Process Business Risk
A methodology for assessing and mitigating the financial impact of process plant accidents

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ABSTRACT

During the 1980’s, oil and chemical companies were cash rich and highly proactive over safety issues, often setting internal standards with more onerous requirements than legislation demanded. In today’s competitive environment safety budgets are usually far more limited. Generally speaking, good safety means good business, but demonstrating this to senior management is not always straightforward. By combining techniques from QRA and Risk Based Inspection (RBI), the business risks inherent in an operation can be demonstrated, as can options for reducing these risks. The “Q” of QRA need not be fatalities, but could equally be effects on the environment, down-time or dollars.

By formulating a hybrid methodology, taking the “best” of process QRA and some of the financial models and methodologies used when performing Risk Based Inspection, we have developed a simple approach for demonstrating the financial risks associated with process plant operation. This has been implemented in a software tool from which we can generate F$ curves, analogous with the FN curves from traditional QRA, and other key financial indicators. By looking at different scenarios and cost mitigation methods it is easy to demonstrate how business risks can be reduced.

The methodology implemented in the prototype is described and some examples are used to show that situations where risk to life is small can have significant financial risks associated with them.
1. INTRODUCTION

Over the last 30 years, the management of risks associated with the operation of major accident hazard facilities has improved steadily. 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. Legislation has generally been focused on reducing the risk of fatalities and injuries, and rightly so. As a result of this, operational safety is far less of an issue than in the past and generally the industry is in good shape from the point of view of safety.

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 addition to these “process” industry accidents, there are other recent low fatality accidents which have resulted in significant cost to industry. The Hatfield rail crash in October 2000 resulted in 4 fatalities, but caused delays on the entire UK rail network for
one year whilst tracks were checked for safety. The 3 Mile Island nuclear accident on 28th March 1979 again had no direct fatalities but a class action suit was filed. Although this found in favour of the defendants in 1996, there were large legal costs and a massive effect on the image of the nuclear power industry.

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. Evans and Thakorlal investigated assessment methods for Business Risks in the process industry. They concluded that the relevant loss prevention considerations from a business perspective should be promoted to a corporate level, from there cascading down into systems, operations and design. 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 in the business environment of the 21st century 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 industry standard software tools, 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.
2. THE FINANCIAL RISK CONCEPT

QRA (Quantitative Risk Analysis) and PHA (Process Hazard Analysis) techniques have been used over many years as tools to assist in the management of the safe operation of process plants\(^4,5\). 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 illustrated in Figure 1 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 risk contours for individual risk and the FN 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 FN curves.

But 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 generally in terms of share price for example. 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. These will be described in more depth in the next section. The additional information required to extend the concepts of QRA to SRA (Financial Risk Analysis) are summarised in Figure 2.

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$ curves (analogous with the FN curves for societal risk from a traditional QRA), as illustrated in Figure 3, can be generated, along with other metrics such as cost per individual equipment failure and likely cost of accidents within a given return period as illustrated in Figure 4.

Chippindall and Butts\(^6\) adopted a similar approach, using PHAST as a consequence engine and performing the cost calculations and risk summations through a number of spreadsheet models. The advantage of the current model 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.

Chippindall and Butts developed a more robust production stream model than will be available in the first release of the SAFETI\(^5\) model, where it is assumed that the production stream dependencies are reflected in the definition of source, asset and equipment sets and the associated business interruption costs entered directly within these sets.
A more robust and automated model for handling these dependencies will be included in a future release of the model. Irrespective of the strengths and weaknesses of the two approaches mentioned above, both the SAFETI$ model and the model developed by Chippindall and Butts contain essentially the same main elements, although the former handles weather information much more rigorously and integrates with Intergraph’s Geomedia GIS for asset, population and equipment handling whilst the latter is far more rigorous when it comes to production stream interactions. 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 FS curves, total loss rates, Estimated Annual Average Losses (EAAL) and Estimated Maximum Losses (EML) (See for example$^2$)

