

MANAGING BUSINESS RISKS FROM MAJOR CHEMICAL PROCESS ACCIDENTS

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Traditional risk management has focused on effects on people, particularly when using Quantitative Risk Assessment (QRA). Nowadays a much broader approach is being adopted as companies begin to consider potential accidental losses in their decision making process. This paper describes a study where business risks from major accident hazards were assessed for a large chemical process company.

Results are presented in the form of F-Cost curves, similar to traditional F-N curves, representing cumulative frequencies of events versus their cost. These are evaluated for various types of loss including property damage, business interruption, inventory loss, environmental loss, clean-up costs, legal costs, fatality and injury costs, amongst others. Adjusting insurance values according to risk is one of the benefits of such an analysis. Evaluating these risk criteria helps organisations to negotiate with their insurers to agree maximum insured loss values that will fit their strategy and satisfy their risk acceptance criteria. Also, values for civil liability insurance can be reviewed, based on the hazards that can result in fatalities and injuries, as well as property losses, for third parties.

This paper presents the results of this study which involved the evaluation of the company's maximum insured losses. The key driver was a board level initiative to implement a more objective approach to quantifying this metric which serves as the main basis for setting the level of insurance premiums. The results of the analysis are presented as F-Cost curves and we describe the risk-based decision making process and criteria adopted by the company to set the maximum loss value to be insured for their plant.

In conclusion, this paper presents results from a real life example of the application of the quantitative evaluation of business risks, illustrating that a financial or business risk approach can help management in day-to-day decisions when considering possible effects of major chemical process accidents.

INTRODUCTION AND BACKGROUND

Over the last 30 years, the management of risks associated with the operation of major accident hazard facilities has been high on the corporate agenda. This has been driven by a number of major accidents including Flixborough (1974), Bhopal (1984), Piper-Alpha (1988) and, more recently, Enschede (2000), Toulouse (2001), Fluxys (2004) and Texas City (2005). All these, and many more, have resulted in significant fatalities and injuries. The most recent three examples have resulted in a total of more than 60 fatalities and 3000 injuries. This has further driven legislation such as the Seveso directives in Europe and the

EPA Risk Management Plan regulations in the US (Fewtrell and Hirst, 1998). Legislation has generally been focused on reducing the risk of fatalities and injuries, and rightly so.

However, 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, both of the operator and more broadly in the vicinity of the plant concerned. Companies have suffered significant financial losses and entire countries have seen major disruption from single incidents involving relatively small direct asset loss and sometimes no fatalities.

The release of dioxin at Seveso, Italy, on 9th July 1976 resulted in no direct fatalities. However, this incident required the evacuation and decontamination of a wide area north of Milan. Although no immediate fatalities were reported, kilogram quantities of the substance, which can be lethal even in microgram doses, were widely dispersed. This resulted in an immediate contamination of some ten square miles of land and vegetation. More than 600 people had to be evacuated from their homes and as many as 2000 were treated for dioxin poisoning. This was a key driver in changing the regulation of major hazard facilities across Europe through the so-called Seveso directives, subsequently brought to the statute books in all member states of the European Community. From 3rd February 1999, the obligations under the Seveso II Directive have been mandatory for industry as well as the public authorities of the Member States responsible for the implementation and enforcement of the Directive. So, although causing no immediate fatalities, the Seveso incident had an enormous cost both to the operator and the environment as a whole.

In 1998 at Esso's Longford liquified petroleum gas processing plant in Australia there was a massive explosion, killing two workers and injuring eight. Although in comparison with some of the events described above, the number of fatalities and injuries were relatively small, gas supplies to the state of Victoria were severely affected for several months after the incident. Most of the state's gas supply was cut for almost two weeks with severe disruption for a further 2 months and a total estimated cost to industry of $1.3 billion.

The Exxon Valdez oil spill on 24th March 1989 resulted in no fatalities but in addition to the direct costs to Exxon, fines of around $150 million dollars were imposed along with a $900 million civil settlement. The lingering oil spill also had affects on the environment which are difficult to put a value on even now.

In recent years focus has moved from improved safety and compliance with legislation to a regime where companies need to look at improvements which can be shown to deliver benefits directly to their bottom line. In general, good safety means good business, as exemplified above, and the business risk concept is a way of demonstrating this to senior management. The techniques for QRA and Consequence analysis can be extended to assess the financial consequences of accidents and associated financial risk exposure. 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.

