Chapter 2
Introduction to Risk Analysis and Risk Management Processes

2.1 Overview

This chapter defines basic terms of risk and equivalently chance analysis: risk (chance) event, frequency of event, exposure, hazard propagation, consequence and damage analysis. It introduces the classical notion of risk being proportional to a measure for probability of events and measure for consequences of an event. It is distinguished between risk computation, visualization, comparison and evaluation. In particular, different sample risk criteria are discussed.

This chapter motivates and introduces phases (steps) for risk and chance management and analysis by discussing state-of-practice schemes, before defining a fine resolved risk management process in 14 steps, which includes risk analysis. Attributes of risk management processes and phases are introduced as well typical dependencies of phases. It also discusses different simplifying versions or tailoring of the processes. For instance, if the initial scenario and all threats are known, it sometimes suffices to consider only few threat events within well-defined settings.

In terms of resilience (catastrophe) management (response) cycle, the risk management steps related to frequency of event, exposure and prevention probability relate most to the prevention phase of the resilience management scheme. The hazard source characterization, the hazard propagation and the damage determination relate mainly to the resilience management protection phase. However, depending on which objectives are chosen within the risk management scheme, also the resilience management phases response, recovery and preparation can be assessed using classical risk/chance management and analysis.

All methods and examples in Chaps. 3–18 can be related to this chapter, since they contribute to fulfill one or more phases of risk management and analysis. This chapter adopts a management perspective when compared to the remaining chapters, since it focuses on top level requirements for the process and the steps rather than showing how to conduct the analyses. This top perspective is very useful to

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structure risk management tasks, since it is likely that all the phases have to be covered.

This chapter is also useful for identifying where interdisciplinary boundaries and responsibilities within risk management projects arise, as well as for structuring engineering, scientific, computer science or implementation boundaries and interfaces.

In the following, besides the further introductory Chap. 3, most of the chapters focus on single methods and their application or at least sets of methods that can be used within one or several risk management phases. The categorization along different methods can also be used for structuring risk analysis and management processes as well as projects. However, likely drawbacks include that limitations of the method and discipline will also limit the coverage of all risk management phases as well as that interfaces between steps are not well defined, since within a single method there is much less need to distinguish between steps, which limits the reusability of risk management steps/phases.

The main advantage of using a step-wise risk analysis and management approach is that in this case often most of the steps can be reused in an informed way, for instance, exposure distributions of persons are almost completely independent for different types of whole sets of hazardous events.

For instance, the statistical quality of empirical-historical data is rather strong when predicting average annual rates of events when compared to predicting an average consequence measure. Consequences for defined scenarios can alternatively be computed using engineering and simulation methods. However, even event probability estimates can be strongly improved when using in addition scenario input, which cannot be drawn from historical-statistical data.

The chapter introduces risk/chance analysis and management. It gives a first impression of the general ideas before going into details throughout the following chapters. It also shows how to divide the analysis into steps.

Section 2.2 describes the scope of this book in terms of the sample hazard events we mainly regard in this book, namely high explosive and impact events. It introduces the fundamental definitions risk, risk analysis and risk management. It also explains the term risk in more detail and ends with a scheme that provides an overview of the definitions in this chapter.

Section 2.3 gives examples of risk analysis and risk management schemes from the literature, one of them being the standard 5-step risk management scheme. Section 2.4 continues with a list of properties of risk management processes based on the preceding schemes and the literature.

Section 2.4 lists the steps of a risk analysis process in more detail and embeds the risk analysis process in the risk management process. The overview scheme of Sect. 2.2 is extended to a larger scheme including the steps that are explained in Sect. 2.4. Section 2.5 presents typical dependencies of the steps of the risk management process.

Fraunhofer EMI sources used for this chapter are (Klomfass and Thoma 1997b; Klomfass and Thoma 1997a; Häring, Schönherr et al. 2009; Radtke, Stacke et al. 2011).

2.2 Fundamental Definitions

2.2.1 Threat Scenario Type, Hazard Events

We mainly consider risk scenarios where either impact or high explosive events are involved, can be used for sufficient modeling or play a major role in the analysis. The focus will be broadened in order to include terrorist threat scenarios as well as natural catastrophes.

High explosive events are characterized by very fast and localized energy release (Klomfass and Thoma 1997, p. 1). In case of high explosions a fast moving detonation front separates the initial material and the detonation products. Examples for high explosives are dynamite or TNT. High explosions do not comprise fast burnings, combustions, the transformation of pyrotechnics, and slow propellants.