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

<table>
<thead>
<tr>
<th>Event</th>
<th>Fatality Costs</th>
<th>Repair / Replacement</th>
<th>Inventory Losses</th>
<th>Business Interruption</th>
<th>Environmental</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine Rupture</td>
<td>$0</td>
<td>$5</td>
<td>$3</td>
<td>$12</td>
<td>$3</td>
<td>$5</td>
<td>$27</td>
</tr>
<tr>
<td>Chlorine Liquid Leak</td>
<td>$0</td>
<td>$5</td>
<td>$3</td>
<td>$12</td>
<td>$3</td>
<td>$5</td>
<td>$27</td>
</tr>
<tr>
<td>Butadiene Rupture</td>
<td>$0</td>
<td>$8</td>
<td>$8</td>
<td>$26</td>
<td>$4</td>
<td>$10</td>
<td>$56</td>
</tr>
<tr>
<td>Tank A1</td>
<td>$0</td>
<td>$40</td>
<td>$20</td>
<td>$84</td>
<td>$20</td>
<td>$36</td>
<td>$200</td>
</tr>
<tr>
<td>Butadiene Vapor Leak</td>
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<td>$8</td>
<td>$8</td>
<td>$26</td>
<td>$4</td>
<td>$10</td>
<td>$56</td>
</tr>
<tr>
<td>Total</td>
<td>$0</td>
<td>$66</td>
<td>$42</td>
<td>$158</td>
<td>$33</td>
<td>$66</td>
<td>$365</td>
</tr>
</tbody>
</table>

Total Costs including Original Failed Equipment and Receptor Assets '000 USD ($)

<table>
<thead>
<tr>
<th>N</th>
<th>Fatality Costs</th>
<th>Repair / Replacement</th>
<th>Inventory Losses</th>
<th>Business Interruption</th>
<th>Environmental</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0</td>
<td>$66</td>
<td>$42</td>
<td>$158</td>
<td>$33</td>
<td>$66</td>
<td>$365</td>
</tr>
<tr>
<td>5</td>
<td>$0</td>
<td>$67</td>
<td>$42</td>
<td>$150</td>
<td>$33</td>
<td>$67</td>
<td>$365</td>
</tr>
<tr>
<td>10</td>
<td>$0</td>
<td>$73</td>
<td>$46</td>
<td>$174</td>
<td>$36</td>
<td>$72</td>
<td>$402</td>
</tr>
<tr>
<td>50</td>
<td>$0</td>
<td>$132</td>
<td>$64</td>
<td>$217</td>
<td>$66</td>
<td>$132</td>
<td>$731</td>
</tr>
<tr>
<td>100</td>
<td>$0</td>
<td>$726</td>
<td>$482</td>
<td>$1,742</td>
<td>$363</td>
<td>$725</td>
<td>$4,018</td>
</tr>
<tr>
<td>Total</td>
<td>$0</td>
<td>$1,063</td>
<td>$677</td>
<td>$2,552</td>
<td>$932</td>
<td>$1,061</td>
<td>$5,885</td>
</tr>
</tbody>
</table>

For example, Every 10 years one can expect an accident which will cost a total of $402,000 dollars

Figure 4 – Typical original equipment failure costs and Average accident cost every N years reported by the SAFETI$ prototype
• 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 reporting
• 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$^5$ model.

3. METHODOLOGY AND MODEL

3.1 Terminology

In order to describe the methodology and its implementation in the SAFETI$^5$ model in more detail, it is first necessary to define some of the key terms used in the business risk analysis.

**Source or Failure case**
This describes a single release scenario of a hazardous material that will have at least one consequence or hazardous outcome to one or more receptors. For example, for a flammable release the possible outcomes may be a VCE, flash fire, pool fire, jet fire and BLEVE.

**Receptor**
This is a generic name for any entity which can be damaged by a hazardous outcome or consequence. These include population, equipment items and asset sets.

**Population Zone**
An area on the model map defined as containing people at a constant population density.

**Asset Zone**
An area on the model map defined as containing assets that have constant business cost data per unit area.

**Equipment Item**
A piece of equipment or machinery that can be damaged as a result of a hazardous outcome and has standard business attributes associated with it.

**Damage**
Damage is a generic term for the effects of a particular outcome on a receptor.
**Damage Levels**
These are levels at which a particular outcome type has a defined effect on a receptor, based on the vulnerability associated with that level of the effect being considered (e.g. radiation levels, overpressure levels, toxic doses, etc.). For each damage level, there is an associated vulnerability factor which defines the degree of damage associated with the level of the specific effect.

