2.1

Qualitative and quantitative approaches to risk assessment

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2.1.1
Risk assessment

2.1.1.1
The importance of risk assessment

Risk assessment is a means not only to understand the risks that society (or a family or business) faces, with their potential probabilities and impacts, but also to provide a framework to determine the effectiveness of disaster risk management, risk prevention and/or risk mitigation.

It would be spurious to pretend that we fully understand all the hazards that society faces and their potential consequences. The process of risk assessment requires a structured approach. Without such a process, risks may be overlooked or implicit assumptions may be made. A risk assessment process requires transparency, opening up assumptions and options to challenge, discussion and review.

> *A structured approach is required to understand all the hazards that society faces and their potential consequences. This requires transparency, opening up assumptions to challenge, discussion and review.*

Risk assessment and mapping guidelines for disaster management (European Commission, 2010) and Overview of natural and man-made disaster risks in the EU (European Commission, 2014), provide a solid outline of the issues in a European context. The first outlines 'the processes and methods of national risk assessments and mapping in the prevention, preparedness and planning stages, as carried out within the broader framework of disaster risk management', whereas the second paper analyses 18 national contributions, identifying 25 hazards, both natural and man-made (malicious and non-malicious).

However, as an example of the importance of risk assessment, the experience of the insurance industry is presented, an industry that has been transformed by the adoption of an increasingly rigorous risk assessment and modelling process over the last 30 years. The lessons learnt are relevant to policymakers and practitioners in government.

2.1.1.2
Example: catastrophe risk and the insurance industry

As recently as the 1980s, the insurance industry's catastrophe risk assessment was almost entirely based on historical experience or 'rule of thumb' assumptions. Catastrophes are, by definition, rare events. It is very unlikely that a mega event will have occurred in recent years and, even if that were the case, it may have had unique features that may not reoccur. If we had a historical event, would it cause similar damage if it reoccurred? The global population is growing and getting wealthier, with the majority now concentrated in cities. Pressure of population growth has created the need to build on land that was wisely avoided by our forefathers. Growth may be unplanned with infrastructure, such as drainage not keeping up with the rate of development. People like living close to water, potential loss may be more than just scaling the historical loss by population change and wealth.

The need for a better approach was clear. In 1984 Don Friedman published a paper that would form the template for modelling insurance catastrophe risk over the following 30 years, breaking the process into hazard, exposure, vulnerability and financial loss. The first United States hurricane model to this template was produced by the reinsurance broker E.W. Blanch in 1987 (White and Budde, 2001), followed by the United States earthquake in 1988. Reinsurance brokers and reinsurers also lead the field in Europe; however, the early 1990s saw the rise of three major catastrophe modelling firms, which still dominated the industry in 2016.

These models were stochastic models — based not on a few historic hazard events but rather on a synthetic event made of many thousands of events that attempt to represent the range of possible events with their associated probabilities. The models required knowledge not only of what properties were insured and their value but also of their location, construction type and occupation. Engineering principles augmented by historical loss analysis attempted to understand the relationship between the event's manifestation at a particular location (e.g., peak ground acceleration, peak gust speed and maximum flood depth) and its likely damage. From this an overall damage estimate for any given property portfolio for each of the synthetic events could be calculated. If the probability of each synthetic event is then applied, we could understand the distribution off loss to the overall portfolio, for example what the annual average loss is and how big a loss from that hazard type can be expected every 5, 10, 20, 50 and 100 years.

> *The process of modelling catastrophe risk has transformed the reinsurance industry by increasing knowledge, scientific engagement, technical competence and, most importantly, the resilience of the industry — its ability to pay claims.*

Decisions could be made based on 'objective fact', not subjective opinion. Underwriters now had much more information to appropriately rate individual policies and to decide how much total risk they could accept across their portfolio and how much to off lay. The concept of risk/return entered the market. Firms began to clearly define their risk appetite to ensure appropriate levels of financial security and then seek to maximise return within that appetite.

It has not been a painless process. Initially, many saw the models as a panacea to the market's problems. There was a tendency by those unaware of the complexity of the models to believe the results. Arguably, the models were oversold and overbought: the vendors sold the models on their technical capabilities and the buyers bought them seeking certainty, but neither publically faced up to the inherent uncertainty within the models, despite growing pains in the process. However, this information has transformed the industry. Twenty years ago the most technical reinsurance broker had perhaps 3 % of staff engaged in risk analytics, whereas now this has become 25 % to 30 %. Chief risk officers were virtually unknown in the insurance industry 20 years ago; now they are embedded.

The models became a mechanism to raise debate above vague opinion to a discussion of the veracity of assumptions within the model. The models' data requirements led to a massive increase in the quality and quantity of data captured, leading in turn to improved models. Knowledge of catastrophe risk has grown immeasurably; firms have become smarter, more financially robust and therefore more likely to meet their claim obligations.

Whilst such modelling originally applied to catastrophe risk only, it has been extended to cover man-made hazards such as terrorism and more esoteric risk such as pandemic. Indeed, the EU's solvency II (Directive

2009/138/EC) an insurance regulatory regime, requires firms to understand all the risk they face, insurance and non-insurance (e.g., market risk, counterparty risk and operational risk), with the carrot that if they can demonstrate that they can adequately model their risks, then they may be allowed to use the capital requirement implied by their model rather than the standard formula. Regulators rather smartly realise that any firm willing and able to demonstrate such capacity and understanding is less likely to fail.

2.1.1.3
The key elements of risk assessment

Whilst the insurance industry is a special case, others are noticing that the same methods can be used to manage risks to governments, cities and communities. They can drive not only a better understanding of the risks that society faces but also a means to determine and justify appropriate risk planning, risk management strategies as well as public and investment decisions.

