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# Risk management — Risk assessment techniques

*Gestion des risques — Techniques d'évaluation des risques*

ICS: 03.100.01



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# CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# RISK MANAGEMENT– RISK ASSESSMENT TECHNIQUES

## FOREWORD



International Standard IEC31010 has been prepared by subcommittee JWG16: of IEC technical committee 56 and ISO TC 262:

This second edition cancels and replaces the first edition published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- more detail is given on the process of planning, implementing, verifying and validating the use of the techniques.
- the number and range of application of the techniques has been increased;
- the concepts covered in ISO 31000 Risk management (which is a normative document) are no longer repeated in this standard.

The text of this International Standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| XX/XX/FDIS | XX/XX/RVD |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The National Committees are requested to note that for this document the stability date is 2024..

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

# INTRODUCTION

This document provides guidance on the selection and application of various techniques that can be used to help improve the way uncertainty is taken into account and to help understand risk.

The techniques are used:

- where further understanding is required about what risk exists or about a particular risk;
- within a decision where a range of options each involving risk need to be compared or optimised;
- within a risk management process leading to actions to treat risk.

They are used within the risk assessment steps of identifying analysing and evaluating risk, described in ISO 31000 and more generally whenever there is a need to understand uncertainty and its effects.

The techniques described in this document can be used in a wide range of settings however the majority originated in the technical domain. Some techniques are similar in concept but have different names and methodologies that reflect the history of their development in different sectors. Techniques have evolved over time and continue to evolve. and many can be used in a broad range of situations outside their original application. Techniques can be adapted, combined and applied in new ways or extended to satisfy current and future needs.

This standard is an introduction to selected techniques and compares their possible applications, benefits, and limitations. It also provides references to sources of more detailed information.

While this standard discusses and provides example techniques, the techniques described are non-exhaustive and no recommendation is made as to the efficacy of any given technique in any given circumstance . Cares should be taken in selecting any technique to ensure that it is appropriate reliable and effective in the given circumstance.

Good management practices should be followed throughout and are not repeated in this standard.

The potential audience for this standard is:

- anyone involved in assessing risk;
- people who are involved in developing guidance that sets out how risk is to be assessed in specific contexts;
- people who need to make decisions where there is uncertainty including
  - those who commission or evaluate risk assessments,
  - those who need to understand the outcomes of assessments, and
  - those who have to choose assessment techniques to meet particular needs.

Organizations that are required to conduct risk assessments for compliance or conformance purposes would benefit from using appropriate formal and standardized risk assessment techniques.

# RISK MANAGEMENT – RISK ASSESSMENT TECHNIQUES

## 1 Scope

This International Standard provides guidance on the selection and application of techniques for assessing risk in a wide range of contexts. The techniques are used to assist in making decisions where there is uncertainty, to provide information about particular risks and as part of a process for managing risk. The document provides summaries of a range of techniques, with references to other documents where the techniques are described in more detail.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO Guide 73:2009, *Risk management – Vocabulary – Guidelines for use in standards*

ISO 31000:2009 *Risk management – Principles and guidelines*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO Guide73:2009 https://www.iso.org/obp/ui/#iso:std:iso:guide:73:ed-1:v1:en and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**opportunity**
a combination of circumstances favourable to the purpose

Note 1 to entry: An opportunity is a source of potential benefit or other desirable outcome.

Note 2 to entry: An opportunity to one party may pose a threat to another.

**3.2**
**risk driver**
driver of risk
factor that has a major influence on risk

**3.3**
**threat**
potential source of danger, harm etc.

## 4 Core concepts

### 4.1 Uncertainty

Uncertainty is a term which embraces many underlying concepts. Many attempts have been made, and continue to be developed, to categorize types of uncertainty.

One distinction that is sometimes useful is between:

- uncertainty which recognises the intrinsic variability of some phenomena, and that cannot be reduced by further research; for example, throwing dice (sometimes referred to as aleatory uncertainty) and

- uncertainty which generally results from a lack of knowledge and that therefore can be reduced by gathering more data, by refining models, improving sampling techniques etc. (sometimes referred to as epistemic uncertainty).

In many situations both types of uncertainty are faced.

Other commonly recognized forms of uncertainty include:

- linguistic uncertainty, which recognizes the vagueness and ambiguity inherent in spoken languages;
- decision uncertainty, which has particular relevance to risk management strategies, and which identifies uncertainty associated with value systems, professional judgement, company values and societal norms.

Thus uncertainty, in its broader sense, can encompass:

- uncertainty as to the truth of assumptions, including presumptions about how people or systems might behave;
- variability in the parameters on which a decision is to be based;
- uncertainty in the validity or accuracy of models which have been established to make predictions about the future;
- events (including changes in circumstances) whose occurrence or character are uncertain;
- uncertainty associated with disruptive events;
- the uncertain outcomes of systemic issues, such as shortages of competent staff, that can have wide ranging impacts which cannot be clearly defined;
- lack of knowledge about something;
- lack of knowledge which arises when uncertainty is recognized but not fully understood.
- unpredictability;
- the inability of the human mind to discern complex data, situations with long-term consequences, and bias-free judgments.

Not all uncertainty can be understood, and the significance of uncertainty might be hard or impossible to define or influence. However, a recognition that uncertainty exists in a specific context enables early warning systems to be put in place to detect change and arrangements to be made to build resilience to cope with unexpected circumstances.

## 4.2 Characteristics of risk

In general terms risk includes the effects of any of the forms of uncertainty described in clause 4.1.

One way of describing risk is as a set of consequences and their likelihoods that might occur as a result of defined but uncertain events. These might have multiple causes and lead to multiple effects. Not all risks can be described in these terms. There is not always an identifiable event. Further, sources of risk also can include inherent variability, human behaviour and organizational structures and arrangements. In addition consequences may take a number of discrete values, be continuous variables or be unknown. They may be positive, negative or both. Consequences may not be discernible or measurable at first, but may accumulate over time. It follows that risk cannot always be tabulated easily as a set of events, their consequences and their likelihoods.

Risk assessment techniques aim to help people understand uncertainty and the associated risk in this broader, more complex and more diverse context, for the primary purpose of supporting better-informed decisions and actions.

# 5 Uses and benefits of risk assessment techniques

## 5.1 Uses of risk assessment techniques

ISO 31000 *Risk Management* describes principles for managing risk, the foundations and organizational arrangements that enable risk to be managed. It specifies a process that enables risk to be recognised, understood and modified as necessary, according to criteria that are established as part of the process. Risk assessment techniques can be applied within this structured approach for establishing context, assessing risk and treating risk, along with ongoing monitoring, review, communication and consultation. This process is illustrated in Figure A1 which also shows examples of where within the process techniques can be applied.

In the ISO 31000 process, risk assessment involves identifying risks, analysing them, and using the understanding gained from the analysis to evaluate risk by drawing conclusions about their comparative significance in relation to the objectives and performance thresholds of the organization. This process provides an input into decisions about whether treatment is required, priorities for treatment and the actions intended to treat risk. In practice an iterative approach is applied.

Risk assessment techniques described in this document are used:

- when a decision involving uncertainty has to be taken;
- within a decision where a range of options need to be compared/optimised;
- where further understanding is required about what risks exist or about a particular risk;
- within any process for deciding how to treat risk.

The way in which risk is assessed depends on the situation's complexity and novelty, and the level of relevant knowledge and understanding.

- In the simplest case, when there is nothing new or unusual about a situation, risk is well understood, with no major stakeholder implications or consequences are not significant, then actions are likely to be decided according to established rules and procedures and previous assessments of risk.
- For very novel, complex or challenging issues, where there is high uncertainty and little experience, conventional techniques of analysis might not be useful or meaningful. This also applies to circumstances where stakeholders hold strongly divergent views. In these cases risk might need to be considered, using multiple methods in the context of organizational and societal values, and stakeholder views.

The techniques described in this standard have greatest application in situations between these two extremes where the complexity is moderate and there is some information available on which to base the assessment.

## 5.2 Benefits of using risk assessment techniques

The techniques described in this standard provide a means to improve understanding of uncertainty and its implications for decision making. When appropriate techniques are applied effectively they can provide a range of practical benefits to an organization including assistance with:

- defining realistic strategic and operational objectives;
- setting (or reviewing) clear and logical priorities;
- determining an organization's risk criteria, such as risk tolerance, risk appetite or risk bearing capacity;
- recognising and understanding risk, including risk that could have extreme outcomes;
- understanding which uncertainties matter most to an organization's objectives and providing a rationale for what should be done about them;
- exploiting opportunities more successfully;
- demonstrating that regulatory requirements have been satisfied.

The use of appropriate techniques provides:

- structured information to support decisions and actions where there is uncertainty;
- clarity on the implications of assumptions on achievement of objectives;
- clear articulation of the factors that contribute to risk and why they are important;
- a means of communicating about risk and its implications;
- the ability to compare multiple options, systems, technologies or approaches etc. where there is multifaceted uncertainty around each option;
- the ability to learn more effectively from incidents (post-incident investigation) that can be used to improve the way risk is managed;
- a means of determining the modifying effect of proposed risk treatments, including any change in the nature or magnitude of risk;
- effective and efficient risk treatment actions;
- improved decision making across an organization.

# 6 Implementing risk assessment

## 6.1 Plan the assessment

### 6.1.1 Define purpose and scope

The purpose of the assessment should be established, including identifying the decisions or actions to which it relates, the decision makers, stakeholders, and the timing and nature of the output required (for example whether qualitative or quantitative information is required).

The scope of the assessment should be defined, with a description of what is included, and excluded. Any conditions, assumptions, constraints or necessary resources relevant to the assessment activity should also be specified.

### 6.1.2 Understand the context

Those undertaking an assessment should be aware of the broader circumstances in which decisions and actions based on their assessment will be made. This includes internal and external issues that contribute to the context of the organization as well as wider societal and environmental aspects. Any context statement relevant to the assessment to be carried out should be reviewed and checked to see that it is current and appropriate. Understanding the bigger picture is particularly important where there is significant complexity.

### 6.1.3 Engage with stakeholders

Stakeholders and those who are likely to be able to contribute useful knowledge or relevant views, should be identified and their perspectives considered, whether or not they are included as participants in the assessment.

Appropriate involvement of stakeholders helps ensure that the information on which risk assessment is based is valid and applicable and that stakeholders understand the reasons behind decisions. Involvement of stakeholders can:

- provide information that enables the context of the assessment to be understood;
- bring together different areas of knowledge and expertise for more effectively identifying and understanding risk;
- provide relevant expertise for use of the techniques;
- enable stakeholder interests to be understood and considered;
- provide input to the process of determining whether risk is acceptable particularly when the stakeholders are impacted;
- fulfil any requirements for people to be informed or consulted;
- obtain support for the outputs and decisions arising from risk assessment.

The means by which the outputs and outcomes of risk assessment are to be reliably, accurately and transparently communicated to relevant stakeholders should be decided.

Techniques for eliciting views from stakeholders and experts are described in B.1.

#### 6.1.4 Consider human aspects

Human, organizational and social factors should be considered explicitly and taken into account as appropriate. Human aspects are relevant to risk assessment in the following ways:

- as a source of uncertainty;
- through influences on the way in which techniques are selected and applied;
- in the ways that information is interpreted and used (for example because of differing perceptions of risk).

Human performance (whether above or below expectation) is a source of risk and can also affect the efficacy of controls. The potential for deviation from expected or assumed behaviours should be specifically considered when assessing risk. Human performance considerations are frequently complex and expert advice can be required to identify and analyse human aspects of risk.

Human factors also influence the selection and use of techniques, particularly where judgements have to be made or team approaches are used. Skilled facilitation is needed to minimise these influences. Biases such as groupthink and over-confidence (for example in estimates or perceptions) should be addressed. Expert opinion should be informed by evidence and data wherever possible and efforts made to avoid or minimise cognitive biases.

People's personal objectives and values can vary and differ from those of the organization. This can result in different perceptions about the level of a risk and different criteria by which individuals make decisions. An organization should endeavour to achieve a common understanding of risk internally and take account of the differing perceptions of stakeholders.

Social aspects, including socioeconomic position, race ethnicity and culture, gender, social relationships and residential and community context can affect risk both directly and indirectly. Impacts may be long term and not immediately visible and can require a long term planning perspective.

#### 6.1.5 Review criteria for decisions

##### 6.1.5.1 General

The basis by which decisions are to be made and actions specified will determine:

- the way in which risk is analysed,
- the outputs required from the analysis and
- the most appropriate techniques to be used.

Criteria that need to be taken into account when making decisions, including risk criteria, should therefore be reviewed prior to undertaking the assessment. Criteria can be qualitative or quantitative. In some cases there might be no explicit criteria specified and stakeholders use their judgement to respond to the results of analysis.

Relevant criteria to review are:

- how it will be decided whether risk is acceptable;
- how the relative significance of risks will be determined;
- how risk will be taken into account in decisions between options in situations where each option is associated with multiple risks that might have positive or negative consequences, or both.

##### 6.1.5.2 Criteria for deciding whether risk can be accepted



Criteria for defining the nature and extent of risk that can be accepted in pursuit of objectives, sometimes referred to as risk appetite can be defined by specifying a technique to determine the magnitude of risk, or a parameter related to risk, together with a limit beyond which risk becomes unacceptable. The limit set for unacceptable adverse risk can depend on potential rewards.

The acceptability of risk can also be defined by specifying the acceptable variation in specific performance measures linked to objectives.

Different criteria might be specified according to the type of consequence. For example, an organization's criteria for accepting financial risk may differ from those defined for risk to human life.

Some examples of considerations used when defining whether risk can be accepted are:

- Risk Capacity (also called risk-bearing capacity (RBC): This is the maximum risk an organisation can bear based on its financial and operational capabilities. RBC is usually defined in terms of adverse consequences rather than risk. For a commercial firm capacity might be specified in terms of maximum retention capacity covered by assets, or the largest financial loss the company could bear without having to declare bankruptcy. The estimated RBC should be reasonably tested by stress testing scenarios to provide a reliable confidence level. An organization's risk appetite reflects management's willingness to utilize its RBC;
- SFAIRP and ALARP: In some jurisdictions legislated criteria for decisions about treating safety related risk, involve ensuring the risk of injury or ill health is as low as is reasonably practicable (ALARP) or demonstrating that controls minimise risk so far as is reasonably practicable (SFAIRP) (see B.8.2);
- Globally At Least Equivalent/Globalement Au Moins Equivalent (GALE)/GAME): it is considered acceptable for risks with adverse consequences from a particular source to increase if it can be demonstrated that risks from other sources have decreased by an equivalent or greater amount;
- cost benefit criteria such as price per life saved or return on investment (ROI).

Note ROI= Annual loss expectancy x percentage risk reduction achieved by control – annual cost of control

#### 6.1.5.3 Criteria for evaluating the significance of a risk

Risk criteria (the terms of reference against which the significance of a risk is determined) can be expressed in terms that involve any of the characteristics and measures of risk elaborated in 6.3.5. Ethical, cultural, legal, social, reputational, environmental, contractual, financial and other considerations can also be relevant.

An evaluation of the significance of a risk compared to other risks is often based on an estimate of the magnitude of risk compared with values which are directly related to thresholds set around the objectives of the organization. Comparison with these criteria can inform an organization which risks should be focused on for treatment, based on their potential to drive outcomes outside of thresholds set around objectives.

The magnitude of risk is seldom the only criterion relevant to decisions about priorities for treatment or for which are the most important to monitor. Other relevant factors can include sustainability (i.e. triple bottom line) and resilience, ethical and legal criteria, the effectiveness of controls, the maximum impact if controls re not present or fail, the costs of controls and stakeholder views.

Techniques for evaluating the significance of risk are described in B.8.

#### 6.1.5.4 Criteria for deciding between options

An organization will be faced with many decisions where several, often competing, objectives are potentially affected, and there are both potential adverse outcomes and potential benefits to consider. For such decisions several criteria might need to be met and trade-offs between competing objectives might be required. Criteria relevant to the decision should be identified and the way in which criteria are to be weighted or trade-offs otherwise made should be decided and accounted for and the information recorded and shared. In setting criteria, the possibility that costs and benefits may differ for different stakeholders should be considered.

The way in which different forms of uncertainty are to be taken into account should be decided.

Techniques in clause B.7 address selecting between options.

## 6.2 Manage information and develop models

### 6.2.1 General

Prior to, and during risk assessment, relevant information should be obtained. This provides an input to statistical analysis, models or to the techniques described in Annexes A and B. In some cases the information can be used by decision makers without further analysis.

The information needed at each point depends on the results of earlier information gathering, the purpose and scope of the assessment, and the method or methods to be used for analysis. The way information is to be collected, stored, and made available should be decided.

The records of the outputs of the assessment that are to be kept should be decided, along with how those records are to be made, stored, updated and provided to those who might need them. Sources of information should always be indicated.

### 6.2.2 Collecting information

Information can be gathered from sources such as literature reviews, observations, and expert opinion. Data can be collected or derived from measurements, experiments, interviews and surveys.

Typically data directly or indirectly represent past losses or benefits. Examples include project failures or successes, the number of complaints, financial gains or losses, health impacts, injuries and fatalities etc. Additional information might also be available such as the causes of failures or successes, sources of complaints, the nature of injuries etc. Data can also include the output from models or other analysis techniques.

The following should be decided:

- the source of information;
- type (e.g. whether it is qualitative, quantitative or both (see 6.3.5.4));
- level (e.g. strategic, tactical, operational);
- quantity and quality of the data needed;
- collection methodology.

When the data to be analysed are obtained from sampling, the statistical confidence that is required should be stated so that sufficient data is collected. Where no statistical analysis is needed this should be stated.

If the data or results from previous assessments are available it should first be established whether there has been any change in context and, if so, whether the earlier data or results remain relevant.

The validity, reliability and limitations of any information to be used in the assessment should be assessed taking into account:

- the age and relevance of information;
- the source of information, and the methods used to collect it;
- uncertainties and gaps in the information;
- the authority or provenance of information, data sets, algorithms and models.

### 6.2.3 Analysing data

Analysis of data can provide:

- an understanding of past consequences and their likelihood to learn from experience;

- trends and patterns, including periodicities, that provide an indication of what might influence the future;
- correlations that can give indications of possible causal relationships for further validation.

Limitations and uncertainties in data should be identified and understood.

Past data cannot be assumed to continue to apply into the future but they can give an indication to decision makers of what is more or less likely to occur in the future.

#### 6.2.4 Developing and applying models

A model is an approximate representation of reality. Its purpose is to transform what might be an inherently complex situation in simpler terms that can be analysed more easily. It can be used to help understand the meaning of data and to simulate what might happen in practice under different conditions. A model may be physical, represented in software or be a set of mathematical relationships.

Modelling generally includes the following steps:

- describing the problem;
- describing the purpose of building a model and the outcomes desired;
- developing a conceptual model of the problem;
- building a physical, software or mathematical representation of the conceptual model;
- developing software or other tools to analyse how the model behaves;
- processing data;
- validating or calibrating the model by reviewing outputs for known situations;
- drawing conclusions from the model about the real world problem.

Each of these steps can involve approximations, assumptions and expert judgement and (if possible) they should be validated by people independent of the developers. Critical assumptions should be reviewed against available information to assess their credibility.

To achieve reliable results when using models the following should be validated:

- the conceptual model adequately represents the situation being assessed;
- the model is being used within the contextual limits for which it was designed;
- there is a good understanding of relevant theory underlying the model and any associated calculations;
- the selection of parameters and mathematical representations of the concepts is sound;
- that there is a good understanding of the theory underlying calculations;
- input data is accurate and reliable, or the nature of the model takes into account the reliability of the input data used;
- the model operates as planned with no internal errors or bugs;
- the model is stable and not overly sensitive to small changes in key inputs.

This can be achieved by:

- performing a sensitivity analysis to check how sensitive the model is to changes in input parameters;
- stress testing the model with particular scenarios, often extreme scenarios;
- comparing outputs with past data (other than that from which it was developed);
- verifying that similar results are obtained when the model is run by different people;
- checking the outputs against actual performance.

Comprehensive documentation of the model and the theories and assumptions on which it is based should be kept, sufficient to enable validation of the model.

#### 6.2.5 Precautions when using software for analysis

Software programs can be used to represent and organise data or to analyse it. Software analysis programmes often provide a simple user interface and a rapid output, but these characteristics might produce invalid results that are unnoticed by the user. Invalid results can arise because of:

- inadequacies in the algorithms used to represent the situation;
- assumptions made in the design and use of the model underlying the software;
- errors in data input;
- data conversion issues when new software is used;
- poor interpretation of outputs.

Commercial software is often black box (commercial in confidence) and might contain any of these errors.

New software should be tested using a simple model with inputs that have a known output, before progressing to test more complex models. The testing details should be retained for use on future version updates or for new software analysis programmes.

Errors in the constructed model can be checked by increasing or decreasing an input value to determine whether the output responds as expected. This can be applied to each of the various inputs. Data input errors are often identified when varying the data inputs. This approach also provides information on the sensitivity of the model to data variations.

A good understanding of the mathematics relevant to the particular analysis is recommended to avoid erroneous conclusions. Not only are the above errors likely, but also the selection of a particular programme might not be appropriate. It is easy to follow a programme and assume that the answer will therefore be right. Evidence should be gathered to check that the outputs are reasonable.

### 6.3 Apply risk assessment techniques

#### 6.3.1 Overview

The techniques described in Annexes A and B are used to develop an understanding of risk as an input to decisions where there is uncertainty, including decisions about whether and how to treat risk.

Assessment techniques can be used when:

- identifying risk;
- determining sources and drivers of risk, and the level of exposure to them;
- investigating the overall effectiveness of controls and the modifying effect of proposed risk treatments;
- understanding consequences, likelihood and risk;
- analysing interactions and dependencies.

These activities are further explained in the following clauses and sub-clauses. Factors to consider when selecting a particular technique for these activities are described in clause 7.

In general, analysis can be descriptive (such as a report of a literature review, a scenario analysis or a description of consequences) or quantitative, where data is analysed to produce numerical values. In some cases rating scales can be applied to compare particular risks.

The way in which risk is assessed and the form of the output should be compatible with any defined criteria. For example, quantitative criteria require a quantitative analysis technique which produces an output with the appropriate units. Mathematical operations should be used only if the chosen metrics allow. In general mathematical operations should not be used with ordinal scales.

Even with fully quantitative analysis, input values are usually estimates. A level of accuracy and precision should not be attributed to results beyond that which is consistent with the data and methods employed.

### 6.3.2 Identifying risk

By identifying risk, uncertainty and its effects are explicitly considered when making predictions, considering options or specifying actions. The output can be recorded in a way that explicitly shows uncertainty, by listing risks, or by other suitable methods.

All sources of uncertainty, and both beneficial and detrimental effects, might be relevant, depending on the context and scope of the assessment.

Techniques for identifying risk usually make use of the knowledge and experience of a variety of stakeholders and include considering:

- what uncertainty exists and what its effects might be;
- what circumstances or issues (either tangible or intangible) have the potential for future consequences;
- what sources of risk are present or might develop;
- what controls are in place and whether they are effective;
- what, how, when, where, and why events and consequences might occur;
- what has happened in the past and how this might reasonably relate to the future;
- human aspects and organizational factors.

Techniques for identifying risk are discussed in B.2.

In addition to paper based techniques physical surveys can be useful in identifying sources of risk or early warning signs of potential consequences

Whatever techniques are used, risk identification should be approached methodically and iteratively so that it is thorough and efficient. Risk should be identified early enough to allow actions to be taken.

### 6.3.3 Determining sources and drivers of risk

Identifying sources and drivers of risk can:

- contribute towards estimating the likelihood of an event or consequences;
- help to identify treatments that will modify risk;
- assist in determining early warning indicators and the thresholds for their detection;
- determine common causes which can help develop priorities for treating risk.

Risk can often only be controlled by modifying risk drivers. They influence the status and development of risk exposures, and often affect multiple risks. As a result risk drivers often need more and closer attention than particular risks.

Selected techniques for determining sources and drivers of risk are described in B.3.

### 6.3.4 Investigating the effectiveness of controls

Risk is affected by the overall effectiveness of any controls that are in place. The following aspects of controls should be considered:

- how the controls act to modify the risk;
- whether the controls are in place, are capable of operating as intended, and are achieving the expected results;
- whether there are shortcomings in the design of controls or the way they are applied;
- whether there are gaps in controls;

- whether controls function independently, or if they need to function collectively to be effective;
- whether there are factors, conditions, vulnerabilities or circumstances that can reduce or eliminate control effectiveness including common cause failures;
- whether controls themselves introduce additional risks.

A distinction should be made between controls that change likelihood, consequences or both, and controls that change how the burden of risk is shared between stakeholders. For example, insurance and other forms of risk financing do not directly affect the probability of an event or its outcomes but can make some of the consequences more tolerable to a particular stakeholder by reducing their extent or smoothing cash flow.

Any assumptions made during risk analysis about the actual effect and reliability of controls should be validated where possible, with a particular emphasis on individual or combinations of controls that are assumed to have a substantial modifying effect. This should take into account information gained through routine monitoring and review of controls.

Techniques primarily used for analysing controls are described in B.4.

### 6.3.5 Understanding consequences, likelihood and risk

#### 6.3.5.1 Analysing the type, magnitude and timing of consequences

Consequence analysis can vary from a description of outcomes to detailed quantitative modelling or vulnerability analysis. Consequential effects, where one consequence leads to another, should be considered where relevant.

Risk can be associated with a number of different types of consequences, impacting different objectives. The types of consequence to be analysed should have been decided when establishing the context of the assessment. The context statement should be checked to ensure that the consequences to be analysed align with the purpose of the assessment and the decisions to be made. This can be revisited during the assessment as more is learned.

The magnitude of consequences can be expressed quantitatively as a point value or as a distribution. A distribution can be appropriate where:

- the value for the consequence is uncertain;
- the consequences vary depending on circumstances;
- the parameters that affect consequences vary.

The magnitude of consequences might also vary according to other parameters. For example, the health consequences of exposure to a chemical generally depend on the dose to which the person or other species is exposed. For this example the risk is usually represented by a dose response curve which depicts the probability of a specified end point (e.g. death) as a function of a short term or an accumulated dose.

Consequences might also change over time. For example the adverse impacts of a failure might become more severe the longer the duration of the failure. Appropriate techniques should be selected to take this into account.

Consideration of the full distribution associated with a consequence provides complete information. It is also possible to summarise the distribution in the form of a point value such as the expected value (mean), variation (variance) or the percentage in the tail or some other relevant part of the distribution (percentile).

For any method of obtaining a point value or values to represent a distribution of consequences, there are underlying assumptions and uncertainties about:

- the form of the distribution chosen to fit the data (e.g. continuous or discrete, normal or highly skewed);
- the most appropriate way of representing that distribution as a point value;

- the value of the point estimate because of inherent uncertainties in the data from which the distribution was produced.

It should not be assumed that data relevant to risk necessarily follows a normal distribution.

In some cases information can be summarised as a qualitative or semi-quantitative rating which can be used when comparing risks.

#### 6.3.5.2 Cumulative risk

Sometimes consequences result from exposures to multiple events or risk sources, or develop over time; for example, environmental or human health effects from the exposure to biological, chemical, physical, and psychosocial sources of risk. In combining such risks the possibility of synergistic effects should be taken into account as well as the influence of the duration and extent of exposure. The possibility of delayed effects should also be considered.

#### 6.3.5.3 Analysing likelihood

Likelihood can refer to the likelihood of an event or to the likelihood of a specified consequence. The parameter to which a likelihood value applies should be explicitly stated and the event whose likelihood is being stated should be clearly and precisely defined.

Likelihood can be described in a variety of ways, including probability distributions, probability density distributions, expected frequencies, and descriptive terms (e.g. “highly likely”).Where relevant, “exposure and duration” parameters are included within likelihood analyses.

Where a percentage is used as a measure of likelihood the nature of the ratio to which the percentage applies should be stated.

EXAMPLE 1 The statement that the chance of a supplier failing to deliver is 5 % is vague in terms of both time period and population. It is also unclear whether the percentage refers to 5 % of projects or 5 % of suppliers. A more explicit statement would be "the probability of one or more suppliers failing to deliver the required goods or services to a project within the life of a project is 5 % of projects".

To minimise misinterpretations when expressing likelihood, either qualitatively or quantitatively, the time period and population concerned should be explicit and consistent with the scope of the particular assessment.

EXAMPLE 2 The probability of one or more suppliers failing to deliver the required goods or services to a project within the next 2 months is 1 % of projects whereas within a 6 month time scale failure may occur in 3 % of projects.

There are many possible biases which can influence estimates of likelihood. Furthermore, interpretation of the likelihood estimate can vary depending on the context within which it is framed. Care should be taken to understand the possible effects of individual (cognitive) and cultural biases.

#### 6.3.5.4 Developing measures of risk

In some situations it is useful to provide a measure of risk as some combination of the magnitude of potential consequences and the likelihood of those consequences. This can involve qualitative, semi-quantitative or quantitative measures.

- Qualitative approaches are usually based on descriptive (nominal) or ranking (ordinal) scales for consequences and likelihoods.
- Semi-quantitative approaches include where:
  - one parameter (usually likelihood) is expressed quantitatively and the other described or expressed on a rating scale;
  - scales are divided into discrete bands the limits of which are expressed quantitatively. Scales are normally logarithmic to fit with data;
  - numeric descriptors are added to scale points the meanings of which are described qualitatively.

  The use of semi-quantitative scales can lead to misinterpretations if the basis for any calculations is not explained carefully. Therefore semi-quantitative approaches should be validated and used with caution.

- Quantitative approaches use measures of consequences and likelihoods that are expressed on numerical (ratio) scales, as ranges or as distributions. Where a risk is measured in quantitative terms a proper dimensional analysis should be conducted and the appropriate units used and carried over through the assessment.

Qualitative and semi-quantitative techniques can be used only to compare risks with other risks measured in the same way or with criteria expressed in the same terms. They cannot be used for combining or aggregating risks and they are very difficult to use in situations where there are both positive and negative consequences or when trade-offs are to be made between risks.

When quantitative values for a consequence and its likelihood are combined to provide a magnitude for a risk, an expected value is sometimes calculated. This might not reflect the true importance of risk because it loses information. In particular the practice loses information about less likely outcomes that may be important for understanding the risk. It also does not distinguish between risks with high consequence and low likelihood and those with low consequences that occur frequently.