The typical questions to be answered are:

- If I have an incident, what will it cost?
- What is the maximum loss I can incur as the result of an accident?

- How can I minimise the likelihood of an incident resulting in loss of production?
- What risks am I exposed to from a financial standpoint?
- How can I perform Cost Benefit Analysis on my operational business risks?

With greater global competition and much more challenging margins, there is now less cash available for activities that do not contribute directly to the bottom line, or are perceived as such. The "Q" of QRA need not only be fatalities, but effects on the environment, downtime or dollars. By quantifying impacts on people, operations or assets, analysts are better able to estimate the likely costs of an incident or incidents in terms of down-time, asset damage, personal injury and loss of life, brand damage, environmental clean-up, litigation and compensation, and so on.

Building on the methodologies and models used over many years for QRA and Hazard Analysis and built into many standard software tools (Worthington and Witlox, 2002 and Cavanagh, 2001), we have extended the classical QRA methodology to calculate financial risks and consequences in addition to the more traditional fatality risks and effects on life. This paper goes on to describe the methodology we have used in extending the classical QRA methodology to take account of other risk measures such as business interruption, environmental impact, loss of production and so on.

THE FINANCIAL RISK CONCEPT

QRA techniques have been used over many years to assist in the management of the safe operation of process plants. The focus has usually been on compliance with safety legislation and the approach taken dependant on whether a quantitative risk based approach is legislated (such as the Purple Book in the Netherlands) or a consequence based approach is used (such as RMP in the USA). Either way, both can be extended to assess the financial risks associated with a plant or the cost of a single event occurring (financial consequence).

The classical QRA methodology provides a technique for quantifying the risks associated with the activities involved in the production and processing of chemicals and petrochemicals. In order to quantify risks it is necessary to first identify all possible risk situations, quantify them in terms of event consequence and likelihood and compare them with acceptance criteria. The main questions to be answered by a QRA are what can go wrong, what are the potential effects if it does go wrong, how often is it likely to go wrong and is it important if it does.

Typical outputs of a QRA study are location specific risk contours, estimates of individual risk and the F-N curve for representation of societal risk. Individual risk can be defined as "the frequency at which an individual may be expected to sustain a level of harm from the realisation of specified hazards" and is usually taken to be the risk of death expressed as a risk per year. Societal Risk is defined as "the relationship between the frequency and the number of people suffering a given level of harm from the realisation of specified hazards". It is normally taken to refer to the risk of death expressed as a risk per year and displayed as F-N curves. These describe the cumulative frequency (F) of all event outcomes leading to N or more fatalities and this representation of societal risk highlights the potential for accidents involving a large number of fatalities.

Risk to life is only one of the risks inherent in the operation of a process plant which may be realised by the occurrence of an accident. Others include risk to the environment, risk to assets and equipment and risk to financial performance. Furthermore, all these "risks" can have a cost associated with them which can be calculated and integrated in the same way as fatality risk provided appropriate cost parameters are available for each cost category. The workflow and data required to extend the concepts of QRA to Financial Risk Analysis (FRA) are summarised in Figure 1.

Typical contributors to overall financial losses resulting from an accident may include:

- Impact on people in terms of fatalities and injuries
- Property damage including capital costs to repair or replace damaged equipment and damage to other assets
- Business interruption including lost production from original failures
- Cost of lost inventory, again from sources and other damaged equipment
- Environmental damage, including clean-up costs, fines, impact on animal and plant life
- Plus many other outcomes with financial impact including legal costs, fines, loss of reputation, brand damage, compensation, reduction of share prices and so on

Typical output from a financial risk analysis, looking purely at consequences of a single accident may be total cost of a single failure case, total cost per outcome or per cost category, or both, and cost ranking per scenario. This is of use in assessing areas of a plant where a single accident may result in unacceptable high risk of loss. Extending this to risk, measures such as Estimated Annual Average Loss and Estimated Maximum Loss may be calculated. Also, F-Cost curves (analogous with the F-N curves for societal risk from a traditional QRA) can be generated, along with other metrics (Cavanagh and Linn, 2006).

The Estimated Annual Average Loss (EAAL) helps to identify the factors contributing to the highest risks in financial terms. The rate of financial loss for a given event outcome is the product of the financial loss for that outcome and its frequency, and the total rate of financial loss is the sum over all outcomes. Each event in an FRA model has a likelihood (typically occurences per year) and consequence (typically in USD, GBP, Euro or other currency). The product of these is the EAAL for the event in USD/year, for example. By aggregating the EAAL for each event, the EAAL for the entire facility can be quantified. So the EAAL for a plant represents the average annual loss rate expected across the complete lifetime of the facility.