An impact is a "sudden time-dependent load" (Bangash 2009). *Impact events* involve fragments generated by high explosions. Impact events also include events with tube launched projectiles, events where debris is generated by explosions or where system components impact the earth's surface.

2.2.2 Risk

Risk considers a measure for the frequency/probability of events and a measure for the consequences. There are different definitions of risk in the literature. Some examples are:

- "Risk is the combination of probability and the extent of consequences" (Ale 2002)
- Risk is the "effect of uncertainty on objectives" (ISO 2009).

Most definitions do not ask for a special relation between probability and consequences on the one hand and risk on the other hand. The classical definition of risk has the strong requirement of proportionality (Dörr and Häring 2006, 2008; Mayrhofer 2010):

> "Risk should be proportional to the probability of occurrence as well as to the extent of damage." Blaise Pascal (1623–1662), see Fig. 2.1.

Formalized this reads as follows:

Classical definition of risk: *Risk is proportional to a measure for the probability P of an event (frequency, likelihood) and the consequences C of an event (impact, effect on objectives)*:

$$R = PC. \tag{2.1}$$

We work with this definition and generalizations thereof for the computation of risks.

Fig. 2.1 Blaise Pascal. © Juulijs—Fotolia

Negligible risks are called *de minimis risks* (Proske 2004).

In the assessment of risks we go beyond just requiring that

$$PC \le R_{crit}, \tag{2.2}$$

where R_{crit} is a critical risk quantity, for example the classical annual de minimis risk of fatalities is $10^{-6}a^{-1}$ (Proske 2004). We typically ask for more inequalities to hold, for example

$$\begin{aligned} P &\le f_1(P, C), \\ C &\le f_2(P, C), \end{aligned} \tag{2.3}$$

which requires that the frequencies and consequences obey inequalities which depend on both the frequency and consequences, respectively.

In generalization of (2.2), it is also possible to bound the risk by a more complex function than the constant value R_{crit}:

$$PC \le f_3(P, C). \tag{2.4}$$

2.2.3 Classification of Risk

Risk can be classified by different attributes of risk. Examples for classifications are:

- local versus non-localized risks,
- risks per event, in case of an event (conditional risks), per time interval, or per life cycle,
- risks on demand versus continuous risks,
- individual versus collective (group) risks,
- voluntary versus involuntary risks,
- perceived or subjective risks versus objective risks,
- risks based on (semi-)quantitative estimates versus quantitative risk computations,
- statistical historic risks versus risks based on models,
- source of risk: man-made, technical, natural, natural-technical,
- objects, persons or body parts at risk: risk for machinery, personnel, third party, health, lung, etc. affected by the risk, e.g. Proske distinguishes between natural risks, technical risks, risks for the health, and social risks (Proske 2004).

Examples of risks which match these classifications are:

- local individual annual risk of injury due to terroristic explosions,
- total average fatal collective annual risk of a given scenario,
- Collective total risk expressed using a frequency-number curve (F-N-curve): frequency of one or more injuries per year, frequency of ten or more injuries per year due to an explosive storage site.

2.2.4 Risk Management and Risk Analysis

Definition of risk analysis: *Risk analysis* is the determination of risks in a given context.

Definition of risk management: *Risk management* consists of risk analysis and the handling (mitigation) of risks, including changing the context.

Definition of risk analysis and risk management process: Risk analysis and risk management can be divided into different steps. The iterative or incremental execution of these steps together with communication between the steps is *the risk analysis/risk management process*.

Remark The risk analysis and the risk management process are often described in schemes, see Sect. 2.3.

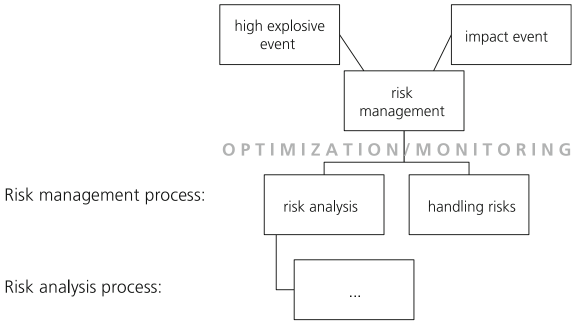

Fig. 2.2 First scheme of the risk management and risk analysis process

2.2.5 *Overview*

The terms that have been defined so far can be summarized in the scheme in Fig. 2.2.