Examples of quantitative metrics of the magnitude of a risk include:

- an expected frequency of occurrence of a specified consequence such as the number of vehicle accidents per thousand kilometers travelled in a region;
- the expected time between events of interest such as the mean up time of an item;
- a probability of a specified end point over a defined period of exposure (relevant when consequences accumulate over a period of exposure) such as the probability of contracting cancer in a life time as a result of exposure to a specified dose of a chemical;
- an expected value, such as the expected returns or financial gains over an investment period, or the expected public health burden in terms of disability adjusted life years /million people per year;
- a statistic representing the shape of a distribution of consequences such as the variance or volatility of returns on an investment;
- a value at or above or below a specified percentile in a consequence distribution, such as the profit that there is a 90 % chance of achieving from a project; or the Value at Risk (VaR) of a portfolio which measures the loss that might arise in a portfolio over a specified time period with a specified probability;
- an extreme measure associated with the distribution of consequences such as the expected maximum consequences.

Consequence based metrics such as the maximum credible loss or probable maximum loss are mainly used when it is difficult to define which controls have the capability of failing or where there is insufficient data on which to base estimates of likelihood.

Risk cannot always be adequately described or estimated as a single value representing the likelihood of a specific consequence. Examples where this applies include situations in which:

- consequences are best expressed as a probability distribution of consequences;
- an event has a number of different causes and leads to a range of outcomes and possible consequential effects;
- consequences arise cumulatively from on-going exposure to a source of risk;
- sources of risk (such as systemic problems) are identifiable, but it is very difficult to specify the nature and or likelihood of the consequences that might arise. (In this case estimating a valid magnitude for risk in terms of likelihood and consequence becomes impossible).

When a risk with a distribution of consequences is summarised into one number, a lot of information is typically lost. In particular, the practice of measuring risk as the probability weighted average of consequences (i.e. the expected value) reflects the mean outcome rather than the less likely outcomes that should be a major focus for risk assessment.

The magnitude of risk depends on the assumptions made about the presence and effectiveness of relevant controls. Terms such as inherent or gross risk (for the situation where those controls which can fail are assumed to do so) and residual or net risk for the level of a risk when controls are assumed to operate as intended are often used by practitioners. However it is difficult to define these terms unambiguously and it is therefore advisable to always state explicitly the assumptions made about controls.

When reporting a magnitude of risk, either qualitatively or quantitatively, the uncertainties associated with assumptions and with the input and output parameters should be specified.

#### 6.3.5.5 Aggregating measures of risk

In some cases (such as for capital allocation) it can be useful to combine values for a set of risks to produce a single value. Provided the risks are characterised by a single consequence, measured in the same units, such as monetary value, they can in principle be combined. That is, they can be combined only when consequences and likelihood are stated quantitatively and the units are consistent and correct. In some situations, a measure of utility can be used as a common scale to quantify and combine consequences that are measured in different units.

Developing a single consolidated value for a set of more complex risks loses information about the component risks. In addition, unless great care is taken, the consolidated value can be inaccurate and has the potential to be misleading. All methods of aggregating risks to a single value have underlying assumptions which should be understood before being applied. Data should be analysed to seek correlations and dependencies which will affect how risks combine. Modelling techniques used to produce an aggregate level of risk should be supported by scenario analysis and stress testing.

Where models incorporate calculations involving distributions they should include correlations between those distributions in an appropriate manner. If correlation is not taken into account appropriately the outcomes will be inaccurate and may be grossly misleading. Consolidating risks by simply adding them up is not a reliable basis for decision-making and could lead to undesired results. Monte Carlo simulation can be used to combine distributions. (See B.5.10.)

Qualitative or semi-quantitative measures of risk cannot be directly aggregated. Equally only general statements can be made about the relative effectiveness of controls based on qualitative or semi-quantitative measures of changes in level of risk.

Relevant data about different risks can be brought together in a variety of ways to assist decision makers. Where quantitative measurements are not available it might be possible to conduct a qualitative aggregation based on expert opinion, taking into account more detailed risk information. The assumptions made and information used to conduct qualitative aggregations of risk should be clearly articulated.

B.5 describes techniques for understanding consequences, likelihood and risk.

#### 6.3.5.6 Societal risk

Where a population is exposed to risk, a simple aggregation of the individual level of risk by multiplying by the population exposed, in most cases, does not adequately represent the true impact of the consequences. For example, an individual's risk of a fatality from an event such as a dam failure might need to be considered differently from the same event affecting a group of individuals together.

Societal risk is typically expressed and evaluated in terms of the relationship between the frequency of occurrence of a consequence (F) and the number of people bearing the consequences (N). (See F-N diagrams in B.8.3).

### 6.3.6 Analysing interactions and dependencies

There are usually many interactions and dependencies between risks. For example, multiple consequences can arise from a single cause or a particular consequence might have multiple causes. The occurrence of some risks may make the occurrence of others more or less likely, and these causal links can form cascades or loops.

To achieve more reliable risk assessments where causal links between risks are significant it can be useful to create a causal model that incorporates the risks in some form.

Common themes can be sought within the risk information such as common causes or drivers of risk, or common outcomes.

Interactions between risks can have a range of impacts on decision making, for example, escalating the importance of activities which span multiple connected risks or increasing the attractiveness of one option over others. Risks might be susceptible to common treatments, or there can be situations such that treating one risk has positive or negative implications elsewhere. Treatment actions can often be consolidated such that the work required is significantly reduced and resources can be more effectively balanced across a portfolio of work. A coordinated treatment plan should take account of these factors rather than assuming that each risk should be treated independently.

B.6 describes methods of analysing dependencies and interactions.

#### 6.3.7 Uncertainty and sensitivity analysis

Those analysing risk should understand the uncertainties in the analysis and appreciate the implications for the reliability of the results. Uncertainties and their implications should always be communicated to decision-makers.

Uncertainty in analysis outputs can arise because:

- there is variability in the system being considered;
- the data is from an unreliable source, inconsistent or insufficient, for example, the type of data collected or methods of collection might have changed;
- there might be ambiguity, for example in the way that qualitative descriptors are stated or understood;
- the analysis method does not adequately represent the complexity of the system;
- there is a high reliance on people’s expert opinion or judgement;
- relevant data might not exist or the organization might not have collected the data needed;
- data from the past might not provide a reliable basis from which to predict the future because something within the context or circumstances has changed;
- there are uncertainties or approximations in the assumptions that are made.

When a lack of reliable data is recognised during the analysis, further data should be collected if practicable. This can involve implementing new monitoring arrangements. Alternatively the analysis process should be adjusted to take account of the data limitations.

A sensitivity analysis can be carried out to evaluate the significance of uncertainties in data or in the assumptions underlying the analysis. Sensitivity analysis involves determining the relative change to the results brought about by changes in individual input parameters. It is used to identify data that need to be accurate, and those that are less sensitive and hence have less effect upon overall accuracy. Parameters to which the analysis is sensitive and the degree of sensitivity should be stated where appropriate.

Parameters that are critical to the assessment and that are subject to change should be identified for on-going monitoring, so that the risk assessment can be updated, and, if necessary, decisions reconsidered.

### 6.4 Verify and validate results

Where practicable, results of analysis should be verified and validated. Verification involves checking that the analysis was done correctly. Validation involves checking that the right analysis was done to achieve the required objectives. For some situations this can involve an independent review process.

Validation can include:

- checking that the scope of the analysis is appropriate for the stated goals;
- reviewing all critical assumptions to ensure they are credible in the light of available information;
- checking that appropriate methods, models and data were used;
- using multiple methods, approximations and sensitivity analysis to test and validate conclusions;

Verification can involve:

- checking the validity of mathematical manipulations and calculations;
- checking that the results are insensitive to the way data or results are displayed or presented;
- comparing results with past experience where data exists or by comparison with outcomes after they occur;
- establishing whether the results are sensitive to the way data or results are displayed or presented and to identify input parameters that have a significant effect on the results of the assessment;
- comparing results with past or subsequent experience including explicitly obtaining feedback as time progresses.

### 6.4 Monitor and review

Monitoring can be used:

- to compare actual outcomes with the results predicted by risk assessment and hence improve future assessments;
- to look for precursors and early indicators of potential consequences that were identified by the assessment;
- to collect data needed for a good understanding of risk;
- to scan for new risk and unexpected changes that can indicate a need to update assessment.

Where a sensitivity analysis indicates parameters of particular importance to the outcome of an analysis these also should be considered for monitoring.

Assessments should be reviewed periodically to identify whether change has occurred, including changes in the context or in assumptions, and whether there is new information, or new methods available.

### 6.5 Apply results to support decisions

#### 6.5.1 Overview

The outcomes from risk analysis are an input to decisions that need to be made or actions to be taken. The factors to consider when making decisions and any specific criteria should have been defined as part of establishing the context for the assessment (see 6.1.5).

Two types of decisions can be distinguished:

- a decision that involves comparing options where each has uncertainties (such as which of several opportunities to pursue);
- a decision about whether and how to treat risk.

#### 6.5.2 Decisions that involve selecting between options

Selecting between options normally involves weighing the potential advantages and disadvantages of each option taking into account:

- uncertainties associated with the potential outcomes of the options and estimates of costs and benefits;
- potential events and developments that may affect outcomes;

- the organisation's appetite for risk;
- the different attitudes and beliefs of stakeholders;
- the varied values that different stakeholders place on costs and benefits;
- trade-offs that may need to be mad between competing objectives

This type of decision is often made using expert judgement based on the understanding from an analysis of the options concerned and the risk associated with each.

Techniques that assist in the comparison of options are described in B.7.

### 6.5.3 Decisions about risks and their treatment

The information from risk identification and analysis can be used to draw conclusions about whether the risk should be accepted and the comparative significance of a risk relative to the objectives and performance thresholds of the organization. This provides an input into decisions about whether risk is acceptable, or requires treatment and any priorities for treatment.

Priorities for treatment, for monitoring or for more detailed analysis are often based on a magnitude of risk obtained by combining a representative consequence and its likelihood, and displayed using a consequence likelihood matrix (B.9.3). This method is, however, limited to those risks for which a single consequence likelihood pair can be defined (see 6.3.5.4). Factors other than the magnitude of risk that can be taken into account in deciding priorities include:

- other measures associated with the risk such as the maximum or expected consequences or the effectiveness of controls;
- the views and perceptions of stakeholders;
- the cost and practicability of further treatment compared with the improvement gained;
- interactions between risks including the effects of treatments on other risks.

Some techniques for evaluating the significance of risk are discussed in B.8.

Once risks have been evaluated and treatments decided, the risk assessment process can be repeated to check that proposed treatments have not created additional adverse risks and that the risk now falls within the organization's risk appetite.

## 6.6 Record, report, and communicate risk

The results of risk assessment and the methodologies used should be documented and a decision made about what information needs to be communicated and to whom.

The purpose of records is to:

- communicate information about risk to decision-makers and other stakeholders including regulators;
- provide a record and justification of the rationale for decisions made;
- preserve the results of assessment for future use and reference;
- track performance and trends;
- enable verification of the assessment;
- provide an audit trail.

It follows that any documentation or records should be in a form that can be understood by those who will read it, but should also provide the necessary technical depth for validation, and sufficient detail to preserve the assessment for future use.

The information provided should be sufficient to allow both the processes followed and the outcomes to be reviewed and validated. Assumptions made, limitations in data or methods, and reasons for any recommendations made should be clear.

Risk should be expressed in understandable terms, and the units in which quantitative measures are expressed should be clear and correct.

Those presenting the results should characterize their/the team`s confidence in the accuracy and completeness of the results. Uncertainties should be adequately communicated so that the report does not imply a level of certainty beyond the reality.

Techniques for reporting information about risk are described in B.9.

# 7 Selection of risk assessment techniques

## 7.1 General

This clause describes factors to consider when selecting a technique or techniques for a particular purpose. The annexes list and further explain some commonly used techniques. They describe the characteristics of each technique and its possible range of application, together with its inherent strengths and weaknesses.

Many of the techniques described in this document were originally developed for particular industries seeking to manage particular types of unwanted outcomes. Several of the techniques are similar, but use different terminologies, reflecting their independent development for a similar purpose in different sectors. Over time the application of many of the techniques has broadened, for example extending from technical engineering applications to financial or managerial situations, or to consider positive as well as negative outcomes. New techniques have evolved and old ones have been adapted to new circumstances. The techniques and their applications continue to evolve. There is potential for enhanced understanding of risk by using techniques outside their original application. The annexes therefore indicate the characteristics of techniques that can be used to determine the range of circumstances to which they can be applied.

## 7.2 Selection of techniques

The choice of technique and the way it is applied should be tailored and scaled to the context and use, and provide information of the type and form needed by the stakeholders. In general terms, the number and type of technique selected should be scaled to the significance of the decision, and take into account constraints on time and other resources, and opportunity costs.

In deciding whether a qualitative or quantitative technique is more appropriate, the main criteria to consider are the form of output of most use to stakeholders and the availability and reliability of data. Quantitative techniques generally require high quality data if they are to provide meaningful results. However, in some cases where data is not sufficient, the rigour needed to apply a quantitative technique can provide an improved understanding of the risk, even though the result of the calculation might be uncertain.

There is often a choice of techniques relevant for a given circumstance. Several techniques might need to be considered, and applying more than one technique can sometimes provide useful additional understanding. Different techniques can also be appropriate as more information becomes available. In selecting a technique or techniques the following aspects of context should therefore be considered:

- the purpose of the assessment;
- the needs of stakeholders;
- any regulatory and contractual requirements;
- the operating environment and scenario
- the importance of the decision (e.g. the consequences if a wrong decision is made).
- any defined decision criteria and their form;
- the time available before a decision must be made;
- information that is available or can be obtained;
- the complexity of the situation

- the expertise available or that can be obtained;

The characteristics of the techniques relevant to these requirements are listed in Table A.1. Table A.2 provides a list of techniques, classified according to these characteristics.

Note Although Annex A and B introduce the techniques severally, it may be necessary to make complementary use of multiple techniques to assess complex systems. IEC TR 63039: 2016, for example, guides how to use ETA, FTA and Markov techniques in a complementarily way so that the combined use is a as an efficient way to analyse risk of complex system.

As the degree of uncertainty, complexity and ambiguity of the context increases then the need to consult a wider group of stakeholders will increase, with implications for the combination of techniques selected.

Some of the techniques described in this document can be applied during steps of the ISO 31000 risk management process other than their usage in risk assessment. Application of the techniques in the risk management process of ISO 31000 is illustrated in Figure A.1.

Annex B contains an overview of each technique, its use, its inputs and outputs, its strengths and limitations and, where applicable, a reference for where further detail can be found. It categorises techniques according to their primary application in assessing risk, namely:

- eliciting views from stakeholders;
- identifying risk;
- analysing sources and drivers of risk;
- analysing controls;
- understanding consequences, likelihood and risk;
- analysing dependencies and interactions;
- selecting between options;
- evaluating the significance of risk;
- reporting and recording.

# Annex A
(informative)

# Categorisation of techniques

## A.1 Introduction to categorization of techniques

Table A.1 explains the characteristics of techniques that can be used for selecting which technique or techniques to use.

**Table A.1 – Characteristics of techniques**

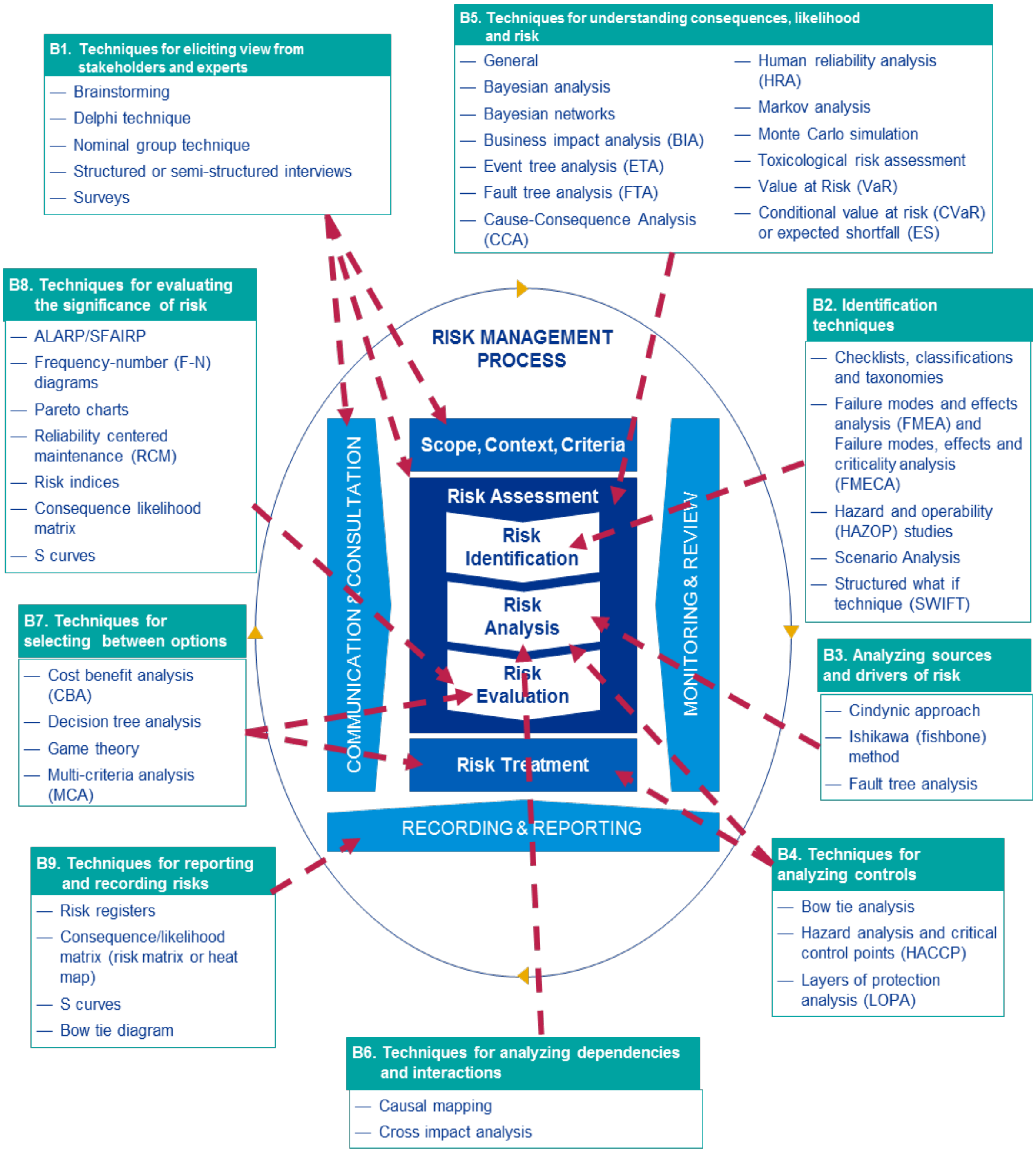
| Characteristic | Description | Details (features indicators etc.) |
|---|---|---|
| Application | How the technique is used in risk assessment | Identify, analyse cause, analyse controls, consequence analysis, decide between options etc. |
| Scope | Applies to risk at enterprise level, departmental or project level or individual processes or equipment | 1. enterprise<br>2. project/department<br>3. equipment/process |
| Time horizon | Looks at short medium or long term risk or is applicable to any time horizon | short<br>medium<br>long |
| Decision level | Applies to risk at a strategic, tactical or operational risk | 1. strategic<br>2. operational<br>3. tactical |
| Starting info/ data needs | The level of starting information or data needed | high<br>medium<br>low |
| Specialist expertise | Level of expertise required for correct use | low; intuitive or 1 – 2 day training<br>moderate; training course of more than 2 days<br>high; requires significant training or specialist expertise |
| Qualitative - quantitative | Whether the method qualitative, semi-quantitative or quantitative | quantitative<br>qualitative<br>semi-quantitative<br>either -can be used qualitatively or quantitatively |
| Effort to apply | Time and cost required to apply technique | 1. high<br>2. medium<br>3. low |

## A.2 Application of categorization of techniques

Table A.2 lists a range of techniques classified according to these characteristics. The techniques described represent structured ways of looking at the problem in hand that have been found useful in particular contexts. The list is not intended to be comprehensive but covers a range of commonly used techniques from a variety of sectors. For simplicity the techniques are listed in alphabetical order without any priority.

Each technique is described in more detail in Annex B. The techniques in Annex B are grouped according to how they are most commonly used in risk assessment. Within each grouping techniques are arranged alphabetically and no order of importance is implied.

Note The majority of techniques in table A2and Annex B assume that risks or sources of risk can be identified. There are also techniques which can be used to indirectly assess residual risk by considering controls and requirements that are in place (see for example IEC 61508).

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1141 **Figure A.1 – Application of techniques in the risk management process**

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**Table A.2 – Techniques and indicative characteristics**

| Ref Ann.B | Technique | Description | Application | Scope | Time horizon | Decision level | Starting info / data needs | Specialist expertise | Qual-quant | Effort to apply |
|---|---|---|---|---|---|---|---|---|---|---|
| B.8.2 | **ALARP/SFAIRP** | Criteria for tolerability of risk to human life. | evaluate. risk | 1 | any | 1/2 | high | high | quant | high |
| B.5.2 | **Bayes analysis** | A means of making inference about model parameters using Bayes theorem which has the capability of incorporating empirical data into prior judgements about probabilities". | analyse likelihood | any | any | any | medium | high | quant | medium |
| B.5.3 | **Bayesian networks/ Influence diagrams** | A graphical model of variables and their cause-effect relationships expressed using probabilities. A basic Bayes net has variables representing uncertainties. An extended version, known as an influence diagram, includes variables representing uncertainties, consequences and actions | identify risk<br>estimate risk<br>decide between options | any | any | any | medium | high | quant | medium /high |
| B.4.2 | **Bow tie analysis** | A diagrammatic way of describing the pathways from source of risk to outcomes and reviewing controls. | analyse controls<br>describe risk | 2/3 | short/ medium | any | low | low/ moderate | qual | low |
| B.1.2 | **Brainstorming** | Technique used in workshops to encourage imaginative thinking. | elicit views | any | any | any | none | low/ moderate | qual | low |
| B.5.4 | **Business impact analysis** | The BIA process analyses the consequences of a disruptive incident on the organization which determines the recovery priorities of an organisation's products and services and, thereby, the priorities of the activities and resources which deliver them. | analyse conseq.<br>analyse controls | 1 | short/ medium | 2 | medium | low | quant | medium |
| B.6.1 | **Causal mapping** | A network diagram representing events, causes and effects and their relationships. | analyse causes | 2/3 | any | 2/3 | medium | moderate | qual | medium |
| B.5.7 | **Cause consequence analysis** | A combination of fault and event tree analysis that allows inclusion of time delays. Both causes and consequences of an initiating event are considered. | analyse causes and conseq. | 2/3 | any | 2/3 | medium/ high | moderate/ high | quant | medium /high |
| B.2.2 | **Check lists classifications, taxonomies** | Lists based on experience or on concepts and models that can be used to help identify risks or controls. | identify risk or controls | 2/3 | any | any | high to develop. Low to use | low/moder ate | qual | low/ medium |
| B.3.2 | **Cindynic approach** | Considers goals, values, rules, data and models of stakeholders and identifies inconsistencies, ambiguities omissions and ignorance. These form systemic sources and drivers of risk. | identify risk drivers | 1/2 | short or medium | 1 | low | moderate | qual | high |

| Ref Ann.B | Technique | Description | Application | Scope | Time horizon | Decision level | Starting info / data needs | Specialist expertise | Qual-quant | Effort to apply |
|---|---|---|---|---|---|---|---|---|---|---|
| B.5.13 | **Conditional value at risk CVaR** | Also called expected shortfall (ES), is a measure of the expected loss from a financial portfolio in the worst a % of cases. | analyse likelihood and conseq. | 1 | short | 3 | high | high | quant | medium |
| B.9.3 | **Consequence likelihood matrix** | Compares individual risks by selecting a consequence likelihood pair and displaying them on a matrix with consequence on one axis and likelihood on the other. | report risks<br>evaluate | any | any | any | medium | low to use, medium to develop | Qual/ semi-quant. | low |
| B.7.2 | **Cost-benefit analysis** | Uses money as a scale for estimating positive and negative, tangible and intangible, consequences of different options. | compare options | any | short/ medium | any | medium /high | moderate/ high | quant | medium/ high |
| B.6.2 | **Cross impact analysis** | Evaluates changes in the probability of the occurrence of a given set of events consequent on the actual occurrence of one of them. | analyse likelihood and cause | any | short medium | any | low to high | moderate/ high | quant | medium/ high |
| B.7.3 | **Decision tree analysis** | Uses a tree-like representation or model of decisions and their possible consequences. Outcomes are usually expressed in monetary terms or in terms of utility.<br>An alternative representation of a decision tree is an influence diagrams (see B.5.3) | compare options | any | any | 2 | low/ medium | moderate | quant | medium |
| B.1.3 | **Delphi technique** | Collects judgements through a set of sequential questionnaires. People participate individually but receive feedback on the responses of others after each set of questions. | elicit views | any | any | any | none | moderate | qual. | medium |
| B.5.5 | **Event tree analysis (ETA)** | Models the possible outcomes from a given initiating event and the status of controls and to analyse the frequency or probability of the various possible outcomes. | analyse conseq. and controls | 2/3 | any | any | low/ medium | moderate | either | medium |
| B.5.6 | **Fault tree analysis (FTA)** | Analyses causes of a focus event using Boolean logic to describe combinations of failures. Variations include a success tree where the top event is desired and a cause tree used to investigate past events. | analyse likelihood<br>analyse causes | 2/3 | medium | 2/3 | high for quant analysis | depends on complexity | either | Medium/ high |
| B.2.3 | **Failure modes and effect and (criticality) analysis FME(C)A** | Considers the ways in which each component of a system might fail and the failure causes and effects. FMEA can be followed by a criticality analysis which defines the significance of each failure mode, (FMECA). | Identify risks | 2/3 | any | 2/3 | Depends on application | moderate | either | low /high |

| Ref Ann.B | Technique | Description | Application | Scope | Time horizon | Decision level | Starting info / data needs | Specialist expertise | Qual-quant | Effort to apply |
|---|---|---|---|---|---|---|---|---|---|---|
| B.8.3 | **F/N diagrams** | Special case of quantitative consequence likelihood graph applied to consideration of tolerability of risk to human life. | evaluate risk | 1 | any | any | high | high | quant | high |
| B.7.4 | **Game theory** | The study of strategic decision making to model the impact of different players' decisions involved in the game. Example application area can be risk based pricing. | decide between options | 1 | medium | 1/2 | High | high | quant | medium/ high |
| B.4.3 | **Hazard analysis and critical control points HACCP** | Analyses the risk reduction that can be achieved by various layers of protection. | analyse controls monitor | 2/3 | short/ medium | 2/3 | medium | moderate | qual. | medium |
| B.2.4 | **Hazard and operability studies HAZOP** | A structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that might represent risk to personnel or equipment, or prevent efficient operation. | identify and analyse risks | 3 | medium/ long | 2/3 | medium | facilitator-high participant s moderate | qual. | medium/ high |
| B.5.8 | **Human reliability analysis** | A set of techniques for identifying the potential for human error and estimating the likelihood of failure. | analyse risk and sources of risk | 2/3 | any | 2/3 | medium | high | qual/ quant | medium to high |
| B.1.5 | **Interviews** | Structured or semi- structured one to one conversations to elicit views. | elicit views | any | any | any | none | moderate | qual. | high |
| B.3.3 | **Ishikawa analysis (fishbone diagram)** | Identifies contributory factors to a defined outcome (wanted or unwanted). Contributory factors are usually divided into predefined categories and displayed in a tree structure or a fishbone diagram. | analyse sources of risk | any | any | any | low | low/ moderate | qual. | Low |
| B.4.4 | **Layers of protection analysis (LOPA)** | Analyses the risk reduction that can be achieved by various layers of protection. | analyse controls | 3 | any | 2/3 | medium | Moderate/ high | quant | medium/ high |
| B.5.9 | **Markov analysis** | Calculates the probability that a system that has the capacity to be in one of a number of states will be in a particular state at a time t in the future. | analyse likelihood | 3 | any | 2/3 | medium/ high | high | quant | medium |
| B.5.10 | **Monte Carlo analysis** | Calculates the probability of outcomes by running multiple simulations using random variables. | analyse likelihood | any | any | any | medium | high | quant | medium/ high |
| B.7.5 | **Multi criteria analysis** | Compares options in a way that makes trade-offs explicit. Provides an alternative to cost benefit analysis that does not need a monetary value to be allocated to all inputs. | decide between options | any | any | any | low | moderate | qual. | low/ medium |

| Ref Ann.B | Technique | Description | Application | Scope | Time horizon | Decision level | Starting info / data needs | Specialist expertise | Qual-quant | Effort to apply |
|---|---|---|---|---|---|---|---|---|---|---|
| B.1.4 | **Nominal group technique** | Technique for eliciting views from a group of people where initial participation is as individuals with no interaction, then group discussion of ideas follows. | elicit views | any | any | any | none | low | qual. | medium |
| B.8.4 | **Pareto charts** | The Pareto principle (the 80–20 rule) states that, for many events, roughly 80 % of the effects come from 20 % of the causes. | set priorities | any | any | any | medium | moderate | qual. | low |
| B.8.5 | **Reliability centred maintenance (RCM)** | A risk based assessment used to identify the appropriate maintenance tasks for a system and its components. | evaluate risk<br>decide controls | 2/3 | medium | 2/3 | medium | High for facilitator moderate to use | either | medium/ high |
| B.8.6 | **Risk indices** | Rates the significance of risks based on ratings applied to factors which are believed to influence the magnitude of the risk. | compare risks | any | any | any | medium | low to use medium to develop | qual. | low |
| B.9.2 | **Risk register** | A means of recording information about risks and tracking actions. | recording risks | any | any | any | low/ medium | low /moderate | qual. | medium |
| B.9.4 | **S curves** | A means of displaying the relationship between consequences and their likelihood. \ plotted as a cumulative distribution function (S curve). | display risk<br>evaluate risk | any | any | 2/3 | Medium/ high | Moderate /high | quant | medium |
| B.2.5 | **Scenario analysis** | Identifies possible future scenarios through imagination, extrapolation from the present or modelling. Risk is then considered for each of these scenarios. | Identify risk, conseq. analysis | any | medium or long | any | low/ medium | moderate | qual. | low/ medium |
| B.1.6 | **Surveys** | Paper or computer based questionnaires to elicit views. | elicit views | any | Medium/ long | 2/3 | low | moderate | qual. | high |
| B.2.6 | **Structured what if technique SWIFT** | A simpler form of HAZOP with prompts of “what if” to identify deviations from the expected. | identify risk | 1/2 | Medium/ long | 1/2 | medium | low /medium | qual. | low/ medium |
| B.5.11 | **Toxicological risk assessment** | A series of steps taken to obtain a measure for the risk to humans or ecological systems due to exposure to chemicals. | assess risk | 3 | Medium/ long | 2/3 | high | high | Mostly quant | high |
| B.5.12 | **Value at risk (VAR)** | Financial technique that uses an assumed probability distribution of losses in a stable market condition to calculate the value of a loss that might occur with a specified probability within a defined time span. | analyse risk | 1 | short | 3 | high | high | quant | medium |

# Annex B
(informative))

# Description of techniques

## B.1 Techniques for eliciting view from stakeholders and experts

### B.1.1 General

Some of the techniques described in B.2 to B.7 involve input from stakeholders and experts. This provides for a breadth of expertise and allows stakeholder involvement. Stakeholder and expert views can be obtained on an individual basis (e.g. through interview or survey) or using a group techniques such as brainstorming, nominal groups or Delphi technique. Views can include disclosure of information, expressions of opinion or creative ideas. B.1 describes some techniques that can be used to elicit information or gain consensus.

