

# What is a risk analysis?

A main objective of a risk analysis is to describe risk, that is, to present an informative risk picture. Figure 1.1 illustrates important building blocks of such a risk picture. Located at the centre of the figure is the initiating event (the hazard, the threat, the opportunity), which we denote by *A*. In the example, the event is that a person (John) contracts a specific disease. An important task in the risk analysis is to identify such initiating events. In our example, we may be concerned about various diseases that could affect the person. The left side of the figure illustrates the causal picture that may lead to the event *A*. The right side describes the possible consequences of *A*.

On the left side are barriers that are introduced to prevent the event *A* from occurring; these are the probability reducing or preventive barriers. Examples of such barriers are medical check-ups/examinations, vaccinations and limiting the exposure to contamination sources. On the right side are barriers to prevent the disease (event *A*) from bringing about serious consequences, the consequence-reducing barriers. Examples of such barriers are medication and surgery. The occurrence of *A* and performance of the various barriers are influenced by a number of factors – the so-called risk-influencing or performance-influencing factors. Examples are the quality of the medical check-ups; the effectiveness of the vaccine, drug or surgery; what is known about the disease and what causes it; lifestyle, nutrition and inheritance and genes.

Figure 1.1 is often referred to as a *bow-tie* diagram. We will refer to it many times later in the book when the risk picture is being discussed.

We refer to the event *A* as an initiating event. When the consequences are obviously negative, the term ‘undesirable event’ is used. We also use terms such as hazards and threats. We say there is a fire hazard or that we are faced with a terrorist threat. We can also use the term initiating event in connection with an opportunity. An example is the opportunity that arises if a competitor goes bankrupt or his reputation is damaged.

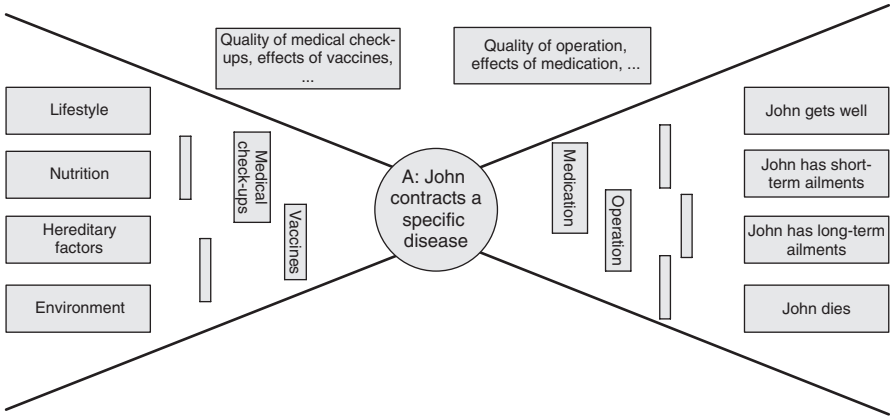


Figure 1.1 Example of a bow-tie.

Table 1.1 Main categories of risk analysis methods.

Main category	Type of analysis	Description
Simplified risk analysis	Qualitative	Simplified risk analysis is an informal procedure that establishes the risk picture using brainstorming sessions and group discussions. The risk might be presented on a coarse scale, for example, low, moderate or high, making no use of formalised risk analysis methods.
Standard risk analysis	Qualitative or quantitative	Standard risk analysis is a more formalised procedure in which recognised risk analysis methods are used, such as Hazard and Operability study (HAZOP) and coarse risk analysis, to name a few. Risk matrices are often used to present the results.
Model-based risk analysis	Primarily quantitative	Model-based risk analysis makes use of techniques such as event tree analysis and fault tree analysis to calculate risk.

The risk analysis shall identify the relevant initiating events and develop the causal and consequence picture. How this is done depends on which method is used and how the results are to be used. However, the intent is always the same: to describe risk.

In this book, we differentiate between three main categories of risk analysis methods: simplified risk analysis, standard risk analysis and model-based risk analysis. These three categories of methods are described in more detail in Table 1.1.