2.3 Examples for Risk Management and Risk Analysis Schemes

2.3.1 *Loading-Based Assessment*

In *loading-based assessment* a predetermined dynamic or static loading is analyzed that the building has to stand in addition to the classical loadings. These classical loadings include loadings due to the structures itself, the working load, and the natural environmental loads like wind, snow, and earth quakes. Obviously this approach already assumes that the threat is well known and can be reduced to characteristic loads. This approach fits well into structural engineering processes in particular when assuming in addition that high-dynamic loading can be reduced to equivalent static loads.

Remark An even simpler approach is to increase the safety factors of constructional engineering by a defined factor.

2.3.2 *Scenario-Based Assessment*

Slightly more general than the known-loading approach is *scenario-based assessment*. In this case a few well defined scenarios are assumed, for example (among

Fig. 2.3 The scenario that a suitcase bomb is being placed next to a building

others), a suitcase bomb with 10 kg net explosive quantity at a distance of 10 m, see Fig. 2.3.

In terms of the more comprehensive risk management and risk analysis schemes of Sects. 2.3.3–2.4 the loading- and scenario-based approach do not make all analysis steps explicit. Typical questions that are not covered in a systematic way include: Are all possible loadings/scenarios considered in the given context (completeness)? How are the assessment criteria derived? Are there mitigation measures beyond structural target enhancement?

2.3.3 5-Step Risk Management Scheme

A standard scheme for the risk management process is the *5-step risk management scheme*. It can be found in many applications. The versions vary slightly, but essentially look like this scheme, based on (Ale et al. 2009):

(1) **Establish context**: Describe the initial situation, define aims such as safety or health.
(2) **Identify hazards/risks**: Define damage scenarios. This involves describing the hazard source and the exposure of persons or objects.
(3) **Analyze/compute risks**: Estimate or specify the probabilities and consequences of events.
(4) **Evaluate/rank/prioritize/assess risks**: Judge whether risks are acceptable or not. This can involve a comparison of the levels of risk with predefined criteria or a comparison of costs and benefits.
(5) **Treat/mitigate risks**: For risks that are not acceptable, change the initial situation or find external solutions such as insurance.

The steps are linked by an iterative or incremental (optimization and) monitoring process. Consultations and communication take place between the steps.

See Fig. 2.4 for a graphical version of the 5-step risk management scheme.

Remark An actual decision process also involves subjective perception and cultural or ethical aspects. This is not displayed in this scheme.

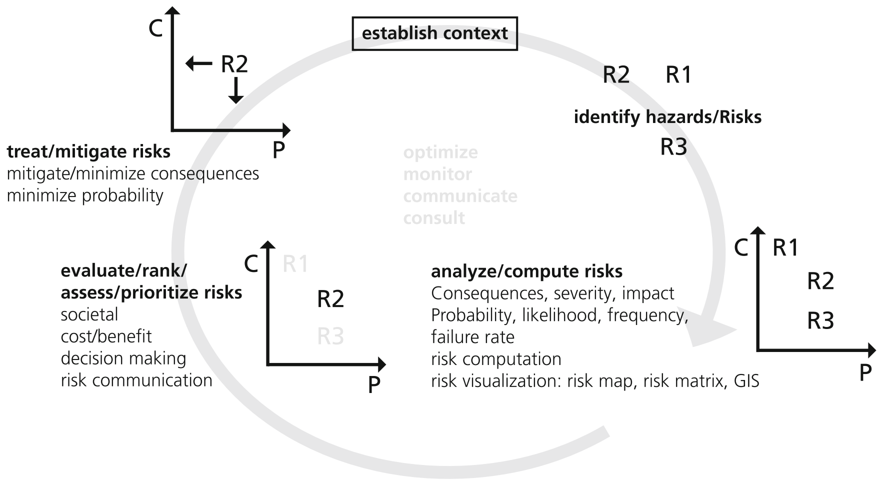

Fig. 2.4 Catchwords and pictograms for the 5-step risk management scheme

2.3.4 Risk Management Schemes for Explosive Safety Scenarios

The German explosive safety quantitative risk analysis (ESQRA-GE) tool uses the scheme from Fig. 2.5 (Radtke et al. 2011). It is applied to ammunition storage scenarios, the disposal of improvised explosive devices (IEDs) in case of terrorist threats and explosive ordnance disposal (EOD) in case of explosive remnants of war (ERW) or again terrorist threats.