In some situations stakeholders have a specific expertise and role, and there is little divergence of opinion. However sometimes significantly varying stakeholder views might be expected and there might be power structures and other factors operating that affect how people interact. These factors will affect the choice of method used. The number of stakeholders to be consulted, time constraints and the practicalities of getting all necessary people together at the same time will also influence the choice of method.

Where a group face-to-face method is used an experienced and skilled facilitator is important to achieving good outputs. The role of the facilitator or coordinator is to:

- organise the team;
- obtain and distribute relevant information and data prior to the meeting/collaboration;
- prepare an efficient structure and format for the meeting/collaboration;
- provoke creative thinking in order to strengthen understanding and to generate ideas;
- ensure the results are accurate and as free from bias as possible.

Check lists derived from classifications and taxonomies can be used as part of the process (see B.2.2).

Any technique for obtaining information that relies on people's perceptions and opinions has the potential to be unreliable and suffers from a variety of biases such as availability bias (a tendency to over-estimate the likelihood of something which has just happened), clustering illusion (the tendency to overestimate the importance of small clusters in a large sample) or Bandwagon effect (the tendency to do or believe things because others do or believe the same).

Guidance on function analysis which can be used to reduce bias and focus creative thinking on aspects which have the greatest impact is given in EN 12973 Value Management.

The information on which judgements were based and any assumptions made should be reported.

### B.1.2 Brainstorming

#### B.1.2.1 Overview

Brainstorming is a process used to stimulate and encourage a group of people to develop ideas related to one of more topics of any nature. The term “brainstorming” is often used very loosely to mean any type of group discussion but effective brainstorming requires a conscious effort to ensure that the thoughts of others in the group are used as tools to stimulate the creativity of each participant. Any analysis or critique of the ideas is carried out separately from the brainstorming.

This technique gives the best results when an expert facilitator is available who can provide necessary stimulation but does not limit thinking. The facilitator stimulates the group to cover all relevant areas and makes sure that ideas from the process are captured for subsequent analysis.

Brainstorming can be structured or unstructured. For structured brainstorming the facilitator breaks down the issue to be discussed into sections and uses prepared prompts to generate ideas on a new topic when one is exhausted. Unstructured brainstorming is often more ad-hoc. In both cases the facilitator starts off a train of thought and everyone is expected to generate ideas. The pace is kept up to allow ideas to trigger lateral thinking. The facilitator can suggest a new direction, or apply a different creative thinking tool when one direction of thought is exhausted or discussion deviates too far. The goal is to collect as many diverse ideas as possible for later analysis.

It has been demonstrated that, in practice, groups generate fewer ideas than the same people working individually. For example:

- In a group people's ideas tend to converge rather than diversify,
- the delay in waiting for a turn to speak tends to block ideas
- people tend to work less hard mentally when in a group

These tendencies can be reduced by:

- provide opportunities for people to work alone for part of the time;
- diversifying teams and changing team membership;
- combining with techniques such as nominal group technique (B1.4) or electronic brainstorming. These encourage more individual participation and can be set up to be anonymous, thus also avoiding personal political and cultural issues.

#### B.1.2.2

Brainstorming can be applied at any level in an organization to identify uncertainties, success or failure modes, causes, consequences, criteria for decisions or options for treatment over. Quantitative use is possible but only in its structured form to ensure that biases are taken into account and addressed especially when used to involve all stakeholders.

Brainstorming stimulates creativity and it’s therefore very useful when working on innovative designs, products and processes.

#### B.1.2.3 Inputs

Brainstorming elicits views from participants so has less need for data or external information than other methods. Participants need to have between them the expertise, experience and range of view-points needed for the problem in hand. A skilled facilitator is normally necessary for brainstorming to be productive.

#### B.1.2.4 Outputs

The outputs are a list of all the ideas generated during the session and the thoughts raised when the ideas were presented.

#### B.1.2.5 Strengths and limitations

Strengths of brainstorming include that it:

- encourages imagination and creativity which helps identify new risks and novel solutions;
- is useful where there is little or no data, new technology or novel solutions are required;
- involves key stakeholders and hence aids communication and engagement;
- is relatively quick and easy to set up.

Limitations include:

- it is difficult to demonstrate that the process has been comprehensive;
- groups tend to generate fewer ideas than the individuals working alone;

- particular group dynamics might mean some people with valuable ideas stay quiet while others dominate the discussion. This can be overcome by effective facilitation.

#### B.1.2.6 Reference documents

THOMPSON, Leigh, Improving the creativity of organizational work groups. *Academy of Management Executive*, 2003, **17**(1), [viewed 2017-6-30]. Available at: http://ww2.valdosta.edu/~mschnake/Thompson2003.

GOLDENBERG, Olga, WILEY, Jennifer. Quality, conformity, and conflict: Questioning the assumptions of Osborn's brainstorming technique, *The Journal of Problem Solving,* 2011, **3**(2),96-108 [viewed 2017-6-30] available at: http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1093&context=jps

### B.1.3 Delphi technique

#### B.1.3.1 Overview

The Delphi technique is a procedure to gain consensus of opinion from a group of experts. It is a method to collect and collate judgments on a particular topic through a set of sequential questionnaires. An essential feature of the Delphi technique is that experts express their opinions individually, independently and anonymously while having access to the other expert's views as the process progresses.

The group of experts who form the panel are independently provided with the question or questions to be considered. The information from the first round of responses is analysed and combined and circulated to panellists who are then able to consider their original responses. Panellists respond and the process is repeated until consensus is reached. If one panellist or a minority of panellists consistently keep their response it might indicate that they have important information or an important point of view.

#### B.1.3.2 Use

The Delphi technique is used for complex problems about which uncertainty exists and for which expert judgment is needed to deal with this uncertainty. It can be used in forecasting and policy making, and to obtain consensus or to reconcile differences between experts. It can be used to identify risks, threats and opportunities and to gain consensus on the likelihood and consequences of future events. It is usually applied at a strategic or tactical level. Its original application was for long time-frame forecasting but it can be applied to any time-frame.

#### B.1.3.3 Inputs

The method relies on the knowledge and continued cooperation of participants through what can be a time scale of several months or even years.

The number of participants can range from a few to hundreds. Written questionnaires can be in pencil-and-paper form or distributed and returned using electronic communication tools including email and the internet.

#### B.1.3.4 Outputs

Consensus on the matter under consideration.

#### B.1.3.5 Strengths and limitations

Strengths include the following:

- as views are anonymous, unpopular opinions are more likely to be expressed;
- all views have equal weight, which avoids the problem of dominating personalities;
- it achieves ownership of outcomes;
- people do not need to be brought together in one place at one time;
- people have time to make a considered response to the questions.

Limitations include:

- it is labour intensive and time consuming;
- participants need to be able to express themselves clearly in writing.

#### B.1.3.6 Reference document

The Delphi technique: Past, present, and future prospects*. Technological forecasting and social change* 2011, **78**, Special Delphi Issue

### B.1.4 Nominal group technique

#### B.1.4.1 Overview

The nominal group technique, like brainstorming, aims to collect ideas. Views are first sought individually with no interaction between group members then are discussed by the group.

The process is as follows:

- the facilitator provides each group member with the questions to be considered;
- individuals write down their ideas silently and independently;
- each member of the group then presents their ideas with, at this stage, no discussion. If group dynamics mean that some voices have more weight than others ideas can be passed on to the facilitator anonymously. Participants can then seek further clarification;
- ideas are then discussed by the group to provide an agreed list;
- members of the group vote privately on the ideas and a group decision is made based on the votes.

#### B.1.4.2 Use

Nominal Group technique can be used as an alternative to brainstorming. It is also useful for prioritising ideas within a group.

#### B.1.4.3 Inputs

The ideas and experience of participants.

#### B.1.4.4 Outputs

Ideas, solutions or decisions as required.

#### B.1.4.5 Strengths and limitations

The strengths of the nominal group technique include:

- it provides a more balanced view than brainstorming when some members of a group are more vocal than others;
- it tends to produce more even participation if all or some group members are new to the team, the issue is controversial, or there is a power-imbalance or conflict amongst the team;
- it has been shown to generate a greater number of ideas than brainstorming;
- it diminishes pressure to conform to the group;
- it can achieve consensus in a relatively short time frame.

Limitations include that cross fertilisation of ideas can be constrained.

#### B.1.4.6 Reference document

MCDONALD, D. BAMMER, G. and DEANE, P. *Research Integration Using Dialogue Methods*, ANU press Canberra 2009 Chapter 3 Dialogue methods for understanding a problem: integrating judgements. Section 7 Nominal Group Technique [viewed 2017-9-20]. available at http://press.anu.edu.au/node/393/download

NOTE This reference also provides details of a range of other methods some of which are also discussed in this document.

### B.1.5 Structured or semi-structured interviews

#### B.1.5.1 Overview

In a structured interview, individual interviewees are asked a set of prepared questions. A semi-structured interview is similar, but allows more freedom for a conversation to explore issues which arise. In a semi-structured interview opportunity is explicitly provided to explore areas which the interviewee might wish to cover.

Questions should be open-ended where possible, should be simple, and in appropriate language for the interviewee and each question should cover one issue only. Possible follow-up questions to seek clarification are also prepared.

The questions should be tested with people of similar background to those to be interviewed to check that the questions are not ambiguous, will be correctly understood and the answers will cover the issues intended. Care should be taken not to “lead” the interviewee.

#### B.1.5.2 Use

Structured and semi-structured interviews are a means of obtaining in-depth information and opinions from individuals in a group. Their answers can be confidential if necessary. They provide in depth information where individuals are not biased by the views of other members of a group.

They are useful if it is difficult to get people together in the same place at the same time or if free-flowing discussion in a group is not appropriate for the situation or people involved. It is also possible to get more detailed information in an interview than is possible by survey or in a workshop situation. Interviews can be used at any level in an organization.

#### B.1.5.3 Inputs

The inputs are a clear understanding of the information required and a prepared set of questions which have been tested with a pilot group.

Those designing the interview and interviewers need some skills in order to obtain good valid responses that are not coloured by the interviewers own biases.

#### B.1.5.4 Outputs

The output is the detailed information required.

#### B.1.5.5 Strengths and limitations

The strengths of structured interviews include:

- they allow people time for considered thought about an issue;
- one-to-one communication can allow more in-depth consideration of issues than a group approach;
- structured interviews enable involvement of a larger number of stakeholders than a face to face group.

Limitations include:

- interviews are time consuming to design, deliver and analyse;
- they require some expertise to design and deliver if answers are to be unbiased by the interviewer;
- bias in the respondent is tolerated and is not moderated or removed through group discussion;
- interviews do not trigger imagination (which is a feature of group methods);
- Semi-structured interviews produce a considerable body of information in the words of the interviewee. It can be difficult to group this unambiguously into a form amenable to analysis.

#### B.1.5.6 Reference documents

HARRELL, M.C. BRADLEY, M.A. 2009 *Data collection methods – A training Manual - Semi structured interviews and focus groups,* RAND National defence research Institute USA [viewed 20-6-2017].Available at: http://www.rand.org/content/dam/rand/pubs/technical_reports/2009/RAND_TR718.pdf

GILL, J. JOHNSON, P. 2010 *Research methods for managers* (4th ed.) London: Sage Publications Ltd

### B.1.6 Surveys

#### B.1.6.1 Overview

Surveys generally engage more people than interviews and usually ask more restricted questions. Typically a survey will involve a computer or paper based questionnaire. Questions often offer yes/ no answers, choices from a rating scale or choices from a range of options. This allows statistical analysis of the results which is a feature of such methods. Some questions with free answers can be included but their number should be limited because of analysis difficulties.

#### B.1.6.2 Use

Surveys can be used in any situation where wide stakeholder consultation is useful, particularly when relatively little information is needed from a large number of people.

#### B.1.6.3 Inputs

Pre-tested, unambiguous questions sent to a large part representative sample of people willing to participate. The number of responses needs to be sufficient to provide statistical validity. (Return rates are often low, meaning many questionnaires need to be sent out). Some expertise is needed in developing a questionnaire that will achieve useful results and in the statistical analysis of results.

#### B.1.6.4 Outputs

The output is an analysis of the views from a range of individuals, often in graphical form.

#### B.1.6.5 Strengths and limitations

The strengths of surveys include:

- larger numbers can be involved than for interviews, providing better information across a group;
- surveys are relatively low cost to run, especially if online software is used that is capable of providing some statistical analysis;
- they can provide statistically valid information;
- results are easy to tabulate and easy to understand: graphical output is usually possible;
- reports of surveys can be made available to others relatively easily.

Limitations include:

- the nature of questions is restricted by the need to be simple and unambiguous;
- it is usually necessary to obtain some demographic information in order to interpret results;
- the number of questions that can be included is limited if a sufficient number of responses is to be expected;
- the person posing the question cannot explain, so respondents may interpret questions differently than was intended;
- it is difficult to design questions that do not lead respondents to particular answers;
- questionnaires tend to have underlying assumptions that might not be valid;
- it can be difficult to obtain a good and unbiased response rate.

#### B.1.6.6 Reference documents

UNIVERSITY OF KANSAS COMMUNITY TOOL BOX *Section 13 Conducting surveys*; [viewed 2017-9-14]. Available at http://ctb.ku.edu/en/table-of-contents/assessment/assessing-community-needs-and-resources/conduct-surveys/main.

SAUNDERS, M. LEWIS, P. THORNHILL, A. 2016. *Research Methods for Business Students* (7th ed.) Harlow: Pearson Education Ltd.

## B.2 Identification techniques

### B.2.1 General

Risk identification techniques can include:

- evidence based methods, such as literature reviews, and analysis of historical data;
- empirical methods, including testing and modelling to identify what might happen under particular circumstances;
- perception surveys, which canvas the views of a wide range of experienced people;
- techniques in which the subject being considered is divided into smaller elements each of which is considered in turn using methods which raise what if questions. Examples are HAZOP (B.2.4) and FMEA (B.2.3) and SWIFT;
- techniques for encouraging imaginative thinking about possibilities of the future, such as scenario analysis (B.2.5.);
- checklists or taxonomies based on past data or theoretical models (B.2.2).

The techniques described in B.2 are examples of some structured approaches to identifying risk. A structured technique is likely to be more comprehensive than an unstructured or semi-structured workshop and be more easily used to demonstrate due diligence in identifying risk.

The techniques described can involve multiple stakeholders and experts. Methods that can be used to elicit views, either individually or in a group are described in B.1.

### B.2.2 Checklists, classifications and taxonomies

#### B.2.2.1 Overview

Checklists are used during risk assessment in various ways such as to assist in understanding the context, in identifying risk and in grouping risks for various purposes during analysis. They are also used when managing risk, for example to classify controls and treatments, to define accountabilities and responsibilities, or to report and communicate risk.

A checklist can be based on experience of past failures and successes but more formally risk typologies and taxonomies can be developed to categorize or classify risks based on common attributes. In their pure forms, typologies are “top down” conceptually derived classification schemes whereas taxonomies are “bottom up” empirically or theoretically derived classification schemes. Hybrid forms typically blend these two pure forms.

Risk taxonomies are typically intended to be mutually exclusive and collectively exhaustive (i.e. to avoid overlaps and gaps). Risk typologies can focus on isolating a particular category of risk for closer examination.

Both typologies and taxonomies can be hierarchical with several levels of classification developed. Any taxonomy should be hierarchical and be able to be subdivided to increasingly fine levels of resolution. This will help maintain a manageable number of categories while also achieving sufficient granularity.

#### B.2.2.2 Use

Check lists, typologies and taxonomies can be designed to apply at strategic or operational level. They can be applied using questionnaires, interviews, structured workshops, or combinations of all three, in face to face or computer based methods.

Examples of commonly used check lists, classifications or taxonomies used at a strategic level include:

- SWOT: strengths, weaknesses, opportunities and threats: identifies factors in the internal and external context to assist with setting objectives and the strategies to achieve them taking account of risk;
- PESTLE, STEEP, STEEPLED etc. are various acronyms representing types of factor to consider when establishing the context or identifying risks. The letters represent Political, Economic, Social, Technological, Environmental, Legal, Ethical and Demographic. Categories relevant to the particular situation can be selected and checklists developed for examples under each category;
- Consideration of strategic objectives, critical success factors for reaching objectives, threats to success factors and risk drivers. From this risk treatments and early warning indicators for the risk drivers can be developed.

At an operational level hazard check lists are used to identify hazards within HAZID and Preliminary Hazard Analysis, (PHA). These are preliminary safety risk assessments carried out at the early design stage of a project.

General categorisations of risk include:

- by source of risk: market prices, counterparty default, fraud, safety hazards, etc.;
- by consequence, aspects or dimensions of objectives or performance.

Pre–identified categories of risk can be useful in directing thinking about risk across a broad range of issues. However it is difficult to ensure such categories are comprehensive, and by subdividing risk in a predefined way, thinking is directed along particular lines and important aspects of risk might be overlooked.

Check lists, typologies and taxonomies are used within other techniques described in this document, for example, the key words in HAZOP (B.2.4) and the categories in an Ishikawa analysis (B.3.2). A taxonomy that can be used to consider human factors when identifying risk or considering causes is given in IEC 62740: 2015 *Root cause analysis.*

In general the more specific the checklist, the more restricted its use to the particular context in which it is developed. Words that provide general prompts are usually more productive in encouraging a level of creativity when identifying risk.

#### B.2.2.3 Inputs

Inputs are data or models from which to develop valid check lists, taxonomies or typographies.

#### B.2.2.4 Outputs:

Outputs are:

- checklists, prompts or categories and classification schemes;
- an understanding of risk from the use of these, including (in some cases) lists of risks and groupings of risks.

#### B.2.2.5 Strengths and limitations

Strengths of checklists, taxonomies, typographies include:

- they promote a common understanding of risk among stakeholders;
- when well designed, they bring wide ranging expertise into an easy to use system for non-experts;
- once developed they require little specialist expertise.

Limitations include:

- their use is limited in novel situations where there is no relevant past history or in situations that differ from that for which they were developed;

- they address what is already known or imagined;
- they are often generic and might not apply to the particular circumstances being considered;
- complexity can hinder identification of relationships (e.g., interconnections and alternative groupings);
- lack of information can lead to overlaps and/or gaps (e.g. schemes are not mutually exclusive and collectively exhaustive);
- they can encourage 'tick the box' type of behaviour rather than exploration of ideas.

#### B.2.2.6 Reference documents

BROUGHTON, Vanda. *Essential classification.* Facet Publishing 2015

BAILEY, Kenneth. Typologies and taxonomies: An introduction to classification technique. *Quantitative Applications in the social sciences* Series **7**,102 1994 Sage publications

Pestle analysis *Free Management E books* [viewed 2017-9-12]. Available at http://www.free-management-ebooks.com/dldebk-pdf/fme-pestle-analysis.pdf

VDI 2225 Blatt 1, Konstruktionsmethodik-Technisch-wirtschaftlisches Konstruiren-Vereinfachte Kostenermittlung, 1997 Beuth Verlag

### B.2.3 Failure modes and effects analysis (FMEA) and Failure modes, effects and criticality analysis (FMECA)

#### B.2.3.1 Overview

In FMEA (Failure Mode and Effect Analysis) a team subdivides hardware, a system, a process or a procedure into elements. For each element the ways in which it might fail, and the failure causes and effects are considered. FMEA can be followed by a criticality analysis which defines the significance of each failure mode, (FMECA).

For each element the following is recorded:

- its function;
- the failure that might occur (failure mode);
- the mechanisms that could produce these modes of failure;
- the nature of the consequences if failure did occur;
- whether the failure is harmless or damaging;
- how and when the failure can be detected;
- the inherent provisions that exist to compensate for the failure.

For FMECA, the study team classifies each of the identified failure modes according to its criticality. Criticality methods include use of a consequence likelihood matrix (B.9.3) or a risk Priority Number (RPN). A quantitative measure of criticality can also be derived from actual failure rates where these are known.

NOTE The RPN is an index method (B.8.6) that multiplies ratings for consequence of failure, likelihood of failure and ability to detect the problem. (A failure is given a higher priority if it is difficult to detect.)

#### B.2.3.2 Use

FMEA/FMECA can be applied during the design, manufacture or operation of a physical system to improve design, select between design alternatives or plan a maintenance program. It can also be applied to processes and procedures, such as in medical procedures and manufacturing processes. It can be performed at any level of breakdown of a system from block diagrams to detailed components of a system or steps of a process.

FMEA can be used to provide qualitative or quantitative information for analysis techniques such as fault tree analysis. It can provide a starting point for a root cause analysis.

#### B.2.3.3 Inputs

Inputs include information about the system to be analysed and its elements in sufficient detail for meaningful analysis of the ways in which each element can fail and the consequences if it does. The information needed can include drawings and flow charts, details of the environment in which the system operates, and historical information on failures where available.

FMEA is normally carried out by a team with expert knowledge of the system being analysed, led by a trained facilitator. It is important for the team to cover all relevant areas of expertise

#### B.2.3.4 Outputs

The outputs of FMEA are:

- a worksheet with failure modes, effects, causes and existing controls;
- a measure of the criticality of each failure mode (if FMECA) and the methodology used to define it;
- any recommendations, e.g. for further analyses, design changes or features to be incorporated in test plans.

FMECA usually provides a qualitative ranking of the importance of failure modes, but can give a quantitative output if suitable failure rate data and quantitative consequences are used.

#### B.2.3.5 Strengths and limitations

The strengths of FMEA/FMECA include the following:

- it can be applied widely to both human and technical modes of systems, hardware, software and procedures;
- it identifies failure modes, their causes and their effects on the system, and presents them in an easily readable format;
- it avoids the need for costly equipment modifications in service by identifying problems early in the design process;
- it provides input to maintenance and monitoring programmes by highlighting key features to be monitored.

Limitations include:

- FMEA can only be used to identify single failure modes, not combinations of failure modes;
- unless adequately controlled and focussed, the studies can be time consuming and costly;
- FMEA can be difficult and tedious for complex multi-layered systems.

#### B.2.3.6 Reference document

IEC 60812*, Analysis techniques for system reliability – Procedures for failure mode and effect analysis (FMEA).*

### B.2.4 Hazard and operability (HAZOP) studies

#### B.2.4.1 Overview

A HAZOP study is a structured and systematic examination of a planned or existing process, procedure or system that involves identifying potential deviations from the design intent, and examining their possible causes and consequences.

Within a facilitated workshop the study team:

- subdivides the system, process or procedure into smaller elements;
- agrees the design intent for each element including defining relevant parameters (such as flow or temperature in the case of a physical system);

- applies guidewords successively to each parameter for each element to postulate possible deviations from the design intent that could have undesirable outcomes;

  NOTE Not all guideword parameter combinations will be meaningful.

- agrees the cause and consequences in each case suggesting how they might be treated;
- documents the discussion and agrees possible actions to treat the risks identified.

Table B.1 provides examples of commonly used guidewords for technical systems. Similar guidewords such as ‘too early’, ‘too late’, ‘too much’, ‘too little’, ‘too long’, ‘too short’, ‘wrong direction’, ‘wrong object’, ‘wrong action’ can be used to identify human error modes.

Guide words are applied to parameters such as:

- physical properties of a material or process;
- physical conditions such as temperature or speed;
- timing;
- a specified intention of a component of a system or design (e.g. information transfer);
- operational aspects.

**Table B.1 – Examples of basic guide words and their generic meanings**

| Guide words | Definitions |
|---|---|
| No or not | No part of the intended result is achieved or the intended condition is absent |
| More (higher) | Quantitative increase |
| Less (lower) | Quantitative decrease |
| As well as | Qualitative modification/increase (e.g. additional material) |
| Part of | Qualitative modification/decrease (e.g. only one of two components in a mixture) |
| Reverse /opposite | Logical opposite of the design intent (e.g. backflow) |
| Other than | Complete substitution, something completely different happens (e.g. wrong material) |
| Early | Relative to clock time |
| Late | Relative to clock time |

#### B.2.4.2 Use

HAZOP studies were initially developed to analyse chemical process systems, but have been extended to other types of system including mechanical and electronic systems, procedures, and software systems, organizational changes and legal contract design and review.

The HAZOP process can deal with all forms of deviation from design intent due to deficiencies in the design, component(s), planned procedures and human actions. It is most often used to improve a design or identify risks associated with a design change. It is usually undertaken at the detail design stage, when a full diagram of the intended process and supporting design information are available, but while design changes are still practicable. It can however, be carried out in a phased approach with different guidewords for each stage as a design develops in detail. A HAZOP study can also be carried out during operation but required changes can be costly at that stage.

#### B.2.4.3 Inputs

Inputs include current information about the system to be reviewed and the intention and performance specifications of the design. For hardware this can include drawings, specification sheets, flow diagrams, process control and logic diagrams, and operating and maintenance procedures. For non-hardware related HAZOP the inputs can be any document that describes functions and elements of the system or procedure under study, for example, organizational diagrams and role descriptions, or a draft contract or draft procedure.

A HAZOP study is usually undertaken by a multidisciplinary team that should include designers and operators of the system as well as persons not directly involved in the design or the system, process or procedure under review. The leader/facilitator of the study should be trained and experienced in handling HAZOP studies.

#### B.2.4.4 Outputs

Outputs include minutes of the HAZOP meeting(s) with deviations for each review point recorded. Records should include: the guide word used, and possible causes of deviations. It can also include actions to address the identified problems and the person responsible for the action.

#### B.2.4.5 Strengths and limitations

Strengths of HAZOP include that it:

- provides the means to systematically examine a system, process or procedure to identify how it might fail to achieve its purpose;
- provides a detailed and thorough examination by a multidisciplinary team;
- identifies potential problems at the design stage of a process;
- generates solutions and risk treatment actions;
- is applicable to a wide range of systems, processes and procedures;
- allows explicit consideration of the causes and consequences of human error;
- creates a written record of the process which can be used to demonstrate due diligence.

Limitations include:

- a detailed analysis can be very time-consuming and therefore expensive;
- the technique tends to be repetitive finding the same issues multiple times, hence it can be difficult to maintain concentration;
- a detailed analysis requires a high level of documentation or system/process and procedure specification;
- it can focus on finding detailed solutions rather than on challenging fundamental assumptions (however, this can be mitigated by a phased approach);
- the discussion can be focused on detail issues of design, and not on wider or external issues;
- it is constrained by the (draft) design and design intent, and the scope and objectives given to the team;
- the process relies heavily on the expertise of the designers who might find it difficult to be sufficiently objective to seek problems in their designs.

#### B.2.4.6 Reference documents

IEC 61882, *Hazard and operability studies (HAZOP studies) – Application guide*

### B.2.5 Scenario Analysis

#### B.2.5.1 Overview

Scenario analysis is a name given to a range of techniques that involve developing models of how the future might turn out. In general terms, it consists of defining a plausible scenario and working through what might happen given various possible future developments.

For relatively close time periods it can involve extrapolating from what has happened in the past. For longer time-scales scenario analysis can involve building an imaginary but credible scenario then exploring the nature of risks within this scenario. It is most often applied by a group of stakeholders with different interests and expertise. Scenario analysis involves defining in some detail the scenario or scenarios to be considered and exploring the implications of the scenario and associated risk. Changes commonly considered include:

- changes in technology;
- possible future decisions that might have a variety of outcomes;
- stakeholder needs and how they might change;
- changes in the macro environment (regulatory, demographics, etc.);
- changes in the physical environment.

#### B.2.5.2 Use

Scenario analysis is most often used to identify risk and explore consequences. It can be used at both strategic and operational level, for the organization as a whole or part of it.

Long-term scenario analysis attempts to aid planning for major shifts in the future such as those that have occurred over the past 50 years in technology, consumer preferences, social attitudes, etc. Scenario analysis cannot predict the probabilities of such changes but can consider consequences and help organizations develop strengths and the resilience needed to adapt to foreseeable change. It can be used to anticipate how both threats and opportunities might develop and can be used for all types of risk.

Short time frame scenario analysis is used to explore the consequences of an initiating event. Likely scenarios can be extrapolated from what has happened in the past or from models. Examples of such applications include planning for emergency situations or business interruptions. If data are not available, experts' opinions are used, but in this case it is very important to give utmost attention to their explanations for their views.

#### B.2.5.3 Inputs

To undertake a scenario analysis data on current trends and changes and ideas for future change are required. For complex or very long term scenarios expertise in the technique is required.

#### B.2.5.4 Outputs

The output can be a "story" for each scenario that tells how one might move from the present towards the subject scenario. The effects considered can be both beneficial and detrimental. The stories may include plausible details that add value to the scenarios.

Other outputs can include an understanding of possible effects of policy or plans for various plausible futures, a list of risks that might emerge if the futures were to develop and, in some applications, a list of leading indicators for those risks.