> *Risk assessment requires the identification of potential hazards as well as a knowledge of those hazard including their probability, what is exposed to that hazard and the vulnerability of that exposure to the hazard.*

Indeed, it can be argued that the process of risk assessment and modelling is more important than the results obtained. Risk assessment does not need to be as complex as a full stochastic model to add real value. Similarly, it is a common misunderstanding that a lack of good-quality, homogeneous data invalidates risk assessment. Any risk assessment methodology requires assumptions to be brought to light and so opened to challenge. Assumptions can then be reviewed, compared and stressed, identifying areas of inconsistency, illogicality, sensitivity and where further research should be concentrated.

The key steps in risk assessment are the following.

- Identify the hazards which might affect the system or environment being studied A brain-storming session to identify all potential hazards should be done at an initial stage. It is important to think beyond events or combinations of events that have occurred in order to consider those that may occur.

- Assess the likelihood or probability that hazards might occur: inputs to this process include history, modelling, experience, corporate memory, science, experimentation and testing. In practice, events with a very, very low probability (e.g. meteor strike) are ignored, focussing on ones more likely to occur and can be either prevented, managed or mitigated.

- Determine the exposure to the hazard, i.e. who or what is at risk.

- Estimate the vulnerability of that hazard to the entity exposed in order to calculate the physical or financial impact upon that entity should the event occur. This may be obtained by a review of historical events, engineering approaches and/or expert opinion and may include the ability of the system to respond after the event so as to mitigate the loss.

- Estimate the potential financial and/or social consequences of events of different magnitudes.

2.1.1.4
Risk tolerance

The likelihood of the hazard and its consequences needs to be compared with the norms of tolerability/acceptability criteria that society or an organisation has formulated. If these criteria are met, the next step would be to manage the risk so that it is at least kept within these criteria and ideally lowered with continuous improvement.

If the risk criteria are not met, the next step would be risk reduction by either reducing exposure to the hazard or by reducing vulnerability by preventative measures or financial hedging, typically through traditional indemnity insurance that pays upon proof of loss, but also increasingly through parametric insurance that pays upon proof of a defined event occurring. Insurance-like products can also be obtained from the financial markets by means of catastrophe or resilience bonds.

In industry, reducing event likelihood is normally the preferred method, since this dimension is amenable to improving reliability and enhancing the protective measures available. In many cases, these can be tested, so are therefore often a dominant feature of risk reduction. Estimating the potential severity of the hazard is harder and often leaves much to expert opinion. If risk cannot be credibly reduced in industry, it may lead to the cessation of an activity. Ideally, a hazard would be completely avoided: a fundamental step in the design of inherently safer processes.

However, for natural hazards and climate risk, where hazard likelihood reduction is often impossible, it is required to work on exposure and vulnerability. Building codes, for example the EU standard Eurocodes, encourage appropriate resilience in design and construction and can include 'build back better' after an event. Spatial planning and the delineation of hazard zones of various levels can promote development in areas less exposed to risk.

Risks can never be eliminated but they can be managed and their consequences reduced, at a cost. Defining risk tolerance allows informed, cost-effective risk management decisions.

The insurance mechanism can be used to encourage appropriate risk behaviours, penalising poor construction, maintenance or location by reduced cover or higher premiums and rewarding mitigation measures, e.g. retro-fitting roof ties in tropical cyclone-exposed areas or installing irrigation systems for crops by premium reductions.

2.1.2
Risk identification process

2.1.2.1
The importance of risk identification

It is necessary to identify unwanted hazardous events (i.e., atypical scenarios) and their consequences. It is very important to include all these in a study. If a possible hazard is overlooked, it will never be assessed. Unfortunately, there are many examples of this failure (Gowland, 2012).

In all risk assessment methods, the failure to include these 'atypical' scenarios will present problems. Examples include the major fire and explosion at Buncefield (December 2005) and the tsunami that inundated the Fukushima nuclear power station (March 2011). Identification of all potential hazards is absolutely fundamental in ensuring success.

The United Kingdom Health and Safety Executive has identified and reviewed almost 40 hazard identification methods.

The scope and depth of study is important and relevant to purpose and the needs of users of the assessment. It is necessary to identify all hazards so that a proper risk assessment may be made. When we are open to considering potential deviations we need to make sure that we are open-minded enough to consider all possibilities even when they may seem to be remote.

It is important to consider all potential hazards, natural and man-made, and their possible interactions and consequences. The process should not be limited to events known to have happened in the past, but also to consider what could happen.

Methods in use greatly depend on the experience of the persons carrying out the study. This is normally a team activity, and how it is made up is important and should be drawn from persons familiar with the technology or natural phenomena and the location being considered. Techniques adopted range from relatively unstructured 'brainstorming' through to the more structured 'what if' analysis.

Potential risks may not be obvious and may not have occurred in the past. It is vital to seek to identify what could occur as well as the consequences.

Other more formalised processes exist in industry, though, including failure mode and effect analysis (FMEA) and the highly structured hazard and operability (HAZOP) study, both of which look to identify hazardous events and to locate causes, consequences and the existing preventive measures. FMEA was developed for the automobile industry and HAZOP was developed for the chemical and process industry. However, similar studies can be applied to any field of risk. For example, the HAZOP (Tyler et al., 2015) use of guide words and deviations, which might seem to be limited to the industry where first applied, can be adjusted or replaced with those relevant to the field being studied; this has been demonstrated in the mining industry in Australia, where modified chemical industry methods have proved useful.

2.1.2.2
What if

This is a form of structured team brainstorming. Once the team understands the process or system being assessed and the kind of risks (potential exposures and vulnerabilities), each discreet part or step is examined to identify things that can go wrong and to estimate their possible consequences.