The different methods mentioned in the table will be discussed in Chapter 6.

## Reflection

An overview of historical data (e.g. accident events) is established. Does this constitute a risk analysis?

No, not in isolation. Such data describe what happened, and the numbers say something about the past. Only when we address the future (e.g. the number of fatalities in the coming year) does the risk concept apply. To analyse what will happen, we can decide to make use of the historical numbers, and the statistics will then provide an expression for risk. In this way, we are conducting a risk analysis.

## 1.1 Why risk analysis?

By carrying out a risk analysis one can

- establish a risk picture;
- compare different alternatives and solutions in terms of risk;
- identify factors, conditions, activities, systems, components and so on that are important (critical) with respect to risk; and
- demonstrate the effect of various measures on risk.

This provides a basis for the following:

- Choosing between various alternative solutions and activities while in the planning phase of a system.
- Choosing between alternative designs of a solution or a measure. What measures can be implemented to make the system less vulnerable in the sense that it can better tolerate loads and stresses?
- Drawing conclusions on whether various solutions and measures meet the stated requirements.
- Setting requirements for various solutions and measures, for example, related to the performance of the preparedness systems.
- Documenting an acceptable safety and risk level.

Risk analyses can be carried out at various phases in the life time of a system, that is, from the early concept phase, through the more detailed planning phases and the construction phase, up to the operation and decommissioning phases.

Risk analyses are often performed to satisfy regulatory requirements. It is, of course, important to satisfy these requirements, but the driving force for carrying out a risk analysis should not be this alone, if one wishes to fully utilise the potential of the analysis. The main reason for conducting a risk analysis

is to support decision-making. The analysis can provide an important basis for finding the right balance between different concerns, such as safety and costs.

We need to distinguish between the planning phase and the operational phase. When we design a system, we often have considerable flexibility and can choose among many different solutions, while often having limited access to detailed information on these solutions. The risk analysis in such cases provides a basis for comparing the various alternatives. The fact that we have many possible decision alternatives and limited detailed information implies, as a rule, that one will have to use a relatively coarse analysis method. As one gradually gains more knowledge regarding the final solution, more detailed analysis methods will become possible. All along, one must balance the demand for precision with the demand for decision support. There is no point in carrying out detailed analyses if the results arrive too late to affect the decisions.

In the operating phase, we often have access to experience data, for example, historical data, on the number of equipment and systems failures. In such cases, one can choose a more detailed analysis method and study these systems specifically. However, here the decision alternatives are often limited. It is easier by far to make changes ‘on paper’ in planning phases than to make changes to existing systems in the operating phase. Risk analyses have, therefore, had their greatest application in the planning phases. In this book, however, we do not limit ourselves to these phases. Risk analyses are useful in all phases, but the methods applied must be suited to the need.

## 1.2 Risk management

*Risk management* is defined as all measures and activities carried out to manage risk. Risk management deals with balancing the conflicts inherent in exploring opportunities on the one hand and avoiding losses, accidents and disasters on the other (Aven and Vinnem 2007).

Risk management relates to all activities, conditions and events that can affect the organisation and its ability to reach the organisation’s goals and vision. To be more specific, we will consider an enterprise, for example, a company. Identification of which activities, conditions and events are important will depend on the enterprise and its goals and vision.

In many enterprises, the risk management is divided into three main categories: strategic risk, financial risk and operational risk.

Strategic risk is risk where the consequences for the enterprise are influenced by mergers and acquisitions, technology, competition, political conditions, laws and regulations, labour market and so on.

Financial risk is risk where the consequences for the enterprise are influenced by the market (associated with changes in the value of an investment due to

movements in market factors: the stock prices, interest rates, foreign exchange rates and commodity prices), credit issues (associated with a debtor's failure to meet its obligations in accordance with agreed terms) and liquidity issues, reflecting lack of access to cash; the difficulty of selling an asset in a timely manner, that is, quickly enough to prevent a loss (or make the required profit).