#### B.2.5.5 Strengths and limitations

Strengths of scenario analysis include the following:

- it takes account of a range of possible futures. This can be preferable to the traditional approach of relying on forecasts that assume that future events will probably continue to follow past trends. This is important for situations where there is little current knowledge on which to base predictions or where risks are being considered in the longer term;
- it supports diversity of thinking;
- it encourages monitoring of lead indicators of change;
- decisions made for the risks identified can help build resilience for whatever does occur.

Limitations include:

- the scenarios used might not have an adequate foundation, for example data might be speculative. This could produce unrealistic results that might not be recognized as such;
- there is little evidence that scenarios explored for the long term future are those that actually occur.

#### B.2.5.6 Reference documents

RINGLAND, Gill. *Scenarios in business*, Chichester: John Wiley, 2002

Van der HEIJDEN, Kees. *Scenarios: The art of strategic conversation*, Chichester; John Wiley, 2005

CHERMACK, Thomas J. *Scenario planning in organizations*, San Francisco: Berrett Koehler publishers Inc. 2011

MUKUL PAREEK, Using Scenario analysis for managing technology risk: http://www.isaca.org/Journal/archives/2012/Volume-6/Pages/Using-Scenario-Analysis-for-Managing-Technology-Risk.aspx

### B.2.6 Structured what if technique (SWIFT)

#### B.2.6.1 Overview

SWIFT is a high-level risk identification technique that can be used independently, or as part of a staged approach to make bottom-up methods such as HAZOP or FMEA more efficient. SWIFT uses structured brainstorming (B.8.2) in a facilitated workshop where a predetermined set of guide words (such as timing, amount etc.) are combined with prompts elicited from participants that often begin with phrases such as "what if?" or "how could?'' It is similar to HAZOP but applied at a system or subsystem rather than on the designer's intent.

Before the study commences the facilitator prepares a prompt list to enable a comprehensive review of risks or sources of risk. At the start of the workshop the context, scope and purpose of the SWIFT is discussed and criteria for success articulated. Using the guidewords and 'what if' prompts, the facilitator asks the participants to raise and discuss issues such as:

- known risks;
- risk sources and drivers;
- previous experience, successes and incidents;
- known and existing controls;
- regulatory requirements and constraints.

The facilitator uses the prompt list to monitor the discussion and to suggest additional issues and scenarios for the team to discuss. The team considers whether controls are adequate and if not considers potential treatments. During this discussion further 'what-if' questions are posed.

In some cases specific risks are identified and a description of the risk, its causes, consequences and controls can be recorded. In addition more general sources or drivers of risk, control problems or systemic issues may be identified.

Where a list of risks is generated a qualitative or semi-quantitative risk assessment method is often used to rank the actions created in terms of level of risk. This normally takes into account the existing controls and their effectiveness.

#### B.2.6.2 Use

The technique can be applied to systems, plant items, procedures and organizations generally. In particular it is used to examine the consequences of changes and the risk thereby altered or created. Both positive and negative outcomes can be considered. It can also be used to identify the systems or processes for which it would be worth investing the resources for a more detailed HAZOPs or FMEA.

#### B.2.6.3 Inputs

A clear understanding of the system, procedure, plant item and/or change and the external and internal contexts is needed. This is established through interviews and through the study of documents, plans and drawings by the facilitator. Normally the system for study is split into elements to facilitate the analysis process. Although the facilitator needs to be trained in the application of SWIFT, this can usually be quickly accomplished.

#### B.2.6.4 Outputs

Outputs include a register of risks with risk-ranked actions or tasks that can be used as the basis for a treatment plan.

#### B.2.6.5 Strengths and limitations

Strengths of SWIFT include the following:

- it is widely applicable to all forms of physical plant or system, situation or circumstance, organization or activity;
- it needs minimal preparation by the team;
- it is relatively rapid and the major risks and risk sources quickly become apparent within the workshop session;
- the study is 'systems orientated' and allows participants to look at the system response to deviations rather than just examining the consequences of component failure;
- it can be used to identify opportunities for improvement of processes and systems and generally can be used to identify actions that lead to and enhance their probabilities of success;
- involvement in the workshop by those who are accountable for existing controls and for further risk treatment actions, reinforces their responsibility;
- it creates a risk register and risk treatment plan with little more effort.

Limitations include:

- if the workshop team does not have a wide enough experience base or if the prompt system is not comprehensive, some risks or hazards might not be identified;
- the high-level application of the technique might not reveal complex, detailed or correlated causes;
- recommendations are often generic, e.g. the method does not provide support for robust and detailed controls without further analysis being carried out.

#### B.2.6.6 Reference Document

CARD, Alan J. WARD, James R. and CLARKSON, P. John. Beyond FMEA: The structured what-if technique (SWIFT) *Journal of Healthcare Risk Management*, 2012, **31**,(4) 23–29

## B.3 Analysing sources and drivers of risk

### B.3.1 General

An understanding of the causes of potential events and the drivers of risk can be used to design strategies to prevent adverse consequences or enhance positive ones. Often there is a hierarchy of causes with several layers before the root cause is reached. Generally causes are analysed until actions can be determined and justified.

Causal analysis techniques can explore perceptions of cause under a set of predetermined headings such as in the Ishikawa method, (B.3.3) or can take a more logic based approach as in fault tree analysis and success tree analysis (B.5.6).

Bow tie analysis (B.4.2) can be used to represent causes and consequences graphically, and show how they are controlled.

Several of the techniques described in IEC 62740 *Root cause analysis* can be used proactively to analyse possible causes of events that might happen in the future, as well as those that have already occurred. These techniques are not repeated here.

### B.3.2 Cindynic approach

#### B.3.2.1 Overview

Cindynics literally means the Science of danger. The cyndinic approach identifies intangible risk sources and drivers that might give rise to many different consequences. In particular it identifies and analyses:

- inconsistencies, ambiguities, omissions, ignorance (termed deficits), and
- divergences between stakeholders (termed dissonances).

The cindynic approach starts by collecting information on the system or organization which is the subject of the study and the cindynic situation defined by a geographical, temporal and chronological space and a set of stakeholder networks or groups.

It then uses semi-structured interviews (B.1.5) to collect information at various times ($T_1$, $T_2$,… $T_i$) about the state of knowledge, and the state of mind, of each stakeholder, as they relate to the five criteria of the cindynic approach as follows:

- goal (primary purpose of the organization);
- values (considered in high esteem by the stakeholder);
- rules (rights, standards, procedures, etc. governing its achievements);
- data (on which decision-making is based);
- models (technical, organizational, human etc. that use data in decision-making).

NOTE The elements characterizing internal and external contexts can be put together according to the five criteria of the cindynic approach.

The approach takes into account perceptions as well as facts.

Once this information is obtained, the coherence between objectives to be reached and the five criteria of cindynics are analysed and tables are set up listing deficits and dissonances.

#### B.3.2.2 Use

The aim of the cindynic approach is to understand why, despite all the control measures taken to prevent disasters, they still happen. The approach has since been extended to improve the economic efficiency of organizations. The technique seeks systemic sources and drivers of risk within an organization which can lead to wide ranging consequences. It is applied at a strategic level and can be used to identify factors acting in a favourable or unfavourable way during the evolution of the system towards new objectives.

It can also be used to validate the consistency of any project and is especially useful in the study of complex systems.

#### B.3.2.3 Inputs

Information as described above. The analysis usually involves a multidisciplinary team including those with real-life operational experience and those who will carry out treatment actions to address the sources of risk identified.

#### B.3.2.4 Outputs

The outputs are tables which indicate dissonances and deficits between stakeholders, as illustrated in the examples below. Table B.2 shows a matrix indicating the deficits of each stakeholder against the five axes of analysis (goals, values, rules, models, and data). By comparing the information gathered as input between situations taken at times $T_1$, $T_2$, ..., $T_{i,}$ it is possible to identify deficits between different situations.

Table B.3 is a matrix where relevant stakeholders are represented on both axes and the difference in views between stakeholders (so called dissonances) are shown in the matrix cells. These tables enable a program for reduction of deficits and dissonances to be established.

**Table B.2 – Table of deficits for each stakeholder**

| Criteria / Stakeholder | Goals | Values | Rules | Data | Models |
|---|---|---|---|---|---|
| **S1** | | Focus on a restricted number of values | No reference to procedures | No reference to measurements | No reference to models |
| **S2** | Inconsistency between goals and rules | Lack of ranking between values | Lack of ranking between rules | Ignorance of experience and feedback from other countries | Ignorance of specific models |
| **S3** | Inconsistency between goals and standards | Focus on a specific value (e.g. employment) | Lack of ranking between rules | No attention paid to specific data e.g. occupational injuries) | Lack of prioritization in selecting models |

**Table B.3 – Table of dissonances between stakeholders**

| Stakeholder / Stakeholder | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| **S1** | | S1 and S2 do not share the same goals | S1 and S3 do not share the same values | S1 and S4 do not share the same measurement systems |
| **S2** | | | S2 and S3 do not agree on interpretation of procedures | S2 and S4 do not agree on data |
| **S3** | | | | S3 and S4 disagree on interpretation of rules |
| **S4** | | | | |

#### B.3.2.5 Strengths and Limitations

Strengths of the cindynic approach include that it:

- is a systemic, multidimensional and multidisciplinary approach;
- provides knowledge of the potential riskiness of a system and its consistency;
- considers human and organizational aspects of risk at any level of responsibility;
- integrates space and time notions;
- yields solutions to reduce risks.

Limitations include:

- it does not attempt to prioritise sources of risk or risks;
- it has only recently begun to be disseminated in industry. It therefore does not benefit from the same maturity acquired through past developments as traditional approaches;
- depending on the number of stakeholders involved it can require significant time and resources.

#### B.3.2.6 Reference documents

KERVERN G-Y *Elements fondamentaux des cindyniques*, Editions Economica 1995

KERVERN G-Y. *Latest advances in cindynics,* Editions Economica,1994

KERVERN G-Y & BOULENGER P. *Cindyniques – Concepts et mode d'emploi*, Edition Economica 2007

### B.3.3 Ishikawa (fishbone) method

#### B.3.3.1 Overview

Ishikawa analysis uses a team approach to identify possible causes of a desirable or undesirable effect, event or issue. The possible contributory factors are organised into broad categories to cover, human, technical and organizational causes. The information is depicted in a Fishbone (also called Ishikawa) diagram (see Figure B.1). The steps in performing the analysis are:

- establish the effect to be analysed and place it in a box as the head of the fishbone diagram. The effect can be either positive (an objective) or negative (a problem);
- agree on the main categories of causes. Categories commonly used include:
  - 5Ms: methods, machinery, management, materials, manpower;
  - materials, methods and processes, environment, equipment, people, measurements;

  NOTE Any set of agreed categories can be used that fit the circumstances being analysed. Figure B1 illustrates another possibility.
- ask "why?" and "how might that occur?" iteratively to explore the causes and influencing factors in each category, adding each to the bones of the fishbone diagram;
- review all branches to verify consistency and completeness and ensure that the causes apply to the main effect;
- identify the most important factors based on the opinion of the team and available evidence.

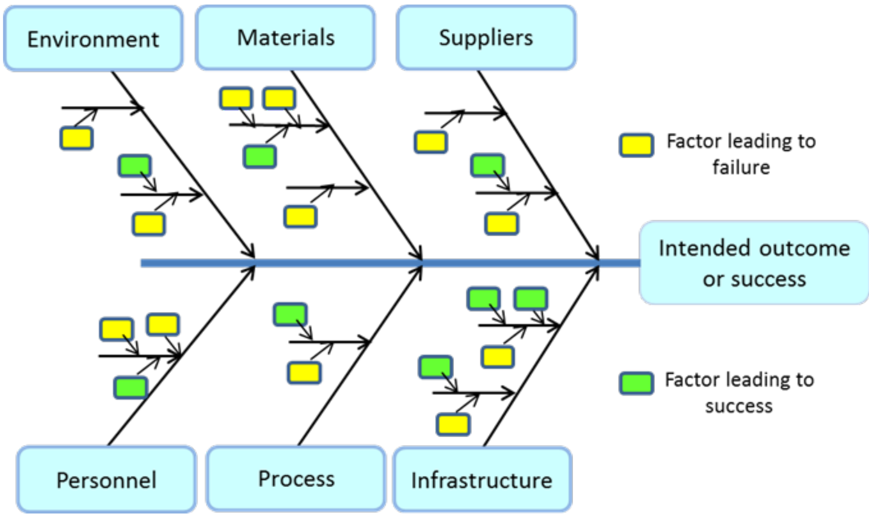



**Figure B.1 – Example Ishikawa (fishbone) diagram**

The diagram is often developed in a workshop scenario.

#### B.3.3.2 Use

Ishikawa analysis provides a structured pictorial display of a hierarchical list of causes of a specified effect, event or issue. It can be used when performing a root cause analysis of events which have occurred, or to identify factors that might contribute to outcomes which have not yet occurred. The method can be used to examine situations at any level in an organization over any timescale.

The diagrams are generally used qualitatively. It is possible to assign probabilities to generic causes, and subsequently to the sub-causes, on the basis of the degree of belief about their relevance. However, contributory factors often interact and contribute to the effect in complex ways and there can be unidentified causes, which make quantification invalid.

#### B.3.3.3 Input

The input is the expertise and experience of participants and an understanding of the situation under examination.

#### B.3.3.4 Output

The output is perceived causes of the effect being analysed, normally displayed as either a fishbone or Ishikawa diagram or a tree diagram. The Fishbone diagram is structured by representing the main categories as major bones off the fish backbone with branches and sub-branches that describe more specific sub-causes in those categories.

#### B.3.3.5 Strengths and limitations

Strengths of the Ishikawa technique include that it:

- encourages participation and utilizes group knowledge;
- provides a focussed approach for brainstorming or similar identification techniques;
- can be applied to a wide range of situations;
- provides a structured analysis of cause with an easy to read graphical output;
- allows people to report problems in a neutral environment;
- can be used to identify contributory factors to wanted as well as unwanted effects. (A positive focus can encourage greater ownership and participation.)

Limitations include:

- the separation of causal factors into major categories at the start of the analysis means that interactions between the categories might not be considered adequately;
- potential causes not covered by the categories selected are not identified.

#### B.3.3.6 Reference documents

ISHIKAWA, K. *Guide to Quality Control*, Asia Productivity Organization, 1986

See also IEC 62740 *Root cause analysis (RCA)* for other causal analysis techniques.

## B.4 Techniques for analysing controls

### B.4.1 General

The techniques in this clause can be used to check whether controls are appropriate and adequate.

Bow tie analysis (B.4.2) and LOPA (B.4.4) identify the barriers between a source of risk and its possible consequences and can be used to check that the barriers are sufficient.

HACCP (B.4.3) seeks points in a process where conditions can be monitored and controls introduced when there is an indication that the conditions are changing.

Event tree analysis (B.5.5) can also be used as a quantitative means of controls analysis by calculating the influence of different controls on the probability of consequences.

Any causal analysis technique can be used as a basis to checking that each cause is controlled.

### B.4.2 Bow tie analysis

#### B.4.2.1 Overview

A bow tie is a graphical depiction of pathways from the causes of an event to its consequences. It shows the controls that modify the likelihood of the event and those that modify the consequences if the event occurs. It can be considered as a simplified representation of a fault tree or success tree (analysing the cause of an event) and an event tree (analysing the consequences). Bow tie diagrams can be constructed starting from fault and event trees, but are more often drawn directly by a team in a workshop scenario.

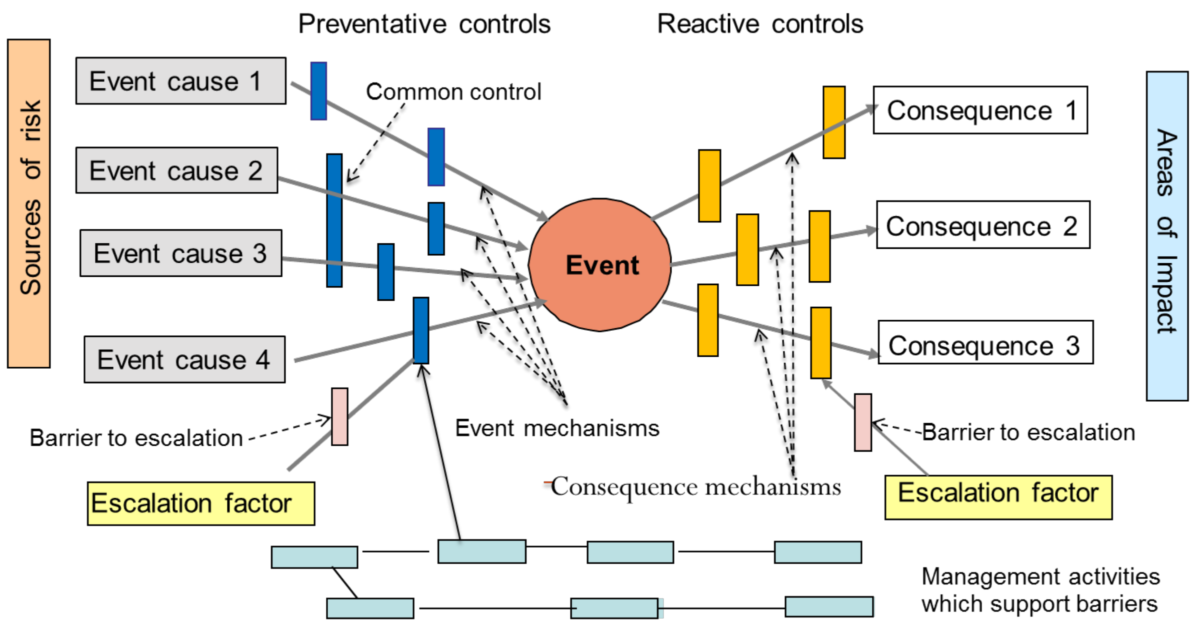



**Figure B.2 – Example Bowtie**

The bow tie is drawn as follows:

- the event of interest is represented by the central knot of the bow tie, see Figure B.2;
- sources of risk (or hazards/ threats in a safety context) are listed at the left hand side of the knot and joined to the knot by lines representing the different mechanisms by which sources of risk can lead to the event;
- barriers or controls for each mechanism are shown as vertical bars across the lines;
- on the right-hand side of the knot lines are drawn to radiate out from the event to each potential consequence;
- after the event vertical bars represent reactive controls or barriers that modify consequences;
- factors that might cause the controls to fail (escalation factors) are added, together with controls for the escalation factors;
- management functions which support controls (such as training and inspection) can be shown under the bow tie and linked to the respective control.

Some level of quantification of a bow tie diagram can be possible where pathways are independent, the probability of a particular consequence or outcome is known and the probability that a control will fail can be estimated. However, in many situations, pathways and barriers are not independent, and controls may be procedural and their effectiveness uncertain. Quantification is often more appropriately carried out using fault tree analysis (B.5.6) and event tree analysis (B.5.5) or LOPA (B.4.4).

### B.4.2.2 Use

Bow tie analysis is used to display and communicate information about risks in situations where an event has a range of possible causes and consequences. It can be used to explore in detail the causes and consequences of events that are recorded in a simple form in a risk register (B.9.2). It is particularly used for analysing events with more serious consequences. A bow tie is used when assessing controls to check that each pathway from cause to event and event to consequence has effective controls, and that factors that could cause controls to fail (including management systems failures) are recognised. It can be used as the basis of a means to record information about a risk that does not fit the simple linear representation of a risk register. It can be used proactively to consider potential events and also retrospectively to model events that have already occurred.

The bow tie is used when the situation does not warrant the complexity of a full fault tree analysis and event tree analysis but is more complex than can be represented by a single cause-event-consequence pathway.

For some situations cascading bow ties can be developed where the consequences of one event become the cause of the next.

#### B.4.2.3 Input

Input includes information about the causes and consequences of the pre-defined event, and the controls that might modify it.

#### B.4.2.4 Output

The output is a simple diagram showing main risk pathways, the controls in place, and the factors that might lead to control failure. It also shows potential consequences and the measures that can be taken after the event has occurred to modify them.

#### B.4.2.5 Strengths and limitations

Strengths of bow tie analysis include:

- it is simple to understand and gives a clear pictorial representation of an event and its causes and consequences;
- it focuses attention on controls which are supposed to be in place and their effectiveness;
- it can be used for desirable consequences as well as undesirable;
- it does not need a high level of expertise to use.

Limitations include:

- a bow tie cannot depict a situation where pathways from causes to the event are not independent (i.e. where there would be AND gates in a fault tree):
- it can over-simplify complex situations particularly where quantification is attempted.

#### B.4.2.6 Reference documents

LEWIS, S. SMITH, K., Lessons learned from real world application of the bow-tie method. 6th AIChE. *Global Congress of Process Safety*, 2010, San Antonio, Texas [viewed 2017-6-30]. Available at: http://risktecsolutions.co.uk/media/43525/bow-tie%20lessons%20learned%20-%20aiche.pdf

HALE, A. R., GOOSSENS L.H.J., ALE, B.J.M., BELLAMY L.A. POST J. Managing safety barriers and controls at the workplace. In *Probabilistic safety assessment and management*.: Editors SPITZER C, SCHMOCKER, U, DANG VN,. Berlin: Springer; 2004. pp. 608–13

MCCONNELL, P. and DAVIES, M Scenario *Analysis under Basel II*. [viewed 2017-9-14]. Available at http://www.continuitycentral.com/feature0338.htm

### B.4.3 Hazard analysis and critical control points (HACCP)

#### B.4.3.1 Overview

Hazard analysis and critical control point (HACCP) was developed to ensure food safety for the NASA space program but can be used for non-food processes or activities. The technique provides a structure for identifying sources of risk (hazards or threats) and putting controls in place at all relevant parts of a process to protect against them. HACCP is used at operational levels although its results can support the overall strategy of an organization. HACCP aims to ensure that risks are minimized by monitoring and by controls throughout a process rather than through inspection at the end of the process.

HACCP consists of the following seven principles:

- identify hazards, the factors which influence the risk and possible preventive measures;
- determine the points in the process where monitoring is possible and the process can be controlled to minimize threats (the critical control points or CCPs);

- establish critical limits for the parameters which are to be monitored; i.e. each CCP should operate within specific parameters to ensure the risk is controlled;
- establish the procedures to monitor critical limits for each CCP at defined intervals;
- establish corrective actions to be used when the process falls outside established limits;
- establish verification procedures;
- implement record keeping and documentation procedures for each step.

#### B.4.3.2 Use

HACCP is a requirement in most countries for organizations operating anywhere within the food chain, from harvesting to consumption, to control risks from physical, chemical or biological contaminants.

It has been extended for use in manufacture of pharmaceuticals, medical devices and in other areas where the biological, chemical and physical risks are inherent to the organization.

The principle of the technique is to identify sources of risk related to the quality of the output of a process, and to define points in that process where critical parameters can be monitored and sources of risk controlled. This can be generalized to many other processes, including for example financial processes.

#### B.4.3.3 Inputs

Inputs include:

- a basic flow diagram or process diagram;
- information on sources of risk that might affect the quality, safety or reliability of the product or process output;
- information on the points in the process where indicators can be monitored and controls can be introduced.

#### B.4.3.4 Outputs

Outputs include records, including a hazard analysis worksheet and a HACCP plan.

The hazard analysis worksheet lists for each step of the process:

- hazards which could be introduced, controlled or exacerbated at that step;
- whether the hazards present a significant risk (based on consideration of consequence and probability using a combination of experience, data and technical literature);
- a justification for the significance rating;
- possible preventative measures for each hazard;
- whether monitoring or control measures can be applied at this step (i.e. is it a CCP?).

The HACCP plan delineates the procedures to be followed to assure the control of a specific design, product, process or procedure. The plan includes a list of all CCPs and for each CCP lists:

- the critical limits for preventative measures;
- monitoring and continuing control activities (including what, how, and when monitoring will be carried out and by whom;
- corrective actions required if deviations from critical limits are detected;
- verification and record-keeping activities.

#### B.4.3.5 Strengths and limitations

Strengths of HACCP include:

- HACCP is a structured process that provides documented evidence for quality control as well as identifying and reducing risks;

- it focuses on the practicalities of how and where, in a process, sources of risk can be found and risk controlled;
- it provides risk control throughout a process rather than relying on final product inspection;
- it draws attention to risk introduced through human actions and how this can be controlled at the point of introduction or subsequently.

Limitations include:

- HACCP requires that hazards are identified, the risks they represent defined, and their significance understood as inputs to the process. Appropriate controls also need to be defined. HACCP might need to be combined with other tools to provide these inputs;
- taking action only when control parameters exceed defined limits can miss gradual changes in control parameters which are statistically significant and hence should be actioned.

#### B.4.3.6 Reference documents

ISO 22000, *Food safety management systems – Requirements for any organization in the food chain*

*Food Quality and Safety Systems - A Training Manual on Food Hygiene and the Hazard Analysis and Critical Control Point (HACCP) System* viewed 2017-9-14]. Available at http://www.fao.org/docrep/W8088E/w8088e05.htm

### B.4.4 Layers of protection analysis (LOPA)

#### B.4.4.1 Overview

LOPA analyses whether a risk is controlled to an acceptable level. It can be considered as a particular case of an event tree and is sometimes carried out as a follow up to a HAZOP study.

A cause-consequence pair is selected from a list of identified risks and the independent protection layers (IPLs) are identified. An IPL is a device, system or action that is capable of preventing a scenario from proceeding to its undesired consequence Each IPL should be independent of the causal event or of any other layer of protection associated with the scenario and should be auditable IPLs include:

- design features;
- physical protection devices;
- interlocks and shutdown systems;
- critical alarms and manual intervention;
- post event physical protection;
- emergency response systems.

Standard procedures and /or inspections do not directly add barriers to failure so in general should not be considered to be IPL's. The probability of failure of each IPL is estimated and an order of magnitude calculation is carried out to determine whether the overall protection is adequate to reduce risk to a tolerable level.

The frequency of occurrence of the undesired consequence can be found by combining the frequency of the initiating cause with the probabilities of failure of each IPL, taking into account any conditional modifiers. (An example of a conditional modifier is whether a person will be present and might be influenced). Orders of magnitude are used for frequencies and probabilities.

#### B.4.4.2 Use

The purpose of a LOPA is to ensure the effectiveness of controls required to treat risk so that the residual level of risk will be acceptable.

LOPA can be used qualitatively to review the layers of protection between a causal factor and a consequence. It can also be used quantitatively to allocate resources to treatments by analysing the risk reduction produced by each layer of protection. It can be applied to systems with a long or short-term time horizon and is usually used in dealing with operational risks.

LOPA can be used quantitatively for the specification of (IPLs) and safety integrity levels (SIL levels) for instrumented systems, as described in the IEC 61508 series and in IEC 61511.

#### B.4.4.3 Input

Inputs to LOPA include:

- basic information about sources, causes and consequences of events;
- information on controls in place or proposed treatments;
- the frequency of the causal event, and the probabilities of failure of the protection layers, measures of consequence and a definition of tolerable risk.

#### B.4.4.4 Output

The outputs are recommendations for any further treatments and estimates of the residual risk.

#### B.4.4.5 Strengths and limitations

Strengths of LOPA include that it:

- requires less time and resources than event tree analysis or fully quantitative risk assessment but is more rigorous than subjective qualitative judgments;
- helps identify and focus resources on the most critical layers of protection;
- identifies operations, systems and processes for which there are insufficient safeguards;
- focuses on the most serious consequences.

Limitations of LOPA include:

- it focuses on one cause-consequence pair and one scenario at a time; complex interactions between risks or between controls are not covered;
- when used quantitatively it might not account for common mode failures;
- it does not apply to very complex scenarios where there are many cause-consequence pairs or where there are a variety of consequences affecting different stakeholders.

#### B.4.4.6 Reference documents

IEC 61508 (all parts*), Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61511*, Functional safety – Safety instrumented systems for the process industry sector*

*Layer of protection analysis - Simplified process risk assessment*: Centre for chemical process safety of the American Institute of Chemical Engineers New York 2001

## B.5 Techniques for understanding consequences, likelihood and risk

### B.5.1 General

Techniques in this clause aim to provide a greater understanding of consequences and their likelihood. In general the consequences can be explored by:

- experimentation, such as cell studies to explore consequences of exposure to toxins with results applied to human and ecological health risks;
- research into past events, including epidemiological studies;
- modelling to determine the way in which consequences develop following some trigger, and how this depends on the controls in place. This can include mathematical or engineering models and logic methods such as event tree analysis (B.5.2);

- techniques to encourage imaginative thinking such as scenario analysis (B.2.5).

The likelihood of an event or of a particular consequence can be estimated by:

- extrapolation from historical data (provided there is sufficient relevant historical data for the analysis to be statistically valid). This especially applies for zero occurrences, when one cannot assume that because an event or consequence has not occurred in the past it will not occur in the near future;
- synthesis from data relating to failure or success rates of components of the systems: using techniques such as event tree analysis (B.5.5), fault tree analysis (B.5.6) or cause consequence analysis (B.5.7);
- simulation techniques, to generate, for example, the probability of equipment and structural failures due to ageing and other degradation processes.

Experts can be asked to express their opinion on likelihoods and consequences, taking into account relevant information and historical data. There are a number of formal methods for eliciting expert judgement that make the use of judgment visible and explicit; (see B.1).

A Consequence and its likelihood can be combined to give a level of risk. This can be used to evaluate the significance of a risk by comparing the level of risk with a criterion for acceptability, or to put risks in a rank order.

Techniques for combining qualitative values of consequence and likelihood include index methods (B.8.6) and consequence likelihood matrices (B.9.3). A single measure of risk can also be produced from a probability distribution of consequences (see for example VaR (B.5.12) and CVaR (B.5.13) and S curves (B.9.4).)

### B.5.2 Bayesian analysis

#### B.5.2.1 B.5.2.1 Overview

It is common to encounter problems where there is both data and subjective information. Bayes analysis enables both types of information to be used in making decisions. Bayesian Analysis is based on a theorem attributed to Reverend Thomas Bayes (1760). At its simplest, Bayes' theorem provides a probabilistic basis for changing one’s opinion in the light of new evidence. It is generally expressed as follows:

$$\Pr(A|B) = \frac{\Pr(B|A)\Pr A}{\Pr(B)}$$

Where:

Pr ($A$) is the prior assessment of the probability of A

Pr ($A|B$) is the probability of A given that B has occurred (the posterior assessment)

Bayes' theorem can be extended to encompass multiple events in a particular sample space.