**Vulnerability**
This is a measure of the degree of damage caused to a receptor at a particular damage level for a particular outcome type.

**PHAST**
Industry standard consequence modeling software - Process Hazard Analysis Software Tools

**SAFETI**
Industry standard QRA software - Software for the assessment of Flammable, Explosive and Toxic Impact.

### 3.2 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.

Considering each asset type individually:

For population zone analysis, total cost is $\text{COST}_P = P_F + P_I$
Where $P_F = $ cost due to fatalities and $P_I = $ cost due to injuries

For original source equipment analysis total cost is $\text{COST}_S = R_S + B_I_S + I_S + U_S + E_S$
Where $R_S =$ source repair and replacement cost, $B_I_S =$ source business interruption cost, $I_S =$ source lost inventory cost, $U_S =$ source user defined cost and $E_S =$ source environmental cost.
For other equipment analysis total cost is \( \text{COST}_E = R_E + BI_E + I_E + U_E + E_E \)

Where \( R_E \) = equipment repair and replacement cost, \( BI_E \) = equipment business interruption cost, \( I_E \) = equipment lost inventory cost, \( U_E \) = equipment user defined cost and \( E_E \) = equipment environmental cost

Note: Equipment which constitutes a source of release of hazardous material is handled differently in the SAFETI\(^3\) model and therefore needs to be specified separately, even though the cost contributors are identical. This is due to the fact that the SAFETI model\(^3\) is used as the basis for the new financial model.

For generic asset analysis total cost is \( \text{COST}_A = R_A + BI_A + I_A + U_A \)

Where \( R_A \) = asset repair and replacement cost, \( BI_A \) = asset business interruption cost, \( I_A \) = asset lost inventory cost and \( U_A \) = asset user defined cost

For user defined costs generally a \( \text{COST}_U \) is specified.

This gives a total cost \( \text{COST}_T = \text{COST}_P + \text{COST}_S + \text{COST}_E + \text{COST}_A + \text{COST}_U \)

For cases with relatively low costs \( \text{COST}_T \) is assumed to be given by the simple summation shown above. For cases with larger costs, the value will be given by the power relation

\[ \text{COST}_T = \max (\text{COST}_T, 0.5 \times \text{COST}_T^{1.05}) \]

This is already commonly used in RBI\(^7\) (Risk Based Inspection) calculations. 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.

### 3.2.1 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 can occur 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.
Figure 5: Threshold and maximum damage levels for each outcome type.

<table>
<thead>
<tr>
<th>Event Type</th>
<th>Threshold damage level</th>
<th>Maximum damage level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool Fire Radiation</td>
<td>12.5</td>
<td>37.5 kW/m²</td>
</tr>
<tr>
<td>Jet Fire Radiation</td>
<td>12.5</td>
<td>37.5 kW/m²</td>
</tr>
<tr>
<td>Final Blow Radiation</td>
<td>12.5</td>
<td>37.5 kW/m²</td>
</tr>
<tr>
<td>Explosion overpressures</td>
<td>0.5</td>
<td>1 bar</td>
</tr>
<tr>
<td>Flash Fires (LFL)</td>
<td>0.5</td>
<td>fraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toxic concentration</td>
</tr>
</tbody>
</table>

Figure 6: Vulnerability factors for each outcome and cost category respectively.

A typical set of damage levels and associated vulnerability factors are illustrated in Figures 5 and 6 respectively. Within the model all of these data are supplied as defaults which can also be changed locally for all sources, equipment items and other assets.

Figure 7: Typical hazard zones and asset types shown on a GIS map

A similar approach is taken for the effects on population. This is already well documented within the SAFETI model. By enabling separate vulnerability factors to be defined for each cost contributor defined in 3.2 above, this allows, for example, to set
different vulnerabilities for replacing a piece of equipment, as compared with the cost of cleaning up after it has been damaged. Vulnerability factors therefore have a dual role; to determine the level of damage specific to each asset and to differentiate further between the different contributors to total cost for each asset. 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.

Figure 7 illustrates 2 hazard zones, one for each damage level shown on a GIS map. Also shown is an example of each receptor type available in the model with a brief description. The data associated with each receptor type will be described more fully in later sections.