With respect to Estimated Maximum Loss (EML), this provides an estimate of the maximum loss that could be sustained at a facility due to a major accident. By assessing the financial consequences of all possible outcomes for all possible release scenarios and integrating these over all possible release directions, an accurate and defendable estimate of the maximum loss which could be sustained at the facility can be derived. This is also the position where the F-Cost curve crosses the cost axis on the F-Cost graph so from Figure 3, for example, we can see that the EML is close to $1billion.

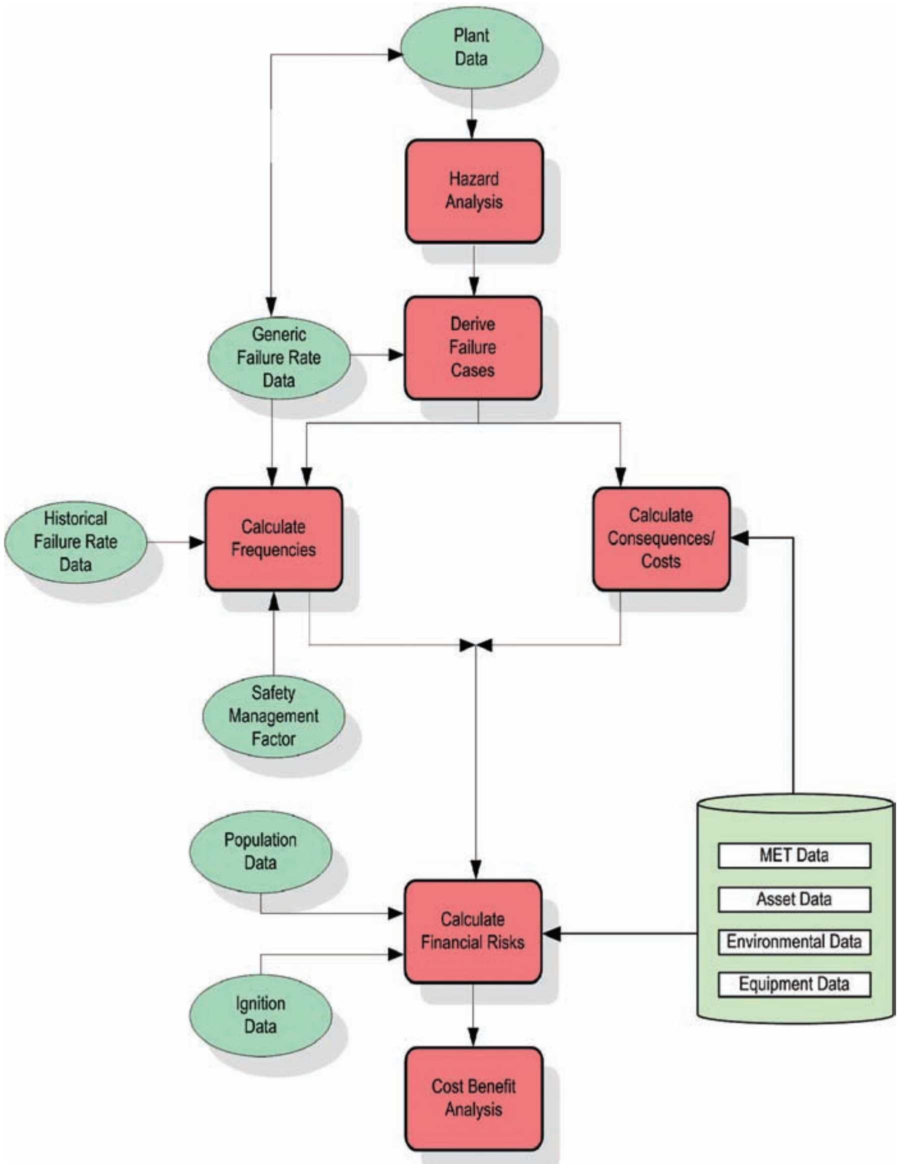

Figure 1. Classical risk analysis methodology extended to include financial risk calculations

Other approaches have defined EML as a "worst-case" or financial consequence measure rather than an absolute maximum possible loss with a given frequency. Marsh's SLAM model, for example, defines EML as "The largest loss that could result from a single incident in the plant" and uses the CAM explosion model for assessment of overpressure whilst SwissRe's ExTool focusses on damage to property only using the TNT model, determining-financial loss due to an individual explosion and extrapolating this to estimate Maximum Possible Loss (MPL), again without consideration of its likelihood of occurrence.

