2

RISK - ESTIMATION, PRESENTATION AND PERCEPTION

"Scientists may be able to explain the facts, but the facts rarely speak for themselves. The facts are interpreted by individuals who may behave in quite different ways to those which scientists or public policy makers or the industrialists originally intended."

Howard Newby (1997)

The previous chapter established the need for risk management and some of the important roles that risk management plays in a range of corporate, legal and social contexts. This chapter discusses the principal issues surrounding the measurement of risk, how it is estimated, how it can be presented for appropriate decision making and how it can be perceived by the stakeholders. It provides an overview that will be expanded in subsequent chapters.

2.1 MEASURES OF RISK

Here we investigate various risk measures that can be used for a variety of applications. These seek to address the key areas of process related risks given in Table 1-1.

2.1.1 Need for Risk Measurement

The discussion so far in Chapter 1 has established the following:

- All activities are associated with some risk.
- In order to make a commercial enterprise successful, it is necessary to identify and manage the risks.
- The two-dimensional nature of risk (likelihood and consequence) has to be recognised for effective risk management.
- Not only the experts' world-view of risk, but that of the non-expert should be given due consideration in the risk management process, if the latter have an input into decision making.
- A decision made based on risk assessment, followed by the implementation of a risk management process would go a long way to ensuring project success.

This raises the question:

'How do we know that a risk is low enough to be acceptable? In other words, how low is low enough?'

To answer this question, we need some measures of risk, so that relative risks can be compared.

2.1.2 Qualitative and Quantitative Measures

Risk measures can range from the purely qualitative to fully quantitative, accompanied by uncertainty analysis. In most cases of risk management, measures are applied along a continuum in order to ensure minimum work for the maximum effect. It is important that appropriate measures are used throughout the process life cycle and within a particular project. It is also important that the measures used in a project are commensurate with the stage of analysis and the level of understanding. Figure 2-1 shows the risk measurement continuum with some examples of techniques in each class.

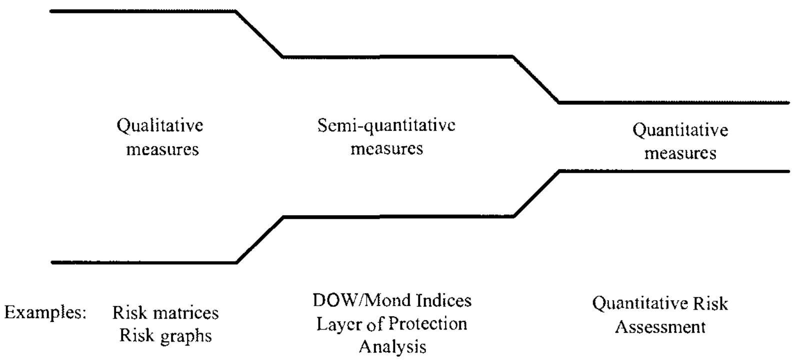

FIGURE 2-1 THE RISK MEASURES SPECTRUM

In Figure 2-1 we can observe a "funnelling" of activity, illustrating that in most cases, events or incidents that are identified can be sorted or ranked and dealt with appropriately across the spectrum. Qualitative analysis can be applied early in the risk management process to sort those events or incidents that need further detailed consideration. As one moves to the right of the risk measurement spectrum the effort expended in analysis and assessment goes up by an order of magnitude at each stage. This is because of the increased complexity and hence time and resources needed to carry out quantitative analyses compared with qualitative analyses. Hence, full quantification of risk is only needed in a minority of process system applications and only for a subset of all identified risks. Quantitative risk assessment (QRA) or probabilistic risk assessment (PRA) studies demand significant time and resources. Hence, only in the case of potentially high impact events are quantitative methods generally justified.

The other issue is to do with insight. By adopting a range of measures that are systematically applied, the analyst or team gains valuable insight into the main risk contributors and those that are low contributors by systematically working through the risk measure stages. This has important implications in the on-going management of these risks. The stage of the process or product life cycle in which the risk management activities take place will also determine the level of analysis possible and justifiable.

2.1.2.1 Qualitative measures

These are the simplest to apply. In adopting a two-dimensional view of risk that considers impact and likelihood as the two principal factors we can develop simple tools to firstly rate the impacts or severity as well as the likelihood for each identified event or incident in the system.

The simplest qualitative risk measure is the risk matrix as seen in Figure 2-2.

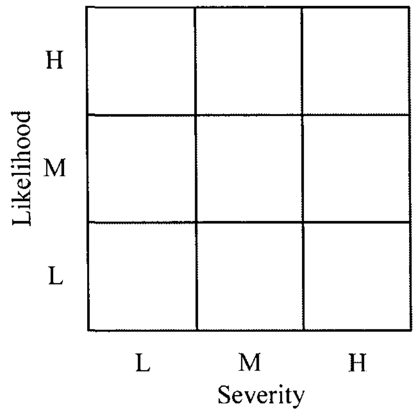

FIGURE 2-2 A RISK MATRIX

Here the two factors of severity and likelihood have 3 classes designated as low (L), medium (M) and high (H). Risk measures need to be allocated so as to place an event in the appropriate cell.

In practice a qualitative risk scale can be set up, such that the risks could be categorized as the product of the severity and the likelihood:

$H \times H$	$\rightarrow$	Extreme risk (E)
$H \times M$	$\rightarrow$	High risk (H)
$M \times M$ or $H \times L$	$\rightarrow$	Medium risk (M)
$M \times L$	$\rightarrow$	Low risk (L)
$L \times L$	$\rightarrow$	Negligible risk (N)

Clearly the extreme risks (E), reside in the top right hand corner of the matrix, whilst negligible risks (N) are located in the bottom left cell. Low to high risks are then distributed across the matrix. It is now possible to place events into a particular cell in the risk matrix. Further action can be taken for risk management purposes on those risks that are extreme or high. It allows ranking and prioritization to take place.

In practice a 3×3 matrix is too coarse to provide useful information for decision making. More complex versions are defined in Chapters 3 (Section 3.4) and 9.

Risk graphs are an alternative to risk matrices and these are discussed in section 9.2.5. They are simply an alternate representation of the basic severity and likelihood factors, and can also include exposure likelihood.

2.1.2.2 Semi-quantitative measures

These measures come in several forms. Risk can be estimated in a semi-quantitative way through the use of indices such as the Dow's Fire and Explosion Index or F&EI (AIChE, 1994a) which allows the estimate of both consequence and likelihood factors in a process unit. This allows a relative ranking of risk to be made for operating units within a process based on total energy content and possible release. Details of this technique are given in Section 4.3.7.1.