Figure 2.6 gives a graphical visualization of the risk analysis steps of the assessment of overhead/overflight scenarios involving moving hazard sources, for example high explosive rounds or rounds with illumination subsystems. The scheme shows the risk analysis steps of the Fuze Safety Quantitative Risk Analysis Software (FSQRA) by grouping them into five steps (Häring et al. 2009).:

(1) Scenario analysis
(2) Physical consequence analysis
(3) Damage analysis
(4) Probability analysis
(5) Risk analysis

The schemes in Figs. 2.7 and 2.8 are from (AASTP-4 Ed. 1 2011). The AASTP (Allied Ammunition Storage and Transport Publication) describes in rather general terms how to apply mainly the quantitative risk analysis and management approach to military ammunition storage sites. Its Part 4 Manual on explosives safety risk analysis is an overview designed for use by policy makers, safety professionals, and analysts. It supports the continued growth and utilization of risk-based methods. It

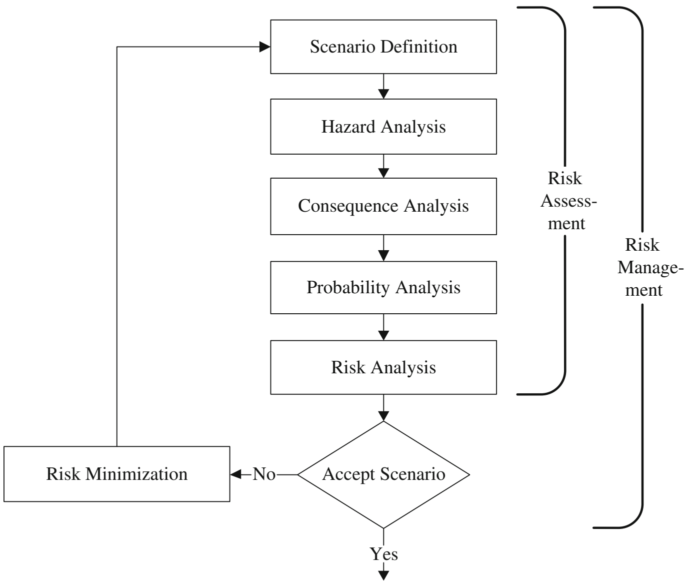

Fig. 2.5 ESQRA-GE risk management scheme (Radtke et al. 2011)

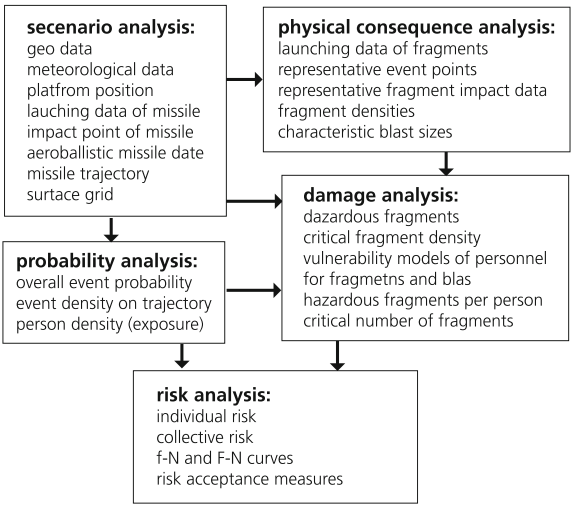

Fig. 2.6 Overview of hazard and risk analysis modeling steps (Häring et al. 2009). Reprinted from Reliability and System Safety Engineering, Vol. 94, Issue 9, I. Häring, M. Schönherr, C. Richter, Quantitative hazard and risk analysis for fragments of high explosive shells in air, pp. 1461–1470, Copyright 2009, with permission from Elsevier