![Figure 8: Definition sketch for asset damage due to upper and lower threshold “damage” levels.](image)

In Figure 8, 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 outside the lower threshold value indicated by the bold outer line above will be undamaged. Any receptor between the inner and outer threshold boundaries will be damaged to the degree indicated by the appropriate vulnerability factor shown in Figure 6 for the lower threshold. Any receptor within the inner threshold boundary will be damaged to the degree indicated by the appropriate vulnerability factor shown in Figure 6 for the upper threshold.

So, for example, in Figure 8, 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. In simple terms, the total loss for each damage level, asset and cost contributor is given by

\[
\text{Cost} = \left( \frac{\text{Area of asset within zone}}{\text{total area of asset}} \right) \times \text{cost of asset} \times \text{vulnerability factor for zone}
\]

The degree of damage to the source of the release will be dependent on the particular scenario type being modelled. For example, a catastrophic event is likely to result in heavy or complete damage, whilst a release due to a lifting relief valve is likely to result in little or no direct damage to the source (not that the source may still be damaged by subsequent hazardous outcomes, an explosion or pool fire for example). For this reason, the immediate damage level for a source is part of the financial risk input data for that source.

### 3.2.2 Original 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, defined in 3.2 as

\[
\text{COST}_S = R_S + B_I_S + I_S + U_S + E_S
\]

In order to calculate the source costs, the following information is required in addition to the release source term information described in \(3\), for example. 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, as currently used by ORBIT Onshore. The model also allows user defined equipment types to be added with their own outage time and repair costs. Further, it allows outage times to be calculated based on the following relationship, often referred to as the API correlation\(^8\).

\[
\text{OutageTime} = \left[ \frac{\text{Property damage value}}{10^6} \right]^{0.58532} + 1.24194
\]

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
<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Outage Time (day)</th>
<th>Repair/Replace Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Pipes</td>
<td>7</td>
<td>50,000</td>
</tr>
<tr>
<td>Medium Pipes</td>
<td>4</td>
<td>20,000</td>
</tr>
<tr>
<td>Small Pipes</td>
<td>2</td>
<td>5,000</td>
</tr>
<tr>
<td>Compressors</td>
<td>14</td>
<td>250,000</td>
</tr>
<tr>
<td>Exchangers</td>
<td>5</td>
<td>50,000</td>
</tr>
<tr>
<td>Vessels</td>
<td>7</td>
<td>40,000</td>
</tr>
<tr>
<td>Filters</td>
<td>1</td>
<td>10,000</td>
</tr>
<tr>
<td>Reactors</td>
<td>14</td>
<td>80,000</td>
</tr>
<tr>
<td>Tanks</td>
<td>7</td>
<td>80,000</td>
</tr>
<tr>
<td>Pumps</td>
<td>0</td>
<td>5,000</td>
</tr>
<tr>
<td>Heater</td>
<td>5</td>
<td>60,000</td>
</tr>
<tr>
<td>Column</td>
<td>21</td>
<td>10,000</td>
</tr>
<tr>
<td>Other / General</td>
<td>7</td>
<td>20,000</td>
</tr>
<tr>
<td>Mobile Buildings</td>
<td>5</td>
<td>25,000</td>
</tr>
<tr>
<td>Brick Buildings</td>
<td>15</td>
<td>100,000</td>
</tr>
<tr>
<td>Asset Zones</td>
<td>5</td>
<td>1/m²</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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

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.

3.2.3 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

3.2.4 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, with
the same options available as described in 3.2.2 for a source. In the same way, the contributors to cost calculations from equipment are:

\[ \text{COST}_E = R_E + BI_E + I_E + U_E + E_E \]

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.

### 3.2.5 Asset set costs

As described in 3.2, 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 and give a cost contribution of:

\[ \text{COST}_A = R_A + BI_A + I_A + U_A \]

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.

### 3.2.6 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 single fatality amongst many, cost of an injury and number of injuries per fatality

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.

4. TYPICAL OUTPUT

The key outputs from a financial risk analysis are the F$ curves as illustrated in Figure 3 and the reports showing individual contributions to risk from the different scenarios and cost contributors, one example of which is shown in Figure 4.