> *A team of experts brainstorming is one way to flush out potential risks, but it is important to use a panel of experts whose experience covers all aspects of risk.*

In order to carry this out successfully, we must stress the need for the team to be properly qualified and to have a full set of data relating to the system being studied. This would include operating instructions, process flow sheets, physical and hazardous properties of the materials involved, potentially exposed persons, environment or assets, protective systems. Most users will simply estimate the likelihood and severity of consequences in a similar way to that used in risk matrix applications.

A brainstorming exercise has the side benefit of encouraging a wide participation in the risk identification and assessment process, increasing ownership of the ultimate conclusions.

2.1.2.3
Failure mode and effect analysis (FMEA)

FMEA is a rigorous, step-by-step process to discover everything that could go wrong in a task or process, the potential consequences of those failures and what can be done to prevent them from happening. In this way, it can be used in risk assessment in industry. As shown in Figure 2.1, it comprises a systemised group of activities designed to:

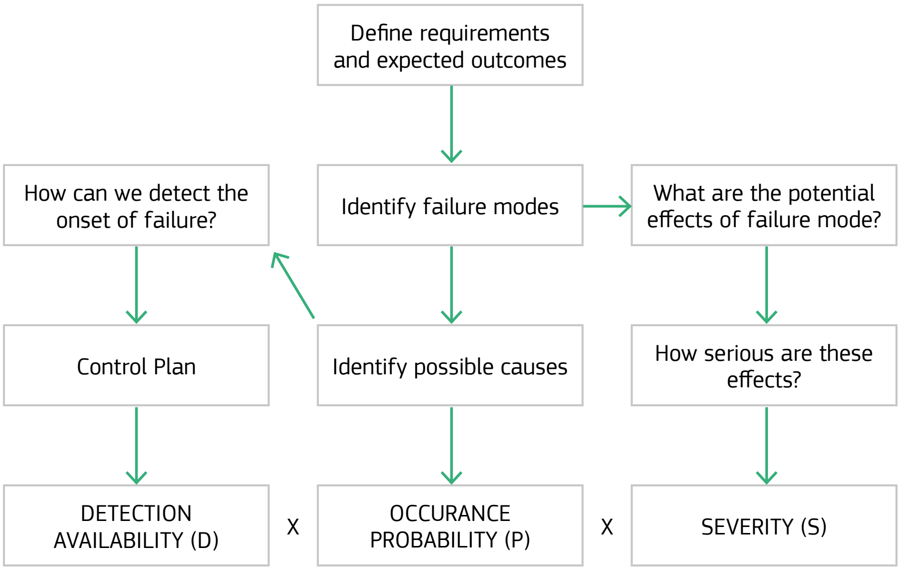
- recognise and evaluate the potential failure of a process or equipment and their effects;
- identify actions which could eliminate or reduce the chance of potential failure;
- document the process.

It captures:

- the failure mode, i.e., what could go wrong;
- the effect analysis, i.e., how it would happen, how likely it is to go wrong and how bad it would be.

FIGURE 2.1

A graphic illustration of the FMEA process.
Source: courtesy of authors



A very good example of a high-risk and high-priority project is the space shuttle where we put fragile human lives in a tin can and send them to space, hoping to get them home safely. Considering the complexity of the shuttle, there are many possible items which can fail, and they all have individual failure modes and effects. Lives are at risk and space shuttles are expensive. FMEA is a tool used to provide a structured process to understand and thereby minimise risk.

FMEA is a structured what-if process widely used in the process industries and provides a template for other potential applications.

The three distinct assessments for each of the three strands of this methodology, detection availability, occurrence probability and severity, are each given a rating: D, P and D, respectively. Risk ranking is calculated by multiplying these factors to give a single rating D x P x S. A risk matrix may be used to illustrate this process (see Chapter 2.1.4.3.).

2.1.2.4
Hazard and operability study (HAZOP)

The technique of HAZOP has been used and developed since the 1970s for identifying potential hazards and operability problems caused by 'deviations' from the design intent of a part of a production process or a procedure for new and existing operations. The technique is most associated with identifying hazardous deviations from the desired state, but it also greatly assists the operability of a process. In this mode it is very helpful when writing operating procedures and job safety analysis (Tyler et al., 2015).

Processes and procedures all have a design intent which is the desired normal state where operations proceed in a good way to make products in a safe way.

With this in mind, equipment is designed and constructed, which, when it is all assembled and working together, will achieve the desired state. In order to achieve this, each item of equipment will need to consistently function as designed. This is known as the 'design intent' for that particular item or section of the process.

HAZOP is a what-if process identifying potential hazards caused by 'deviations' from the design intent of a part of a production process or procedures.

Each part of this design intent specifies a 'parameter' of interest. For example, for a pump this could be flow, temperature or pressure. With a list of 'parameters' of interest, we can then apply 'guide words' to show deviations from the design intent. Interesting deviations from the design intent in the case of our cooling facility could include less or no flow of water, high temperature or low (or high) pressure. When these deviations are agreed, all the causes associated with them are listed. For example, for no or less flow, causes will include pump failure, power failure, line blockage, etc.

The possible hazardous consequences can now be addressed, usually in a qualitative manner without significant calculation or modelling. In the example, these might be, for example, for line blockage pump overheats or loss of cooling to process, leading to high temperature problems with product.

These simple principles of the method are part of the study normally carried out by a team that includes designers, production engineers, technology specialists and, very importantly, operators. The study is recorded in a chart as in the study record. A decision can then be made about any available safeguards or extra ones that might be needed — based on the severity or importance of the consequence.

It is believed that the HAZOP methodology is perhaps the most widely used aid to loss prevention in industry. The reason for this can be summarised as follows:

- it is easy to learn;
- it can be easily adapted to almost all the operations that are carried out within process industries;
- no special level of academic qualification is required.