Other risk indices of this type include Dow's Chemical Exposure Index or CEI (AIChE, 1994b). Again this provides semi-quantitative analysis of toxic risks for prioritization purposes. (see section 4.3.7.2)

Other variants of these indices exist which attempt to classify risks into various categories. One such is the Safety Weighted Hazard Index (SWeHI) proposed by Khan et al. (2001). Others include insurance based indices such as the Instantaneous Fractional Annual Loss (IFAL) index (Whitehouse 1985).

2.1.2.3 Quantitative measures

Risk can be measured and presented in quantitative terms, where both the severity and the likelihood are quantified. Risk quantification is normally undertaken when acceptance or tolerability criteria are available for comparison or acceptance purposes. It can often be used to assess alternate designs and thus used in a relative risk approach. Quantitative criteria are often available for employee and public fatality and injury risk. In this case, the risk values that are computed take a variety of forms which include:

a) Individual fatality risk per year

b) Individual injury risk per year covering such issues as:
   - thermal radiation impacts
   - toxic exposures
   - explosion impacts
c) Societal or group risks that consider the fatality risk to more than 1 person.

Other quantitative risk measures can relate to:

d) Probability of specified levels of environmental impact per year
e) Probability of specific business losses in a year
f) Probability of specific public complaints in a year.

In what follows we introduce the societal risk concept first rather than individual risk, as the latter is a subset of the former.

2.2 SOCIETAL RISK

When a hazardous incident can affect a group of people, resulting in potential multiple fatalities, a societal or 'group' risk estimate is the most appropriate measure of impact. The number of fatalities depends on the area of impact, the population density within the area and the vulnerability of the population to the hazard.

Societal risk assesses risk to the exposed population as a whole, without being location specific. It is often expressed as the frequency with which a given number of fatalities may occur from the realisation of a hazard, or alternatively, the product of these two, known as Potential Loss of Life (PLL). This is often termed the expected value of the number of deaths per year.

The uncertainty in the assessment of societal risk is much higher than that for individual risk. The following information is required:

1. Population distribution over the potential impact area of an accident. This may be available only in well established population areas and not in new developments.
2. Probability of fatality given an accident in the area. This value depends on what is impacted - whether the object of impact is clear ground or a building, and the robustness of the building to take the impact.
3. Expected number of fatalities from the incident. The value depends on such factors as the degree of injury sustained and the availability and skills of emergency responders.

In spite of the uncertainties, it is useful to assess societal risk where it is possible, and where relevant data is available with minimal uncertainty. The societal risk is often expressed as a curve of frequency (F) versus number of fatalities (N), for a range of hazards, the F-N curve. A relative evaluation of risk reduction measures can be made by observing the movement of the curve. A typical set of F-N curves for historical accidents is seen in Figure 2-3.

2.3 INDIVIDUAL RISK

Individual risk is a measure or estimate based on the exposure of a person to a hazard. However, individual risk can be stated in various ways. These include:

(i) Location specific individual risk (LSIR)
The LSIR relates to an individual at a specific geographic location in the vicinity of a hazard who is exposed continuously to that hazard. No account is taken of evasive action in this case. This is dealt with in section 2.4.3.3. It is commonly used in land use planning criteria for fatality or injury.

(ii) Risk to the most vulnerable person.
This could be related to the young, elderly or an individual with some specific sensitivity to the hazard, such as an asthmatic to gas exposure. This measure is important in land use safety planning in the vicinity of major hazard facilities. However, this measure is difficult to calculate and is not normally used. Instead, the risk tolerability criterion is reduced.

(iii) Risk to most exposed worker per annum (IRPA). In this measure, the risk from each hazardous event on a worker category is calculated based on the area of impact and the probability of a nominated worker group present within the impact area, and summed over all the events. The worker groups include process operators, maintenance personnel and technical professionals. The risk is compared with an internal corporate criteria.

(iv) Averaged risk to exposed individuals
This relates to a risk value averaged across the whole exposed population to a particular hazard, such as the risk of fatality due to train travel. This is discussed in section 2.4.3.2. The average individual risk is the PLL divided by the exposed population, assuming that the risk is equally distributed among the exposed population.

(v) Averaged risk to total population
This is the risk to an individual in a population, whether or not the whole population is exposed to that risk (CCPS 2000). This measure is the equivalent of the PLL divided by the total population. The averaged risk to the total population is less than or equal to the averaged risk to the exposed population, since the total population is less than or equal to the exposed population.

Of the 5 different measures of individual risk described above, the most useful measures are the LSIR (used in land use safety planning decisions), IRPA (corporate criteria for employee risk), and averaged risk to an individual in exposed population (comparison measure for different types of risks).

What is important to remember is that individual risk values can be presented and estimated in different ways. To avoid confusion, the type of individual risk being considered needs to be clearly defined.

2.4 RISK ESTIMATIONS

Estimating risk is an important aspect of risk management. In many cases there are good historical data available for a wide range of human activities and for specific risk categories. In this section we review some of the key industry and societal risk estimates. These can be of importance in comparative studies of actual and predicted risks. They often provide a means of target setting which is the subject of section 2.6.24.

2.4.1 Units of Risk

Risk is essentially an abstract concept as it involves uncertainty. Risk estimation is largely concerned with the estimation of uncertainty. In the case of quantitative risk analysis (QRA), risk estimation is the quantification of uncertainty. Even though QRA risk results are expressed in numerical terms, the results must be considered in relation to other risks, or relative to risks from other options or activities, in order to make meaningful interpretations.

EXAMPLE 2-1 RISK UNITS

The following give some risk expressions:

- 1 chance of fatality per 10,000 per year (10^{-4} per year)
- 4 fatalities per 100 million worked hours in the plant (fatal accident rate of 4)
- Bulk road tanker accident probability of 3.2 per million truck-kilometres (3.2×10^{-6}/truck-km)
- 10% chance of an accident event within the lifetime of facility
- 5% chance of production loss for 1 week per year
- 1 in 1000 chance of a 2-tonne environmental spill per year

Depending on the category of risk (risk to people, environment or production loss risk), appropriate units are chosen.

The measure that is often used to define risk is time rate of loss events. For example, if an undesirable event or adverse outcome is chosen as fatality and the time period is taken as one year, then the risk unit is the probability of fatality per year.

Other measures are:

- Frequency of a major accident or incident. In nuclear power generation facilities, this could relate to the frequency with which a radioactive emission might occur that could escape off-site.
- Frequency of loss of defined percentage of production. In an open-cut coal mine, one measure of risk was the frequency with which total production could shut down, say, for two weeks. One cause could be a major failure of the drag line (e.g. drag line tipped over).
- Frequency of loss of defined percentage of assets.