Extending the example illustrated in Figures 7 and 8 above, Figure 9 shows a typical GIS map from the model which has been populated with a number of assets and sources as labeled. This is the basis for a simple SRA study created for a fictitious off-loading and refining facility to illustrate some of the benefits of performing these types of analyses. Standard individual risk contours for this study are illustrated in Figure 10, with the equivalent FN curves shown in Figure 11.

Figure 9: Example GIS map showing population, equipment, asset and source items.
Figure 10: Typical individual risk contours for example financial risk study.

Figure 11: Typical FN curves for example financial risk study.
By broadening this to include the additional business risk data described above, we are able to generate detailed $F$ curves and individual financial risk ranking per scenario as illustrated in Figures 12 and 13 respectively. At this stage we have not developed the financial equivalent of the individual risk contour shown in Figure 10, but we plan to
derive some formulation for individual cost contours or an overall cost footprint once it becomes clear how this should be calculated.

Referring to Figure 12, since the model is able to determine the financial risk for each cost category separately, the individual curves can be produced for each category, with the combined cost also shown. As well as showing the total costs, it also gives a good overview of the main contributors to overall financial risk. From Figure 12 we can see that for frequent lower cost incidents the main contributors are business interruption and loss of inventory, whilst for infrequent high cost events the main contributors are injuries and fatalities. It should be noted however that this is only the case for this fictitious example and this does not represent a generic trend. The contributions from different categories are completely dependent on the specific model developed.

This type of curve can be of significant benefit in assessing appropriate levels for maximum insured losses and sensible levels for deductibles. The curve for all costs shows a rapid decrease in cumulative frequency of losses at around £1,000,000. Therefore the value of insuring for maximum losses in excess of this value is questionable, since the benefits are small and the likelihood of a larger loss is very low. Also, the cost of insuring for larger maximum total losses is likely to be significantly higher.

At the other end of the spectrum, it can be seen that the frequency of having a £1,000 event is around $3 \times 10^{-2}$ per year. Also, the F$ curve up to this point is almost horizontal indicating that this is likely to represent the base frequency for the occurrence of any event, and any event is likely to cost at least £1,000. This information is extremely useful in helping to decide on appropriate levels for setting deductibles.

Moving on to discuss Figure 13 in more detail, this forms part of the standard reports provided by the SAFETI model and illustrates the relative cost contribution of each scenario to the overall expected maximum loss. This, in conjunction with the original equipment failure costs illustrated in Figure 4 are of particular use in looking at the main financial risk contributors when deciding on risk mitigation and reduction strategies. For example, Figure 13 illustrates that the LNG Vessel 1 catastrophic rupture contributes 72% of the financial risk, whilst 16% is due to the 100 mm hole scenario. Since these two failure case contribute 88% of the risk of financial losses, focusing on these will significantly reduce the overall risk exposure.

Similar conclusions can be drawn from Figure 4 which shows original equipment failure costs and average accident cost every N years for a different example. Here we can see that Tank A1 contributes more than 50% of the financial risk, whilst around 40% of the financial risk overall is a result of business interruption. We can also deduce that without taking any risk reduction measures, we can expect to have an accident costing in excess $400,000 every 10 years or more.
5. CONCLUSIONS

Traditionally QRA has been used to ensure safe operation, usually from a compliance perspective. But, as demonstrated above, as well as costing lives, major accidents can have other social, environmental and economic consequences. Classical methodologies like QRA can be extended to evaluate a broader range of business risks and assess their financial impact – we have christened this $RA, or Financial Risk Analysis.

A methodology and model have been described which facilitate the estimation of the overall financial risks associated with process plant accidents. This model, SAFETI$ is an extension of the well known SAFETI QRA model. The same principles could be used with any fatality risk model to extend applicability to financial risk as described above.

Key benefits of using this kind of model are the ability to identify key contributors to financial risk, assess the benefits of different risk reduction strategies and their effects on the overall risk picture. The use of such models also provides an easily understandable way of assessing appropriate insurance levels and of demonstrating to senior management the benefits of financial risk analysis and how the overall operational risks can be reduced.

6. REFERENCES

7. ORBIT Onshore 2.4, On-line Documentation, 2005