2.1.3
Risk analysis methodologies

2.1.3.1
Types of risk analysis

Risk analysis is a complex field requiring specialist knowledge and expertise but also common sense. It is not just a pure scientific field but will necessarily include judgements over issues such as risk appetite and risk management strategy. It is vital that the process be as comprehensive, consistent, transparent and accessible as possible. If a risk cannot be properly understood or explained, then it is difficult if not impossible for policymakers, companies and individuals to make rational choices.

The appropriate form of risk analysis will depend on the purpose and the data available from simple scenarios to full probabilistic analysis, but all can lead to better decision-making.

Currently, there is no universally agreed risk analysis method applied to all phenomena and uses, but the methods used rather are determined by a variety of users, such as industrial and transport companies, regulators and insurers. They are selected on the basis of their perceived relevance, utility and available resources. For example, a method adopted in industry may not be suitable in the field of natural hazards. Legal requirements may also dictate the degree of study as well as such factors as the 'allowable' threat to the community. This last matter is common in 'deterministic' risk analysis where the requirement may be that there is no credible risk for a community in the location of an industrial operation.

Deterministic methods consider the consequences of defined events or combinations of events but do not necessarily consider the probability of these events or guarantee that all possible events are captured within the deterministic event set. Often this is the starting point for risk analysis. At the other extreme, stochastic or probabilistic analysis attempts to capture all possible outcomes with their probabilities; clearly coming with a much higher data and analytical requirement and, if correct, forming the basis for a sophisticated risk assessment process.

2.1.3.2
Deterministic methods

Deterministic methods seek to consider the impact of defined risk events and thereby prove that consequences are either manageable or capable of being managed. They may be appropriate where a full stochastic model is impossible due to a lack of data; providing real value whilst a more robust framework is constructed.

Risk standards may be set at national and international level and, if fully complied with, are believed to prevent a hazard that could impact the community. This is akin to the managing of risk in the aviation industry, where adherence to strict rules on the design and operation of aircraft and flights has produced a very safe industry. The same approach to rule- based operations exists in some countries and companies.

How are deterministic events framed? For example, to check the safety of an installation against a severe flood, severity is assessed according to the worst recently seen, the worst seen in the last 20 years or the worst that may be expected every 100 years based on current climatic conditions and current upstream land use. A different choice of event will have a different outcome and potentially a very different conclusion about manageability. Can we ensure that all deterministic events used in risk assessment across hazards are broadly equivalent in probability? If not, assessments and conclusions may be skewed.

Deterministic methods seek to consider the impact of defined risk events and thereby prove that consequences are either manageable or capable of being managed.

In recent times there has been a shift from a totally rule- based system to one where an element of qualitative, semi- quantitative and quantitative risk assessment (QRA) may influence decisions. But deterministic risk assessment is also carried out as a reality check for more complex stochastic models and to test factors that may not be adequately modelled within these models.

For example, over the past 20 years the insurance industry has enthusiastically embraced advances risk assessment techniques, but deterministic assessment of the form 'if this happens, this is the consequence' is still required by regulators. They may be referred to as:

- a scenario test, where a defined event or series of events is postulated and the consequences assessed;
- a stress test, where pre-agreed assumptions of risk, for example implied within a business plan (e.g. interest rate assumptions), are stressed and challenged to determine their impact on results and company sustainability;
- a reverse stress test, where events or combinations of events are postulated that could cause insolvency of the firm if unhedged.

Scenario, stress and reverse stress tests may be informed by science and modelling or expert opinion, or both, and often an assessment of probability will be estimated. Insurance regulators often focus on a 0.5 % probability level as a benchmark, i.e. the worse that may be expected every 200 years. If stress and scenario tests give numbers for an estimated 1 in 200 events that the stochastic model says could happen, say, every 10 years, then it casts doubt on the assumptions within the model or the test itself — they could be assessed and challenged. Similarly, the framing of multievent reverse stress tests may challenge assumptions about dependency and correlation within the model.

Realistically, deterministic methods are not 100 % reliable, taking as they do only a subset of potential events, but their practical performance in preventing hazard -impacting communities is as good and in some cases even better than other methods. If properly presented they can be clear, transparent and understandable. The process of developing deterministic stress and scenario sets can also be a means to engage a range of experts and stakeholders in the risk analysis process, gaining buy-in to the process.

Whether rules and standards derived from such tests work may depend on the risk culture of the region or firm where the risk is managed. Some risk cultures have a highly disciplined approach to rules, whereas others allow or apparently tolerate a degree of flexibility. Furthermore, the effort required to create, maintain and check for compliance where technical standards are concerned is considerable and may be beyond the capacity of those entrusted with enforcement.

2.1.3.3
Semi-quantitative risk analysis

Semi-quantitative risk analysis seeks to categorise risks by comparative scores rather than by explicit probability and financial or other measurable consequences. It is thus more rigorous than a purely qualitative approach but falls short of a full comprehensive quantitative risk analysis. But rather like deterministic methods, it can complement a full stochastic risk analysis by inserting a reality check. Semi-quantitative methods can be used to illustrate comparative risk and consequences in an accessible way to users of the information. Indeed, some output from complex stochastic models may be presented in forms similar to that used in semi-quantitative risk analysis, e.g., risk matrices and traffic light rating systems (for example where red is severe risk, orange is medium risk, yellow is low risk and green is very low risk).

Semi-quantitative risk analysis seeks to categorise risks by comparative scores rather than by explicit probability and financial or other measurable consequences.

A risk matrix is a means to communicate a semi-quantitative risk assessment: a combination of two dimensions of risk, severity and likelihood, which allows a simple visual comparison of different risks.