For example, assume we have some data, $D$, that we wish to use to update our previous understanding (or lack thereof) of risk. We want to use these data to assess the relative merits of a number ($N$) of competing and non-overlapping hypotheses, which we will denote by $H_n$ (where $n= 1, 2,\ldots,N$). Then Bayes' theorem can be used to calculate the probability of the $j$th hypothesis using the formula:

$$\Pr(H_j|D) = \Pr(H_j)\left[\frac{\Pr(D|H_j)}{\sum \Pr(H_n \Pr(D|H_n)}\right]$$

where $j = 1,2\ldots\ldots,n$

This shows that once the new data is accounted for, the updated probability for hypothesis j [i.e. Pr($Hj|D$)] is obtained by multiplying its prior probability Pr($H_j$) by the bracketed fraction.

This fraction's numerator is the probability of getting these data if the *j*th hypothesis is true. The denominator comes from the "law of total probability" - the probability of getting these data if, one-by-one, each hypothesis were to be true.

A Bayesian probability can be more easily understood if it is considered as a person's degree of belief in a certain event as opposed to the classical which is based upon physical evidence.

#### B.5.2.2 Use

Bayesian analysis is a means of inference from data, both judgemental and empirical. Bayesian methods can be developed to provide inference for parameters within a risk model developed for a particular context, for example, the probability of an event, the rate of an event, or the time to an event.

Bayesian methods can be used to provide a prior estimate of a parameter of interest based upon subjective beliefs. A prior probability distribution is usually associated with subjective data since it represents uncertainties in the state-of-knowledge. A prior can be constructed using subjective data only or using relevant data from similar situations. A prior estimate can provide a probabilistic prediction of the likelihood of an event and be useful for risk assessment for which there is no empirical data.

Observed event data can then be combined with the prior distribution through a Bayesian analysis to provide a posterior estimate of the risk parameter of interest.

Bayes theorem is used to incorporate new evidence into prior beliefs to form an updated estimate

Bayesian analysis can provide both point and interval estimates for a parameter of interest. These estimates capture uncertainties associated with both variability and the state of knowledge. This is unlike classical frequentist inference which represents the statistical random variation in the variable of interest.

The probability model underpinning a Bayesian analysis depends on the application. For example, a Poisson probability model might be used for events such as accidents, non-conformances or late deliveries, or a Binomial probability model might be used for one-shot items. Increasingly it is common to build a probability model to represent the causal relationships between variables in the form of a Bayesian network (B.5.3).

#### B.5.2.3 Inputs

The input to a Bayesian analysis is the judgemental and empirical data needed to structure and quantify the probability model.

#### B.5.2.4 Outputs

Like classical statistics, Bayesian analysis provides estimates, both single numbers and intervals for the parameter of interest s and can be applied to a wide range of outputs.

#### B.5.2.5 Strengths and Limitations

Strengths are the following:

- inferential statements are easy to understand;
- it provides a mechanism for using subjective beliefs about a problem;
- it provides a mechanism for combining prior beliefs with new data.

Limitations are:

- it can produce posterior distributions that are heavily dependent on the choice of the prior;
- solving complex problems can involve high computational costs.

#### B.5.2.6 Reference documents

GHOSH, J., DELAMPADY, M. and SAMANTA, T. *An introduction to Bayesian analysis*, New York Springer-Verlag, 2006

QUIGLEY, J.L., BEDFORD, T.J. and WALLS, L.A. Prior Distribution Elicitation. In: *Encyclopaedia of Statistics in Quality and Reliability*. Wiley. 2008 ISBN 9780470018613

### B.5.3 Bayesian networks

#### B.5.3.1 Overview

A Bayesian network (Bayes' net or BN) is a graphical model whose nodes represent the random variables (discrete and/or continuous) (Figure B.3). The nodes are connected by directed arcs that represent direct dependencies (which are often causal connections) between variables.

The nodes pointing to a node X are called its parents, and are denoted pa(X). The relationship between variables is quantified by conditional probability distributions (CPDs) associated with each node, denoted P(X|pa(X)); where the state of the child nodes depends on the combination of the values of the parent nodes. In the figure probabilities are indicated by point estimates.

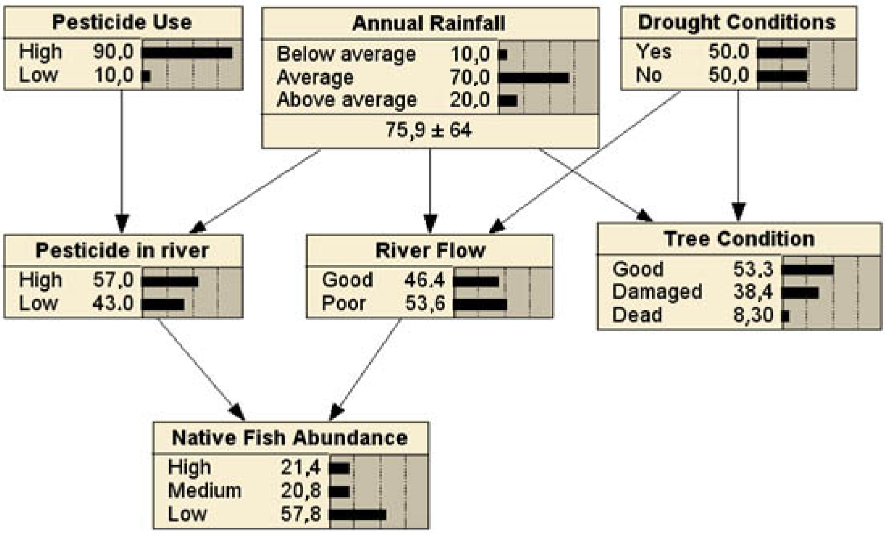



**Figure B.3 – A Bayesian Network showing a simplified version of a real ecological problem: modelling native fish populations in Victoria Australia**

#### B.5.3.2 Use

A basic BN contains variables that represent uncertain events and can be used to estimate likelihood or risk or to infer key risk drivers leading to specified consequences.

A BN can be extended to include decision actions and valuations as well as uncertainties, in which case it is known as an influence diagram, which can be used to assess the impact of risk controls/mitigations or to value intervention options

A BN model can be built as a qualitative representation of a problem by stakeholders then quantified using relevant data, including judgemental (e.g. medicine distribution centre risk analysis), or a BN model can be learnt from empirical data only (e.g. web search engines, financial risk). Regardless of the form of a BN, the underlying inference mechanism is based on Bayes Theorem and possesses the general properties of Bayesian analysis (B.5.2).

BN have been used across a wide range of applications: including environmental decision making, medical diagnosis, critical infrastructure life extension, supply chain risk, new product and process development image modelling, genetics, speech recognition, economics, space exploration and in web search engines.

In general BNs provide visual models that support articulation of problems and communication between stakeholders. BN models allow sensitivity analysis to be conducted to explore "what if" scenarios. Constructing the qualitative BN structure can be supported by the use of causal mapping (B.6.1) and a BN can be used in conjunction with scenario analysis (B.2.5) and cross impact analysis (B.6.2)

BNs are useful for gaining stakeholder input and agreement for decisions where there is high uncertainty and a divergence of stakeholder views. The representation is readily comprehensible although expertise is required to produce it.

BNs can be useful for mapping risk analyses for non-technical stakeholders, by promoting transparency of assumptions and process and by treating uncertainty in a way that is mathematically sound.

#### B.5.3.3 Input

The inputs for BNs require an understanding of system variables (nodes), the causal links between them (arcs) and the prior and conditional probabilities for these relationships.

In the case of an influence diagram, the valuations are also required (e.g. financial loss, injuries etc.).

#### B.5.3.4 Output

BNs provide posterior distributions in a graphical output that is generally considered easy to interpret, at least compared with other, black box models. The BN model and the data can be readily modified to easily visualise relationships and explore the sensitivity of parameters to different inputs.

#### B.5.3.5 Strengths and Limitations

Strengths of BNs include:

- there is readily available software that is relatively easy to use and understand;
- they have a transparent framework and are able to rapidly run scenarios and analyse sensitivity of output to different assumptions;
- they can include subjective beliefs about a problem, together with data.

Limitations include:

- defining all interactions for complex systems is difficult, and can become computationally intractable when conditional probability tables become too large;
- BNs are often static and don’t typically include feedback loops. However, the use of dynamic BNs is increasing;
- setting parameters requires knowledge of many conditional probabilities which are generally provided by expert judgement. BNs can only provide answers based on these assumptions, (a limitation that is common to other modelling techniques);
- the user can input errors but the output might still give a believable answer; checking extremes can help to locate errors.

#### B.5.3.6 Reference document

NEIL, Martin and FENTON, Norman. *Risk Assessment and Decision Analysis with Bayesian Networks* CRC Press, 2012

JENSEN, F.V., NIELSEN T. D. *Bayesian Networks and Decision Graphs*, 2nd ed. Springer, New York, 2007

NICHOLSON, A., WOODBERRY O and TWARDY C, The “Native Fish” Bayesian networks. *Bayesian Intelligence Technical Report 2010/3*, 2010

*Netica tutorial* https://www.norsys.com/tutorials/netica/secA/tut_A1.htm

### B.5.4 Business impact analysis (BIA)

#### B.5.4.1 Overview

Business impact analysis analyses how incidents and events could affect an organization’s operations, and identifies and quantifies the capabilities that would be needed to manage it. Specifically, a BIA provides an agreed understanding of:

- the criticality of key business processes, functions and associated resources and the key interdependencies that exist for an organization;
- how disruptive events will affect the capacity and capability of achieving critical business objectives;
- the capacity and capability needed to manage the impact of a disruption and recover to agreed levels of operation.

The BIA process analyses the potential consequences of a disruptive incident on the organization

BIA can be undertaken using questionnaires, interviews, structured workshops or a combination of all three.

#### B.5.4.2 Use

BIA is used to determine the criticality and recovery timeframes of processes and associated resources (e.g. people, equipment and information technology) to enable appropriate planning for disruptive events. BIA also assists in determining interdependencies and interrelationships between processes, internal and external parties and any supply chain linkages.

It can also be used as part of consequence analysis when considering consequences of disruptive events.

The BIA provides information that helps the organization determine and select appropriate business continuity strategies to enable effective response and recovery from a disruptive incident.

#### B.5.4.3 Inputs

Inputs include:

- information concerning the objectives, strategic direction, environment, assets, and interdependencies of the organization;
- an assessment of priorities from previous management review;
- details of the activities and operations of the organization, including processes, resources, relationships with other organizations, supply chains, outsourced arrangements, and stakeholders;
- information to enable assessment of financial, legal and operational consequences of loss of critical processes;
- a prepared questionnaire or other means of collecting information;
- outputs of other risk assessment and critical incident analyses relating to outcomes of disruptive incidents
- a list of people from relevant areas of the organization and/or stakeholders that will be contacted.

#### B.5.4.4 Outputs

The outputs include:

Documents detailing the information collected as inputs

- a prioritized list of critical processes and associated interdependencies;
- documented financial and operational impacts from a loss of the critical processes;
- information on supporting resources and activities needed to re-establish critical processes;
- a prioritized list of the organizations products and services;
- an assessment of the impacts over time of not delivering those products and services;

- prioritized time frames for resuming delivery of those products and services at a specified minimum level, taking into account the time after which impacts of not resuming them would become unacceptable;
- outage time frames for the critical process and the associated information technology recovery time frames.

#### B.5.4.5 Strengths and limitations

Strengths of the BIA include that it provides:

- A deep understanding of the critical processes that enable an organization to achieve its objectives and which can indicate areas for business improvement;
- information needed to plan an organization's response to a disruptive event;
- an understanding of the key resources required in the event of a disruption;
- an opportunity to redefine the operational process of an organization to assist in improving the resilience of the organization.

Limitations include:

- BIA relies on the knowledge and perceptions of the participants involved in completing questionnaires, or undertaking interviews or workshops;
- group dynamics can adversely affect the complete analysis of a critical process;
- there can be simplistic or over-optimistic expectations of recovery requirements;
- it can be difficult to obtain an adequate level of understanding of the organization's operations and activities.

#### B.5.4.6 Reference documents

ISO TS 22317 *Business continuity management systems -,Guidelines for Business Impact Analysis*

ISO 22301, *Societal security - Business continuity management systems – Requirements*

### B.5.5 Event tree analysis (ETA)

#### B.5.5.1 Overview

ETA is a graphical technique that represents the mutually exclusive sequences of events that could arise following an initiating event according to whether the various systems designed to change the consequences function or not. The tree can be quantified to provide the probabilities of the different possible outcomes (see Figure B.4).

The tree starts with the initiating event then, for each control, lines are drawn to represent its success or failure. A probability of failure or success can be assigned to each line, by expert judgement, from data, or from individual fault tree analyses. The probabilities are conditional probabilities. For example, the probability of an item functioning is not the probability obtained from tests under normal conditions, but the probability of functioning under the conditions of the initiating event.

The frequency of the different outcomes is represented by the product of the individual conditional probabilities and the probability or frequency of the initiation event, given that the various events are independent.

#### B.5.5.2 Use

ETA can be used qualitatively to help analyse potential scenarios and sequences of events following an initiating event, and to explore how outcomes are affected by various controls. It can be applied at any level of an organization and to any type of initiating event.

Quantitative ETA can be used to consider the acceptability of the controls and the relative importance of different controls to the overall level of risk. Quantitative analysis requires that controls are either working or not (i.e. it cannot account for degraded controls) and that controls are independent). This is mostly the case for operational issues. ETA can be used to model initiating events which might bring loss or gain. However, circumstances where pathways to optimize gain are sought are more often modelled using a decision tree (B.7.3).

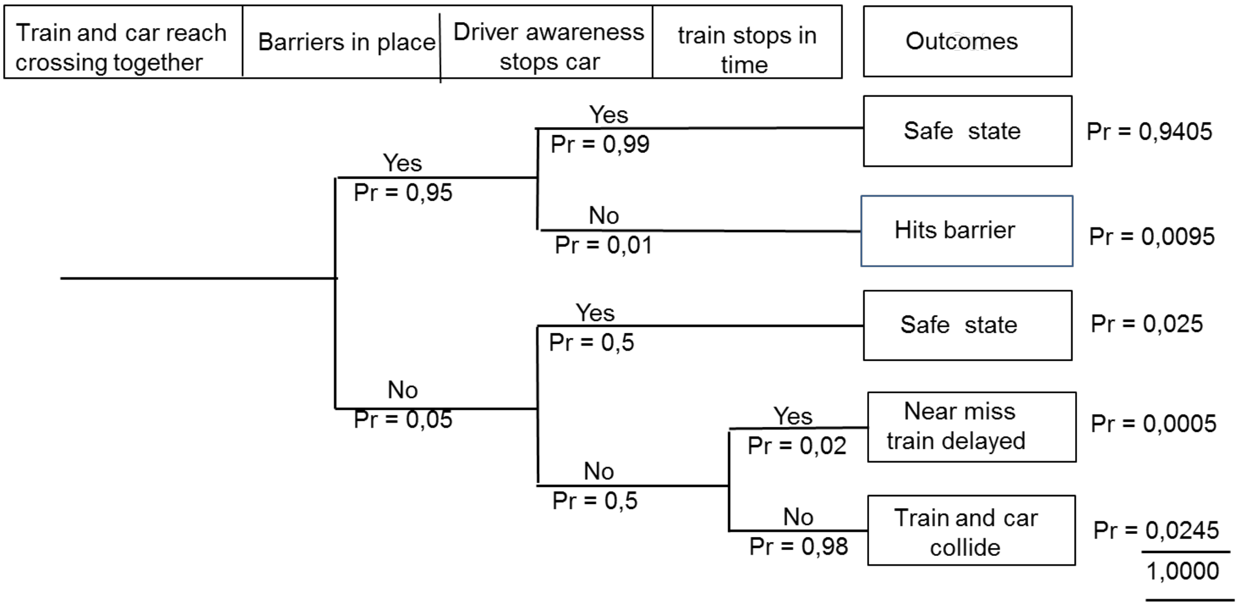



**Figure B.4 – Example of event tree analysis**

### B.5.5.3 Inputs

Inputs include:

- a specified initiating event;
- information on barriers and controls, and, for quantitative analyse, their failure probabilities;
- an understanding of possible scenarios.

### B.5.5.4 Outputs

Outputs from ETA include the following:

- qualitative descriptions of potential outcomes from initiating events;
- quantitative estimates of event rates/frequencies or probabilities and the relative importance of various failure sequences and contributing events;
- quantitative evaluations of effectiveness of controls.

### B.5.5.5 Strengths and limitations

Strengths of ETA include the following:

- potential scenarios following an initiating event, are analysed and the influence of the success or failure of controls shown in a clear diagrammatic way that can, if required, be quantified;
- it identifies end events that might otherwise not be foreseen;
- it identifies potential single point failures, areas of system vulnerability and low payoff counter measures and hence can be used to improve control efficiency;
- the technique accounts for timing, and domino effects that are cumbersome to model in fault trees.

Limitations include the following:

- for a comprehensive analysis all potential initiating events need to be identified. There is always a potential for missing some important initiating events or event sequences;

- only success and failure states of a system are dealt with, and it is difficult to incorporate partially operating controls, delayed success or recovery events;
- any path is conditional on the events that occurred at previous branch points along the path. Many dependencies along the possible paths are therefore addressed. However, some dependencies, such as common components, utility systems and operators, might be overlooked leading to optimistic estimations of the likelihood of particular consequences;
- for complex systems the event tree can be difficult to build from scratch.

#### B.5.5.6 Reference document

IEC 62502 *Analysis techniques for dependability – Event tree analysis*

IEC TR 63039 *Probabilistic risk analysis of technological systems*

### B.5.6 Fault tree analysis (FTA)

#### B.5.6.1 Overview

FTA is a technique for identifying and analysing factors that contribute to a specified undesired event (called the “top event”). The top event is analysed by first identifying its immediate and necessary causes. These could be hardware or software failures, human errors or any other pertinent events. The logical relationship between these causes is represented by a number of gates such as AND and OR gates. Each cause is then analysed step-wise in the same way until further analysis becomes unproductive. The result is represented pictorially in a tree diagram. (See Figure B.5.)

#### B.5.6.2 Use

FTA is used primarily at operational level and for short to medium term issues. It is used qualitatively to identify potential causes and pathways to the top event, or quantitatively to calculate the probability or frequency of the top event. For quantitative analysis strict logic has to be followed. (I.e. the events at inputs of an AND gate have to be both necessary and sufficient to cause the event above and the events at an OR gate represent all possible cause of the event above, any one of which might be the sole cause). Techniques based on binary decision diagrams or Boolean algebra are then used to account duplicate failure modes.

FTA can be used during design, to select between different options, or during operation to identify how major failures can occur and the relative importance of different pathways to the top event.

Closely related techniques are the cause tree, which is used retrospectively to analyse events which have already occurred, and the success tree, where the top event is a success. This is used to study the causes of success in order to achieve future successes.

NOTE Probabilities tend to be higher in a success tree than a fault tree and when calculating the probability of the top event the possibility that events might not be mutually exclusive should be taken into account.

#### B.5.6.3 Inputs

Inputs for fault tree analysis are:

- an understanding of the system and the causes of failure or success is required, as well as a technical understanding of how the system behaves in different circumstances. Detailed diagrams are useful to aid the analysis;
- for quantitative analysis of a fault tree, data on failure rates, or the probability of being in a failed state, or the frequency of failures and where relevant repair/recovery rates etc. are required for all base events;
- for complex situations software and an understanding of probability theory and Boolean algebra is required so inputs to the software are made correctly.

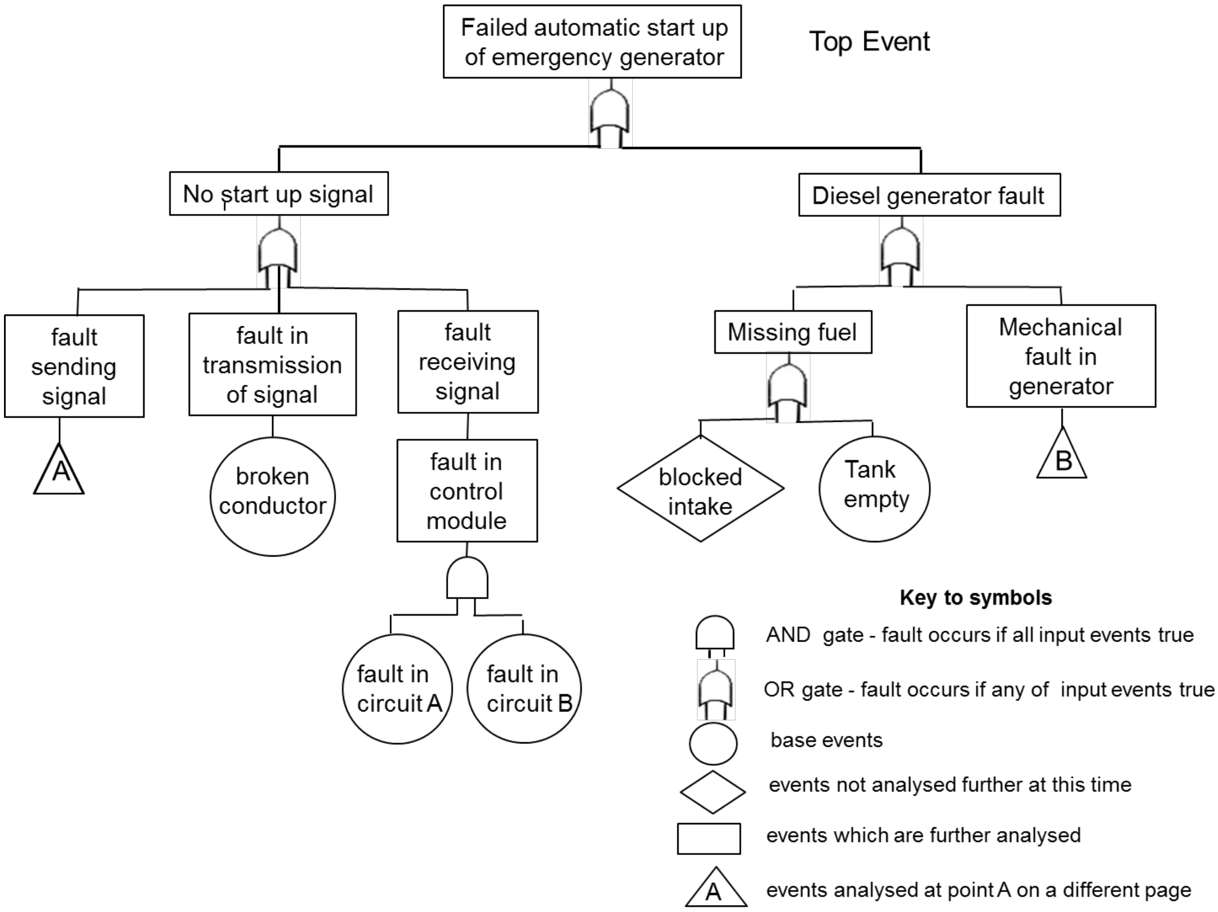



**Figure B.5 – Example of fault tree**

#### B.5.6.4 Outputs

The outputs from fault tree analysis are:

- a pictorial representation of how the top event can occur which shows interacting pathways each of which involves the occurrences of two or more (base) events;
- a list of minimal cut sets (individual pathways to failure) with, provided data is available, the probability that each will occur;
- in the case of quantitative analysis, the probability or frequency of the top event and the relative importance of the base events.

#### B.5.6.5 Strengths and limitations

Strengths of FTA include:

- it is a disciplined approach which is highly systematic, but at the same time sufficiently flexible to allow analysis of a variety of factors, including human interactions and physical phenomena;
- it is especially useful for analysing systems with many interfaces and interactions;
- it provides a pictorial representation leading to an easier understanding of the system behaviour and the factors included;
- logic analysis of the fault trees and the determination of cut sets is useful in identifying simple failure pathways in a complex system where particular combinations of events and event sequences which lead to the top event could be overlooked;
- it can be adapted to simple or complex problems with level of effort depending on complexity.

Limitations include:

- in some situations it can be difficult to ascertain whether all important pathways to the top event are included;  for example, including all ignition sources in an analysis of a fire. In this situations it is not possible to calculate the probability of the top event;
- time interdependencies are not addressed;
- FTA deals only with binary states (success/failure);
- while human error modes can be included in a fault tree, the nature and extent of such failures can be difficult to define;
- FTA analyses one top event. It does not analyse secondary or incidental failures;
- An FTA can get very large for large scale systems.

#### B.5.6.6 Reference document

IEC 61025, *Fault tree analysis (FTA)*

*IEC62740 Root cause analysis(RCA)*

IEC TR 63039 *Probabilistic risk analysis of technological systems*

### B.5.7 Cause-Consequence Analysis (CCA)

#### B.5.7.1 Overview

In some circumstances an event that could be analysed by a fault tree is better addressed by CCA. For example:

- if it is easier to develop event sequences than causal relationships;
- if the FTA might become very large;
- if there are separate teams dealing with different parts of the analysis.

In practice it is often not the top event that is defined first but potential events at the interface between the functional and technical domain.

For example, consider the event "loss of crew or vehicle" for a space craft mission. Rather than building a large fault tree based on this top event, intermediate undesired events such as ignition fails or thrust failure can be defined as top events and analysed as separate fault trees. These top events would then in turn be used as inputs to event trees to analyse operational consequences. This combination of FTA and ETA is sometimes referred to as cause-consequence analysis.

Two types of CCA can be distinguished, depending on which part of the analysis is more relevant to the circumstances. When detailed causes are required but a more general description of consequence is acceptable then the FTA part of the analysis is expanded and the analysis is referred to as CCA-SELF (Small event tree large fault tree). When a detailed description of consequence is required but cause can be considered in less detail the analysis is referred to as CCA-LESF (large event small fault tree).

Figure B.6 shows a conceptual diagram of a typical cause-consequence analysis.

#### B.5.7.2 Use

Like fault tree analysis, CCA is used to represent the failure logic leading to a critical event but it adds to the functionality of a fault tree by allowing time sequential failures to be analysed. The method also allows time delays to be incorporated into the consequence analysis which is not possible with event trees.  It analyses the various paths a system could take following a critical event depending on the behaviour of particular subsystems (such as emergency response systems).

If quantified, a cause-consequence analysis will give an estimate of the probability of different possible consequences following a critical event.

As each sequence in a cause-consequence diagram is a combination of sub-fault trees, cause-consequence analysis can be used to build large fault trees.

Since the diagrams are complex to produce and use the technique tends to be applied when the magnitude of the potential consequence of failure justifies intensive effort.

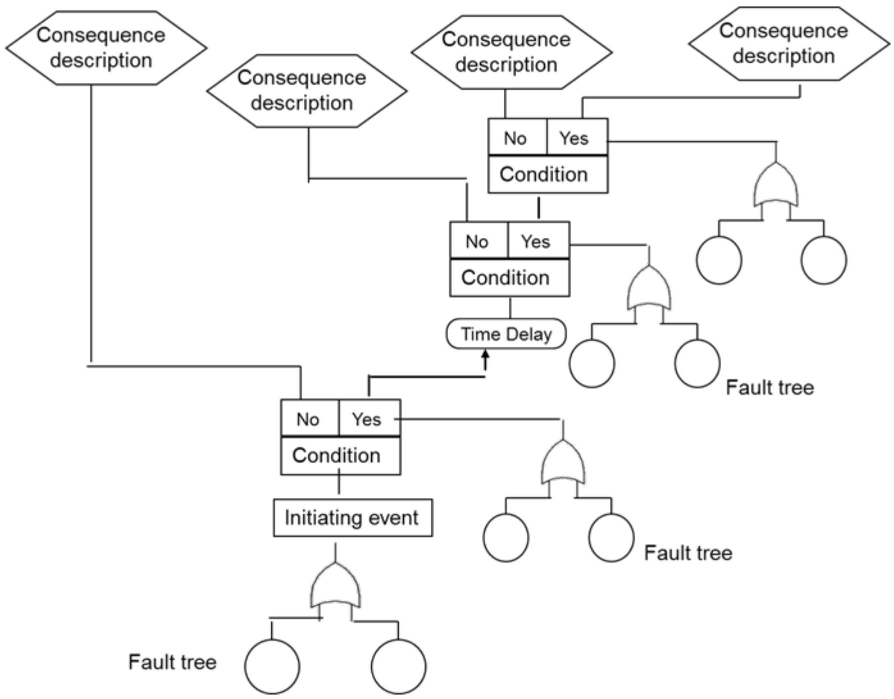



**Figure B.6 – Example cause-consequence diagram**

### B.5.7.3 Inputs

An understanding of the system and its failure modes and failure scenarios is required.

### B.5.7.4 Output

The outputs of CCA are:

- a diagrammatic representation of how a system might fail showing both causes and consequences;
- an estimation of the probability of occurrence of each potential consequence based on analysis of probabilities of occurrence of particular conditions following the critical event.

### B.5.7.5 Strengths and limitations

In addition to strengths of fault and event trees CCA is better able to simultaneously represent the causes and consequences of a focus event and time dependencies than these techniques.

Limitations include that CCA is more complex than fault tree and event tree analysis, both to construct, and in the manner in which dependencies are dealt with during quantification.

### B.5.7.6 Reference documents

ANDREWS J.D, RIDLEY L.M. 2002. Application of the cause consequence diagram method to static systems, *Reliability engineering and system safety* 75(1) 47-58: also at https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/695/1/01-22.pdf

NIELSEN D.S, "*The Cause/Consequence Diagram Method as a Basis for Quantitative Accident Analysis*", Danish Atomic Energy Commission, RISO-M-1374, May 1971

### B.5.8 Human reliability analysis (HRA)

#### B.5.8.1 Overview

HRA refers to a group of techniques that aim to evaluate a person's contribution to system reliability and safety by identifying and analysing the potential for an incorrect action. Although most often applied to degraded performance of operators in a safety context, similar methods can be applied to enhanced levels of performance. HRA is applied at a tactical level to particular tasks where correct performance is critical.

A hierarchical task analysis is first carried out to identify steps and sub-steps within an activity. Potential error mechanisms are identified for each sub step often using a set of key word prompts (e.g. too early, too late, wrong object, wrong action, right object, etc.).