Operational risk is risk where the consequences for the enterprise are a result of safety- or security-related issues (accidental events, intentional acts, etc.).

For an enterprise to become successful in its implementation of risk management, the top management needs to be involved, and activities must be put into effect on many levels. Some important points to ensure success are:

- Establishment of a strategy for risk management, that is, the principles of how the enterprise defines and runs the risk management. Should one simply follow the regulatory requirements (minimal requirements) or should one be the 'best in the class'? We refer to Section 1.3.
- Establishment of a risk management process for the enterprise, that is, formal processes and routines that the enterprise has to follow.
- Establishment of management structures, with roles and responsibilities, such that the risk analysis process becomes integrated into the organisation.
- Implementation of analyses and support systems, for example, risk analysis tools and recording systems for occurrences of various types of events.
- Communication, training and development of a risk management culture, so that the competence, understanding and motivation level within the organisation is enhanced.

The risk analysis process is a central part of the risk management, and has a basic structure that is independent of its area of application. There are several ways of presenting the risk analysis process, but most structures contain the following three key elements:

- Planning
- Risk assessment (execution)
- Risk treatment (use).

In this book, we use the term 'risk analysis process', when we talk about the three main phases: planning, risk assessment and risk treatment, while we use 'risk management process' when we include other management elements also, which are not directly linked to the risk analysis.

We make a clear distinction between the terms risk analysis, risk evaluation and risk assessment:

$$\text{Risk analysis} + \text{Risk evaluation} = \text{Risk assessment}$$

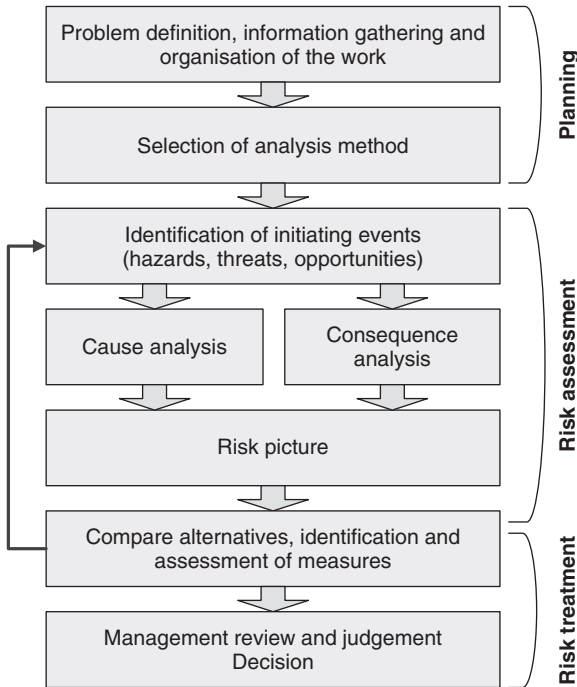


Figure 1.2 The main steps of the risk analysis process.

The results from the risk analysis are evaluated. How does alternative I compare with alternative II? Is the risk too high? Is there a need to implement risk-reducing measures? We use the term risk assessment to mean both the analysis and the evaluation.

Risk assessment is followed by risk treatment. This represents the process and implementation of measures to modify risk, including tools to avoid, reduce, optimise, transfer and retain risk. Transfer of risk means to share with another party the benefits or potential losses connected with a risk. Insurance is a common type of risk transfer.

Figure 1.2 shows the main steps of the risk analysis process. We will frequently refer to this figure in the forthcoming chapters. It forms the basis for the structure of and discussions in Chapters 3, 4 and 5.

### 1.2.1 Decision-making under uncertainty

Risk management often involves decision-making in situations characterised by high risk and large uncertainties, and such decision-making presents a challenge in that it is difficult to predict the consequences (outcomes) of the decisions. Generally, the decision process includes the following elements:

1. The decision situation and the stakeholders (interested parties):
  - What is the decision to be made?
  - What are the alternatives?
  - What are the boundary conditions?
  - Who is affected by the decision?
  - Who will make the decision?
  - What strategies are to be used to reach a decision?
2. Goal-setting, preferences and performance measures:
  - What do the various interested parties want?
  - How to weigh the pros and cons?
  - How to express the performance of the various alternatives?
3. The use of various means, including various forms of analyses to support the decision-making:
  - Risk analyses
  - Cost-benefit analyses (see Chapter 3)
  - Cost-effectiveness analyses (see Chapter 3).
4. Review and judgement by the decision-maker. Decision.