Severity can be considered for any unwanted consequence such as fire, explosion, toxic release, impact of natural hazards (e.g. floods and tsunamis) with their effects on workers and the community, environmental damage, property damage or asset loss. A severity scale from minor to catastrophic can be estimated or calculated, perhaps informed by some form of model. Normal risk matrices usually have between four and six levels of severity covering this range with a similar number of probability scales. There is no universally adopted set of descriptions for these levels, so stakeholders can make a logical selection based on the purpose of the risk assessment being carried out. The example depicted in Figure 2.2, below, is designed for risk assessment by a chemical production company and is based on effects on people. Similar matrices can be produced for environmental damage, property or capital loss. See also Chapter 2.5, Figure 2.21 for the risk matrix suggested by European Commission (2010).

In this illustrative example the severity scale is defined as:

- insignificant: minor injury quick recovery;
- minor: disabling injury;
- moderate: single fatality;
- major: 2 -10 fatalities;
- severe: more than 11 fatalities.

Similarly, the likelihood scale is defined as:

- rare: no globally reported event of this scale — all industries and technologies;
- unlikely: has occurred but not related to this industry sector;
- possible: has occurred in this company but not in this technology;
- likely: has occurred in this location — specific protection identified and applied;
- almost certain: has occurred in this location — no specific protection identified and applied.

When plotted in the matrix (Figure 2.2), a link may be provided to rank particular risks or to categorise them into tolerable (in green), intermediate (in yellow and orange) or intolerable (in red) bands. A risk which has severe consequences and is estimated to be 'likely' would clearly fall into the intolerable band. A risk which has minor consequences would be intermediate and 'very rare' in likelihood would be in the tolerable band. For risks which appear in the intolerable band, the user will need to decide what is done with the result.

There are choices to be made, either to reduce the severity of the consequence or the receptor vulnerability and/or to reduce the event's likelihood. All may require changes to the hazardous process. Many users would also require intermediate risks to be investigated and reduced if practicable.

Some users apply numerical values to the likelihood and/or severity axes of the matrix. This produces a 'calibrated' matrix.

The following matrix, in Figure 2.3 is derived from the Health and Safety Executive's publication Reducing risks, protecting people (2001) as well as from its final report on the

FIGURE 2.2

A risk matrix
Source: courtesy of authors

LIKELIHOOD	CONSEQUENCES				
	Insignificant	Minor	Moderate	Major	Severe
Almost Certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Buncefield fire and explosion, Safety and environmental standards for fuel storage sites (2009).

Sometimes matrices are used to compare different risk types as per this example from the United Kingdom's National risk register of civil emergencies report (2015). Such matrices are intuitively attractive, but in practice they can be misleading (Cox, 2008).

Very often an assessment of both frequency and severity is highly subjective and so can greatly differ , even when produced by two people with similar experiences; the impact of expert judgement can be profound (Skjong and Wentworth, 2001). It is vital for reasoning to be given for any

FIGURE 2.3

A calibrated risk matrix
Source: Health and Safety Executive (2001, 2009)

FREQUENCY/ LIKELIHOOD		SINGLE FATALITY	2 - 10 FATALITIES	11 - 50 FATALITIES	51 - 100 FATALITIES	101+ FATALITIES
Likely	$>10^{-2}$/yr	Intolerable	Intolerable	Intolerable	Intolerable	Intolerable
Unlikely	$>10^{-4}$/yr but $<10^{-2}$/yr	Tolerable (but intolerable if individual risk of fatality $>10^{-3}$/yr)	Tolerable (but intolerable if individual risk of fatality $>10^{-3}$/yr)	Intolerable	Intolerable	Intolerable
Very unlikely	$>10^{-6}$/yr but $<10^{-4}$/yr	Tolerable	Tolerable	Tolerable	Tolerable	Intolerable
Remote	$>10^{-8}$/yr but $<10^{-6}$/yr	Broadly Acceptible	Broadly Acceptible	Tolerable	Tolerable	Tolerable

FIGURE 2.4

A comparative risk matrix
Source: United Kingdom Cabinet Office (2015)

OVERALL RELATIVE IMPACT SCORE	Between 1 in 20,000 and 1 in 2,000	Between 1 in 2,000 and 1 in 200	Between 1 in 200 and 1 in 20	Between 1 in 20 and 1 in 2	Greater than 1 in 2
5				Pandemic Influenza	
4			Coastal Flooding Widespread electricty failure		
3		Major transport accidents Major industrial accidents	Effusive volcanic eruptions Emerging infectuaous diseases Inland flooding	Severe space weather Low temperatures/heavy snow Heatwaves Poor air quality events	
2		Public disorder Severe wildfires	Animal diseases Drought	Explosive volcanic eruption Storms and gales	
1			Disruptive industrial action		

RELATIVE LIKELIHOOD OF OCCURING IN NEXT 5 YEARS assessment, therefore allowing debate and challenge.

If subject to a full probabilistic modelling exercise, we would not just have one value for coastal flooding but rather a complete distribution of coastal floods from frequent but very low severity to rare but very high severity.

Which point of the curve should be picked for each peril? Different selections will give very different impressions of comparative risk.