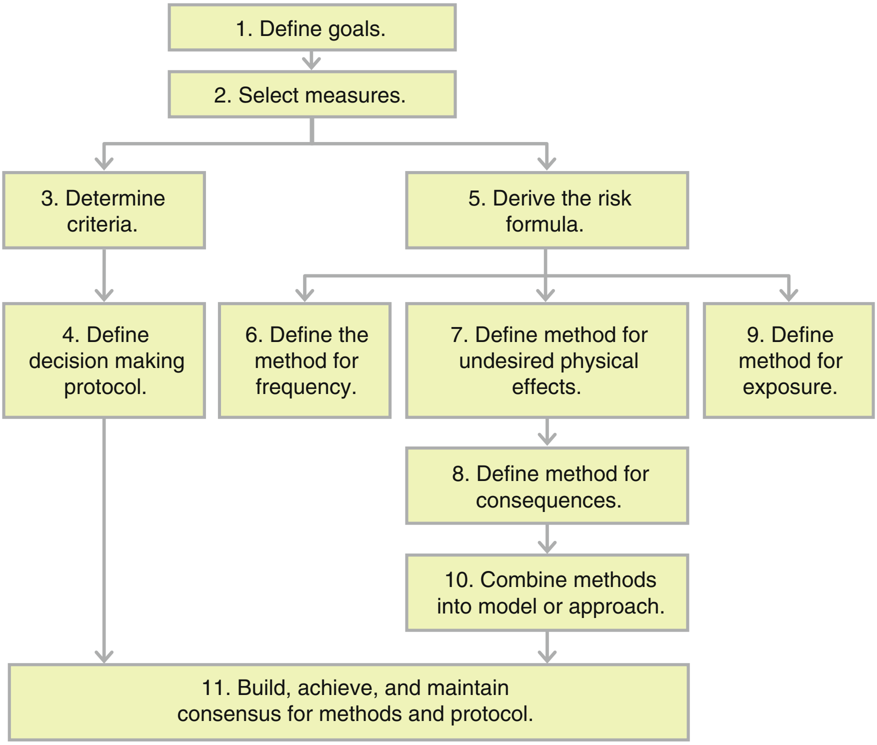

Fig. 2.7 AASTP 4—scheme to develop a risk-based decision approach (AASTP-4 Ed. 1 2011) Reprinted from Allied Ammunition Storage and Transport Publication: Manual on explosives safety risk analysis (AASTP-4 Ed.1), Nato Standardization Organization, 2011

is designed to assist in developing and using new applications and to provide examples of current international uses. Towards these purposes, it

- "Provides guidance in the establishment of risk-based decision methods,
- Describes existing risk-based methods in use by the participating nations,
- Identifies common features of risk-based approaches, so that assessments done by individual nations in multinational operations may be understood and, if appropriate, used by other countries" (AASTP-4 Ed. 1 2008).

During the last 15 years this approach was implemented in various NATO countries including associated non-NATO states like Norway and Singapore. Similar approaches can also be used for non-military high explosive sources, e.g. improvised explosive devices (IEDs) as well as for related scenarios like impacting threats.

We note that the schemes of Figs. 2.5, 2.6, and 2.8 all distinguish between physical effects and damage effects. The determination of these steps seems to require more effort than the steps covering the determination of the frequency/probability quantities. Comparing the 5-step-scheme of Fig. 2.4 and the schemes of Figs. 2.7 and 2.8 we find that the risk computation step is much extended.

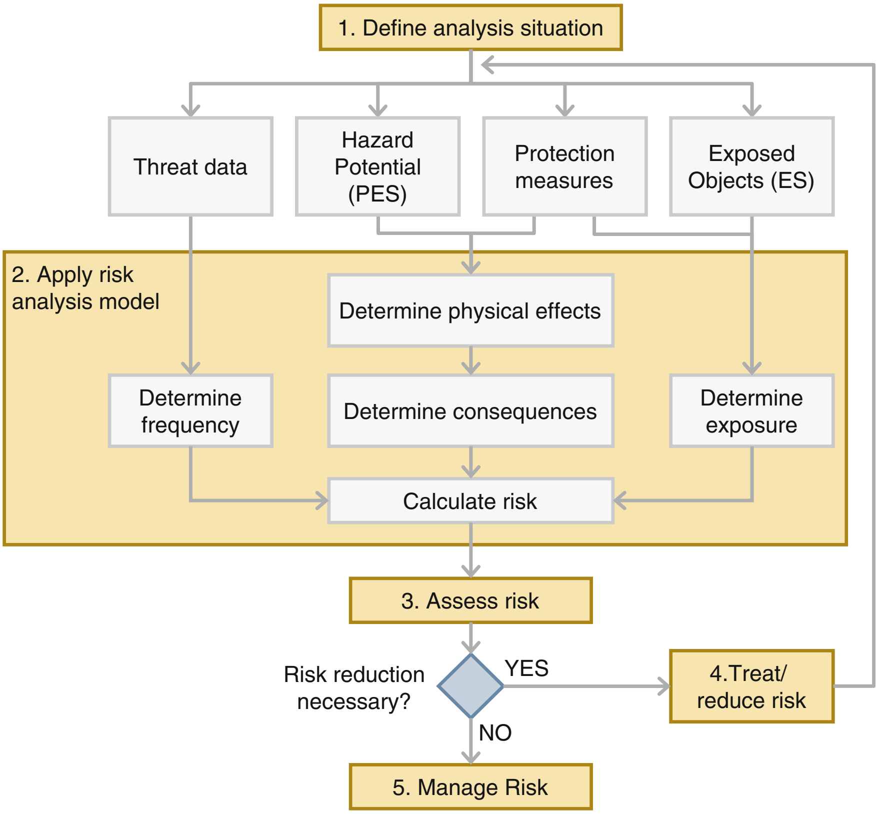

Fig. 2.8 AASTP 4—scheme to apply a risk-based decision aid. The scheme uses the abbreviations for potential explosive site (*PES*) and exposed site (*ES*) (AASTP-4 Ed. 1 2011). Reprinted from Allied Ammunition Storage and Transport Publication: Manual on explosives safety risk analysis (AASTP-4 Ed.1), Nato Standardization Organization, 2011