It is clear that risk measurement requires the estimate of probability of occurrence of an event. This can be from historical data or can involve more complex causal analysis as discussed in Chapter 8.

2.4.2 Risk of Injury to People

In estimating historical measures of risk to people a number of established approaches for both injury and fatality are used. These relate to occupational risks in various industry sectors or specific activities. They are useful indices.

The measure conventionally used for lost time injuries is expressed as the Lost Time Injury Rate (LTIR). It is also sometimes referred to as Lost time injury frequency rate (LTIFR), even though the frequency and the rate refer to the same thing.

LTIR may be defined as the number of lost time injuries per million hours worked. It is calculated as follows:

$$\text{LTIR} = \frac{\text{Number of LTI} \times 10^6}{\text{Number of hours worked}} \qquad (2.1)$$

In some organisations, a basis of 100,000 hours is used instead of a million hours.

Other similar measures for measuring safety performance are:

a) Major injury severity rate:

$$\text{MISR} = \frac{\text{Number of days lost} \times 10^6}{\text{Number of hours worked}} \qquad (2.2)$$

(i.e. days lost due to lost time injuries per million hours worked)

b) Lost time injury incidence rate:

$$\text{LTIIR} = \frac{\text{Number of LTI} \times 100}{\text{Average number of employees}} \qquad (2.3)$$

Data on lost time injuries, number of days lost for different industries are collected by government agencies responsible for administering the health and safety at work.

2.4.3 Risk of Fatality

2.4.3.1 Fatal Accident Rate

For risk of fatality to employees, a commonly used index in the manufacturing industries is the fatal accident rate (FAR). It is used extensively in industry as a measure of risk.

FAR is defined as the number of fatalities per 100 million worked (exposed) hours. Historical FAR is normally calculated using fatality statistics over a defined period and an estimate of the total number of hours worked by all employees over this period:

$$\text{FAR} = \frac{\text{Number of fatalities over M years} \times 10^8}{\text{Total number of hours worked in M years}} \quad (2.4)$$

You can think of this as approximately equivalent to 1000 people each working for 40 years. The FAR provides a common basis for comparing industrial risks.

The fatal accident rates for a few industries in Australia are listed in Table 2-1.

In other contexts, FAR values are quoted in other units such as deaths per 100,000 workers per year (HSE, 2003). Values can be converted to other FAR definitions as well as to individual risk estimates.

TABLE 2-1 FATAL ACCIDENT RATES IN AUSTRALIAN INDUSTRY

Industry category	FAR
Mining (non-coal)	27
Mining (coal)	17
Agricultural, forestry	11
Construction	9
Chemicals, petroleum	4
Other manufacturing	3

Source: Calculated from Australian Bureau of Statistics data.

EXAMPLE 2-2 FAR RISK CONVERSIONS

British fatalities in the base metals, coke and extractive industries lie in the range of 6.4 to 8 fatalities per 100,000 workers per year (HSE, 2003). Assuming a 40 hour week and 48 week per year working period, the higher level equates to a FAR of:

$$\text{FAR} = \frac{8}{100{,}000\,\frac{\text{workers}}{\text{year}}} \cdot \frac{1}{\frac{40\text{ hours}}{\text{worker week}} \cdot \frac{48\text{ weeks}}{\text{year}}} = 4.1 \text{ per } 10^8 \text{ exposed hours}$$

Hence FAR = 4.1.

2.4.3.2 Average Individual Risk

Average IR is the risk of fatality to an individual in the exposed population. It is not person specific or location specific.

In the general community, analysis of fatalities for individuals can also be made, these based on historical data. Table 2-2 complied by Higson (1989), shows some average individual fatality rates in chances per million per year for various activities or events.

In these cases, the individual risk is calculated as:

$$\hat{I}_R = \frac{\text{number of deaths per year for event/activity}}{\text{exposed population to the event/activity}} \tag{2.5}$$

Voluntary and involuntary risks

In order to understand average individual risk, it is necessary to distinguish between voluntary and involuntary risks. A risk is "voluntary" when the person at risk has chosen to be exposed to the hazard. Of course, the real risks might not be truly appreciated. This applies to people who gamble, ride motor bikes, dabble in the stock market, climb mountains etc. The list is almost endless. Risk values to the population exposed to that risk are quoted in Table 2-2.

Most of the risks listed in Table 2-2 are voluntary. The voluntary risk values cannot be applied to a population not exposed to that risk. We all make choices every day which involve some form of risk. We may not consciously think about it but every time you get in your car and drive you are exposed to the hazards of injury or death.

TABLE 2-2 RISKS TO INDIVIDUALS IN NEW SOUTH WALES (Higson, 1989)

	Chances of Fatality per million person years
Voluntary Risks (average to those who take the risk)	
Smoking (20 cigarettes/day)	
• all effects	5000
• all cancers	2000
• lung cancers	1000
Drinking alcohol (average for all drinkers)	
• all effects	380
• alcoholism and alcoholic cirrhosis	115
Swimming	50
Playing rugby football	30
Owning firearms	30
Transportation Risks (average to travellers)	
Travelling by motor vehicle	145
Travelling by train	30
Travelling by aeroplane	
• accidents	10
Risks averaged over the Whole Population	
Cancers from all causes	
• total	1800
• lung	380
Air pollution from burning coal to generate electricity	0.07-300
Being at home	
• accidents in the home	110
Accidental falls	60
Pedestrians being struck by motor vehicles	35
Homicide	20
Accidental poisoning	
• total	18
• venomous animals and plants	0.1
Fires and accidental burns	10
Electrocution (non-industrial)	3
Falling objects	3
Therapeutic use of drugs	2
Cataclysmic storms and storm floods	0.2
Lightning strikes	0.1
Meteorite strikes	0.001

There is however another form of risk which is not voluntary. This is termed “involuntary” risk and it refers to a risk imposed on an individual or group of people by activities outside of their choice or control. For example, a local community might be exposed to the risk of injury or death by a rerouting of the transport of dangerous goods through their neighbourhood. It might arise from a new nearby process facility which could impose risks due to fires, explosions or toxic gas releases.

Withers (1988) uses a useful analogy in attempting to illustrate the meaning of a risk level of 1 in a million per year, which is a crucial target in many land use applications. It interprets the levels in terms of life expectancy due to various risks if we were to live for ever but for that single risk. These are given in Table 2-3.

When considering the risk of harm to population exposed to hazards, two measures of risk are used - individual risk and societal risk.