Sources of these errors (such as distraction, time available too short, etc.) can be identified and the information used to reduce the likelihood of error within the task. Factors within the person themselves, the organization or the environment that influence the probability of error (performance shaping factors (PSFs)) are also identified.

The probability of an incorrect action can be estimated by various methods including using a data base of similar tasks or expert judgement. Typically a nominal error rate for a task type is defined then a multiplier is applied to represent behavioural or environmental factors that increase or decrease the probability of failure. Various methods have been developed to apply these basic steps.

Early methods placed a strong emphasis on estimating the likelihood of failure. More recent qualitative methods focus on cognitive causes of variations in human performance with greater analysis of the way performance is modified by external factors and less on attempting to calculate a failure probability.

#### B.5.8.2 Use

Qualitative HRA can be used:

- during design so that systems are designed to minimise the probability of error by operators;
- during system modification to see whether human performance is likely to be influenced in either direction;
- to improve procedures so as to reduce errors;
- to assist in identifying and reducing error inducing factors within the environment or in organizational arrangements.

Quantitative HRA is used to provide data on human performance as input to logic tree methods or other risk assessment techniques.

#### B.5.8.3 Inputs

Inputs include:

- information to define tasks that people should perform;
- experience of the types of error or extraordinary performance that occur in practice;
- expertise on human performance and the factors which influence it;
- expertise in the technique or techniques to be used.

#### B.5.8.4 Outputs

Outputs include:

- a list of errors or extraordinary performance that may occur and methods by which they can be enhanced through redesign of the system;
- human performance modes, types, causes and consequences;
- a qualitative or quantitative assessment of the risk posed by differences in performance.

#### B.5.8.5 Strengths and limitations

Strengths of HRA include:

- it provides a formal mechanism to include human performance when considering risks associated with systems where humans play an important role;
- formal consideration of human performance modes and mechanisms based on an understanding of cognitive mechanisms can help identify ways modify the risk.

Limitations include:

- the methods are best suited to routine tasks carried out in well controlled environments. They are less useful for complex tasks or where actions must be based on multiple and possibly contradictory sources of information;
- many activities do not have a simple pass/fail mode. HRA has difficulty dealing with partial impacts on performance as in the quality of actions or decisions;
- quantification tends to be heavily reliant on expert opinion with little verified data available.

#### B.5.8.6 Reference documents

BELL Julie, HOLROYD Justin,. *Review of human reliability assessment methods*. Health and Safety Executive UK, HMSO 2009, [viewed 2017-9-14]. Available at http://www.hse.gov.uk/research/rrpdf/rr679.pdf

IEC 62508 *Guidance on human aspects of dependability*

OECD *Establishing the Appropriate Attributes in Current Human Reliability Assessment Techniques for Nuclear Safety,* NEA/CSNI/R 2015 [viewed 2017-9-14] Available at http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=NEA/CSNI/R(2015)1&docLanguage=En

### B.5.9 Markov analysis

#### B.5.9.1 Overview

Markov analysis is a quantitative technique that can be applied to any system that can be described in terms of a set of discrete states and transitions between them, provided the evolution from its current state does not depend on its state at any time in the past.

It is usually assumed that transitions between states occur at specified intervals with corresponding transition probabilities (discrete time Markov chain). In practice this most commonly arises if the system is examined at regular intervals to determine its state.) In some applications the transitions are governed by exponentially distributed random times with corresponding transition rates (continuous-time Markov chain). This is commonly used for dependability analyses, see IEC 61165).

States and their transitions can be represented in a Markov diagram such as Figure B.7. Here the circles represent the states and the arrows represent the transitions between states and their associated transition probabilities. This example has only four states: good (S1), fair (S2), poor (S3) and failed (S4). It is assumed that each morning, the system is inspected and classified in one of these four states. If the system has failed, it is always repaired that day and returned t a good state.

The system can also be represented by a transition matrix as shown in Table B.4. Note that in this table the sum for each of the rows is 1 as the values represent the probabilities for all the possible transitions in each case.

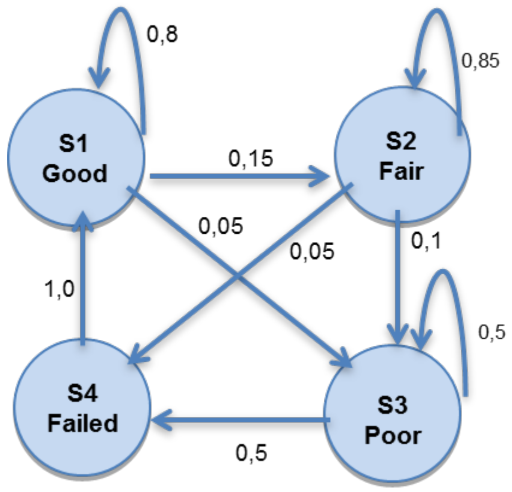



**Figure B.7 – Example of Markov diagram**

**Table B.4 – Example Markov matrix**

| | | Next state after transition | | | |
|---|---|---|---|---|---|
| | | **S1, Good** | **S2, Fair** | **S3, Poor** | **S4, Fail** |
| Current state | **S1, Good** | 0,8 | 0,15 | 0,05 | 0 |
| | **S2, Fair** | 0 | 0,85 | 0,1 | 0,05 |
| | **S3, Poor** | 0 | 0 | 0,5 | 0,5 |
| | **S4, Failed** | 1 | 0 | 0 | 0 |

### B.5.9.2 Use

Markov analysis can be used to estimate:

- the long-run probability of the system being in a specified state; for example, this might be the chance of a production machine operating as required, a component failing or a supply level falling below a critical threshold;
- the expected time to the first failure for a complex system (the first passage time), or the expected time before a system returns to a specified state (the recurrence time).

Examples of systems, states and transitions in different areas are provided in Table B.5.

**Table B.5 – Examples of systems to which Markov analysis can be applied**

| System | States | Transitions |
|---|---|---|
| Technical systems | Condition of machines | Deterioration, breakdown, repair |
| Production | Production level | Operation, clean, reset |
| Marketing | Brand purchased | Brand loyalty, brand switching |
| Accounting | Accounts receivable status | Payment, write-off, extension |
| Health care | Patient status | Infection, recovery, treatment, relapse |
| Reservoir | Quantity of water | Inflows, outflows, evaporation |
| Human Resources | Job categories | Movement between job categories and exit |

### B.5.9.3 Input

The inputs to a Markov analysis are a set of discrete states that the system can occupy, an understanding of the possible transitions that need to be modelled and estimates of the transition probabilities or transition rates as appropriate.

#### B.5.9.4 Output

Markov analysis generates estimates of the probability of a system being in any specified state. It supports many kinds of decisions about the kinds of interventions a manager might make in a complex system (for example, to modify the states of the system and the transitions between them).

#### B.5.9.5 Strengths and limitations

Strengths of Markov analysis include:

- it can be used to model dynamic, multistate systems;
- state-transition diagrams provide simple and easily-communicated structures.

Limitations include:

- the assumptions might not apply to all systems of interest, in particular the transition probabilities or transition rates between states can change through time as the system deteriorates or adapts or as managers make decisions;
- accurate modelling can require extensive data collection and validation;
- too much data reduces the answer to a mean.

#### B.5.9.6 Reference documents

IEC 61165, *Application of Markov techniques*

ALAN OXLEY Markov Processes in Management Science, published by Applied Probability Trust, 2011 [viewed 2017-9-14]. Available at http://ms.appliedprobability.org/data/files/feature%20articles/43-2-6.pdf

IEC TR 63039 *Probabilistic risk analysis of technological systems*

### B.5.10 Monte Carlo simulation

#### B.5.10.1 Overview

Some calculations carried out when analysing risk involve distributions. However, performing calculations with distributions is not easy as it is often not possible to derive analytical solutions unless the distributions have well-specified shapes, and then only with restrictions and assumptions that might not be realistic. In these circumstances, techniques such as Monte Carlo simulation provide a way of undertaking the calculations and developing results. Simulation usually involves taking random sample values from each of the input distributions, performing calculations to derive a result value, and then repeating the process through a series of iterations to build up a distribution of the results. The result can be given as a probability distribution of the value or some statistic such as the mean value.

Systems can be developed using spreadsheets and other conventional tools, but more sophisticated software tools are available to assist with more complex requirements.

#### B.5.10.2 Use

In general, Monte Carlo simulation can be applied to any system for which:

- a set of inputs interact to define an output;
- the relationship between the inputs and outputs can be expressed as a set of dependencies;
- analytical techniques are not able to provide relevant results or when there is uncertainty in the input data.

Monte Carlo simulation can be used as part of risk assessment for two different purposes:

- uncertainty propagation on conventional analytical models;
- probabilistic calculations when analytical techniques don't work.

Applications include, amongst other things, modelling and the assessment of uncertainty in financial forecasts, investment performance, project cost and schedule forecasts, business process interruptions and staffing requirements.

### B.5.10.3 Input

The inputs to a Monte Carlo simulation are:

- a good model of the system;
- information on the types of inputs or the sources of uncertainty, that are to be represented;
- the form of output required.

Input data with uncertainty is represented as random variables with distributions which are more or less spread, according to the level of uncertainties. Uniform, triangular, normal and log normal distributions are often used for this purpose.

### B.5.10.4 Output

The output could be a single value, or could be expressed as the probability or frequency distribution or it could be the identification of the main functions within the model that have the greatest impact on the output.

In general, the output of a Monte Carlo simulation will be either the entire distribution of outcomes that could arise, or key measures from a distribution such as:

- the probability of a defined outcome arising;
- the value of an outcome in which the problem owners have a certain level of confidence will not be exceeded or beaten. Examples are a cost that there is less than a 10 % chance of exceeding or a duration that is 80 % certain to be exceeded.

An analysis of the relationships between inputs and outputs can throw light on the relative significance of the uncertainty in input values and identify targets for efforts to influence the uncertainty in the outcome.

### B.5.10.5 Strengths and limitations

Strengths of Monte Carlo analysis include:

- the method can, in principle, accommodate any distribution in an input variable, including empirical data derived from observations of related systems;
- models are relatively simple to develop and can be extended as the need arises;
- any influences or relationships can be represented, including effects such as conditional dependencies;
- sensitivity analysis can be applied to identify strong and weak influences;
- models can be easily understood as the relationship between inputs and outputs is transparent;
- it provides a measure of the accuracy of a result;
- software is readily available and relatively inexpensive.

Limitations include:

- the accuracy of the solutions depends upon the number of simulations which can be performed (this limitation is becoming less important with increased computer speeds);
- use of the technique relies on being able to represent uncertainties in parameters by a valid distribution;
- it can be difficult to set up a model that adequately represents the situation;
- large and complex models can be challenging to the modeller and make it difficult for stakeholders to engage with the process;

- the technique tends to de-emphasise high consequence/low probability risks.

Monte Carlo analysis prevents excessive weight being given to unlikely, high consequence, outcomes by recognising that all such outcomes are unlikely to occur simultaneously across a portfolio of risks. However it also has the effect of removing all extreme events from consideration, particularly where a large portfolio is being considered. This can give unwarranted confidence to the decision maker.

#### B.5.10.6 Reference documents

IEC 62551 *Analysis techniques for dependability – Petri net modelling*

ISO/IEC Guide 98-3-SP1 *Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM 1995) - Propagation of distributions using a Monte Carlo method*

### B.5.11 Toxicological risk assessment

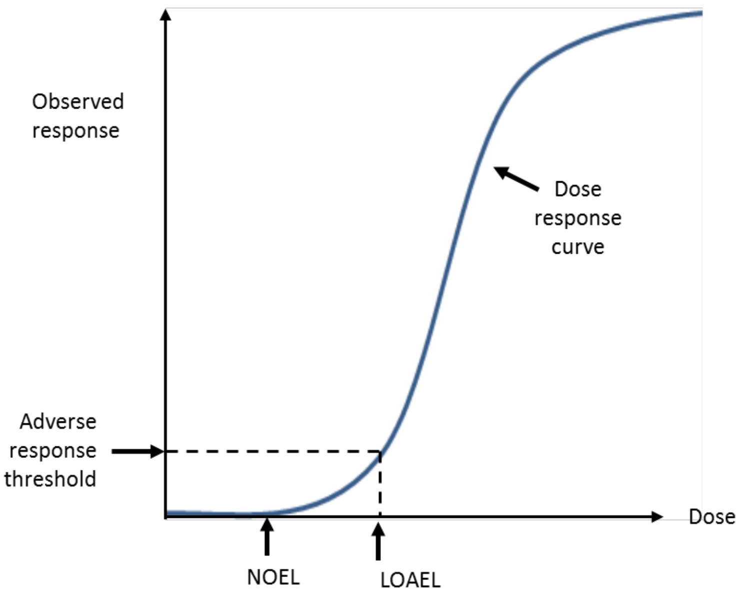
#### B.5.11.1 Overview

Risk assessment in the context of risks to plants, animals, ecological domains, and humans as a result of exposure to a range of environmental hazards involves the following steps.

a) Problem formulation: This involves establishing the context of the assessment by defining the purpose of the assessment, the range of target populations and the hazard types of interest.

b) Hazard identification and analysis: This involves identifying all possible sources of harm to the target population within the scope of the study and understanding the nature of the hazard and how it interacts with the target. For example, in considering human exposure to a chemical, the consequences considered could include the potential to damage DNA, or to cause cancer or birth defects. Hazard identification and analysis normally relies on expert knowledge and a review of literature.

c) Dose response assessment: The response of the target population is usually a function of the level of exposure or dose. Dose response curves are usually developed from tests on animals, or from experimental systems such as tissue cultures. For hazards such as micro-organisms or introduced species the response curve can be determined from field data and epidemiological studies. Wherever possible, the mechanism by which the effect is produced is determined. Figure B.8 shows a simplified dose response curve.




Key NOEL No Observable Effect Limit, LOAEL Lowest observable adverse effect level

**Figure B.8 - Dose response curve**

d) Exposure assessment: The dose that will be experienced in practice by the target population is estimated. This often involves a pathway analysis which considers the different routes the hazard might take, the barriers which might prevent it from reaching the target and the factors that might influence the level of exposure. For example in considering the risk from chemical spraying the exposure analysis would consider how much chemical was sprayed and under what conditions, whether there was any direct exposure of humans or animals, how much might be left as residue on plants, the environmental fate of any pesticide reaching the ground, whether it can accumulate in animals, whether it enters groundwater etc.

e) Risk characterisation: The information from the previous steps is brought together to estimate the likelihood of particular consequences when effects from all pathways are combined.

#### B.5.11.2 Use

The method provides a measure for the magnitude of risk to human health or the environment. It is used in environmental impact statements to show whether the risk from a particular exposure is acceptable. It is also used as the basis for defining limits for acceptable risk.

#### B.5.11.3 Inputs

Inputs include information about the toxicological hazards, the ecological system of concern (including human health) and, where possible, the mechanisms involved. Typically physical measurements are required to estimate exposures.

#### B.5.11.4 Outputs

The output is an estimate of the risk to human or ecological health, expressed either quantitatively or with a mixture of qualitative and quantitative information provided. The output may include limits to be used for defining acceptable limits for the hazard in the environment such as the No Observable Adverse Effect Limit. (See Figure B.8.)

#### B.5.11.5 Strengths and Limitations

The strengths of this form of analysis include:

- it provides a very detailed understanding of the nature of the problem and the factors which increase risk;
- pathway analysis is a very useful tool generally for all areas of risk to identify how and where it may be possible to improve controls or introduce new ones;
- the analysis can form the basis for simple rules about acceptable exposures that can be generally applied.

Limitations include:

- it requires good data which might not be immediately available so significant research might be required;
- it requires a high level of expertise to apply;
- there is often a high level of uncertainty associated with dose response curves and the models used to develop them;
- where the target is ecological rather than human and the hazard is not chemical, there might not be a good understanding of the systems involved.

#### B.5.11.6 Reference documents

*Human health risk assessment toolkit – chemical hazards*. WHO 2010[viewed 2017-9-14]. Available at http://www.inchem.org/documents/harmproj/harmproj/harmproj8.pdf

*Guidelines for ecological risk assessment* US EPA 1998 [viewed 2017-9-14]. Available at https://www.epa.gov/sites/production/files/2014-11/documents/eco_risk_assessment1998.pdf

### B.5.12 Value at Risk (VaR)

#### B.5.12.1 Overview

Value at risk (VaR) is used widely in the financial sector to provide an indicator of the amount of possible loss in a portfolio of financial assets over a specific time period within a given confidence level. Losses greater than the VaR are suffered only with a specified small probability.

The distribution of profit and loss is usually derived in one of three ways.

- Monte Carlo simulation (see B.5.10) is used to model the drivers of variability in the portfolio and derive the distribution. This approach is particularly useful as it provides information about risks in the distribution tails, and it allows correlation assumptions to be tested.
- Historical simulation models make projections on the basis of looking back at observed outcomes and distributions. This is a simple approach, but it can be very misleading if the future is not the same as the past, an important limitation in periods of market stress.
- Analytical methods, based on assumptions that the underlying market factors are multivariate normal distributed. In this way, the profit and loss, which is also normally distributed, can be determined.

Many financial organizations use a combination of these approaches.

There is a requirement in some sectors for VaR to be calculated on the basis of stressed markets and conditions of high volatility to provide a credible set of ‘worst case’ outcomes.

Common measures of VaR are related to losses over one-day and two-week horizons, with probabilities of loss of 1 % and 5 %. By convention, VaR is reported as a positive number, although it refers to a loss.

For example, Figure B.9 shows the distribution of value for a portfolio of financial assets over a period, with the distribution shown in cumulative form. Figure B.10 shows the region in which the portfolio suffers a loss, with VaR values of 1,16 million at 1 % (a probability of loss of 0,01) and 0,28 million at 5 % (a probability of loss of 0,05).

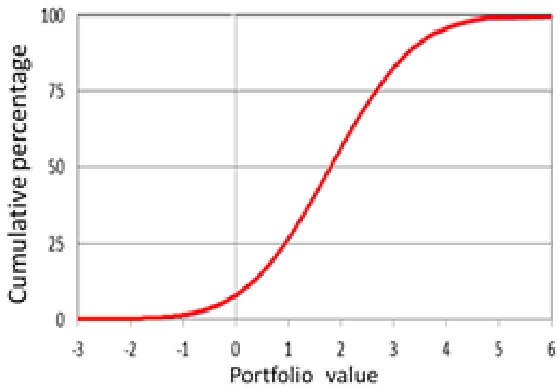



**Figure B.9 – Distribution of value**

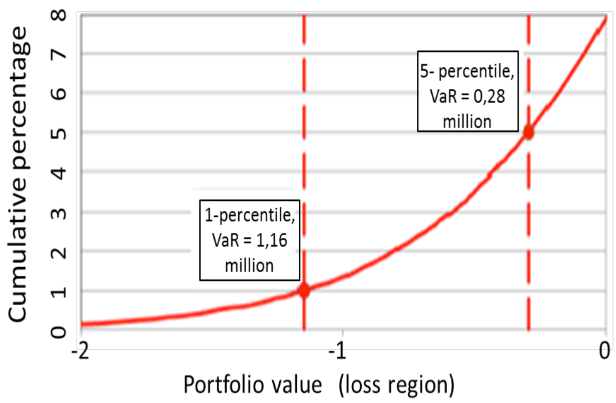



**Figure B.10 – Detail of loss region VaR values**

#### B.5.12.2 Use

VaR has three parameters: an amount of potential loss, the probability of that amount of loss, and the time period over which the loss might occur. It is used for the following purposes:

- to set limits for a portfolio manager on the maximum loss in the portfolio within an agreed risk tolerance or risk appetite;
- to monitor the ‘riskiness’ of a portfolio of assets at a point in time and trends in ‘riskiness’;

- to determine how much economic, prudential or regulatory capital might need to be set aside for a specified portfolio;
- to report to regulators.

#### B.5.12.3 Input

The inputs are market factors that affect the value of the portfolio, such as exchange rates, interest rates and stock prices. Typically, these are identified by decomposing the instruments in the portfolio into simpler instruments directly related to basic market risk factors, then interpreting the actual instruments as portfolios of the simpler instruments. Funders and regulators can require specific methods to be adopted when assessing input variables.

#### B.5.12.4 Output

Over a nominated time period, VaR generates the potential loss from a portfolio of financial assets for a specified probability, or the probability for a specified amount of loss.

#### B.5.12.5 Strengths and limitations

Strengths include:

- the approach is straightforward, and accepted (or required) by financial regulators;
- it can be used to calculate economic capital requirements, on a daily basis if needed;
- it provides a means of setting limits on a trading portfolio in accordance with an agreed risk appetite, and monitoring performance against those limits, and so supporting governance.

Limitations include the following:

- VaR is an indicator not a specific estimate of possible loss. The maximum possible loss for any given situation is not evident from a single figure corresponding to VaR with 1 % or 5 % likelihood of loss derived from VaR analysis;
- VaR has a number of undesirable mathematical properties; for example VaR is coherent risk measure when based on an elliptical distribution such as the standard normal distribution but not in other circumstances. Calculations in the tail of the distribution are often unstable, and can depend on specific assumptions about distribution shapes and correlations that can be hard to justify and might not hold in times of market stress;
- simulation models can be complex and time-consuming to run;
- organizations might require sophisticated IT systems to capture market information in a form that can be used easily, and in a timely manner, for VaR calculations;
- it is necessary to assume values for a set of parameters which are then fixed for the model. If the situation changes so these assumptions are not relevant the method will not give reasonable results. I.e. it is a risk model that cannot be used in unstable conditions.

#### B.5.12.6 Reference documents

CHANCE, D., BROOKS, R. (2010). *An introduction to derivatives and risk management* (9th ed.). Published Mason, Ohio: South-Western Cengage Learning 2013

THOMAS J. and PEARSON Neil D. Value at risk. *Financial Analysts Journal 2000* ***56****,* 47-67

### B.5.13 Conditional value at risk (CVaR) or expected shortfall (ES)

#### B.5.13.1 Overview

Conditional value at risk (CVaR), also called expected shortfall (ES), is a measure of the expected loss from a financial portfolio in the worst *a* % of cases. This is a similar measure to VaR, but it is more sensitive to the shape of the lower (loss) tail of the portfolio value distribution. CVaR(*a*) is the expected loss from those losses that only occur *a* % of the time. For example in Figure B.10, when *a* is 5, then CVaR(5) is the expected value of losses represented by the curve to the left of the vertical line at 5 %, i.e. the average of all losses greater than 0,28 million.

#### B.5.13.2 Use

CVaR techniques have been applied to credit risk measurement, which provides lenders with an insight into changes in extreme risk across industries since the onset of the financial crisis. The following diagram best illustrates the difference between CVaR and VaR in a portfolio at risk situation.

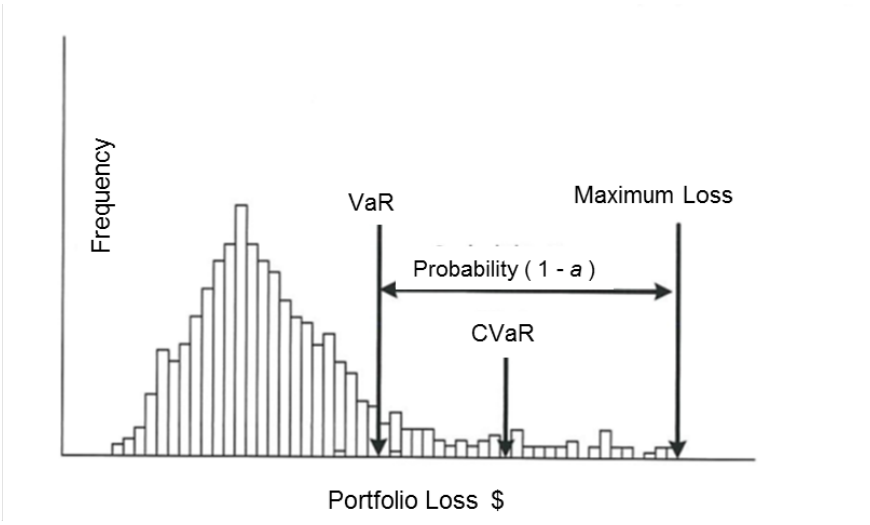



**Figure B.11 – VaR and CVaR for possible loss portfolio**

#### B.5.13.3 Inputs and outputs

See the description for value at risk (VaR) in B.5.12.

#### B.5.13.4 Strengths and limitations

Strengths include:

- CVaR is more sensitive to the shape of the distribution tail than VaR;
- CVaR avoids some of the mathematical limitations of VaR;
- CVaR is a more conservative measure than VaR because it focuses on the outcomes that generate the greatest losses.

Limitations include:

- CVaR is an indicator of potential for loss not an estimate of maximum possible loss;
- as with VaR, CVaR is sensitive to fundamental assumptions on volatility of asset value;
- CVaR relies on complex mathematics and requires a large range of assumptions.

#### B.5.13.5 Reference documents

CHOUDHRY , M. *An introduction to Value at Risk,* Ed. 5, John Wiley and Sons, Chichester UK, 2013

*Value at Risk* New York University. [viewed 2017-9-14]. Available at: http://people.stern.nyu.edu/adamodar/pdfiles/papers/VAR.pdf

## B.6 Techniques for analysing dependencies and interactions

### B.6.1 Causal mapping

#### B.6.1.1 Overview

Causal mapping captures individual perceptions in the form of chains of argument into a directed graph amenable for examination and analysis. Events, causes and consequences can be depicted in the map.

Typically the maps are developed in a workshop environment where participants from a range of different disciplines are tasked with the elicitation, structuring and analysis of the material. Perceptions are augmented with information from documents where appropriate. Inputs can be captured using various tools ranging from “post-it notes" to specialised group decision support software. The latter allow for direct entry of issues and can be a highly productive means of working. The tools selected should allow for anonymous capture of issues so that an open and non-confrontational environment can be created to support focussed discussion of causal relationships.

In general, the process starts by generating contributions that either impact or cause events in relation to the issue under consideration. These are then clustered according to their content and subsequently explored to ensure a comprehensive coverage.

Participants then consider how each of the events might impact upon one another. This enables the discrete events to be linked together to form causal reasoning paths in the map. The process aims to facilitate shared understanding of uncertain events as well as triggering further contributions through the enforced explanatory process, which is necessary for building up the chains of argument of how one event impacts another. There are clear rules for the capture of both the nodes representing events and the relationships to ensure robust and comprehensive modelling.

Once the network of events has been developed to form a complete map, it can be analysed to determine properties that can be useful for managing risk. For example, to determine central nodes which are those events whose occurrence is central and can have substantial systemic effects; or, to determine feedback loops, which can result in dynamic and destructive behaviours.

#### B.6.1.2 Use

Causal mapping identifies links and interactions between risks and themes within a list of risks.

It can be used forensically to develop a causal map for an event that has occurred (e.g. project overrun, system failure). Forensic causal maps can reveal triggers, consequences and dynamics. They allow for the determination of causality, which might be critical to claims.

Causal maps can also be used proactively to capture a comprehensive and systemic appreciation of event scenarios. The map can then be examined to allow deep learning as well as forming the basis for quantitative analysis of risks to help determine priorities.

They enable an integrated treatment program to be developed rather than each risk being considered separately.

Causal analysis workshops can be run at regular intervals to ensure that the dynamic nature of risk is appreciated and managed appropriately.

#### B.6.1.3 Inputs

Data to inform the development of causal maps can come from a range of different sources such as from individual interviews where the maps produced give an in-depth representation of what occurred, or could occur. Data can also be drawn from documentation such as reports, claim materials etc. This data can be used directly or can be used to inform the explication of the chains of argument relating to events by participants in a workshop.

#### B.6.1.4 Outputs

The outputs include:

- causal maps which provide a visual representation of risk events and the systemic relationships between these events;
- the results of an analysis of the causal maps used to identify emergent clusters of events, critical events due to their centrality, feedback loops etc.;
- a document translating the maps into text and reporting the key results, as well as explaining the selection of participants and the process used to develop the maps.

The outputs should provide information relevant to risk management decisions and an audit trail of the process used to generate this information.

#### B.6.1.5 Strengths and limitations

Strengths of causal maps include:

- the risks relevant to the issue under consideration is considered from the multiple perspectives of participants;
- the divergent and open nature of the process allows risk to be explored reducing the chance of overlooking critical events or relationships;
- the process allows the effective and efficient capture of the interactions between events and provides an understanding of their relationships;
- the process of determining the network of events that form the map can build the common language and understanding that are vital for effective risk management.

Limitations include:

- the process of mapping is not easy to learn as it demands not only skill in the mapping technique but also the ability to manage groups while working with the mapping tool;
- the maps are qualitative in nature and where quantification is required the maps need to be used as input to other appropriate models;
- the content of the map is determined by the sources and so careful consideration of participant make up is critical otherwise vital areas can be omitted.

#### B.6.1.6 Reference document

ACKERMANN, F, HOWICK, S, QUIGLEY, J, WALLS, L, HOUGHTON, T. 2014. Systemic risk elicitation: Using causal maps to engage stakeholders and build a comprehensive view of risks*, European Journal of Operational Research*, **238(**1) 290-299

### B.6.2 Cross impact analysis

#### B.6.2.1 Overview

Cross-impact analysis is the general name given to a family of techniques designed to evaluate changes in the probability of the occurrence of a given set of events consequent on the actual occurrence of one of them.

Cross-impact analysis involves constructing a matrix to show the interdependencies of different events. A set of events or trends that might occur is listed along the rows, and the events or trends that would possibly be affected by the row events along the columns. Experts are then required to estimate:

- the probability for each event (in isolation of the others) at a given time horizon;
- the conditional probability of each event given that each other event occurs. i.e. for the *i*/*j* pair of events the experts estimate:
  - P*(i*/*j*)- the probability of *i* if *j* occurs
  - P(*i*/not *j*) – the probability of *i* if *j* does not occur.

This is entered into a computer for analysis.

There are several different methods to calculate the probabilities of one event taking into account all other events. Regardless of how this is done, the usual procedure is to carry out a Monte Carlo simulation where the computer model systematically selects consistent sets of events and iterates a number of times. As more and more computer runs are performed, a new posteriori probability of occurrence of each event is generated.