2.4 Attributes of the Risk Analysis and Risk Management Processes

Comparing the schemes from Sect. 2.3 we find that the processes and their describing schemes have different properties. Table 2.1 lists those and some further attributes.

2.5 Risk Analysis and Management Process

We now give a more detailed description of the **risk analysis process** that will be used in the following chapters. It divides into 9 steps that are connected by an iterative or incremental optimization and monitoring process. We start the

Table 2.1 Complementary attributes of risk and chance analysis and management processes

Implicit	Explicit
With software support	Without software support
Graphical description/visualization	Textual description
Coarse process steps	Refined process steps
Standardized, formalized	Ad hoc, situation/scenario driven
Described from decision maker perspective	Described from end-user perspective
Time critical process steps	Not time critical process steps
Real time risk analysis, risk management for decision support	Preventive risk analysis, ex-post risk analysis, forensic risk analysis
Virtual environment to exchange information	Exchange information in person
Multidisciplinary	One discipline
Multiple stakeholders	One stakeholder
Multinational	National
Based on existing database	Collect data by oneself
Threat assessment focusing on Consequences or likelihood	Threat assessment based on risk (i.e. consequences and likelihood)
Considering only first order effects (effects on health and first actions)	Considering also second and third order effects (effects on society, economy, and politics)
Scenario-based	Covering multiple scenarios
Focusing on worst-case scenario	Considering a broader range of scenarios
Application to real scenarios (ex-post, for validation purposes)	Application to fictitious scenarios (preventive analysis)

enumeration with (2) to add another step in front of it when we treat the risk management process.

(2) **Initial situation without hazard source**: All information needed to apply hazard and damage schemes is being collected. This includes geometrical, geographical, meteorological, and topological data and information about materials and meteorological conditions.
(3) **Description of the hazard source**: The description includes geometry, mass, position, orientation, and velocity of the hazard source as well as mitigation measures close to the hazard source.
(4) **Hazard propagation/hazard analysis**: This includes the potential dispersion, distribution, and impact load distribution of the physical hazard.
(5) **Damage/consequence analysis/modeling**: Here the effects of the physical hazard potential on objects like persons, vehicles, buildings, and infrastructure are determined.
(6) **Analysis of hazard event frequency**: It is analyzed how often the hazard source becomes active. This is determined by considering, for example, the frequency of the hazard source being present, the frequency of an unintended

event within the hazard source and the frequency of a failure of the containment. This step also covers location-dependent event frequencies.

(7) **Distribution of objects**: The distribution describes how many and where objects of interest are located in the area. Exposition/exposure describes that they are actually exposed to the damaging effects.

(8) **Success frequency of avoiding hazard event consequences**: This step considers the success frequency of organizational and training measures, of spontaneous reactions (for example flight) as well as the success rates of placing passive, reactive, or active physical barriers.

(9) **Risk computation and visualization**: This involves the computation of various risk quantities. The visualization options include risk maps, risk tables, and F-N-diagrams.

(10) **Risk comparison with criteria**: The risk quantities are compared to risk assessment criteria, for example risk matrices, critical values, and F-N criteria. For example, one checks whether the nonlocal annual individual risk is smaller than the de minimis risk.

To describe **the risk management process**, the following steps are added.

(1) **Background/Context**: This includes information about the country where the event is located, the cultural and ethical background, the legal and technical requirements, and the types of scenarios that are considered.

(11) **Risk assessment**: Risk assessment is the combination of the previous step (10) with other steps that enables to make a final risk evaluation. In particular, legal, social, and psychological effects on the assessment of risks are considered.

(12) **Risk communication** focuses on the communication of risks to experts, responders, the public, and third party. For instance, risks comparable to the risks that are to be assessed are named. This should be risks the persons addressed can relate to. An emotional link to the risk should be created.

(13) **Evaluate risk**: Taking the steps (10)–(12) into account, It is being judged whether risks are acceptable or not.