TABLE 2-3 RISK ASSESSMENT CRITERIA - INTERPRETING RISK LEVELS

Risk (activity)	Life Expectancy (years)
Smoking 40 cigarettes per day	100
Drinking a bottle of wine a day	1300
Driving a car 10 hours a week	3500
Struck by lightning	10,000,000
1×10^{-6} p.a. risk level	1,000,000

Source: Withers (1988)

2.4.3.3 *Location Specific Individual Risk (LSIR)*

Individual risk refers to the risk for any individual at a specified location. This is also referred to as Location Specific Individual Risk or LSIR. It refers to a location, and does not refer to any specific person.

The risk criterion assumes that *an* individual (any one, not a specific person) would be at the given location for 24 hours per day, 365 days per year. This is commonly referred to as the "tied to a post", or "peak individual risk" assumption. The basis for the assumption is to address members of the public at the given location who may not be able to escape from the location, when exposed to the hazard. This assumption may be reasonable for residential areas, but not for other land uses, where the location occupancy would be less than 100%, or there are vulnerable members of population who cannot escape without assistance (aged care or child care centres, hospitals etc). In order to accommodate this, the target criterion is increased for locations with lower occupancy, compared to residential areas, and reduced for sensitive land uses. The risk is still calculated as peak individual risk.

Hence the individual risk (LSIR) is the total risk from all (n) possible events or incidents that can impact on an individual at a specific location (x, y) from a particular operation. This can be given by:

$$I_{LSIR}(x,y) = \sum_{i=1}^{n} I_{R_i}(x,y) \tag{2.6}$$

where:

$I_{R_i}(x,y)$ = risk value for an event/incident i. (yr^{-1})

In the case of process operations, these events relate to fires, toxic gas releases and explosions. Also, the level of harm can be nominated. It could be fatality but can also be injury in terms of fire radiation or explosion overpressure. Section 9.5.2 discusses these risks.

Different target criteria are set for different land uses. (NSWDOP 1990; Ale 1991). It should be noted that risk criteria are mainly used to determine if the risk is "unacceptable". However, risks that are "not unacceptable" are not always

"acceptable". Such risks are still subject to the principle of continual risk reduction to reasonably practicable levels (the ALARP principle).

2.4.3.4 *Societal or group risk*

Societal risk attempts to address the issue of multiple fatalities or injuries. It is useful in assessing situations where other significant factors not addressed by individual risk are present. These could include:

- multiple fatalities in a process facility
- events which affect many people on and offsite such as a toxic gas cloud
- situations where a community might be exposed for a short period such as shopping complexes or sports fields
- transport situations where exposure time is brief and population densities vary along the route.

We are familiar with multiple road accident fatalities or where a number of people are killed or injured in an incident such as a plane crash, boating disaster or rail accident.

Why use such a risk measure? Recent events show that society is particularly averse to multiple deaths compared with a single, isolated death. An individual shooting death does not generate the same societal outrage as one that leads to many deaths as seen in Columbine (USA), Port Arthur (Australia) and Dunblane (Scotland). In a similar fashion we want to ensure that technology or other activities give rise to an extremely low risk of death for multiple fatalities.

Societal risk expresses the relationship between the frequency and the number of people suffering from a specified level of harm.

As seen in section 2.2 it is typically expressed as a frequency-number (F-N) curve. Figure 2-3 shows actual historical data for various categories of hazards (Technica 1987). Looking at these values, it is clear that historically, shipping in Australia has the highest societal risks for large loss of life followed by rail travel. For lower levels of fatality, air travel has the highest societal risk, with these relating to light aircraft operations.

How do we interpret such a graph? The curves on Figure 2-3 show historical data for various accident groups. The x-axis shows the number of fatalities (N) and the y-axis shows the fatality frequency at which N or more people are affected due to that activity. When N = 1 we do not have the same frequency value as average individual risk which is not the same as LSIR.

Estimation of societal risk requires the number of fatalities N_i from event I that occurs with frequency F_i. Hence for a value N, the frequency F_N is given by:

$$F_N = \sum_i F_i \quad \text{for events } i \text{ where: } N_i \geq N \tag{2.7}$$

Hence, F_N is the cumulative frequency of all events i where the number of fatalities N_i is greater or equal to a nominated value N. Software is readily

available to compute F-N curves (TNO 2004) and for smaller studies a simple spreadsheet suffices.

AUSTRALIAN GROUP RISKS

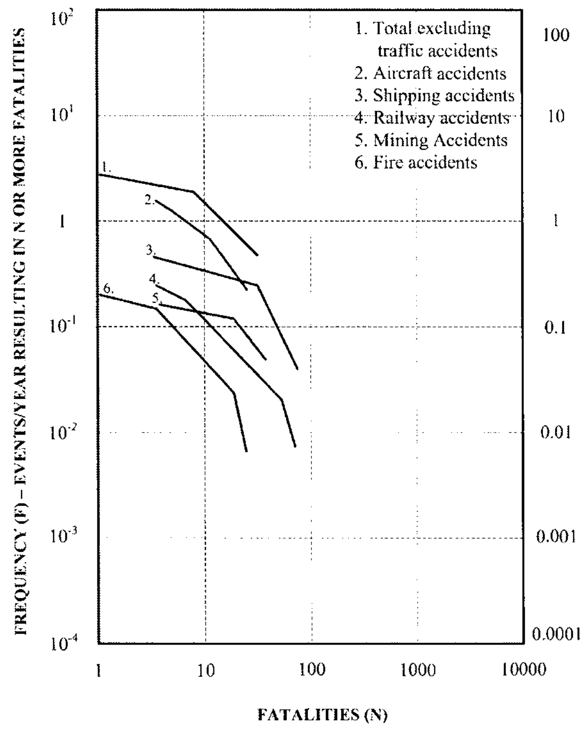

FIGURE 2-3 HISTORICAL GROUP RISKS FOR AUSTRALIA (SOURCE: TECHNICA 1987).

2.4.4 Corporate Reputation and Public Outrage Risk

Corporate reputation is a vital aspect of any company's risk management strategy. Reputation is a multifaceted concept just like risk assessment. Corporate rankings such as those given by the Fortune Survey involve a wide range of attributes that can include:

- quality of products and services
- social responsibility
- management quality
- innovative character
- employee talent
- use of corporate assets
- honesty and openness

The reputation of a corporation is directly related to the key stakeholders of that company. The shareholders can encompass those that live next to the operations as well as those who deal directly with the business. As such, corporate reputation risk is highly dependent on which attribute is to be highlighted.