A model for decision-making, based on the above elements, is presented in Figure 1.3. The starting point is a decision problem, and often this is stated as a problem of choosing between a set of alternatives, all meeting some stated goals and requirements. In the early phase of the process, many alternatives that are more or less precisely defined are considered. Various forms of analyses provide

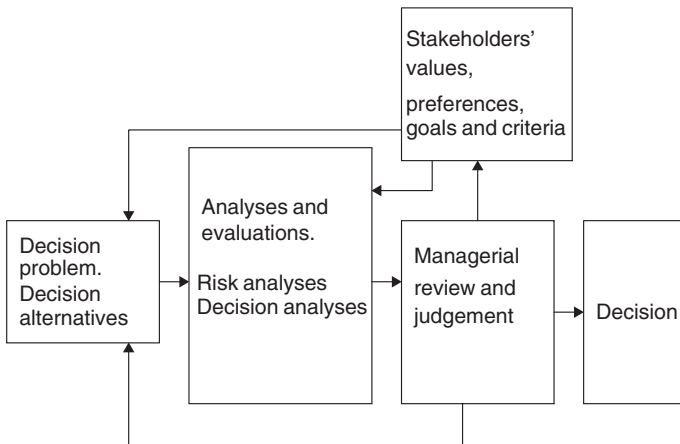


Figure 1.3 A model for decision-making under uncertainty (Aven 2012d).

a basis for sorting these and choosing which ones are to be processed further. Finally, the decision-maker must perform a review and judgement of the various alternatives, taking into account the constraints and limitations of the analyses. Then, the decision-maker makes a decision.

This is a simple model of the decision-making process. The model outlines how the process should be implemented. If the model is followed, the process can be documented and traced. The model is, however, not very detailed and specific.

The decision support produced by the analyses must be reviewed by the decision-maker prior to making the decision: What is the background information of the analyses? What are the assumptions and suppositions made? The results from the analyses must be evaluated in the light of factors, such as the following:

- Which decision-making alternatives have been analysed?
- Which performance measures have been assessed?
- The fact that the analyses represent judgements (expert judgements).
- Difficulties in determining the advantages and disadvantages of the different alternatives.
- The fact that the results of the analyses are based on models that are simplifications of the real world and real-world phenomena.

The decision-making basis will seldom be in a format that provides all the answers that are important to the decision-maker. There will always be limitations in the basis information, and the review and judgement described here means that one views the basis in a larger context. Perhaps the analysis did not take into consideration what the various measures mean for the reputation of the enterprise, but this is obviously a factor that is of critical importance for the enterprise. The review and judgement must also cover this aspect.

The weight the decision-maker gives to the basis information provided depends on the confidence he/she has in those who developed this information. However, it is important to stress that even if the decision-maker has maximum confidence in those doing this work, the decision still does not come about on its own.

The decisions often encompass difficult considerations and weighing with respect to uncertainty and values, and this cannot be delegated to those who create the basis information. It is the responsibility of the decision-maker (manager) to undertake such considerations and weighing and to make a decision that balances the various concerns.

## Reflection

In high-risk situations, should the decisions be ‘mechanised’ by introducing pre-defined criteria, and then letting the decisions be determined by the results of the analyses?

No, we need a management review and judgement that places the analyses into a wider context.



Various decision-making strategies can form the basis for the decision. By ‘decision-making strategy’, we mean the underlying thinking and the principles that are to be followed when making the decision and how the process prior to the decision should be. Of importance to this are the questions of who will be involved and what types of analysis to use.