A sensitivity analysis is carried out by selecting an initial probability estimate or a conditional probability estimate, about which uncertainty exists. This judgment is changed and the matrix is run again.

#### B.6.2.2 Use

Cross impact analysis is used in forecasting studies and as an analytic technique to predict how different factors impact future decisions. It can be combined with scenario analysis (B.2.5) to decide which of the scenarios produced are the most likely. It can be used when there are multiple interacting risks, for example in complex projects, or in managing security risks.

The time horizon of cross impact analysis is usually medium to long term and can be from the present to 5 years or up to 50 years into the future. The time horizon should be explicitly stated.

The matrix of events and their interdependencies can be useful to decision makers as general background even without the probability calculated from the analysis.

#### B.6.2.3 Input

The method requires experts who are familiar with the issue under study, and have the capacity to envisage future developments, and who are able to estimate probabilities realistically.

Supporting software is needed to calculate the conditional probabilities. The technique requires specific modelling knowledge if the user wants to understand how the data are processed by the software. Significant time (several months) is usually required to develop and run the models.

#### B.6.2.4 Output

The output is a list of possible future scenarios and their interpretation.

Each run of the model produces a synthetic future history, or scenario, which includes the occurrence of some events and the non-occurrence of others. On the basis of the specific cross-impact model applied, the output scenarios attempt to generate either the most likely scenario, or a set of statistically consistent scenarios, or one or more plausible scenarios from the total set.

#### B.6.2.5 Strengths and limitations

Strengths of cross impact analysis include:

- it is relatively easy to implement a cross impact questionnaire;
- it forces attention into chains of causality (*a* affects *b; b* affects *c* etc.);
- it can clarify and increase knowledge on future developments;
- it is useful in exploring a hypothesis and in finding points of agreement and divergence.

Limitations include:

- the number of events that can be included is limited in practice by both the software and the time required by experts. The number of runs required and the number of conditional probabilities to estimate increases rapidly as the number of events included increases (e.g. with a set of ten events an expert needs to provide 90 conditional probability judgments);
- a realistic study requires considerable work by experts and a high dropout rate is often experienced;
- it is difficult to define the events to be included and any influence not included in the set of events will be completely excluded from the study; conversely, the inclusion of irrelevant events can unnecessarily complicate the final analysis of the results;
- as with other techniques based on eliciting experts' knowledge, the method relies on the level of expertise of respondents.

#### B.6.2.6 Reference documents



*Cross impact analysis;* Joint Research Centre, European Commission; [viewed 2017-9-14] Available at: http://forlearn.jrc.ec.europa.eu/guide/2_design/meth_cross-impact-analysis.htm

## B.7 Techniques for selecting between options

### B.7.1 General

Techniques in this group are used to help decision makers decide between options which involve multiple risks and where trade-offs have to be made. The techniques help to provide a logical basis to justify reasons for a decision. Since the methods have different philosophies it can be valuable to explore options using more than one method.

Decision tree analysis and cost benefit analysis base decisions on expected financial loss or gain. Multi criteria analysis allows different criteria to be weighted and trade-offs made. Scenario analysis (see B.2.5) can also be used to explore the possible consequences if different options are followed. This method is particularly useful where there is high uncertainty. Decision problems can also be modelled using influence diagrams (B.5.3).

### B.7.2 Cost benefit analysis (CBA)

#### B.7.2.1 Overview

Cost benefit analysis weighs the total expected costs of options in monetary terms against their total expected benefits in order to choose the most effective or the most profitable option. It can be qualitative or quantitative, or involve a combination of quantitative and qualitative elements, and can be applied at any level of an organization.

The stakeholders who might experience costs or receive benefits (tangible or intangible) are identified together with the direct and indirect benefits and costs to each.

NOTE Direct costs are those that are directly associated with the action. Indirect costs are those additional opportunity costs, such as loss of utility, distraction of management time or the diversion of capital away from other potential investments.

In quantitative CBA a monetary value is assigned to all tangible and intangible costs and benefits. It often happens that the cost is incurred over a short period of time (e.g. a year) and the benefits flow for a long period. It is then necessary to discount the costs and benefits to bring them into “today’s money” so that a valid comparison can be made between costs and benefits. The Present Value of all Costs (PVC) and Present Value of Benefits (PVB) to all stakeholders can be combined to produce a Net Present Value (NPV): NPV = PVB – PVC.

A positive NPV implies that the action might be a suitable option. The option with the highest NPV is not necessarily the best value option. The highest ratio of NPV to the present value of costs is a useful indicator of the best value option. Selection based on CBA should be combined with strategic choice between satisfactory options which could individually offer lowest cost treatment, highest affordable benefit, or best value (most profitable return on investment). Such strategic choice can be required at both policy and operational level.

Uncertainty in costs and benefits can be taken into account by calculating the probability weighted average of net benefits (the expected net present value or ENPV). In this calculation the user is presumed to be indifferent between a small payoff with a high probability of occurrence, and a large payoff with a low probability of occurrence, so long as they both have the same expected value. NPV calculations can also be combined with decision trees (B.7.3) to model uncertainty in future decisions and their outcomes. In some situations it is possible to delay some of the costs until better information is available about costs and benefits. The possibility of doing this has a value which can be estimated using real options analysis.

In qualitative CBA no attempt is made to find a monetary value for intangible costs and benefits and, rather than providing a single figure summarizing the costs and benefits, relationships and trade-offs between different costs and benefits are considered qualitatively.

A related technique is a cost-effectiveness analysis. This assumes that a certain benefit or outcome is desired, and that there are several alternative ways to achieve it. The analysis looks only at costs and seeks to identify the cheapest way to achieve the benefit.

Although intangible values are usually dealt with by giving them a monetary value it is also possible to apply a weighting factor to other costs, for example to weight safety benefits more highly than financial benefits.

#### B.7.2.2 Use

CBA is used at operational and strategic levels to help decide between options. In most situations those options will involve uncertainty. Both variability in the expected present value of costs, and benefits, and the possibility of unexpected events need to be taken into account in the calculations. A sensitivity analysis or Monte Carlo analysis (B.5.10) can be used for this.

CBA can also be used in making decisions about risks and their treatments, for example:

- as input into a decision about whether a risk should be treated;
- to decide on the best form of risk treatment;
- to compare long term and short term treatment options.

#### B.7.2.3 Inputs

Inputs include information on costs and benefits to relevant stakeholders and on uncertainties in those costs and benefits. Tangible and intangible costs and benefits should be considered. Costs include any resources which might be expended, including direct and indirect costs, attributable overheads and negative impacts. Benefits include positive impacts, and cost avoidance (which can result from risk treatments). Sunk costs already expended are not part of the analysis. A simple spreadsheet analysis or qualitative discussion does not require substantial effort but application to more complex problems involves significant time in collecting necessary data and in estimating a suitable monetary value for intangibles.

#### B.7.2.4 Output

The output of a cost/benefit analysis is information on relative costs and benefits of different options or actions. This can be expressed quantitatively as a net present value (NPV), a best ratio (NPV/PVC) or as the ratio of the present value of benefits to the present value of costs.

A qualitative output is usually a table comparing costs and benefits of different types of cost and benefit, with attention drawn to trade-offs.

#### B.7.2.5 Strengths and limitations

Strengths of CBA include:

- CBA allows costs and benefits to be compared using a single metric (money);
- it provides transparency for information used to inform decisions;
- it encourages detailed information to be collected on all possible aspects of the decision (this can be valuable in revealing ignorance as well as communicating knowledge).

Limitations include:

- CBA requires a good understanding of likely benefits so it does not suit a novel situation with high uncertainty;
- quantitative CBA can yield dramatically different numbers, depending on the assumptions and methods used to assign economic values to non-economic and intangible benefits;
- in some applications it is difficult to define a valid discounting rate for future costs and benefits;
- benefits which accrue to a large population are difficult to estimate, particularly those relating to public good which is not exchanged in markets. However, when combined with “Willingness to Pay or Accept”, it is possible to account for such external or societal benefits;
- depending on the discounting rate chosen, the practice of discounting to present values means that benefits gained in the long term future can have negligible influence on the decision so discouraging long term investment.

CBA does not deal well with uncertainty in the timing of when costs and benefits will occur or with flexibility in future decision making.

#### B.7.2.6 Reference documents

*The Green book, Appraisal and Evaluation in Central Government*; 2011 Treasury Guidance LONDON: TSO London.

ANDOSEH, S., et al. The case for a real options approach to ex-ante cost-benefit analyses of agricultural research projects. *Food policy* **44**, 2014, 218-226 [viewed 2017.6.30] Available at: http://pdf.usaid.gov/pdf_docs/pnaec758.pdf

### B.7.3 Decision tree analysis

#### B.7.3.1 Overview

A decision tree models the possible pathways that follow from an initial decision that must be made (for example whether to proceed with Project A or Project B). As the two hypothetical projects proceed, a range of events might occur and different predictable decisions will need to be made. These are represented in tree format, similar to an event tree. The probability of the events can be estimated together with the expected value or utility of the final outcome of each pathway.

Information concerning the best decision pathway is logically that which produces the highest expected value calculated as the product of all the conditional probabilities along the pathway and the outcome value.

#### B.7.3.2 Use

A decision tree can be used to structure and solve sequential decision problems, and is especially beneficial when the complexity of the problem grows. It enables an organization to quantify the possible outcomes of decisions and hence helps decision makers select the best course of action when outcomes are uncertain. The graphical display can also help communicate reasons for decisions.

It is used to evaluate a proposed decision, often using subjective estimates of event probabilities and helps decision makers to overcome inherent perception biases towards success or failure. It can be used on short, medium and long term issues at an operational or strategic level.

#### B.7.3.3 Input

Developing a decision tree requires a project plan with decision points, information on possible outcomes of decisions and on chance events that might affect decisions. Expertise is needed to set up the tree correctly, particularly in complex situations.

Depending on the construction of the tree, quantitative data, or sufficient information is needed to justify expert opinion for probabilities.

#### B.7.3.4 Outputs

Outputs include:

- a graphical representation of the decision problem;
- a calculation of the expected value for each possible path;
- a prioritised list of possible outcomes based on expected value, or the recommended pathway to be followed.

#### B.7.3.5 Strengths and limitations

Strengths of decision tree analysis include:

- it provides a clear graphical representation of the details of a decision problem;
- the exercise of developing the tree can lead to improved insights into the problem;
- it encourages clear thinking and planning;
- it enables a calculation of the best pathway through a situation and the expected result.

Limitations include:

- large decision trees can become too complex for easy communication;
- there can be a tendency to oversimplify the situation so as to be able to represent it as a tree diagram;
- it relies on historical data which might not apply to the decision being modelled.

#### B.7.3.6 Reference documents

*Decision Tree Primer* 2002, Craig Kirkwood, University of Arizona in Decision Analysis and System Dynamics resources 2002 available at : http://www.public.asu.edu/~kirkwood/DAStuff/decisiontrees/DecisionTreePrimer-Front.pdf

### B.7.4 Game theory

#### B.7.4.1 Overview

Game theory is a means to model the consequences of different possible decisions given a number of possible future situations. The future situations can be determined by a different decision maker (e.g. a competitor) or by an external event, such as success or failure of a technology or a test. For example, assume the task is to determine the price of a product taking into account the different decisions that could be made by different decision makers (called players) at different times. The pay-off for each player involved in the game, relevant to the time period concerned, can be calculated and the strategy with the optimum payoff for each player selected. Game theory can also be used to determine the value of information about the other player or the different possible outcomes (e.g. success of a technology).

There are different types of games, for example cooperative/non–cooperative, symmetric/asymmetric, zero-sum/non-zero-sum, simultaneous/sequential, perfect information and imperfect information, combinatorial games, stochastic outcomes.

##### B.7.4.1.1 Communication and cooperative/non-cooperative games

An important factor is whether communication among players is possible or allowed. A game is cooperative if the players are able to form binding commitments. In non-cooperative games, this is not possible. Hybrid games contain cooperative and non-cooperative elements. For instance, coalitions of players are formed in a cooperative game, but these play in a non-cooperative fashion.

The classical example of games without communication between the players is the so called “prisoners dilemma”. It shows that in some cases the act of each player to improve their own outcome without regard for the other may cause the worst situation for both. This sort of game has been used to analyse conflict and cooperation between two players where lack of communication may cause an unstable situation that could result in the worst possible result for both players. In the “prisoners dilemma game” it is supposed that two persons committed a crime together. They are kept separate and cannot communicate. The police suggest a deal. If each prisoner will admit their guilt and witness against the other he will receive a low sentence, but the other prisoner will receive a larger sentence. A prisoner gets maximum penalty if he does not confess and witness and the other one does. Therefore to improve their situation both are tempted to confess and witness, but in that case they will both get the maximum penalty. Their best strategy would have been to reject the deal and not admit anything. In that case both would get the minimum penalty.

##### B.7.4.1.2 Zero-sum/non-zero-sum and symmetric/asymmetric games

In a zero-sum game, what one player gains, the other player loses. In a non-zero sum game the sum of the outcomes may vary with the decisions. For example lowering the prices may cost one player more than the other, but may increase the market volume for both.

##### B.7.4.1.3 Simultaneous/ sequential games.

In some games the calculation is made for just one interaction between the players. But in sequential games the players interact many times, and may change their strategy from one game to the next.

For example simulated games have been made to investigate the effect of cheating in a market. There are two possibilities for each player. The supplier can deliver or not deliver, and the customer can pay or not pay. Of the 4 possible outcomes the normal outcome advantages both players (the supplier delivers and the customer pays). The outcome where the supplier does not deliver and the customer does not pay is a lost opportunity. The last two possibilities is a loss to the supplier (the customer does not pay) or to the customer (the supplier does not deliver). The simulation tried different strategies like always playing honest, always cheating or cheating at random. It was determined that the optimum strategy was to play honest in the first interaction and the next time to do what the other player did last time (play honest or cheat). (In real life it is likely that the supplier would recognise the customers that cheat and stop playing with them).

#### B.7.4.2 Use

Game theory allows risk to be evaluated in cases where the outcome of a number of decisions depends on the action of another player (e.g. a competitor) or on a number of possible outcomes (e.g. whether a new technology will work). The following example illustrates the information that can be achieved by a game analysis.

Table B.6 illustrates a situation where a company can choose between 3 different technologies. But the profit will depend on the action of a competitor (action 1, 2 or 3). It is not known what action the competitor will choose, but the probabilities are estimated as shown. The profits, in million monetary units (MU), are calculated in the table.

**Table B.6 – Example of a game matrix**

| | Competitor | | | Expected profit | Guaranteed profit | Maximum regret |
|---|---|---|---|---|---|---|
| | **Action 1** | **Action 2** | **Action 3** | | | |
| **Probability** | 0,4 | 0,5 | 0,1 | | | |
| **Technology 1** | 0,10 | 0,50 | 0,90 | 0,38 | 0,10 | 0,50 |
| **Technology 2** | 0,50 | 0,50 | 0,50 | 0,50 | 0,50 | 0,40 |
| **Technology 3** | 0,60 | 0,60 | 0,30 | 0,57 | 0,30 | 0,60 |

The following information can be extracted from the table to support the decision.

Clearly technology 3 is the best, with an expected profit of 0,57 Mill. MU. But the sensitivity to the action of the competitor should be considered. The column guaranteed profit states what the profit will be for a given technology independent of what the competitor does. Here technology 2 is the best with a guaranteed profit of 0,50 Mill. MU. It should be considered whether it is worth choosing technology 3 to gain only 0,07 Mill. MU, risking the loss of 0,20 Mill. MU.

It is further possible to compute the maximum regret, which is the difference between the profit from choosing a given technology compared to the profit possible had the action of the competitor been known. This gives the monetary benefit of increased knowledge of the competitor's decision. This may be achieved by negotiation or by other legal means. In this example the value of increased information is largest for technology 3.

#### B.7.4.3 Inputs

To be fully defined, a game must specify at least the following elements as inputs:

- the players or alternatives of the game;
- the information and actions available to each player at each decision point.

#### B.7.4.4 Output

The output is the payoff for each option in the game, generally taken to represent the utility of the individual players. Often in modelling situations the payoffs represent money but other outcomes are possible (for example, market share or delay of a project).

#### B.7.4.5 Strengths and Limitations

Strengths of game theory include:

- it develops a framework for analysing decision making where several possible decisions are possible, but where the outcome depends on the decision of another player or the outcome of a future event;
- it develops a framework for analysing decision making in situations where the interdependence of decisions made by different organizations is taken into account;
- it gives insights into several less-known concepts, which arise in situations of conflicting interest; for example, it describes and explains the phenomena of bargaining and coalition-formation;
- at least in zero sum games in two organizations, game theory outlines a scientific quantitative technique that can be used by players to arrive at an optimal strategy.

Limitations include:

- the assumption that players have knowledge about their own payoffs and the actions and pay offs of others might not be practical;
- the techniques of solving games involving mixed strategies (particularly in the case of a large pay-off matrix) are very complicated;
- not all competitive problems can be analysed with the help of game theory.

#### B.7.4.6 Reference documents

MYERSON, ROGER B, *Game Theory: Analysis of Conflict*:, Harvard University Press, 1991

MARYNARD, SMITH JOHN *Evolution and Theory of Games*, Cambridge University Press 1982

ROSENHEAD, J.. AND MINGER, J. (Eds), Rational Analysis for a Problematic World Revisited, 2nd ed. Wiley, Chichester UK 2001,

### B.7.5 Multi-criteria analysis (MCA)

#### B.7.5.1 Overview

MCA uses a range of criteria to transparently assess and compare the overall performance of a set of options. In general, the goal is to produce an order of preference for a set of options. The analysis involves the development of a matrix of options and criteria which are ranked and aggregated to provide an overall score for each option. These techniques are also known as multi (or multiple) attribute or multi objective decision-making. There are many variants of this technique, with many software applications to support them.

In general, a group of knowledgeable stakeholders undertakes the following process:

- define the objective(s);determine the attributes (criteria or functional performance measures) that relate to each objective;
- structure the attributes into a hierarchy of necessary and desirable requirements;
- determine the importance of each criterion and assign weights to each;
- gain stakeholder consensus on the weighted hierarchy;
- evaluate the alternatives with respect to the criteria (this can be represented as a matrix of scores);
- combine multiple single-attribute scores into an overall weighted multi attribute score;
- evaluate the results for each option;
- assess the robustness of the ranking of options by performing a sensitivity review to explore the impact of changing the attribute hierarchy weightings.

There are different methods by which the weighting for each criterion can be elicited and different ways of aggregating the criteria scores for each option into a single multi-attribute score. For example, scores can be aggregated as a weighted sum or a weighted product or using the analytic hierarchy process (an elicitation technique for the weights and scores based on pairwise comparisons). All these methods assume that the preference for any one criterion does not depend on the values of the other criteria. Where this assumption is not valid, different models are used.

Since scores are subjective, sensitivity analysis is useful to examine the extent to which the weights and scores influence overall preferences between options.

#### B.7.5.2 Use

MCA can be used for:

- comparing multiple options for a first pass analysis to determine preferred and inappropriate options;
- comparing options where there are multiple and sometimes conflicting criteria;
- reaching a consensus on a decision where different stakeholders have conflicting objectives or values.

#### B.7.5.3 Inputs

The inputs are a set of options for analysis and criteria, based on objectives that can be used to assess the performance of options.

#### B.7.5.4 Outputs

The results can be presented as:

- rank order presentation of the options from best to least preferred;
- a matrix where the axes of the matrix are criteria weight and the criteria score for each option.

Presenting the results in a matrix allows options that fail highly weighted criteria or that fail to meet a necessary criterion to be eliminated.

#### B.7.5.5 Strengths and limitations

Strengths of MCA include that it can:

- provide a simple structure for efficient decision-making and presentation of assumptions and conclusions;
- make more manageable complex decision problems, which are not amenable to cost/benefit analysis;
- help consider problems rationally where trade-offs need to be made;
- help achieve agreement when stakeholders have different objectives and hence different values and criteria.

Limitations include:

- MCA can be affected by bias and poor selection of the decision criteria;
- aggregation algorithms which calculate criteria weights from stated preferences or aggregate differing views can obscure the true basis of the decision;
- the scoring system can oversimplify the decision problem.

#### B.7.5.6 Reference documents

EN 16271:2012: *Value management - Functional expression of the need and functional performance specification - Requirements for expressing and validating the need to be satisfied within the process of purchasing or obtaining a product*.

NOTE This European Standard sets out approaches to reconcile conflicting stakeholder needs, methods which can be used to derive functional performance requirements, and guidance to set the granularity for multi-criteria analysis before comparing options.

DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT, *Multi-criteria analysis: a manual* 2009 [viewed 2017-30-6]. Available at: https://www.gov.uk/government/publications/multi-criteria-analysis-manual-for-making-government-policy

RABIHAH MHD.SUM (2001). Risk Management Decision Making,[viewed 2017-6-30] Available at: http://www.isahp.org/uploads/47.pdf

VELASQUEZ, M., HESTER, P. , An Analysis of Multi-criteria Decision Making Methods, *International Journal of Operations Research*, **10** (2), 55-66 2013 [viewed 2017-6-30]. Available at: http://www.orstw.org.tw/ijor/vol10no2/ijor_vol10_no2_p56_p66.pdf

## B.8 Techniques for evaluating the significance of risk

### B.8.1 General

Techniques discussed in this clause are used within a process involving deciding whether and how to treat risk. Some can be used to decide whether a particular risk is tolerable or acceptable others to indicate the relative significance of a risk or to rank risks in a priority order.

### B.8.2 ALARP/SFAIRP

#### B.8.2.1 Overview

ALARP and SFAIRP are acronyms that embody the principle of 'reasonably practicable'. They represent criteria where the test for acceptability or tolerability of a risk is whether it is reasonably practicable to do more to reduce risk. ALARP generally requires that the level of risk is reduced to As Low AS Reasonably Practicable. SFAIRP generally requires that safety is ensured So Far As Is Reasonably Practicable. Reasonably practicable has been defined in legislation or in case law in some countries.

The SFAIRP and ALARP criteria are intended to achieve the same outcome, however they differ on one semantic point. ALARP achieves safety by making risk as low as reasonably practicable, whereas SFAIRP makes no reference to the level of risk. SFAIRP is usually interpreted as a criterion by which controls are assessed to see if further treatments are possible; then, if they are possible, whether they are practicable. Both ALARP and SFAIRP make allowances for discounting risk treatments on the basis that the costs are grossly disproportionate to the benefits gained, although the extent to which this is available is jurisdiction dependent. For example in some jurisdictions cost benefit studies (see B.7.2) can be used to support an argument that ALARP/SFAIRP have been achieved.

The concept of ALARP, as originally expressed by the UK Health and Safety Executive, is illustrated in Figure B.12. In some jurisdictions quantified levels of risk are placed on the boundaries between intolerable ALARP and broadly acceptable regions.

#### B.8.2.2 Use

ALARP and SFAIRP are used as criteria for deciding whether a risk needs to be treated. They are most commonly used for safety related risk and are used by legislators in some jurisdictions.

The ALARP model can be used to classify risks into one of three categories as follows:

- an intolerable risk category, where activities must be stopped and risk treated to reduce it to an acceptable level;
- a broadly acceptable risk category where the risk is so low that further risk reduction need not be considered (but could be implemented if practicable and reasonable);
- a region between these limits, (the ALARP region) where further risk reduction should be implemented if it is reasonably practicable.

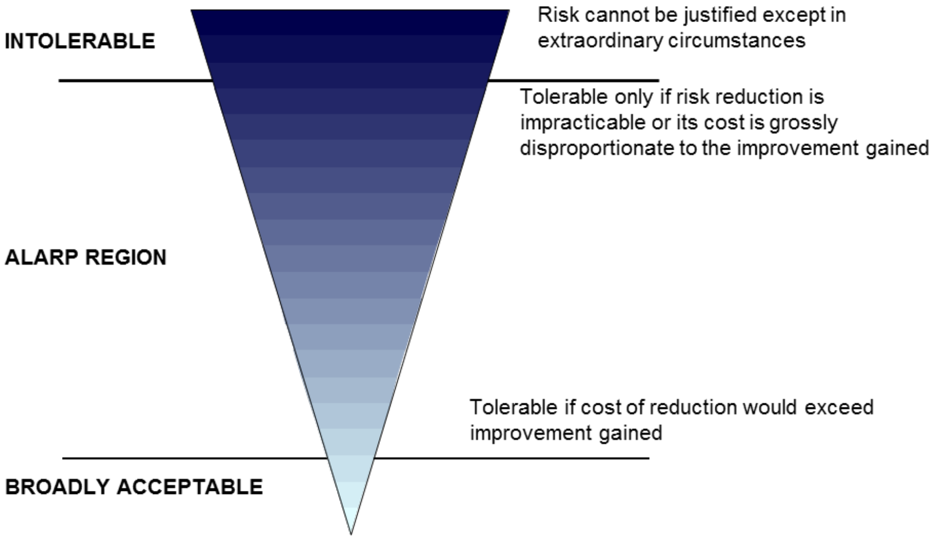



**Figure B.12 – ALARP diagram**

#### B.8.2.3 Inputs

Information about:

- the source of risk and the associated risk;
- controls in place and what other controls would be possible;
- potential consequences;
- the likelihood those consequences would occur;
- the cost of possible treatments.

#### B.8.2.4 Output

The output is a decision about whether treatment is required and the treatment to be applied.

#### B.8.2.5 Strengths and limitations

The strengths of using the ALARP/SFAIRP criterion include that they:

- set a common standard of care, based on case law and legislation, that supports the principle of equity in that all individuals are entitled to an equal level of protection from risks which is deemed by law and not a variable deemed tolerable or acceptable by their organization;
- support the principle of utility as risk reduction should not require more effort than is reasonably practicable;
- allow for non-prescriptive goal setting;
- support continuous improvement towards the goal of minimising risk;
- provide a transparent and objective methodology for discussing and determining acceptable or tolerable risk through stakeholder consultation.

Limitations include:

- interpreting ALARP or SFAIRP can be challenging because it requires organizations to understand the legislative context of reasonably practicable and to exercise judgement with respect to that context;
- applying ALARP or SFAIRP to new technologies can be problematic because risks and possible treatments might not be known or well understood;
- ALARP and SFAIRP set a common standard of care that may not be financially affordable for smaller organizations, resulting either in risk-taking or halting an activity.

#### B.8.2.6 Reference documents

HSE, 2010a: HID'S Approach To 'As Low As Reasonably Practicable' (ALARP) Decisions, http://www.hse.gov.uk/risk/theory/alarpglance.htm

HSE, 2010b: Guidance on (ALARP) decisions in control of major accident hazards (COMAH), 2010. http://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/

HSE, 2014c: Principles and guidelines to assist HSE in its judgments that duty-holders have reduced risk as low as reasonably practicable, http://www.hse.gov.uk/risk/theory/alarp1.htm

### B.8.3 Frequency-number (F-N) diagrams

#### B.8.3.1 Overview

An F-N diagram is a special case of a quantitative consequence likelihood graph (B.9.3). In this application the X axis represents the cumulative number of fatalities and the Y axis the frequency with which they occur. Both scales are logarithmic to fit with typical data. The risk criteria are generally displayed as straight lines on the graph where the higher the slope of the line, the higher the aversion to a higher number of fatalities compared to a lower number.

#### B.8.3.2 Use

F-N diagrams are used either as a historical record of the outcome of incidents involving loss of human life, or to display the results of a quantitative analysis of the risk of loss of life in comparison with predefined criteria for acceptability.

Figure B.13 shows two examples of criteria labelled A and A-1 and B and B-1. They distinguish between an intolerable region (above A or B), a broadly acceptable region (below A-1 and B-1), and a region between the lines where the risks are acceptable if they are as low as reasonably practicable (ALARP) (B.8.2). The B criteria show both a higher slope (i.e. less tolerance for multiple fatalities) and more conservative limits overall. Also shown are six points on curve C, representing the results from a quantitative analysis of the level of risk to be compared with the criteria.

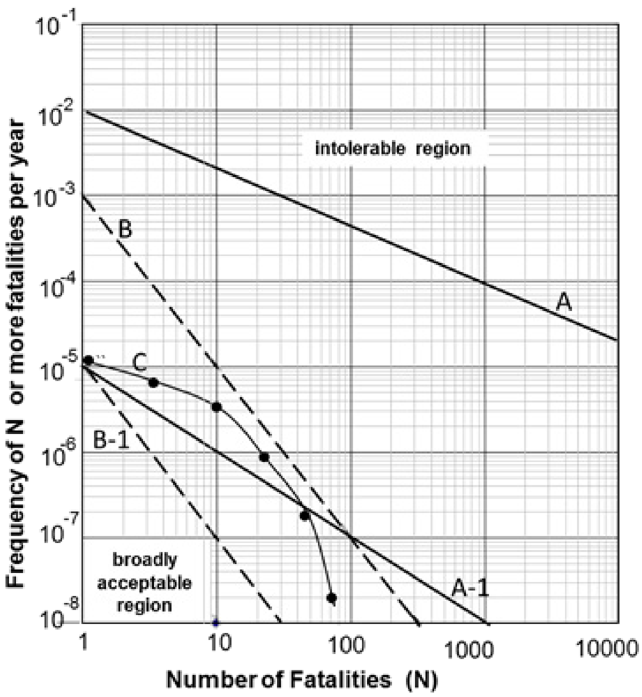



**Figure B.13 – Sample F-N diagram**

The most common application is for representing the societal risk from proposed major hazards sites that are subject to land use planning or similar safety evaluations.

#### B.8.3.3 Inputs

Data from incidents or from quantitative risk analysis that predict the probability of fatalities.

#### B.8.3.4 Output

A graphical representation of the data compared with predefined criteria.

#### B.8.3.5 Strengths and limitations

The strengths of F-N diagrams include:

- they provide an easily understood output on which decisions can be based;
- the quantitative analysis necessary to develop an F/N plot provides a good understanding of the risk and its causes and consequences.

Limitations include:

- the calculations to produce the plots are often complex with many uncertainties;
- a full analysis requires all potential major accident scenarios to be analysed. This is time consuming and requires a high level of expertise;
- F-N diagrams cannot easily be compared with each other for the purpose of ranking (e.g. deciding which development provides the higher societal risk).