Chippindall and Butts (2004) adopted a similar approach to the current authors, using Phast as a consequence engine and performing the cost calculations and risk summations through a number of spreadsheet models. The advantage of the Safeti Financial model used in this study is that asset, equipment, source, population and ignition information is entered onto a map directly through the existing Safeti GIS and grouping and combination functionality enabling multiple combinations to be analysed easily.

For the model under consideration here, the key elements are:-

- A geographical model of the facility and surroundings including population, ignition and asset and equipment data sets
- A complete set of major accident hazard scenario failure cases for the facility
- A set of representative weather conditions and their directional probabilities (wind rose)
- Estimation of the likelihood of each failure case
- Modelling of the range of potential consequences for each failure case
- Assessment of the impact of each failure case on the plant, surrounding assets and population
- Calculation and assessment of the financial risks associated with these impacts reported in terms of F-Cost curves, total loss rates, Estimated Annual Average Losses (EAAL) and Estimated Maximum Losses (EML). (See for example Evans and Thakorlal, 2004)

Typical uses of this kind of financial risk analysis include

- Aiding the decision making process with risk reduction recommendations supported by cost benefit analysis techniques
- Reducing exposure to financial risk by assessing the relative benefits of different risk mitigation strategies
- Comparison of financial risk exposure for a range of process conditions
- Financial risk trends with time
- Direct assessment of financial risks from major process plant hazards
- Demonstrating a strong culture of corporate social responsibility (CSR) and adherence to the principles of triple bottom line (TBL) reporting which explicitly considers an organisation's economic, environmental and social performance (Elkington, 1994)
- Better understanding of appropriate levels of insurance in terms of both maximum insured losses and deductible levels

The next section goes on to describe in more detail the methodology we have adopted and its implementation in the Safeti Financial model.

METHODOLOGY AND MODEL

FINANCIAL RISK CALCULATIONS

The total financial risk is the summation of the total risk due to impacts on people (fatalities and injuries), impacts on equipment and other assets in terms of damage and replacement cost, cost of business interruption, cost of environmental impact and the cost of other outcomes such as legal costs, fines, brand damage, etc.

The methodology used in this model considers financial risk in terms of the following asset types:

- Population;
- Original Source Equipment;
- Other Specific Equipment;
- Other Assets (buildings, non specific plant, infrastructure, etc.);
- User Defined costs.

Cost contributors within each of these asset groups may include equipment damage, lost inventory, business interruption and environmental cleanup.

For population zone analysis, the cost of each release is calculated summing up the cost of a fatality and the cost due to injuries.

If the analysis involves specific equipment that constitutes a source of a release of hazardous material or that can be affected by the accident, the following different costs could be considered:

- Equipment repair: the cost of repairing the damage or replacing the equipment;
- Equipment business interruption cost: the financial loss incurred when production is halted because of the damage;
- Equipment lost inventory cost: the value of any inventory that had to be scrapped as a result of the damage.
- Equipment environmental: the cost of cleaning up any environmental effects associated with the damage;
- Or any other costs associated with the damage.

The same cost categories indicated for equipment can be applied to any asset zone (such as an industrial area, process area, adminstrative building, residencial area) that can be affected by a hazardous event.

The total cost related to any accidental release is calculated considering all the above individual costs and any aditional cost that can be defined by the analyst, as environmental fees and legal costs.

For cases with relatively low costs, total cost, $\mathbf{COST_T}$, is assumed to be given by a simple summation. For cases with larger costs, the value will be given by the power relation:

$$\mathbf{COST_{Total}} = \max\left(\mathbf{COST_T}, 0.5\ \mathbf{COST_T}^{1.05}\right)$$

This is already commonly used in Risk Based Inspection (RBI) calculations (Topalis and Cavanagh, 2001, Risk Based Inspection, 2000). The power relation accounts in a general way for the additional costs such as litigation, fines, etc., which increase with the size of the incident. This is commonly referred to as escalation.

DAMAGE LEVEL AND VULNERABILITY FACTOR CONCEPT

The simplest method 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 concept will be familiar to Safeti users, where typically 2 threshold values are used for each outcome type. For explosions, jet-fires and pool fires an upper and lower damage level are defined, with a vulnerability factor between zero and 1 associated with each level. For flash fires a fraction of LFL is defined below which no damage occurs and above which maximum damage occurs, as defined by the appropriate vulnerability factor.