A decision-making strategy takes into consideration the effect on risk (as it appears in the risk analysis) and the uncertainty dimensions that cannot be captured by the analysis. The result is thus decisions founded both in calculated risk and applications of the *cautionary principle* and *precautionary principle*. The cautionary principle means that caution, for example, by not starting an activity or by implementing measures to reduce risks and uncertainties, shall be the overriding principle when there is uncertainty linked to the consequences, that is, when risk is present (HSE 2001, Aven and Vinnem 2007). The level of caution adopted will, of course, have to be balanced against other concerns, such as costs. However, all industries would introduce some minimum requirements to protect people and the environment, and these requirements can be considered justified by reference to the cautionary principle.

For example, in the Norwegian petroleum industry, it is a regulatory requirement that the living quarters on an installation plant should be protected by fireproof panels of a certain quality, for walls facing process and drilling areas. This is a standard adopted to obtain a minimum safety level. It is based on the established practice of many years of operation in process plants. A fire may occur, which represents a hazard for the personnel, and in the case of such an event, the personnel in the living quarters should be protected. The assigned probability for the living quarters on a specific installation plant being exposed to fire may be judged as low, but we know that fires occur from time to time on such installations. It does not matter whether we calculate a fire probability of  $x$  or  $y$ , as long as we consider the risks to be significant; and this type of risk has been judged to be significant by the authorities. The justification is experience from similar plants and sound judgements. A fire may occur, since it is not an unlikely event, and we should then be prepared. We need no references to cost–benefit analysis. The requirement is based on cautionary thinking.

Risk analyses, cost–benefit analyses and similar types of analyses are tools providing insights into risks and the trade-offs involved. But they are just tools – with strong limitations. Their results are conditioned on a number of assumptions and suppositions. The analyses do not express objective results. Being cautious also means reflecting this fact. We should not put more emphasis on the predictions and assessments of the analyses than what can be justified by the methods being used.

In the face of uncertainties related to the possible occurrences of hazardous situations and accidents, we are cautious and adopt principles of safety management, such as

- robust design solutions, such that deviations from normal conditions are not leading to hazardous situations and accidents;
- design for flexibility, meaning that it is possible to utilise a new situation and adapt to changes in the frame conditions;

- implementation of safety barriers to reduce the negative consequences of hazardous situations if they should occur, for example, a fire;
- improvement of the performance of barriers by using redundancy, maintenance/testing and so on;
- quality control/quality assurance;
- the precautionary principle, which basically says that in the case of lack of scientific certainty on the possible consequences of an activity, we should implement precautionary measures or not carry out the activity
- the ALARP principle, which says that the risk should be reduced to a level that is As Low As Reasonably Practicable.

Thus, the precautionary principle may be considered a special case of the cautionary principle, as it is applicable in cases of scientific uncertainties (Sandin 1999, Löfstedt 2003, Aven 2011f). There are, however, many definitions of the precautionary principle. The well-known 1992 Rio Declaration uses the following definition:

In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Seeing beyond environmental protection, a definition such as the following reflects what is a typical way of understanding this principle:

The precautionary principle expresses that if the consequences of an activity could be serious and subject to scientific uncertainties, then precautionary measures should be taken or the activity should not be carried out.

We refer to Aven (2011f) for further discussion of these principles.

It is prudent to distinguish between management strategies for handling the risk agent (such as a chemical or a technology) from those needed for the risk absorbing system (such as a building, an organism or an ecosystem) (Renn 2005); see also Aven and Renn (2009b). With respect to risk-absorbing systems, robustness and resilience are two main categories of strategies/principles. *Robustness* refers to the insensitivity of performance to deviations from normal conditions. Measures to improve robustness include inserting conservatism or safety factors as an assurance against individual variation, introducing redundant and diverse safety devices to improve structures against multiple stress situations, reducing the susceptibility of the target organism (e.g. iodine tablets for radiation protection), establishing building codes and zoning laws to protect against natural hazards and improving the organisational capability to initiate, enforce, monitor and revise management actions (high reliability, learning organisations).