(14) **Mitigation measures**: There are mitigation measures that reduce the frequency, mitigation measures that reduce the physical hazards, mitigation measures that reduce the consequences of events, and mixed mitigation measures. We also count feasible changes of the background among mitigation measures.

Figure 2.9 extends the first overview of the risk management process from Fig. 2.2. The iterative or incremental (optimization and) monitoring process between the steps is indicated as well.

Figure 2.10 and Table 2.2 show how the 5-step risk management scheme of Fig. 2.4 and the 14-step risk analysis and management scheme from this section Fig. 2.9 relate to each other.

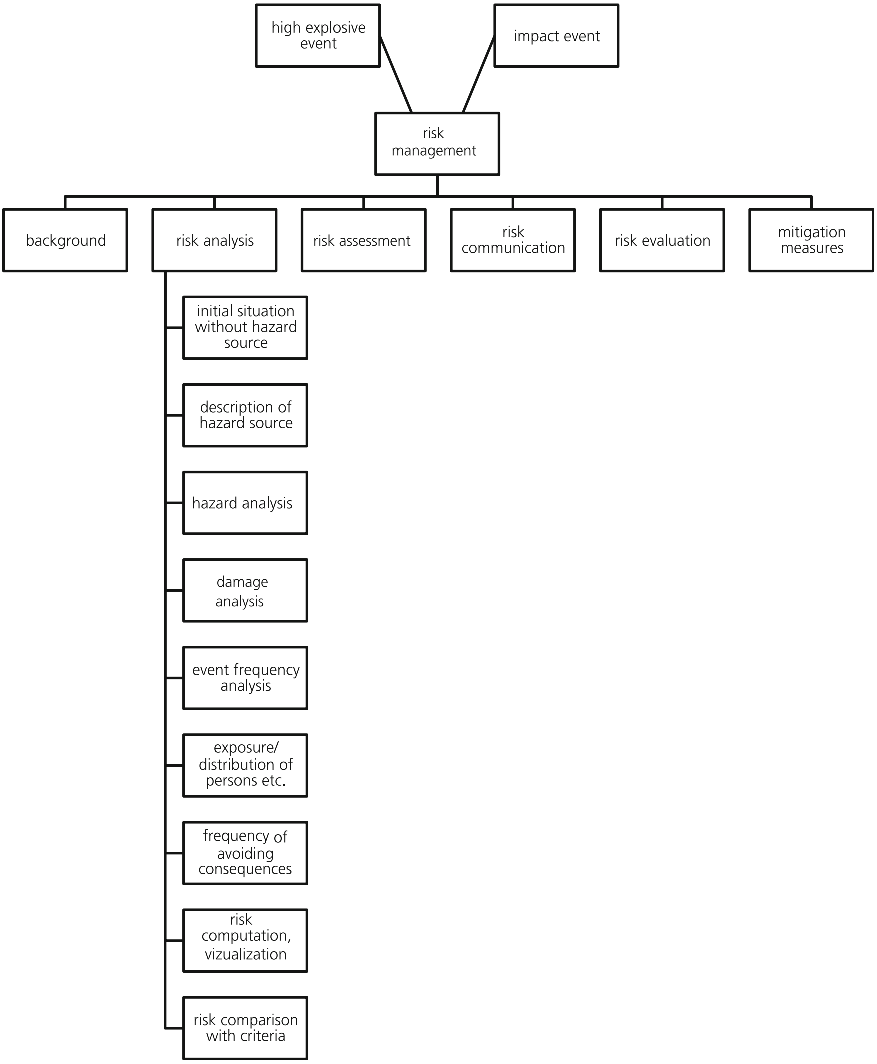

Fig. 2.9 First scheme of the risk management and risk analysis process

Table 2.2 reads as follows: Take for example step 3 in the left column ("Description of the hazard source"). The black "X" in the column "(2) Identify risk/hazards" means that step 3 can definitely be assigned to the second step of the 5-step scheme. The gray "X" in the column "(1) Establish context" means that some aspects of step 3 can also be assigned to the first step of the 5-step scheme.