For toxic releases, a concentration level is provided below which no damage occurs and above which maximum damage occurs, again based on the relevant vulnerability factor. Toxic damage is intended primarily for use with assets where damage will result in some kind of pollution which has an environmental clean up cost associated with it.

A similar approach is taken for the effects on population and this is already well documented within the Safeti model (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 cost for each cost category.

In Figure 2, 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 population and asset zones and a single equipment item. Any receptor

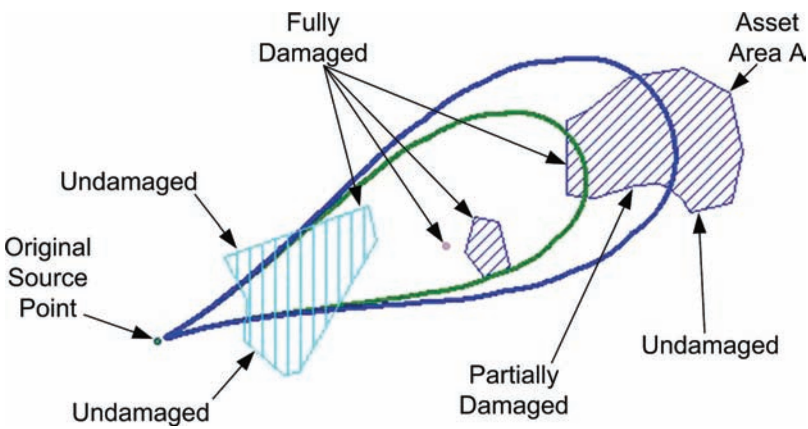

Figure 2. Definition sketch for asset damage due to upper and lower damage levels

outside the lower threshold value indicated by the bold outer line will be undamaged. Any receptor between the inner and outer threshold boundaries will be damaged to the degree indicated by the appropriate vulnerability factor for the lower threshold. Any receptor within the inner threshold boundary will be damaged to the degree indicated by the appropriate vulnerability factor shown for the upper threshold.

So, for example, in Figure 2, if upper and lower vulnerability factors are set to 1.0 and 0.5 respectively, then the section of asset area A outside the outer footprint will be unaffected, 50% of asset area A between the inner and outer footprints will be affected and 100% of asset area A within the inner footprint will be affected. Similarly, for the single equipment item illustrated, this will be 100% affected, since it is in the inner zone, as will the population which is also within the inner zone.

SOURCE COSTS

Sources or failure cases result in hazardous releases which in turn result in damage to other assets. However, each release will have a cost associated with it whether it impacts other assets or not. In order to calculate the source costs, the following information is required in addition to the release source term information. Each source is defined as a particular equipment type, which will have its own unique outage time and repair cost, based on the information in Table 1. The model also allows user defined equipment types to be added with their own outage time and repair costs.

Table 1. Outage time and repair cost look-up table for range of equipment types

Equipment type	Outage time (day)	Repair/replace cost ($)
Large Pipes	7	50,000
Medium Pipes	4	20,000
Small Pipes	2	5,000
Compressors	14	250,000
Exchangers	5	50,000
Vessels	7	40,000
Filters	1	10,000
Reactors	14	80,000
Tanks	7	80,000
Pumps	0	5,000
Heater	5	60,000
Column	21	10,000
Other/General	7	20,000
Mobile Buildings	5	25,000
Brick Buildings	15	100,000
Asset Zones	5	$1/m^2$
None	0	0

In addition the following information is required to calculate costs in each of the cost categories described earlier:

- Cost of lost Production per day
- Cost of Environmental clean-up per kg
- Other Environmental costs for other effects per kg
- Value of lost inventory

The Inventory mass and spilled mass, which may not be the same, are also required, although the spilled mass can be calculated as part of the discharge calculation performed in the source term modelling if desired.

POPULATION ZONE COSTS

Population information can be entered through the GIS in the same way as in the Safeti model, as can ignition source information. However, for financial risk calculations based on population the following additional parameters are required:

- Cost of a Solitary Fatality
- Number of Injuries Per Fatality
- Cost of a Single Fatality Among Many Fatalities
- Cost of One Injury

EQUIPMENT COSTS

An equipment item in terms of financial risk is essentially the same as a source, merely acting as a point receptor to a hazard zone generated by a source. From that point of view an original source and an item of equipment require the same financial data. Typical examples of specific items of equipment which you may want to enter into the model as "equipment" rather than "sources" or "assets" are individual large capital value items of plant which do not represent a hazard themselves, or storage facilities for non hazardous material which have a high capital value.