#### B.8.3.6 Reference documents

Understanding and using F-N Diagrams: Annex A in *Guidelines for Developing Quantitative Safety Risk Criteria.* American Institute for Chemical Engineers New York. John Wiley 2009

EVANS, A. Transport fatal accidents and FN-curves: 1967-2001*. Health and Safety Executive Research Report RR 073 [viewed 20179-14]* available at: http://www.hse.gov.uk/research/rrhtm/rr073.htm2003

### B.8.4 Pareto charts

#### B.8.4.1 Overview

A Pareto chart is a tool for selecting a limited number of tasks that will produce significant overall effect. It uses the Pareto principle (also known as the 80/20 rule) which is the idea that by doing 20 % of the work one can generate 80 % of the benefit, or that 80 % of problems are produced by 20 % of causes.

Producing a Pareto chart that selects causes to be addressed involves the following steps:

- identify and list problems;
- identify the cause of each problem;
- group problems together by cause;
- add up the scores for each group;
- draw a column graph with the causes displayed with those with the higher scores first.

The Pareto principle applies to the number of problems and takes no account of significance. I.e. high consequence problems may not be associated with the most common causes of lower consequence problems. This can be accommodated by scoring the problems according to consequence to provide a weighting. A Pareto analysis is a bottom-up approach and can deliver quantitative results.

NOTE The figures 80 % and 20 % are illustrative – the Pareto Principle illustrates the lack of symmetry that often appears between work put in and results achieved. For example, 13 % of work could generate 87 % of returns. Or 70 % of problems could be resolved by dealing with 30 % of the causes.

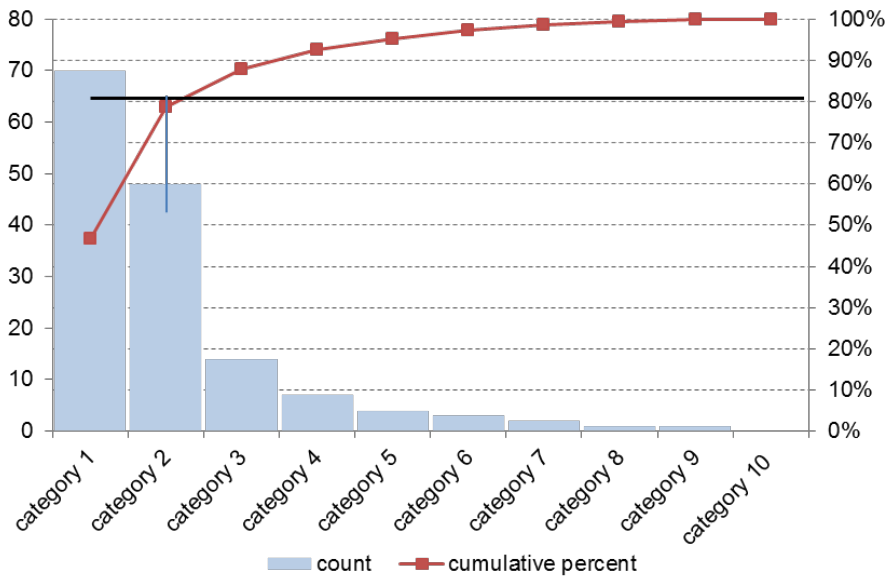



**Figure B.14 – Example Pareto chart**

### B.8.4.2 Use

Pareto analysis is useful at an operational level when many possible courses of action are competing for attention. It can be applied whenever some form of prioritisation is needed. For example it can be used to help decide which risk treatments are the most beneficial or which causes are the most important to address.

A typical representation of a Pareto analysis is shown in the bar chart in which the horizontal axis represents categories of interest (e.g. material types, sizes, scrap codes, process centres), rather than a continuous scale (e.g. 0-100). The categories are often “defects”, sources of defects, or inputs into a process. The vertical axis represents some type of count or frequency (e.g., occurrences, incidents, parts, time). A line graph of the cumulative percentage is then drawn.

The categories to the left of where the cumulative percentage is intersected by the 80 % line are those that are dealt with.

### B.8.4.3 Input

Pareto analysis requires reliable data to analyse, such as data relating to past success and failures and their causes.

Although there is no sophisticated tool, or particular training or competence needed to apply this technique, some experience is very helpful to avoid common limitations and errors.

### B.8.4.4 Outputs

The output is a Pareto chart that helps demonstrate which categories are most significant, so that effort can be focussed on areas where the largest improvements can be made. A Pareto chart can help visually determine which of the categories comprise the “vital few,” and which represent the “trivial many.” Although the analysis is quantitative the output is a categorisation of problems, causes etc. ranked by importance.

If the first analysis contains many small or infrequent problems, they can be consolidated together into an “other” category. This is shown last on the Pareto chart (even if it is not the smallest bar). The cumulative percentage contribution line (the rolling sum of each category’s contribution as a fraction of the total) can also be shown.

### B.8.4.5 Strengths & limitations

Strengths of Pareto analysis include the following:

- Pareto analysis looks at the common causes of individual risks as a basis for a treatment plan;
- it provides a graphical output clearly indicating where the largest gains can be made;
- the time and effort needed to achieve results is likely to be moderate to low.

Limitations include:

- no account is taken of the cost or relative difficulty of dealing with each underlying cause;
- data applicable to the situation being analysed needs to be available;
- the data needs to be able to be divided into categories and to fit the 80/20 rule for the method to be valid;
- it is difficult to construct relative weights when data is inadequate;
- only historical data is taken into consideration.

#### B.8.4.6 Reference documents

Pareto Chart, Excel Easy at: http://www.excel-easy.com/examples/pareto-chart.html

http://www.uphs.upenn.edu/gme/pdfs/Pareto%20Chart.pdf

### B.8.5 Reliability centred maintenance (RCM)

#### B.8.5.1 Overview

Reliability centred maintenance (RCM) is a risk-based assessment technique used to identify the appropriate maintenance policies and tasks for a system and its component so as to efficiently and effectively achieve the required safety, availability and economy of operation for all types of equipment. It encompasses all of the process steps to perform a risk assessment, including risk identification, risk analysis and risk evaluation.

The basic steps of an RCM programme are:

- initiation and planning;
- functional failure analysis;
- maintenance task selection;
- implementation;
- continuous improvement.

Functional analysis within RCM is most commonly carried out by performing a failure mode, effect and criticality analysis (FMECA B.2.3 ), focusing on situations where potential failures can be eliminated or reduced in frequency and/or consequence by carrying out maintenance tasks. Consequences are established by defining failure effects then risk is analysed by estimating the frequency of each failure mode without maintenance being carried out. A risk matrix (B.9.3) allows categories for levels of risk to be established.

The appropriate failure management policy for each failure mode is then selected. Usually a standard task selection logic is applied to select the most appropriate tasks.

A plan is prepared to implement the recommended maintenance tasks by determining the detailed tasks, task intervals, procedures involved, required spare parts and other resources necessary to perform the maintenance tasks. An example is shown in Table B.7.

The entire RCM process is extensively documented for future reference and review. Collection of failure and maintenance-related data enables monitoring of results and implementation of improvements.

#### B.8.5.2 Use

RCM is used to enable applicable and effective maintenance to be performed. It is generally applied during the design and development phase of a system, then implemented during operation and maintenance. The greatest benefit is achieved by targeting the analysis on cases where failures would have serious safety, environmental, economic or operational effects.

RCM is initiated after a high level criticality analysis identifies the system and equipment that requires maintenance tasks to be determined. This can occur either during the initial design phase, or later, during utilization, if it has not been done in a structured manner before or there is a need to review or improve maintenance.

#### B.8.5.3 Input

Successful application of RCM needs a good understanding of the equipment and structure, the operational environment and the associated systems, subsystems and items of equipment, together with the possible failures, and the consequences of those failures.

The process requires a team with requisite knowledge and experience, controlled by a trained and experienced facilitator.

#### B.8.5.4 Output

The end result of working through the process is a judgment as to the necessity of performing a maintenance task or other action such as operational changes.

The output is appropriate failure management policies for each failure mode, such as condition monitoring, failure finding, schedule restoration, replacement based on an interval (such as calendar, running hours, or number of cycles) or run-to-failure. Other possible actions that can result from the analysis include redesign, changes to operating or maintenance procedures or additional training. An example is given in Table B.7.

A plan is prepared to implement the recommended maintenance tasks. This details tasks, task intervals, procedures involved, required spare parts and other resources necessary to perform the maintenance tasks.

#### B.8.5.5 Strengths and limitations

Strengths include the following:

- the process enables magnitude of risk to be used to make maintenance decisions;
- tasks are based on whether they are applicable, i.e. whether they will achieve the expected outcome;
- tasks are evaluated to ensure they will be cost effective and worthwhile implementing;
- unnecessary maintenance actions are eliminated with proper justification;
- the process and decisions are documented for later review.

Limitations include:

- the process is generally time-consuming if it is to be effective;
- the process is very dependent on a trained and experienced facilitator;
- the team must have all of the necessary expertise and maintenance experience for the decisions to be valid;
- there may be a tendency to take shortcuts with the process with impact to the validity of decisions being made;
- potential tasks being considered will be limited by knowledge of available techniques such as those for condition monitoring.

#### B.8.5.6 Reference documents

IEC 60300-3-11 *Application guide - Reliability centred maintenance*

**Table B.7 – An example of RCM task selection**

| Functional failure – Fails to provide compressor protection and shutdown | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Equipment** | **Failure mode** | **Failure interval (hours)** | **Failure detection** | **Causes** | **Task type** | **Task description** | **Task interval in hours** |
| Pressure transmitter – compressor oil pressure | Inaccurate output | 80.000 | Evident | Out of calibration | Time directed | Verify calibration | 16.000 |
| Vibration transducer – compressor vibration | Fails to provide proper output | 40.000 | Evident | Detector/ sensor failure | Condition directed | Verify accuracy if change in vibration occurs | Continuous on control panel |
| Level switch – low compressor oil level | Fails to change state on demand | 80.000 | Hidden | Detector/ sensor failure | Failure finding | Functional test of level switch | 8.000 |
| Sensor and wiring – compressor oil temperature | Output high | 160.000 | Evident | Open circuit | Time directed | Check for loose connections | 8.000 |
| Level transmitter – glycol tank | Inaccurate output | 40.000 | Hidden | Out of calibration | Time directed | Calibrate transmitter preceded by confirmation of glycol fill level | 8.000 |
| Pressure transmitter – compressor suction/discharge pressure | Inaccurate output | 80.000 | Evident | Out of calibration | Time directed | Verify calibration | 16.000 |
| Sensor and wiring – compressor suction/discharge temperature | Output high | 160.000 | Evident | Open circuit | Time directed | Check for loose connections | 8.000 |
| Vibration transducer – cooler vibration | Fails to provide proper output | 40.000 | Evident | Detector/ sensor failure | Condition directed | Verify accuracy if change in vibration occurs | Continuous on control panel |

## B.8.6 Risk indices

### B.8.6.1 Overview

Risk indices provide a measure of risk which is derived using a scoring approach and ordinal scales. Factors which are believed to influence the magnitude of risk are identified, scored and combined using an equation that attempts to represent the relationship between them. In the simplest formulations factors that increase the level of risk are multiplied together and divided by those that decrease the level of risk. Where possible the scales and the way they are combined are based on evidence and data.

It is important that the scores for each part of the system are internally consistent and maintain their correct relationships.

Mathematical formulae cannot be applied to ordinal scales. Therefore, once the scoring system has been developed, the model should be validated by applying it to a system that is well understood.

Developing an index is an iterative approach and several different systems for combining the scores should be tried to validate the method.

### B.8.6.2 Use

Risk indices are essentially a qualitative or semi-quantitative approach to rank and compare risks. They can be used for internal or external risks of limited or extended scope. They are often specific to a particular type of risk and used to compare different situations where that risk occurs. While numbers are used, this is simply to allow for manipulation. In cases where the underlying model or system is not well known or not able to be represented, it is usually better to use a more overtly qualitative approach which does not imply a level of accuracy which is impossible using ordinal scales.

EXAMPLE 1 A disease risk index is used to estimate an individual's risk of contracting a particular disease by combining scores for various known risk factors identified in epidemiological studies, taking into account the strength of association between the risk factor and the disease.

EXAMPLE 2 Bush fire hazard ratings compare fire risk on different days taking account of predicted conditions such as humidity, wind strength, the dryness of the landscape and the fuel load.

EXAMPLE 3 Lenders calculate the credit risks for customers using indices that represent components of their financial stability.

#### B.8.6.3 Input

The inputs are derived from analysis of the system. This requires a good understanding of all the sources of risk, and how consequences can arise.

Tools such as artificial neural networks, FTA (B.5.6), ETA (B.5.5) and multi criteria decision analysis (B.7.5) can be used as well as historical data to support the development of risk indices.

Since the choice of the ordinal scale used is, to some extent, arbitrary, sufficient data is needed to validate the index.

#### B.8.6.4 Output

The output is a series of numbers (composite indices) that relate to a particular risk and which can be compared with indices developed for other risks within the same system.

#### B.8.6.5 Strengths and limitations

Strengths of risk indices include:

- they can provide a simple easy to use tool for ranking different risks;
- they allow multiple factors which affect the level of risk to be incorporated into a single numerical score.

Limitations include:

- if the process (model) and its output are not well validated, the results can be meaningless;
- the fact that the output is a numerical value for risk can be misinterpreted and misused, for example in subsequent cost/benefit analysis;
- in many situations where indices are used, there is no fundamental model to define whether the individual scales for risk factors are linear, logarithmic or of some other form, and no model to define how factors should be combined. In these situations, the rating is inherently unreliable and validation against real data is particularly important;
- it is often difficult to obtain sufficient evidence to validate scales;
- the use of numerical values can imply a level of accuracy that cannot be justified.

#### B.8.6.6 Reference documents

MACKENZIE Cameron A. Summarising risk using risk measures and risk indices. *Risk Analysis,* **34,**12 2143-2163 *2014*

## B.9 Techniques for reporting and recording risks

### B.9.1 General

This clause covers techniques used for reporting and recording general information about risks. Requirements for detailed reports are covered in 6.6.

A common approach to reporting and recording information about risks is to enter basic information for each risk in a risk register such as a spreadsheet or data base, (B.9.2). Some risks can require a more complex description than can be accommodated in a traditional register of risks. For example a description might need to include multiple sources of risk leading to a single event, multiple possible outcomes from a single event or source, knock on effects and potential control failures, The bow tie diagram is an example of a tool which can be used to organise and communicate this sort of information. (See B.4.2.)

Information about the magnitude of a risk can also be reported in a number of different ways. The most common method uses the consequence/likelihood matrix (B.9.3). As well as the likelihood, consequence and level of risk, indicated by the position in the matrix, additional information such as the nature of controls, the extent to which treatments have been implemented etc. can be provided through the size of the points marking the risk or their colour.

The consequence/likelihood matrix requires that a risk can be represented by a single consequence likelihood pair. Risks, where this is not the case, can sometimes be represented by a probability distribution function or a cumulative distribution function. (See B.9.4.)

### B.9.2 Risk registers

#### B.9.2.1 Overview

A risk register brings together information about risks to inform those exposed to risks and those who have responsibility for their management. It can be in paper or data base format and generally includes:

- a short description of the risk (e.g. a name, the consequences and sequence of events leading to consequences, etc.);
- a statement about the likelihood of consequences occurring;
- sources or causes of the risk;
- what is currently being done to control the risk.

Risks can be classified into different categories to aid reporting (B.2.2).

Risks are generally listed as separate events but interdependencies can be flagged.

In recording information about risks the distinction between risks (the potential effects of what might happen) and risk sources (how or why it might happen) and controls that might fail should be explicit. It can also be useful to indicate the signs that the event might be about to occur

Many risk registers also include some rating of the significance of a risk, an indication of whether a risk is considered to be acceptable or tolerable, or whether further treatment is needed and the reasons for this decision. Where a significance rating is applied to a risk based on consequences and their likelihood, this should take account of the likelihood that controls will fail. A level of risk should not be allocated for the failure of a control as if it were an independent risk.

Risks where consequences are positive can be recorded in the same document as those where consequences are negative or separately. Opportunities (which are circumstances or ideas that could be exploited rather than chance events) are generally recorded separately and analysed in a way that takes account of costs, benefits and any potential negative consequences. This can sometimes be referred to as a value and opportunities register.

#### B.9.2.2 Use

A risk register is used to record and track information about individual risks and how they are being controlled. It can be used to communicate information about risks to stakeholders and highlight particularly important risks. It can be used at corporate, departmental or project level, but is generally of most use at an operational level where there are a large number of risks, controls and treatments that need to be tracked. Information from a risk register can be consolidated to provide information for top management.

A risk register can be used as the basis for tracking implementation of proposed treatments, so can contain information about treatments and how they will be implemented, or make reference to other documents or data bases with this information. (Such information can include risk owners, actions, action owners, action business case summaries, budgets and timelines, etc.). A form of risk register can be mandated in some situations.

#### B.9.2.3 Inputs

Inputs to a risk register are generally the outputs from risk assessment techniques such as described in B.1 to B.4, supplemented by records of failures.

#### B.9.2.4 Output

The output is a record of information about risks.

#### B.9.2.5 Strengths and limitations.

Strengths of risk registers include:

- information about risks is brought together in a form where actions required can be identified and tracked;
- information about different risks is presented in a comparable format, which can be used to indicate priorities and is relatively easy to interrogate;
- the construction of a risk register usually involves many people and raises general awareness of the need to manage risk.

Limitations include:

- risks captured in risk registers are typically based on events, which can make it difficult to accurately characterize some forms of risk (see 4.2);
- the apparent ease of use can give misplaced confidence in the information because it can be difficult to describe risks consistently and sources of risk, risks, and weaknesses in controls for risk are often confused;
- there are many different ways to describe a risk and any priority allocated will depend on the way the risk is described and the level of disaggregation of the issue;
- considerable effort is required to keep a risk register up to date (for example, all proposed treatments should be listed as current controls once they are implemented, new risks should be continually added and those that no longer exist removed);
- risks are typically captured in risk registers individually. This can make it difficult to consolidate information to develop an overall treatment program.

#### B.9.2.6 Reference documents

There are no reference documents for this technique.

### B.9.3 Consequence/likelihood matrix (risk matrix or heat map)

#### B.9.3.1 Overview

The consequence/likelihood matrix (also referred to as a risk matrix or heat map) is a way to display risks according to their consequence and likelihood and to combine these characteristics to display a rating for the significance of risk.

Customised scales for consequence and likelihood are defined for the axes of the matrix. The scales can have any number of points, 3, 4 or 5 point scales are most common, and can be qualitative, semi-quantitative or quantitative. If numerical descriptions are used to define the steps of the scales, they should be consistent with available data and units should be given. Generally, to be consistent with data, each scale point on the two scales will need to be an order of magnitude greater than the one before.

The consequence scale (or scales) can depict positive or negative consequences. Scales should be directly connected to the objectives of the organization, and should extend from the maximum credible consequence to the lowest consequence of interest. A part example for adverse consequences is shown in Figure B.15.

| Rating | Financial | Health and safety | Environment and community | Etc. |
|---|---|---|---|---|
| 5 | Max credible Loss ($ ) | Multiple fatalities | Irreversible significant harm; community outrage | |
| 4 | | | | |
| 3 | | | | |
| 2 | | | | |
| 1 | Minimum of interest ($) | First aid only required | Minor temporary damage | |

**Figure B.15 – Part example of table defining consequence scales**

NOTE 1 Part examples are used so that the examples cannot be used directly to stress that the scales should always be customized.

NOTE 2 Additional or fewer consequence categories may be used and the scales may have fewer or more than 5 points, depending on the context. The consequence rating column can be words, numbers or letters.

The likelihood scale should span the range relevant to data for the risks to be rated. A part example of a likelihood scale is shown in Figure B.16.

| rating | descriptor | Descriptor meaning |
|---|---|---|
| a | Likely | Expected to occur within weeks |
| b | | |
| c | | |
| d | | |
| e | Remotely possible | Theoretically possible but extremely unlikely |

**Figure B.16 – Part example of a likelihood scale**

NOTE The likelihood rating scale can have more or less than 5 points and the ratings may be given as words numerals or letters.

The likelihood scale should be tailored to the situation and may need to cover a different range for positive or negative consequences. The lowest step on the likelihood scale to be used with negative consequences should represent an acceptable likelihood for the highest defined consequence, (otherwise all activities with the highest consequence are defined as intolerable and cannot be made tolerable). In deciding the tolerable likelihood for a single high consequence risk the fact that multiple risks can lead to the same consequence should be taken into account.

A matrix is drawn with consequence on one axis and likelihood on the other corresponding to the defined scales. A rating for priority can be linked to each cell. In the example provided there are 5 priority ratings, indicated here by Roman numerals. Decision rules (such as the level of management attention or the urgency of response) can be linked to the matrix cells. These will depend on the definitions used for the scales and the organizations attitude to risk. The design should enable the priority of a risk to be based on the extent to which the risk leads to outcomes that are outside the organization's defined performance thresholds for its objectives.

The matrix can be set up to give extra weight to consequences (as shown in Figure B.17) or to likelihood, or it can be symmetrical, depending on the application.

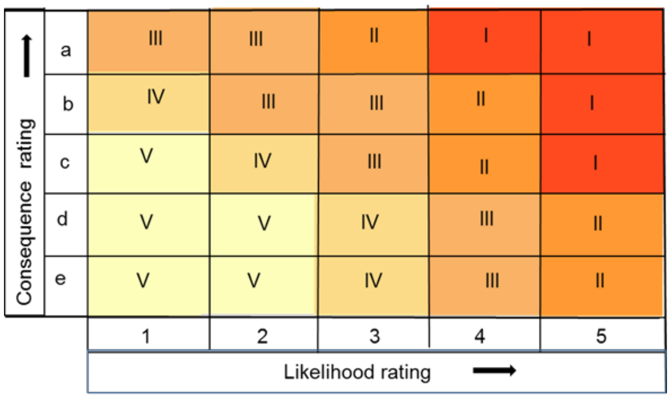



**Figure B.17 – Example of consequence likelihood matrix**

### B.9.3.2 Use

A consequence/likelihood matrix is used to evaluate and communicate the relative magnitude of risks on the basis of a consequence likelihood pair that is typically associated with a focal event.

To rate a risk, the user first finds the consequence descriptor that best fits the situation then defines the likelihood with which it is believed that consequence will occur. A point is placed in the box which combines these values, and the level of risk and associated decision rule is read off from the matrix.

Risks with potentially high consequences are often of greatest concern to decision makers even when the likelihood is very low, but a frequent but low impact risk can have large cumulative or long-term consequences. It can be necessary to analyse both kinds of risks as the relevant risk treatments can be quite different.

NOTE Where a range of different consequence values are possible from one event, the likelihood of a particular consequence will differ from the likelihood of the event that produces that consequence.

The matrix can be used to compare risks with different types of potential consequence and has application at any level in an organization. It is commonly used as a screening tool when many risks have been identified, for example to define which risks need to be referred to a higher level of management. It can also be used to help determine if a given risk is broadly acceptable, or not acceptable according to the zone where it is located on the matrix. It can be used in situations where there is insufficient data for detailed analysis or the situation does not warrant the time and effort for a more detailed or quantitative analysis. A form of consequence/likelihood matrix can be used for criticality analysis in FMECA (B.2.3) or to set priorities following HAZOP (B.2.4) or SWIFT (B.2.6).

### B.9.3.3 Input

A consequence likelihood matrix needs to be developed to suit the context. This requires some data to be available in order to establish realistic scales. Draft matrices need to be tested to ensure that the actions suggested by the matrix match the organization's attitude to risk and that users correctly understand the application of the scales.

Use of the matrix needs people (ideally a team) with an understanding of the risks being rated and such data as is available to help in judgements of consequences and their likelihood.

### B.9.3.4 Output

The output is a display which illustrates the relative consequence likelihood and level of risk for different risks and a significance rating for each risk.

### B.9.3.5 Strengths and limitations

Strengths include:

- it is relatively easy to use;
- it provides a rapid ranking of risks into different significance levels;

- it provides a clear visual display of the relevant significance of risk by consequence, likelihood or level of risk;
- it can be used to compare risks with different types of consequence.

Limitations include:

- it requires good expertise to design a valid matrix;
- it can be difficult to define common scales that apply across a range of circumstances relevant to an organization;
- it is difficult to define the scales unambiguously to enable users to weight consequence and likelihood consistently;
- the validity of risk ratings depends on how well the scales were developed and calibrated;
- it requires a single indicative value for consequence to be defined, whereas in many situations a range of consequence values are possible and the ranking for the risk depends on which is chosen;
- a properly calibrated matrix will involve very low likelihood levels for many individual risks which are difficult to conceptualise;
- its use is very subjective and different people often allocate very different ratings to the same risk;
- risks cannot be aggregated (e.g. one cannot define whether a particular number of low risks, or a low risk identified a particular number of times, is equivalent to a medium risk);
- it is difficult to combine or compare the level of risk for different categories of consequences;
- a valid ranking requires a consistent formulation of risks (which is difficult to achieve);
- each rating will depend on the way a risk is described and the level of detail given; (I.e. the more detailed the identification, the higher the number of scenarios recorded, each with a lower likelihood). The way in which scenarios are grouped together in describing risk should be consistent and defined prior to ranking.

#### B.9.3.6 Reference documents

ELMONSTRI, Mustafa *Review of the strengths and weaknesses of risk matrices*, Journal of Risk Analysis and Crisis Response, 2014 **4**, (1) 49-57; [viewed 2017-9-14] Available at http://www.atlantis-press.com/php/download_paper.php?id=11718

BAYBUTT, Paul. Calibration of risk matrices for process safety. *Journal of Loss Prevention in the Process Industries*, 2015 **38** 163-168.

### B.9.4 S curves

#### B.9.4.1 Overview

Where a risk might have a range of consequence values they can be displayed as a probability distribution of consequences (pdf). See for example the red curve in Figure B.18. The data can also be plotted as a cumulative distribution (cdf), sometimes referred to as an S curve.

The probability that a consequence will exceed a particular value can be directly read off the S curve. For example, Figure B.18 indicates that there is a 90 % probability the consequences will not exceed consequence value C

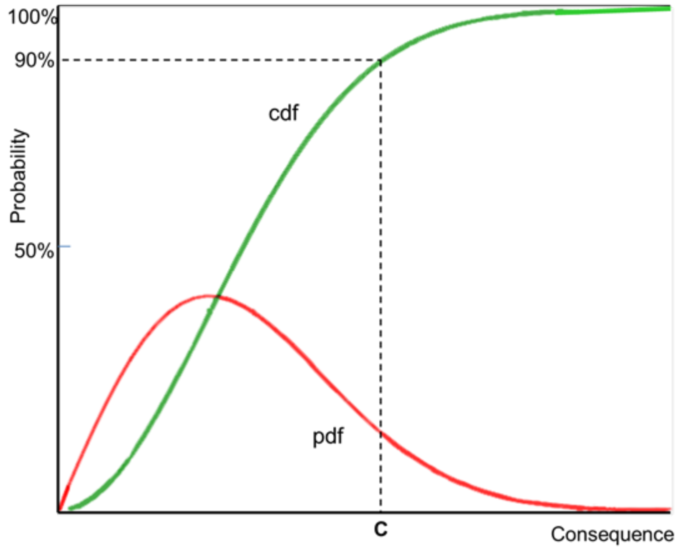



**Figure B.18 – Probability distribution function and cumulative distribution function**

In some cases the shape of the distribution is known on theoretical grounds (for example the probability that a person will have a particular height follows a normal distribution). In others the shape of the distribution can be obtained from data or is the output of a Monte Carlo analysis (B.5.10).

It is also possible to use expert judgment to estimate the low point of the consequence range, the likely mid-point, and the upper point of the range. Various formulae can then be used to determine the mean value for the consequence and the variance and a curve plotted from this information.

### B.9.4.2 Use

A pdf indicates the probability of different consequence values in a visual form that shows the most likely value, the extent of variability, and the extent to which there is a likelihood of an extreme event.

In some circumstances it can be useful to obtain a single representative value from the probability distribution, for example to compare with evaluation criteria. Often the expected value (equivalent to the mean) is used to represent the best estimate of the magnitude of consequences. (This is equivalent to the sum of the probabilities of each consequence represented by the curve.) Other measures include the variance of the distribution or some percentile range such as the interquartile spread (the scale width enclosed by the 25th and the 75th percentile) or 5th and 95th percentile. (See for example VaR B.5.12). However such measures might still not give sufficient emphasis to the possibility of extreme consequences, which can be important to the decisions to be made.

EXAMPLE 1 In selecting an investment both the expected return and the fluctuations in returns can be taken into account.

EXAMPLE 2 In planning how to respond to fire, extreme events need to be considered as well as expected consequences.

The S curve is a useful tool when discussing consequence values that represent an acceptable risk. It is a means of presenting data that makes it easier to see the probability that consequences will exceed a particular value.

### B.9.4.3 Inputs

Producing an S curve requires data or judgements from which a valid distribution can be produced. Although distributions can be produced by judgement with little data, the validity of the distribution and the statistics obtained from it will be greater the more data is available.

#### B.9.4.4 Outputs

The outputs are a diagram which can be used by decision makers when considering acceptability of a risk, and various statistics from the distribution that can be compared with criteria.

#### B.9.4.5 Strengths and limitations

Strengths include:

- the technique represents the magnitude of a risk where there is a distribution of consequences;
- experts can usually make judgments of maximum, minimum and most likely values of consequence and produce a reasonable estimate of the likely shape of a distribution. Transferring this to the form of a cumulative distribution makes it easier for a lay person to use this information.

Limitations include:

- the method can give an impression of accuracy which is not justified by the level of certainty of the data from which the distribution was produced;
- for any method of obtaining a point value or values to represent a distribution of consequences, there are underlying assumptions and uncertainties about:
  - the form of the distribution (e.g. normal, discrete, or highly skewed),
  - the most appropriate way of representing that distribution as a point value, and
  - the value of the point estimate because of inherent uncertainties in the data from which it is derived;
- distributions and their statistics based on experience or past data still provide little information on the likelihood of future events with extreme consequences but low likelihood.

#### B.9.4.6 Reference document

GARVEY, P., BOOK S.A., COVERT R.P. *Probability Methods for Cost Uncertainty Analysis: A Systems Engineering Perspective*, Ed 2 Annex E Unravelling the S curve. CRC 2016.

# Annex C
(informative)

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