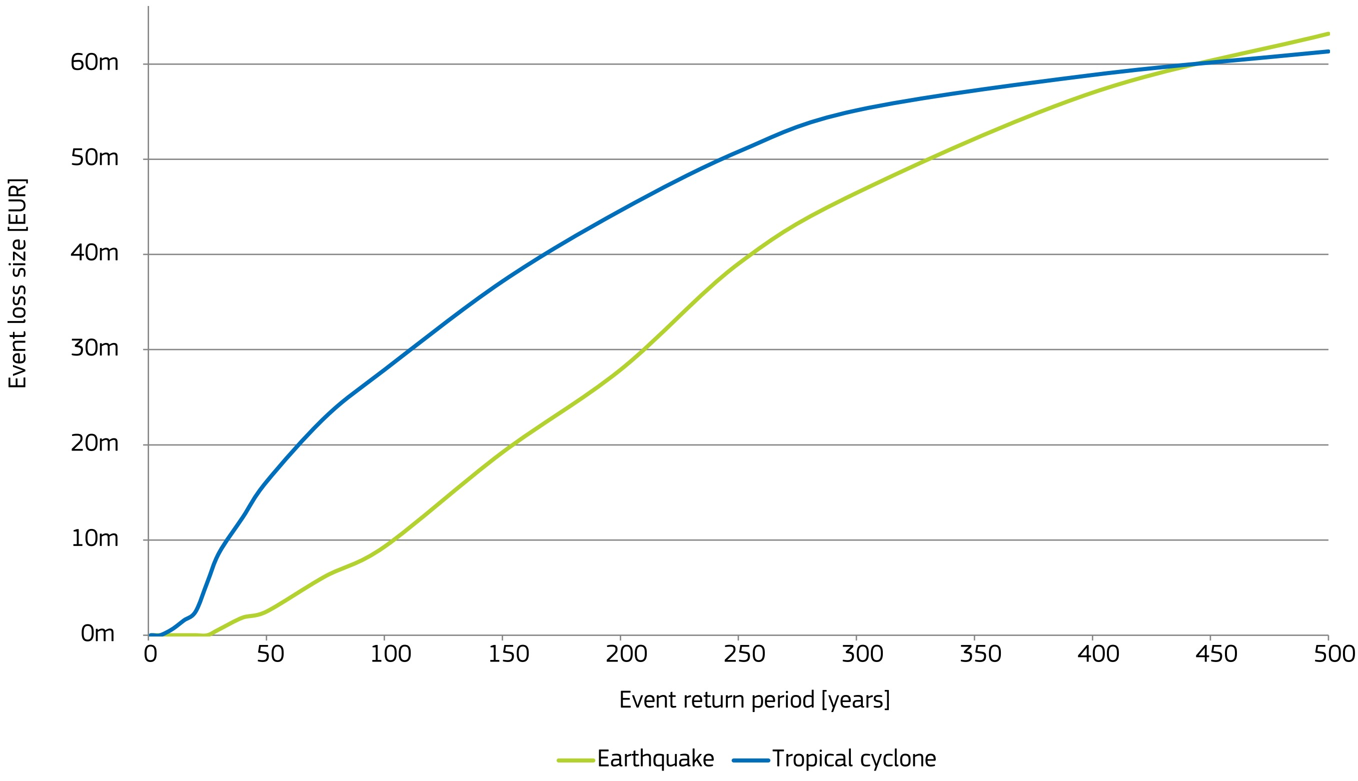
Semi-quantitative methods can be a useful stepping stone towards a full quantitative system, particularly where detailed data are lacking, and can be used as a means to capture subjective opinion and hold it up to challenge, opening debate and becoming a framework to identify where additional analytical effort is required.

2.1.3.4
Probabilistic risk analysis

This method originated in the Cold War nuclear arms race, later adopted by the civil nuclear industry. It typically attempts to associate probability distributions to frequency and severity elements of hazards and then run many thousands of simulated events or years in order to assess the likelihood of loss at different levels. The method is often called Monte Carlo modelling after the gaming tables of the principality's casinos. These methods have been widely adopted by the insurance industry, particularly where problems are too complicated to be represented by simple formulae, including catastrophic natural hazard risks.

FIGURE 2.5

Anonymised insurer comparative event exceedence curve
Source: Willis Towers Watson



A commonly used generic term for these methods is QRA or probabilistic or stochastic risk modelling. Today it is frequently used by industry and regulators to determine individual and societal risks from industries which present a severe hazard consequence to workers, the community and the environment. EU legislation such as the Seveso III directive (Directive 2012/18/EU) requires risks to be mapped and managed to a tolerable level. These industrial requirements have resulted in the emergence of organisations, specialists and consultants who typically use specially designed software models. The use of probabilistic methods is spreading from the industrial field to others, for example the Netherlands flood defence planning.

Probabilistic or stochastic risk analysis seeks to understand and model all potential events with their associated probabilities and outcomes, allowing a sophisticated cost/benefit analysis of different risk management strategies.

Stochastic risk modelling has been wholeheartedly embraced by the re/insurance industry over the past 30 years, particularly for natural catastrophes, though increasingly for all types of risks. EU solvency II regulation (Directive 2009/138/EC), a manifestation of the advisory insurance core principles for regulators set by the International Association of Insurance Supervisors in Basel (IAIS, 2015), allows companies to substitute some or all of their regulatory capital calculation with their own risk models if approved by their regulatory and subject to common European rules.

The main advantage of a quantitative method is that it considers frequency and severity together in a more comprehensive and complex way than other methods. The main problem is that it can be very difficult to obtain data on risks: hazard, exposure, vulnerability and consequential severity. If it is difficult to understand and represent the characteristics of a single risk then it is even harder to understand their interdependencies. There is inevitably a high level of subjectivity in the assumptions driving an 'objective' quantitative analysis. A paper by Apostolakis (2004) on QRA gives a coherent argument for appropriate review and critique of model assumptions. The level of uncertainty inherent in the model may not always be apparent or appreciated by the ultimate user, but the results of a fully quantitative analysis, if properly presented, enhance risk understanding for all stakeholders.

Often the process of building a probabilistic model is as valuable as the results of the model, forcing a structured view of what is known, unknown and uncertain and bringing assumptions that may otherwise be unspoken into the open and thereby challenging them.

Typically for a full stochastic model, severities for each peril would be compared for different probability levels, often expressed as a return period; the inverse of annual probability, i.e. how many years would be expected to pass before a loss of a given size occurred.

Figure 5 gives an example of output of such a model, here showing the size of individual loss for two different perils with return periods of up to the worst that may be expected every 500 years. Note that a return period is a commonly used form of probability notation. A 1-in-200 year loss is the worst loss that can be expected every 200 years, i.e. a loss with a return period of 200 years. A return period is the inverse of probability; a 1- in -200 year event has a 0.5 % probability (1/200).