EXAMPLE 2-3 CORPORATE REPUTATION

a) BHP Ok Tedi copper mine.
The corporate reputation of BHP, a large Australian resource company, was seriously affected by significant environmental damage in the Fly River of Papua New Guinea in the 1990's. It lead to significant opposition to other BHP mining developments in other countries and demands for tighter regulations on future developments.

b) Exxon Valdez
During a March night in 1989 the oil tanker Exxon Valdez struck a reef in Prince William Sound, Alaska. Over 11 million gallons of crude oil was released. The incident caused long term harm to Exxon's corporate reputation and led to the largest ever environmental fine on a US corporation.

c) Union Carbide, Bhopal
The 1984 catastrophe at Bhopal, India which led to massive loss of life and injury, severely damaged Union Carbide's reputation. The company has been vilified ever since by action groups. It continues, even after the Dow Chemical Company takeover in 2001.

Public outrage is clearly closely aligned with corporate reputation. The outrage can be of such a level that in the case of a major accident, government or communities can directly affect corporate liability or planning. Conversely, public outrage can positively contribute to improved risk management as seen for example in the demand for improved motorways that avoid major "blackspots".

Software such as EMSOFT (1989) developed by Sandman (1991) exists to predict outrage risk using well-documented outrage factors.

2.5 RISK REPRESENTATION

As seen in Section 2.1.2 risks can be measured in qualitative, semi-quantitative and fully quantitative forms. Qualitative risks are typically presented in risk matrix or tabular form for easy prioritization. With increasing quantification of risk more visual presentations are used.

2.5.1 Spatially Distributed Risks

Risks from sources that are geographically fixed, such as warehouses, process plants and storage terminals have spatially distributed risks that reduce as the distance from the hazard increases. This is typically represented in 3 ways.

2.5.1.1 Iso-risk contours

Iso-risk contours, that display contours of equal risk estimates projected onto an underlying land use map. This representation shows the spatial distribution of the risk.

Here the map of the facility and surrounding area is divided into a grid. At each point on the grid, individual risk is calculated and then contours joining equal risks are generated in a similar manner to a topographical map.

EXAMPLE 2-4 LPG STORAGE TERMINAL RISKS

Figure 2-4 shows the estimated iso-risk contours for an LPG storage facility. The contours relate to individual fatality risks (LSIR) from all hazard sources and show both 1 in a million per year and 10 in a million per year individual risk contours.

2.5.1.2 Risk transects

An alternate representation is the risk transect that shows the risk profile for a specified direction away from the source of the risk. This can be a useful alternative to the iso-risk contours in visualizing risk profiles.

Any plane can be proposed to represent a risk transect. Typically the transects are taken in key directions and pass through the centre of the facility being considered.

EXAMPLE 2-5 RISK TRANSECT, LPG FACILITY

For the LPG facility shown in Figure 2-4 we can view the individual fatality risk along various transects, in particular those directions which have the largest impact. Individual fatality risk along a NE-SW transect through the centre of the site is seen in Figure 2-5.

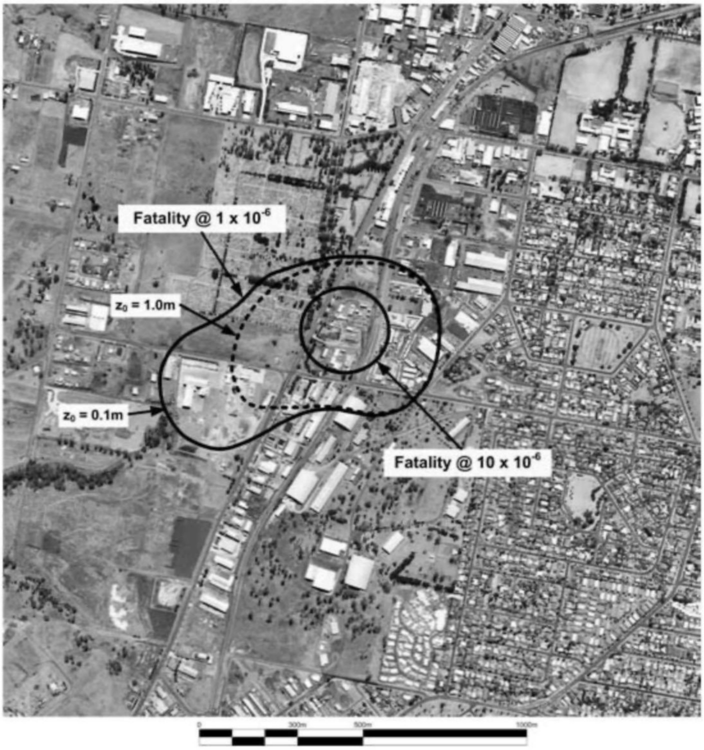

FIGURE 2-4 FATALITY RISK CONTOURS FOR LPG STORAGE FACILITY (ENERGEX 2003)

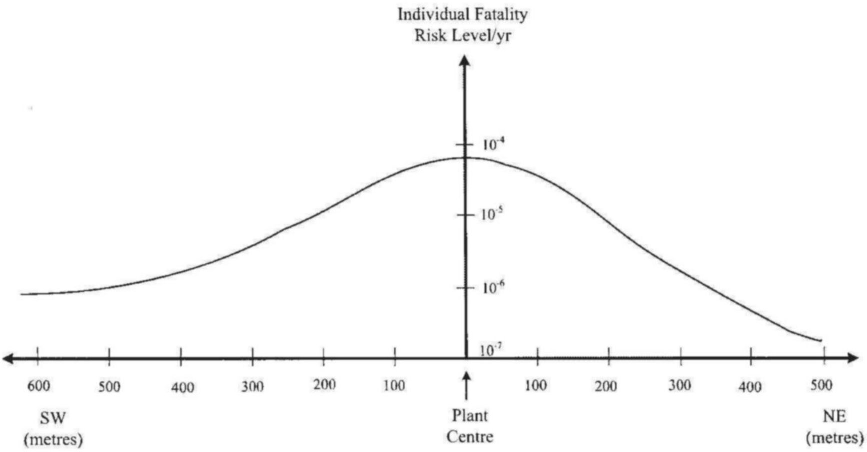

FIGURE 2-5 FATALITY RISK TRANSECT ALONG NE-SW PLANE

2.5.1.3 *Societal (group) risks*

In the case where multiple fatalities are important, risks can be displayed as a frequency-number or F-N curve displayed on a log-log plot. This displays the frequency of fatality (F) for N or more fatalities. This is seen in Figure 2-6. In this case there is a sharp cut-off in the area of 100 fatalities, illustrating a requirement on the facility design.