ASSET SET COSTS

An asset is a generic receptor type, which will result in a cost being incurred if it is impacted by a hazard zone with a large enough damage level. An asset zone is treated in the same way as an equipment item in terms of financial risk, but with no contribution from environmental costs. Assets can be defined at a point, or over an area. Typical examples of assets may be on-site buildings like control rooms and offices, off site buildings and infrastructure including, for example, houses, commercial buildings, factories, warehouses, etc. Areas of a plant which do not contribute directly to risk as possible sources of hazardous releases may be defined by a series of assets, to account for background plant value.

FINANCIAL RISK PARAMETERS

Much of the data described above is available as a set of default parameters within the model which may be modified on a case by case basis for each receptor and cost category type. Data available as defaults includes:

- Damage levels and vulnerability factors for each outcome type, cost category and receptor type
- Cost of lost production per day, environmental clean-up per kg, environmental costs for other effects per kg and value of lost inventory
- Outage time and repair cost for each equipment type with ability to add new types
- Financial information relating to fatalities and injuries including cost of a solitary fatality, cost of an injury and number of injuries per fatality and cost of single fatality amongst many in order to deal with the concept of "risk aversion" (see for example Wiggins 1984) when dealing with multiple fatality events.

In addition, calculations and results may only be required for a sub-set of the complete set of cost categories available. For example, in certain situations it is undesirable to place a value on a life and therefore you may wish to exclude fatality and injury costs from the calculations. The complete set of cost categories is original source, fatality, injury, repair and replacement, lost inventory, business interruption and user defined. Any of these can be excluded at any level, either from defaults, so that they are not included in calculations and never appear in the results, at the study level so that they are not calculated for a particular study and don't appear in the results for that study, or at the results level so that they are calculated but not displayed individually in the results. The study described below was used to assess the financial risks associated with the business interruption cost category only.

PRACTICAL EXAMPLE OF MANAGING BUSINESS RISKS USING FRA

This real life study was performed by DNV Energy in order to support its client in assessing the adequacy of the maximum insurance values for their plant. The client wanted to review the maximum value for their insurance based on a quantitative risk assessment of accidents that could happen on their site. A typical QRA study was developed based on the classical approach supported by Safeti and the workflow illustrated in Figure 1. Subsequently equipment data was added to the model using the GIS capabilities of Safeti Financial and appropriate repair costs were defined for each asset zone within the plant.

Accident scenarios from eleven different systems on two of the client's Olefin plants were analysed. Frequencies were estimated for a range of typical failure case scenarios categorised within each of the systems. These were combined with the financial loss consequences calculated using Safeti Financial. The combined result from the frequencies per year and the financial consequences in US dollars based only on equipment damage costs were presented as F-Cost curves, thus representing cumulative frequency with which losses exceeding a particular dollar value would be expected to occur.

The major phases of the analysis were:

Phase 1: Identification of release events, based on material, release conditions, inventory, control systems, location and confinement, that could represent significant losses to the site.
Phase 2: Likelihood and consequence calculation for each selected event.
Phase 3: Financial loss calculation for each scenario and results assessment.

The processes on each plant which were included in the analysis were:

Plant Olefins A: Propylene refrigeration, Propylene separation, Ethylene refrigeration, Ethylene separation, Demethanizer and Deetanizer.
Plant Olefins B: Propylene refrigeration, Propylene separation, Ethylene separation, Deetanizer and Demetanizer,

All the calculations were performed using the Safeti Financial software, developed by DNV Software. Safeti Financial calculates the frequency of occurrence of each representative release scenario. This is based on individual equipment release frequencies factored by the number of pieces of equipment within the segment or area on the plant for which that scenario type could occur. This is achieved by "counting" equipment items for which similar releases may occur and factoring the individual release frequencies based on the equipment count.

These frequencies are then factored by probabilities associated with each possible weather condition (in terms of wind direction and velocity – the wind rose), ignition source probabilities for immediate and delayed ignition, as well as event trees providing the probabilities with which each possible outcome type is expected to occur (e.g. probability of ignition, flash fire, jet fire, VCE, etc.). This methodology is described in detail in the Safeti user manuals (Worthington and Witlox, 2002).

