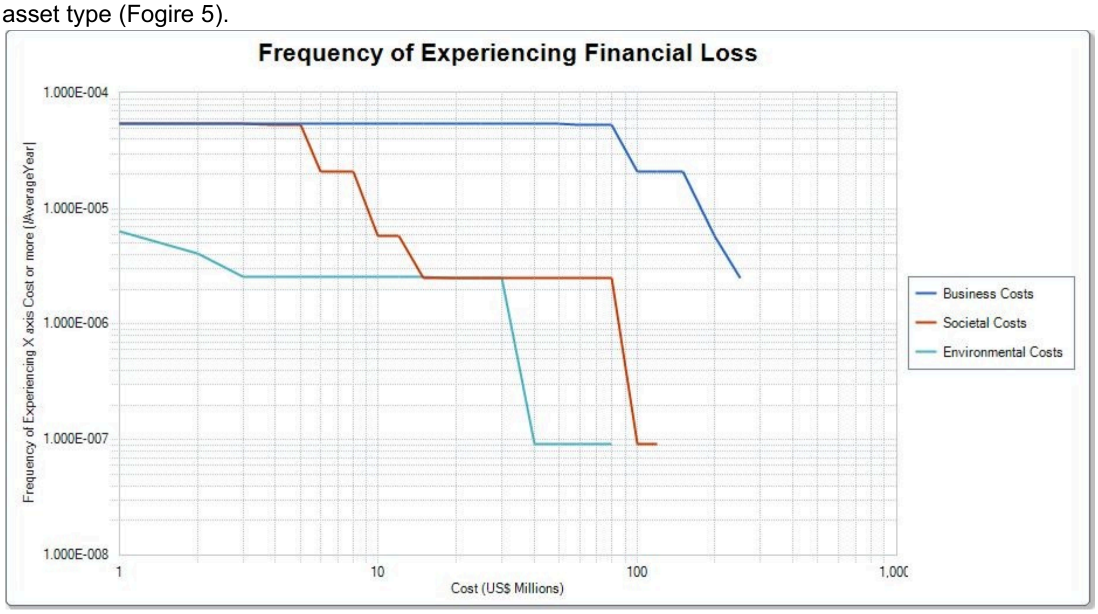


Figure 5: "Frequency-Cost" curve analogous to traditional FN curve

The F-Cost curve shows us that business risk costs have the greatest Risk Integral (the area under the F-Cost curve). The business cost curve has the highest frequencies and highest possible costs. We can interpret from this that near-field effects are of higher intensity (higher radiation levels and higher overpressures) and are contributing most to the risk.

Societal costs also present significant risk exposure. In this basic case study it can be seen that < $ 10 M costs occur with relatively high frequency. This is important information with regard to risk management. This type of analysis offers critical information for decision support, for example, investment in risk reduction can be quantified in units of financial loss, providing instant feedback for Cost Benefit Analysis. The integral of the sum of F-Cost pairs can be calculated in the traditional PLL (Potential Loss of Life) approach, giving us a Potential Loss of Money

Table 4: Risk Integral, or 'Potential Loss of Money' values

Asset Type	PLM [US$/Average Year]
Business Costs	7058.23
Societal Costs	543.95
Environmental Costs	109.52

6. Conclusions

By using the well-established methods developed for QRA over the past 40 years, we can extend the methodology to perform risk analysis for business, societal and environmental impact. Knowledge of the vulnerability of assets allows us to construct a study whereby impact from hazardous scenarios can be assessed. The results from such an investigation can be used to determine the triple bottom line risk exposure from process operations. Such information can be used for decision support when dealing with design, operation, change management, financial planning, insurance, corporate social responsibility and other requirements of today's demanding business environment.

Phast Risk QRA software supports this type of study in a manner recognisable to the large community of users globally, and follows standard QRA workflow meaning this kind of broad spectrum 3BL risk analysis is accessible to all safety professionals.

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