A resilient system can withstand or even tolerate surprises. In contrast to robustness, where potential threats are known in advance and the absorbing system needs to be prepared to face these threats, resilience is a protective strategy against unknown or highly uncertain events. Instruments for resilience include strengthening of the immune system, diversification of the means for approaching identical or similar ends, reduction of the overall catastrophic potential or vulnerability even in the absence of a concrete threat, design of systems with flexible response options and improvement of conditions for emergency management and system adaptation. Robustness and resilience are closely linked, but they are not identical and require partially different types of actions and instruments.

The decision-making strategy is dependent on the decision-making situation. The differences are large, from routine operations where codes and standards are used to a large extent, to situations with high risks, where there is a need for comprehensive information about risk.

## **1.3 Examples: decision situations**

In this book, we will present a number of examples of the use of risk analysis. A brief introduction to some of these examples is provided below.

### **1.3.1 Risk analysis for a tunnel**

A road tunnel is under construction. This is a 2-km-long, dual carriageway tunnel, with relatively high traffic volumes. Fire-related ventilation in the tunnel has been dimensioned based on regulatory requirements stating that the project must be able to handle a 20 MW fire, that is, a fire in several vehicles, trucks, and the like. Partway in the construction process, however, new regulatory requirements came into effect stating that the design should withstand a fire of 100 MW, which means a fire involving a heavy goods vehicle or a fire in a hazardous goods transport. To upgrade the fire-related ventilation now, when the tunnel is more or less completed, will lead to significant costs and will delay the opening of the tunnel by 6–12 months.

A risk analysis is carried out to assess the effect of upgrading the ventilation system in accordance with the new regulatory requirements and to assess the effect of alternative safety measures. In the regulations, there is an acceptance for introducing alternative measures if it can be documented that they would lead to an equivalent or higher level of safety. The aim of the risk analysis is to provide a basis for determining which measure or measures should be implemented. The reader is referred to Chapter 7.

### **1.3.2 Risk analysis for an offshore installation**

A significant modification of an offshore installation is to be carried out. This would require more production equipment and result in increased accident risk. An increase in production equipment provides more sources of hydrocarbon leakages that can cause fire and explosion if ignited. The problem is to what extent one should install

extra fire protection to reduce the consequences in the event of a fire. A risk analysis is to be carried out to provide a basis for making the decision.

How is this analysis to be carried out? How should the risk be expressed? To what degree should we quantify the risk? We have many years of experience records from the operation of this installation. How can we utilise this information? To what degree is the use of cost–benefit analysis relevant in this context?

The reader is referred to Chapter 8 where these problems are discussed.

### 1.3.3 Risk analysis related to a cash depot

In May 2005, the NOKAS cash depot moved into its new premises at Gausel close to Stavanger in Norway. NOKAS is owned by Norges Bank (the Central Bank of Norway), DNB (the Norwegian Bank) and others. The area where the building is located is called *Frøystad* and is zoned for industry. The closest neighbour, however, is a cooperative kindergarten, and the NOKAS facility is located not far from a residential area. In light of the risk exposure to the children in the kindergarten and other neighbours – caused by possible robberies – the residents feel that the NOKAS facility must be moved, as the risk is unacceptable. The municipality of Stavanger carried out a process to help them take a position to this question and hired consultants to describe and assess the risk. There was a significant amount of discussion on how the risk management process should be carried out. Here, we deal especially with the risk analysis and how it was used. The central problems to be addressed were:

- How should the risk be expressed?
- Should criteria for acceptable risk level be defined, so that we can compare the results from the risk analysis with these?
- How should one take into consideration the significant uncertainty associated with the future regarding the scope of robberies and which methods the perpetrators will use?
- How are the results of the risk analysis to be communicated?
- How can the results from the analysis be utilised in the municipal administrative process?

The process carried out showed that without a clear understanding of the fundamental risk analysis principles, it is not possible to carry out any meaningful analysis and management of the risk. The reader is referred to the discussion of this example in Chapter 10.