The financial consequences are estimated using the Phast modelling integrated in Safeti Financial. This takes account of the release conditions such as material, temperature, pressure, inventory and release hole size. These "source-terms" are then used to calculate the associated hazard zones from which the cost of repair of the equipment on the installation damaged by the release is calculated.

The cost of repair within each area, based on the damage for each release scenario, are then calculated considering the hazard zone, as follows:

$$F_{Repair,h,o} = v_{Repair,h}\ C_{Repair}\ a_{h,0}$$

where $v_{Repair,h}$ is the **repair vulnerability** for hazard zone h that is defined for each outcome type, as shown in Table 2 below, C_{Repair} is the cost of repairing or replacing the entire area and $a_{h,o}$ is the fraction of the area that is covered by hazard zone h for outcome o.

The result from the analysis are used to create the F-Cost curves shown in Figure 3, from which we can see the estimated repair costs we can expect to incur with frequencies between 0.2 and 10^{-6} (or 1 in a million) occurrences per year. The blue curve shows expected losses considering all possible consequences from the eleven events analysed, considering day weather conditions and the pink curve is related to night weather conditions.

Table 2. Repair vulnerability per outcome (based on API RP 581 (2000))

Outcome	Threshold		Maximum	
Pool Fire Jet Fire Fireball	12,5 kW/m^2	50% damage	37,5 kW/m^2	100% damage
Flash Fire	–	–	100% LFL	100% damage
Explosion	0,3 bar	50% damage	0,5 bar	100% damage

Based on the above, the client decided to use an accumulated frequency of 10^{-5}/year as acceptable for their maximum loss, which implies a total insured loss of USD 1 billion. The main contributors from each system to the maximum expected losses are shown in Table 3 below. From this we can see that the 3 largest contributors to expected maximum loss are the Propylene Refrigeration in Plant A, Propylene Separation in Plant A and the Propylene Separation unit within Plant B. It should also be noted that all scenarios with a frequency of occurrence less than 10^{-9}/year were neglected and that all

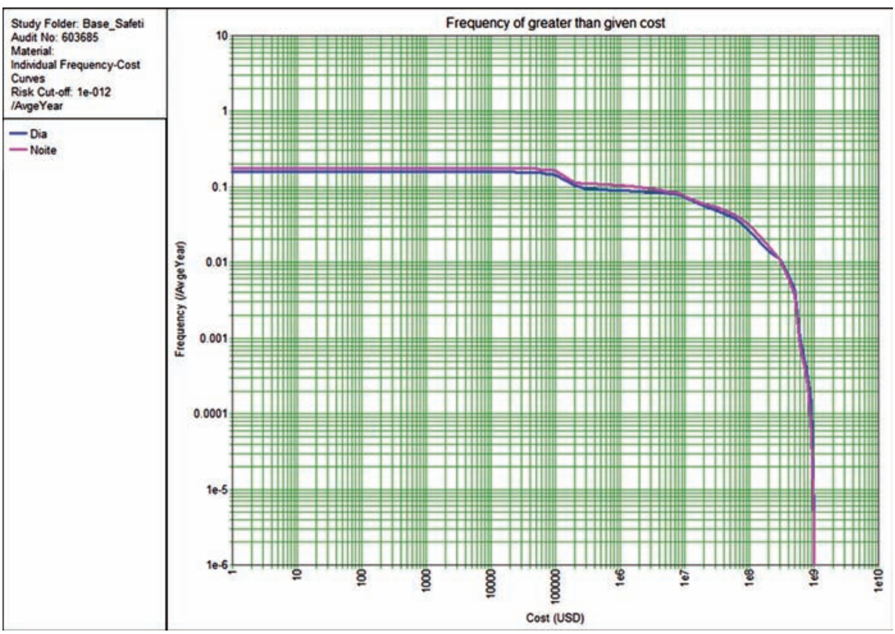

Figure 3 F-Cost curve

Table 3. Maximum loss by system

System	Event number	Maximum cost (USD)
Plant Olefins A		
Propylene Separation	6	$\mathbf{1.32 \times 10^9}$
Propylene Refrigeration	2	$\mathbf{1.20 \times 10^9}$
Ethylene Separation	1	9.30×10^8
Demethaniser	5	8.30×10^8
Ethylene Refrigeration	3	8.05×10^8
Deethaniser	4	8.00×10^8
Plant Olefins B		
Propylene Separation	10	$\mathbf{1.15 \times 10^9}$
Deethaniser	11	6.50×10^8
Propylene Refrigeration	7	6.30×10^8
Ethylene Separation	9	5.00×10^8
Demethaniser	8	4.00×10^8

scenarios with losses above USD 1 billion had frequencies of occurrence of less than 10^{-8}/year.