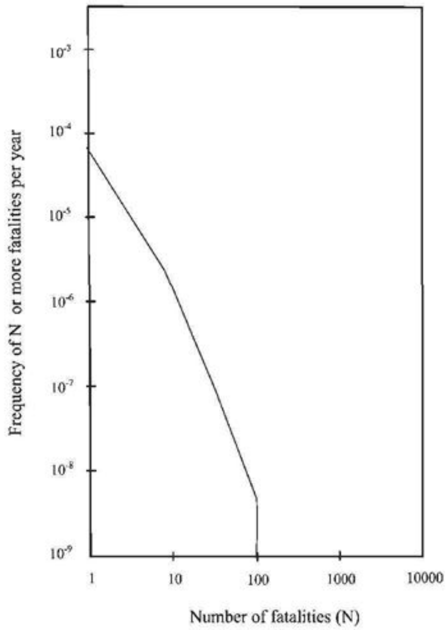

FIGURE 2-6 SOCIETAL RISK ESTIMATE FOR FACILITY

2.5.2 Linear Risks

In some cases, such as pipeline and transport risks, the hazard lies within a corridor such as a pipeline, railway easement or a highway. These are commonly called "linear" risks.

In these cases, the risks extend along the length of the corridor and reduce in the direction perpendicular to the corridor. Depending on the terrain, population density and activities along the corridor the risks will extend outwards to a greater or lesser extent. What is often preferable is a presentation of risk transects along the corridor at key locations of interest.

EXAMPLE 2-6 GAS OR LIQUID PIPELINE RISK TRANSECTS

Analysis of buried and above ground pipelines for risk management purposes is an important issue, especially where pipelines are near to local populations or sensitive environmental receptors. Figure 2-7 shows the individual fatality risk transects for a major natural gas pipeline of 0.45 m diameter and line pressure of 15.3 MPa. The line was buried to a depth of 1.2 m. The transects are given for both horizontal and vertical flames from the pipeline (Uniquest, 1995).

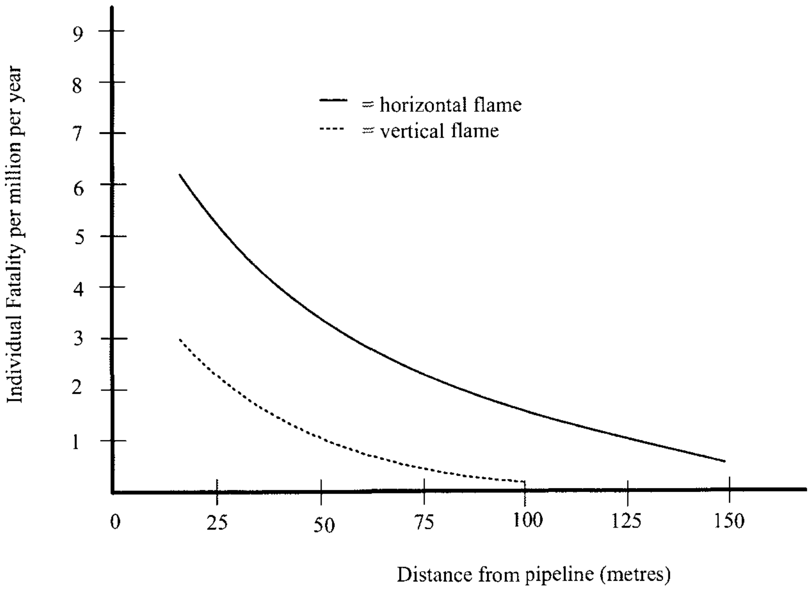

FIGURE 2-7 RISK TRANSECTS FOR GAS PIPELINE (SOURCE: UNIQUEST, 1995)

EXAMPLE 2-7 MARINE TRANSPORT RISKS

An analysis by the UK Health and Safety Commission (HSC, 1991) of gas carriers at the port of Felixstowe led to the risk contours shown in Figure 2-8. Around the port the risk contours show a typical radial geographic distribution. For the risks along the shipping canal the risks show a typical "linear" characteristic following the path of shipping traffic.

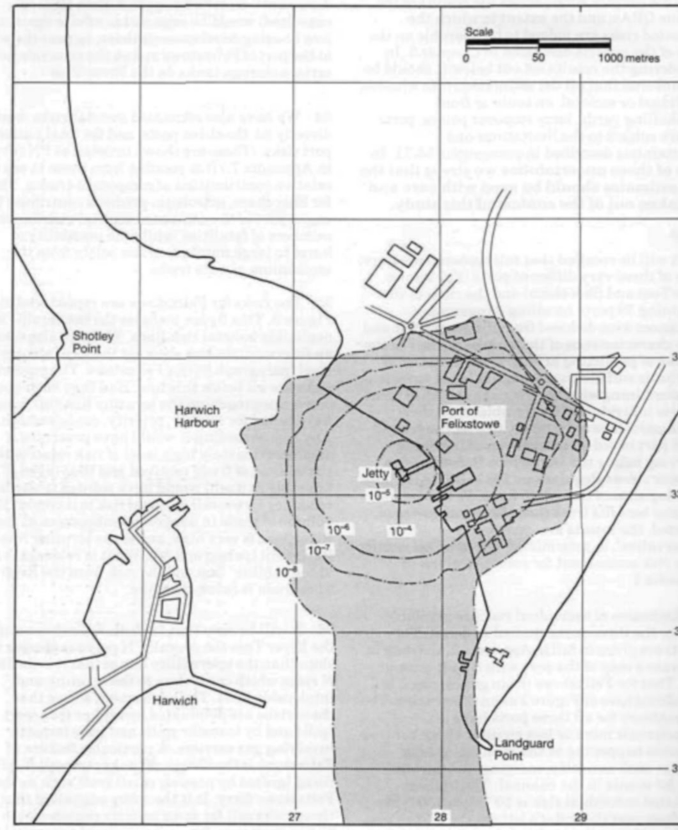

FIGURE 2-8 FELIXSTOWE (UK) INDIVIDUAL RISK FOR GAS CARRIERS (UK, HEALTH AND SAFETY COMMISSION, 1991)

2.6 RISK TARGETS, TOLERABILITY AND ACCEPTABILITY

2.6.1 Tolerability and Acceptability of Risk

A risk might be tolerated but not accepted due to the range of actual or perceived benefits to the individual or corporation that takes the risk. These two risk concepts are quite different.

In dealing with this issue the UK Health and Safety Executive (HSE, 2001) discusses the issues of risk being:

- tolerable
- unacceptable and intolerable
- broadly acceptable.

The HSE (HSE, 2001) comments that:

" 'tolerable' does not mean 'acceptable'. It refers instead to a willingness by society as a whole to live with a risk so as to secure certain benefits in the confidence that the risk is one that is worth taking and that it is properly controlled".