We can see that, for example, every 100 years the worst tropical cyclone loss we can expect is over EUR 28 million compared to the worst earthquake loss we can expect every 100 years of EUR 10 million.

In fact, a tropical cyclone gives rise to significantly higher economic loss than an earthquake, up until the 1 -in-450-year probability level. But which is the most dangerous? A more likely event probabilities tropical cyclone is much more damaging, but at very remote probabilities it is earthquake. Notice too the very significant differences in loss estimate for the probability buckets used in the National risk register for civil emergencies report (United Kingdom Cabinet Office 2015) risk matrix example in Figure 2.4. The national risk register looks at the probability of an event occurring in a 5-year period, but compares the 1-in-40-year loss to the 1-in-400-year loss, broadly equivalent to the 1-in-200 to 1-in-2 000 5-year bucket: the loss for both perils at these probability levels is very different.

Terms like '1-in-100 storm' or '1-in -100 flood' are often used in the popular press, but it is important to define what is meant by these terms. Is this the worst flood that can be expected every 100 years in that town, valley, region or country? It is also important not just to look at the probability of single events as per Figure 2.5, an occurrence exceedance probability curve, but also annual aggregate loss from hazards of that type, i.e. an annual aggregate exceedance probability curve. For a given return period the aggregate exceedance probability value will clearly be greater or at least equal to the occurrence exceedance probability — the 1 in 200 worst aggregate exceedance probability could be a year of one mega event or a year of five smaller ones that are individually unexceptional but cumulatively significant.

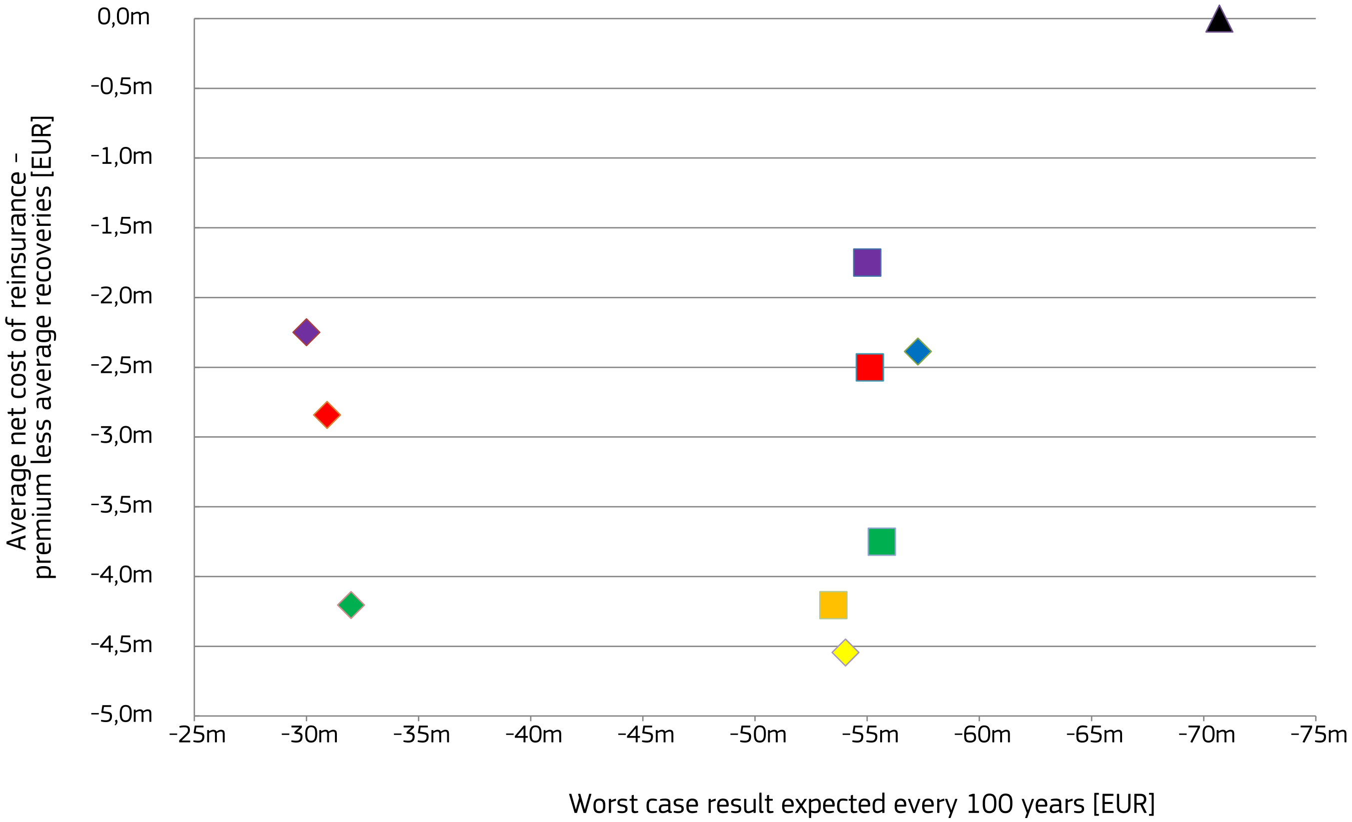
The models can be used to compare the outcome of different strategies to manage and mitigate risk. The cost and benefit of different solutions can be compared, and so an optimal strategy rationalised. An anonymised insurance example is shown in Figure 2.6.

Figure 2.6 compares 10 reinsurance hedging options to manage insurance risk against two measures, one of risk and one of return. On the horizontal axis we have the risk measure: the worse result that we may expect every 100 years, while on the vertical axis we have the return measure, or rather its inverse here, the cost of each hedging option.