Drilling down further we can use the facilities of Safeti Financial to identify the scenarios contributing most to the overall financial risk in terms of Expected Maximum Loss (EML). This enables us to isolate the key failure cases we should focus on should we wish to recommend mitigating measures for reducing overall financial risk exposure. In this study the following were found to be the largest contributors.

EML above USD 1 billion

- Propylene Refrigeration – Plant Olefins A
- Propylene Separation – Plant Olefins A
- Propylene Separation – Plant Olefins B

EML above USD 900 millions

- Ethylene Separation – Plant Olefins A

We have also looked at individual F-Cost curves for each system in order to assess more accurately which system are contributing most to the financial risk exposure at different frequencies of occurrence and these are illustrated in Figure 4.

From here we can see that the main contributors at frequencies of 10^{-6}, 10^{-5} and 10^{-4} per year, in order of highest contributor are:

10^{-6}/year: Systems 6, 10, 2, 1 and 5
10^{-5}/year: Systems 10, 2, 6, 1 and 9
10^{-4}/year: Systems 10, 2, 9, 3 and 11

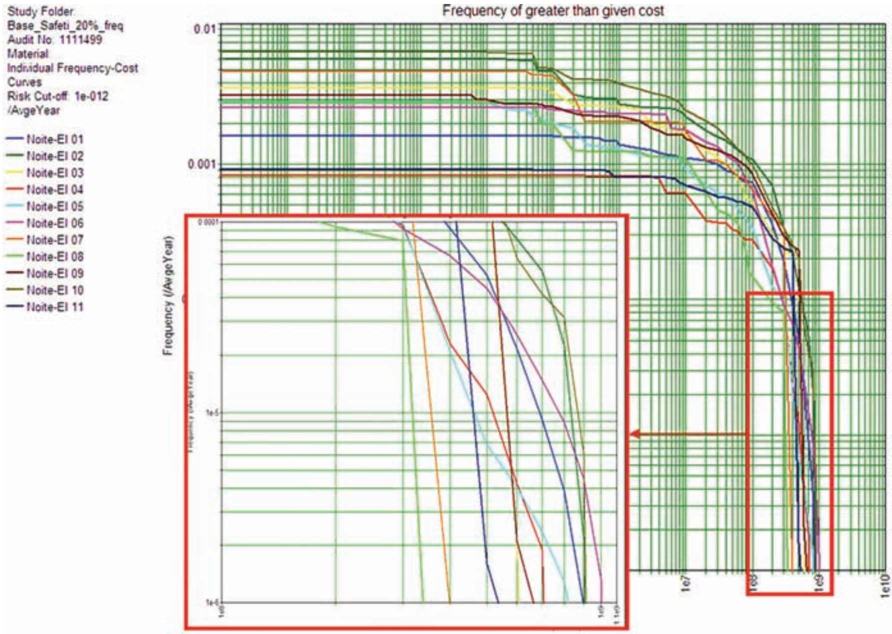

Figure 4. F-Cost curve per system

FUTURE POTENTIAL

The results presented above represent the actual conditions of the analysed systems. In order to reduce the estimated losses as well as the expected losses for each frequency, mitigation measures can be evaluated and the results reviewed. This mitigation should focus on inventory isolation to minimize consequences and reduction of frequency of release.

A cost benefit analysis can be performed, comparing the reduction on the insurance premium per year with the cost for the implementation of the mitigation proposed. This way a risk management approach based on the continuous reduction of the estimated losses can be used.

Also, as an extension to the study presented in this paper, other specific insurance products such as third party insurance can be analysed using the same approach taking account of property damage as well as business interruption and fatality/injury costs.

CONCLUSIONS

We have extended the classical approach to QRA to enable the calculation of broader financial or business risks and built this extended methodology into the Safeti QRA model.

We have then used this model to assess the financial risk exposure of an olefin production plant focusing on financial risk from accident scenarios resulting in damage or destruction of equipment and other assets. The Safeti Financial FRA model has been used to make recommendations on appropriate levels of insurance. We have also used the model to identify the main contributors to these broader business risks in order to propose measures to reduce our client's exposure to possible financial losses.

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