EXAMPLE 2-8 TOLERABLE AND ACCEPTABLE RISKS

We tolerate the risks of driving on busy motorways due to the benefits we derive and the general knowledge that controls such as speed restrictions, vehicle design or checks and good road design are in place. However, we might not consider the risk as 'acceptable' because we regard human life as sacrosanct.

In dealing with risk tolerability/acceptability, the concept of 'as low as reasonably practicable' (ALARP) is important. This is a process to reduce risks to a level that is technically feasible without excessive cost.

When determining if a risk is ALARP there are several parameters that should be considered:

1. Benefits versus cost–who gains the benefit and who wears the cost?
2. Is it technically possible to reduce the risk further?
3. Ethical issues come in–the risk may be low but is it right?
4. Do we have enough information to make the decision? – "the precautionary principle".
5. What happens if we do nothing to reduce the risk?
6. What happens if we do not proceed?

In general the decision is made by management or the management committee, or in some instances the regulator. However it must be remembered that risk is an assigned quantity and only gains acceptance by consensus, and therefore it could be soon that the ultimate decision-makers are those that will bear the cost.

What is clear is that application of ALARP is not simply a technical issue of benefit-cost analysis. Other important aspects such as relevant stakeholders, risk bearers and tolerability play their part in the application of ALARP (HSE 1992; Melchers, 2000; HSE, 2001).

Further considerations on the application of ALARP are given in Chapter 10 when discussing decision making under uncertainty.

2.6.2 Risk Target Setting

Setting of target risk for an activity has always been a difficult issue since the following factors need to be considered for which there are no ready answers:

- How safe is safe enough?
- How to strike an optimum balance between risk reduction and cost?
- What is an acceptable target?

For hazardous industries such as chemical or petroleum operations the above issues have been addressed in considerable depth during recent years, particularly because of risk to the public in residential areas surrounding installations.

Many countries have legislated for a target risk for LSIR to be achieved during the plant design stage as part of the environmental impact reporting and assessment methods for planning approvals. However, when it comes to societal risk, setting an acceptance criteria poses a problem. For instance, two values of PLL can be the same, one arising from say, a single fatality once in 2 years (PLL = 0.5 year), and the second, 5 fatalities once in 10 years (PLL = 0.5/ year). Numerically the PLL values may be the same, but the societal impact is vastly different, as it includes considerations such as public outrage, and the potential to impact on distinct population groups, such as a family or a business enterprise. In some cases, risk aversion factors can be applied to modify the PLL value by weighting multiple fatalities higher than single fatalities (CCPS 2000; Jonkman et al. 2002).

Because of the uncertainties associated with it, and several factors other than a numerical value of risk influencing decision making, no numerical criteria has been set for societal risk from industrial activities by such agencies as the NSW Department of Infrastructure, Planning and Natural Resources in Australia (DIPNR). This has followed a similar decision by the Health & Safety Executive in the UK (HSE 1990). Nevertheless, some criteria do exist, notably in The Netherlands (Ale, 1991; Jonkman et al. 2003) and in Hong Kong.

In the safety area, risk measures and targets have been well established for public risk from major hazard facilities and set in a regulatory framework, but no legislative target has been set for major risks to employees at the workplace. Many large companies have adopted internal standards consistent with industry average FAR values. The approach is performance-based, rather than prescriptive. Details of available targets are discussed in section 9.5.2.

Almost all organisations have targets for LTIR as this is a measurable quantity against which safety performance can be evaluated. However, it has been well established (Hopkins, 2000) that LTIR reduction does not implicitly mean a high degree of process safety management (PSM) performance.

For risks other than injury or fatality, such as business interruption risk, an organisation would set its goals based on financial considerations.

2.7 RISK PERCEPTION

"I am an expert, You are ignorant, They are irrational" was a pertinent quotation given by Howard Newby during a lecture entitled "Risk Analysis and Risk Perception: The social limits of technological change" (Newby 1997). The statements capture many common elements in risk perception and communication. The importance of perception is emphasized by the social psychologist W.I. Thomas who was quoted as saying:

"Things which are perceived as real will be real in their consequences"

This is certainly the case with the concept of risk, which has already been described in section 1.2.3 as an *ascribed quantity*. That ascription means risk is a "value-laden" quantity and an individual's risk perception creates a reality that must be appreciated in all risk management activities. This is the concept of the social amplification of risk (Kasperson et al. 1988). The key concepts in risk

perception are developed and discussed in this section. Failing to appreciate this in the risk management process, invariably spells disaster to any project.

2.7.1 The Importance of Risk Perception

The perception of risk has been a well-studied area over the last 30 years (Marshall 1990; Sandman 1991; Renn 1998; Walker et al. 1998; Pidgeon 1998; Slovic 2000; Renn 2004). Perception relates to the mental processes that take in, deal with and assess data via our many senses. Risk perception includes numerous factors that encompass beliefs, experiences, feelings and attitudes. It reflects wider cultural and social dispositions adopted towards threats to things that are valued (Pidgeon 1998).

Perceptions play important roles in a wide range of risk management areas including:

(i) Risk communication
(ii) Risk tolerability and acceptability, including criteria used for judgement
(iii) Policy making
(iv) Land use planning decisions
(v) Dealing with uncertainties
(vi) Trade-offs between cost and safety including the ALARP concept.

This simply enforces the fact that process risk management practice, although rooted in technical analysis, cannot afford to neglect the broader social perspectives that address such issues as fairness, benefits and loss of amenities to affected individuals or communities.

Everyone perceives risk in different ways as illustrated by Jesper Deleuran in Figure 2-9 (Grønberg & Rasmussen 1992). This is what makes risk presentation and communication such a challenge!

FIGURE 2-9 ATTITUDE TO LIFE'S RISKS (BY PERMISSION OF JESPER DELEURAN)

2.7.2 Factors Affecting Risk Perception

In acknowledging that individuals and communities often do not look at risks in the sole light of scientific analysis, Sandman (1991) suggested that an alternate form of risk expression can be given by:

Risk = Hazard + Outrage

The hazard is clearly identified by the individual and the person understands the potential for harm due to the proposed activity. They then respond to the hazard by a specific level of outrage that ranges from indifference to vigorous opposition!. That level of outrage is driven by a number of factors such as:

- The familiarity with the hazard
- Whether a recent incident has occurred elsewhere
- The perception that something is being hidden in the proposal
- The credibility of the proponent.

These factors and more, go to determine the level of 'outrage' produced. Sandman (1991) has given 12 principal outrage components which are listed in

Table 2-4. These components show what is generally regarded as "safe" and "risky". Table 2-5 gives a secondary list of outrage components which are known to be important.