Ideally we would be to the top left

FIGURE 2.6

An anonymised example of a risk return analysis
Source: Willis Towers Watson



of the chart: low risk but low cost. The 'do nothing' option is the black triangle at the top right: high risk (a EUR 70 million 1-in-100 year loss) but zero additional cost. The nine reinsurance hedging options fall into two clusters on the chart.

The purple diamond option to the extreme left has the least risk, reducing the 1-in-100 loss to EUR 30 million, but at an annual cost of EUR 2.25 million. The other two options in that cluster cost more and offer less benefit so can be ignored. The best opinion of the middle group is the purple square, reducing the 1-in-100 loss to EUR 55 million but at an annual average cost of EUR 1.75 million. Again, this option clearly offers the best risk return characteristics of all the others in the middle group, so the others in that group may be discounted.

Therefore, from 10 options including the 'do nothing', option we have a shortlist of three:

- black triangle: high risk (EUR 70 million 1-in-100 loss), zero cost;
- purple square: medium risk (EUR 55 million 1-in-100 loss), medium cost (EUR1.75million);
- purple diamond: lowest risk (EUR 30 million 1-in-100 loss), highest cost (EUR2.25million).

Which to pick depends on the risk appetite of the firm. If they are uncomfortable with the unhedged risk then the purple diamond seems to offer much better protection than the purple square option for comparatively little additional cost.

Similar methods can be used to compare options for, say, managing flood risk in a particular location and/or process risk for a particular plant. The same metrics can be used to look at and compare different perils and combinations of perils. The methods make no moral judgements but allowing the cost of a particular strategy to be compared against the reduction is a risk as defined by a specific risk measure. It is at this point that more subjective, political decisions can be made on an informed, objective basis.

An example of a comparative peril analysis for a European city is outlined in a paper by Grünthal et al. (2006) on the city of Cologne.

It must always be remembered that models advise, not decide. Such charts and analyses should not be considered definitive assessments; like any model they are based upon a set of defined assumptions.

2.1.4
Conclusions and key messages

Partnership

The process of risk assessment acts as a catalyst to improve risk understanding and so to encourage a process of proactive risk management. An early adapter of these methods, the global catastrophe insurance and reinsurance industry has been transformed by the process and has become more technically adept, more engaged with science and more financially secure, providing more resilience for society. Similarly, the manufacturing and process industries have embraced structured risk identification and assessment techniques to improve the safety of the manufacturing process and the safety of the consumer.

Disaster risk assessment requires a combination of skills, knowledge and data that will not be held within one firm, one industry, one institution, one discipline, one country, or necessarily one region. Risk assessment requires input from a variety of experts in order to identify potential hazards, those that could occur as well as those in the historical record.

Rigorous approaches to risk assessment require scientific modelling and a precise understanding of risk and probability. Scientific models can be compared in order to challenge the underlying assumptions of each and lead to better, more transparent decisions.

As risk assessments get more quantitative, scientific, and technical, it is important that policymakers are able to interpret them. The assumptions within models must be transparent, and qualitative risk assessment (such as deterministic scenario impacts or risk matrixes) can be useful and complementary to stochastic modelling. It is important that policymakers can demonstrate that appropriate expertise and rigor has been engaged to found risk management decisions firmly.

The practitioner lies in the centre of the many opportunities for partnerships in disaster risk assessment. In order to think beyond accepted ways of working and challenge ingrained assumptions, links between other practitioners in familiar fields as well as other sectors and industries and academia are extremely valuable.

Knowledge

The risk assessment process is structured and covers risk identification, hazard assessment, determining exposure and understanding vulnerability.

Depending on the objective of risk assessment and data availability, risk assessment methods can range in formalization and rigor. There are more subjective scenario based deterministic models, semi quantitative risk analyses such as risk matrixes, and fully quantitative risk assessment; probabilistic or stochastic risk modelling. The more qualitative approaches to risk add value through the process of developing a framework to capture subjective risk perception and serve as a starting point for a discussion about assumptions and risk recognition engaging a wide variety of experts and stakeholders in the process. They also provide a means to reality check more theoretical models. Probabilistic and stochastic analyses provide the potential to perform cost/benefit or risk/return analysis, creating an objective basis for decision making.

Rigorous quantitative approaches to risk assessment and probabilistic analysis raise awareness of the need for further scientific input and the requirement to transfer of knowledge and engagement between science and practitioners.

Risk assessment and analysis provides a framework to weigh decisions, and risk models provide an objective basis against which policy decisions can be made and justified. However, it is important that the limitations of modelling are recognized and inherent uncertainty is understood. Having the ability to compare and challenge assumptions, as well as requiring evidence based analysis, is required.

Risk perception is subjective, but practitioners have valuable information in the fields of data, methodologies and models that further solidify frameworks through which hazards can be understood and compared in an objective fashion.

Innovation

Innovation is required to meet the challenges of lack of data and partial information in risk identification and modelling. Creative approaches can be made to capture and challenges assumptions implicitly or explicitly made and so test them against available data and defined stresses.

> *Risk analysis creates a framework; a starting point for debate about policy, risk and what we know and cannot know. This leads to greater understanding and better, more transparent decision-making.*

No model is perfect. New scientific input can improve and challenge models – testing sensitivity to prior assumption, so leading to a greater understanding of disaster events which in turn leads to safer companies, communities and countries A deeper understanding of the quantitative and qualitative approaches to risk management can help innovate ways of thinking about subjective public risk perception, and risk assessment frameworks can develop a more objective understanding of risk and risk-informed decision making.

Risk assessment and associated modelling contain inherent uncertainty and are not fully complete. It is important to innovate in areas where hazards are less known and capable of anticipation; truly "unknown unknowns" and "known unknowns" must be considered. Similarly assumptions held for "known knowns" should be continuously challenged and tested as new information arises.

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