TABLE 2-4 TWELVE PRINCIPAL OUTRAGE COMPONENTS

	"Safe"	"Risky"
1	Voluntary	Coerced
2	Natural	Industrial
3	Familiar	Exotic
4	Not memorable	Memorable
5	Not dreaded	Dreaded
6	Chronic	Catastrophic
7	Knowable	Unknowable
8	Individually controlled	Controlled by others
9	Fair	Unfair
10	Morally irrelevant	Morally relevant
11	Trustworthy sources	Untrustworthy sources
12	Responsive process	Unresponsive process

TABLE 2-5 EIGHT SECONDARY OUTRAGE COMPONENTS

	"Safe"	"Risky"
13	Affects average populations	Affects vulnerable populations
14	Immediate effects	Delayed effects
15	No risk to future generations	Substantial risk to future generations
16	Victims statistical	Victims identifiable
17	Preventable	Not preventable (only reducible)
18	Substantial benefits	Few benefits (foolish risk)
19	Little media attention	Substantial media attention
20	Little opportunity for collective action	Much opportunity for collective action

From these components, Sandman makes the following seven conclusions about hazard and outrage.

1. The public responds more to outrage than to hazard
2. Activists and the media amplify outrage, but they don't create it.
3. Outraged people don't pay much attention to hazard data.
4. Outrage isn't just a distraction from hazard. Both are legitimate and important.
5. When hazard is high, risk communicators try to nurture more outrage.
6. When hazard is low, risk communicators try to reduce the outrage.
7. Companies and agencies usually can't reduce outrage much until they change their own organizations.

This hazard + outrage definition is not necessarily technical but in fact is often the one which can dominate the whole risk management process.

Perceptions about hazards and risks must be taken seriously. No matter what technical advice is offered, people's perception of a risk can dominate the particular

issue. And there are good reasons why that is the case. How do we characterise our attitudes to risk?

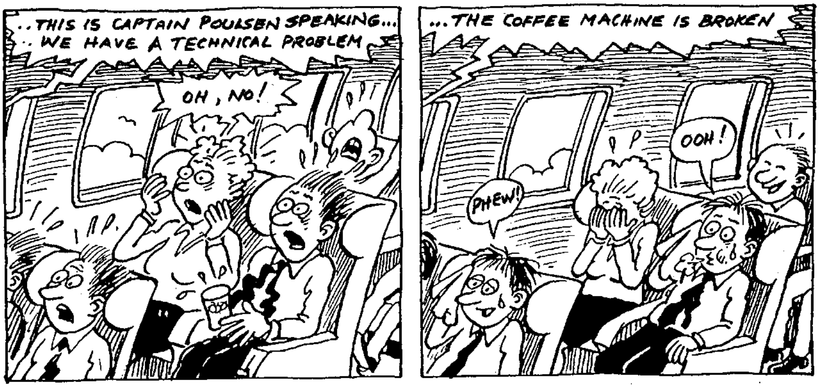

FIGURE 2-10 THE FLIGHT OR FRIGHT? (BY PERMISSION OF JESPER DELEURAN)

Some of the key characteristics are:

The familiarity we have with the risk:
- If we have personal knowledge about the risk then we are often more accepting of it.

Whether we are in control:
- We all think we do better than others etc. in driving a car we believe we have control over the risk of injury or death.

If there has been a recent incident:
- Our perceptions are heightened if there has been a recent incident e.g. a plane crash or multiple deaths in a vehicle accident.

Risk perceptions must be addressed by those proposing activities or by those responsible for planning decisions. Ultimately, the perception of risk, whether it is in line with actual risk values could be the final arbiter in decision making. Hence, perception becomes reality.

In the context of major hazard facilities (MHFs), which are dealt with at length in Chapter 14, risk perceptions play a major role. In particular, the understanding of risk perception is strongly influenced by the local context involving such aspects as (Walker et al. 1998):

(i) local memories of incidents
(ii) first hand experiences of accidents or emergencies at the site
(iii) sensory evidence such as things seen or smelled
(iv) interpretation of company information issued to the public

In contrast to the earlier quote about "They are irrational", a 1998 UK HSE sponsored study (Walker et al. 1998) showed that risk reasoning in local communities was quite complex and was often framed in moral rather than technical terms.

Lack of toleration to risks often stemmed from distrust, worry, a sense of powerlessness and vulnerability. In contrast, those that adopted a more tolerant attitude were characterised by pragmatism, stoicism or resignation. This polarization of views aligns closely with studies done by Allen (1997) where the cost versus safety debate typically produces a bimodal response. This is a key factor in application of ALARP principles considered in Chapter 10. All these factors simply reinforce the value-laden nature of risk management and emphasize the need to take seriously these aspects in risk management practice.

Subsequent chapters will reinforce the influence of values and perception on key areas of risk management.

2.8 REVIEW

We need risk measurement within effective risk management practice, be it qualitative or quantitative in character. Risk measures allow decision-making processes to take place in an informed manner. Decisions based on qualitative measures using simple rating systems can prove invaluable in sorting out what needs further attention and potentially more quantification.

As the chapter shows, there is a variety of ways that risks can be presented– most are visual, some need careful interpretation because of the many available risk definitions. This is one of the most difficult areas to grasp and one that can lead to much controversy if not clearly enunciated.

Chapters 9 and 10 expand on the issues of risk estimation and assessment as well as dealing in-depth with issues of risk criteria often used in decision making.

We have also emphasized that risk is an ascribed quantity and the perceptions of individuals or communities can have a major impact on the social amplification of risk. It will impact on risk presentation, decision making and communication. It is a theme that pervades other areas of risk management in the subsequent chapters of the book.

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2.10 NOTATION

AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonably Practicable
CCPS	Center For Chemical Process Safety, AIChE
CEI	Dow's Chemical Exposure Index
DIPNR	Department of Infrastructure, Planning and Natural Resources, NSW, Australia
F&EI	Dow's Fire And Explosion Index
FAR	Fatal Accident Rate
F-N	Frequency-Number of Fatalities (Curve)
IFAL	Instantaneous Fractional Annual Loss
IR	Individual Risk
LPG	Liquefied Petroleum Gas
LSIR	Location Specific Individual Risk
LTIFR	Lost Time Injury Frequency Rate
LTIR	Lost Time Injury Rate
LTIIR	Los Time Injury Incident Rate
MISR	Major Injury Severity Rate
PLL	Potential Loss of Life
PRA	Probabilistic Risk Assessment
PSM	Process Safety Management
QRA	Quantitative Risk Assessment
SWeHI	Safety Weighted Hazard Index