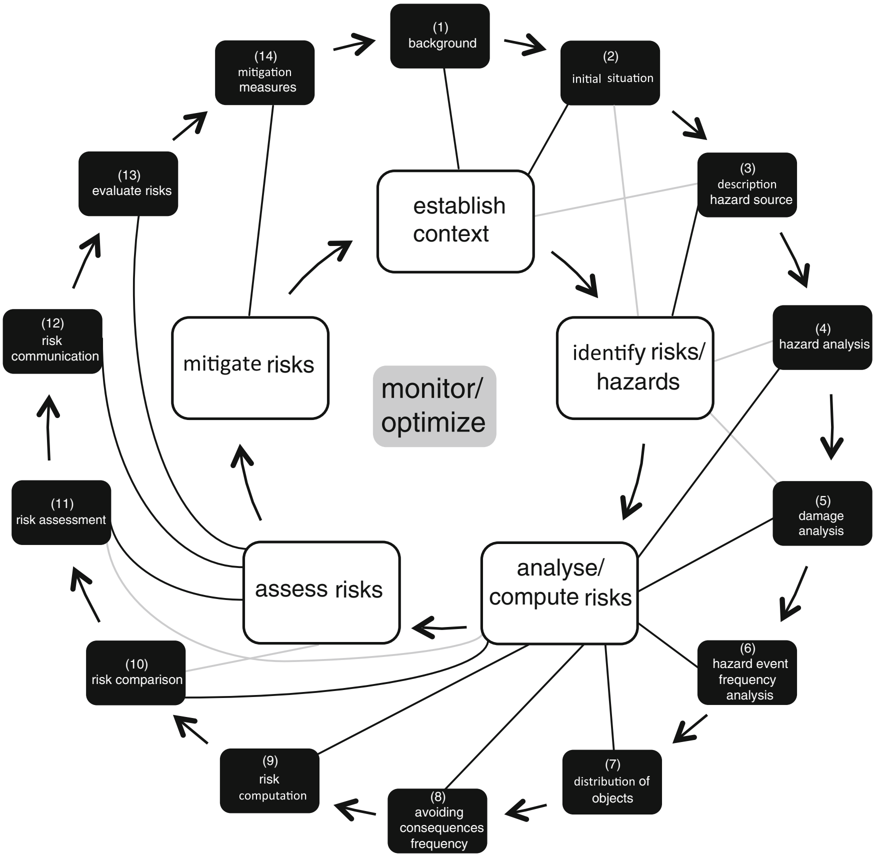

Fig. 2.10 Second scheme of the risk management and risk analysis process

2.6 Typical Dependencies of Risk Management Steps

Table 2.3 shows how the different risk management steps depend on each other in the process. Example for how to read the table: Take a look at the line where it says step 7 in the column furthest on the right and where there are “x” in the columns for input steps 1, 2, 6, 12, and 14. The line should be read in the following way: The steps 1, 2 and 6 should be executed before step 7 and the results of step 7 should be reconsidered after finishing steps 12 and 14.

Remark Remember that the risk management model it is an iterative model. The reconsidering can be understood as being part of a complete redoing of all steps after step 14.

Table 2.2 Placement of the 14 risk management steps of Sect. 2.4 in the 5-step risk management scheme of Sect. 2.3.3

	(1) Establish context	(2) Identify risk/hazards	(3) Analyze/ compute risks	(4) Access risks	(5) Mitigate risks
(1) Background	**X**				
(2) Initial situation without hazard source	**X**	X			
(3) Description of the hazard source	X	**X**			
(4) Hazard propagation/hazard analysis		X	**X**		
(5) Damage analysis/modeling		X	**X**		
(6) Analysis of hazard event frequency			**X**		
(7) Distribution of objects			**X**		
(8) Success frequency of avoiding hazard event consequences			**X**		
(9) Risk computation and visualization			**X**		
(10) Risk comparison with criteria			**X**	X	
(11) Risk assessment			X	**X**	
(12) Risk communication				**X**	
(13) Evaluate risk				**X**	
(14) Mitigation measures					**X**

2.7 Summary and Outlook

This chapter introduced different risk analysis and management processes and schemes to represent them.

In the following we focus on the 14-step risk management process of Sect. 2.4. After analyzing the dependencies of the different steps in Sect. 2.5, the most appropriate scheme for the risk management process appears to be the one from Fig. 2.10 while keeping in mind that it is possible to go around the circle several times and to leave out steps on the way. We note that the steps 10–13 are rather elaborate to allow for societal input in the decision process.

Table 2.3 Dependencies of the different risk management steps on each other

Steps relevant for input/output														Step
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
													x	1
x													x	2
x	x												x	3
	x	x											x	4
	x		x			x							x	5
x	x	x				x							x	6
x	x				x						x		x	7
x	x				x	x			x		x		x	8
			x	x	x	x	x						x	9
x	x							x					x	10
x								x	x				x	11
x	x								x	x			x	12
x	x							x	x	x	x		x	13
x	x	x										x		14

After two chapters on database analysis to have the necessary tools at hand, the steps of the 14-steps risk management process will be explained in more detail, focusing, in particular, on the nine steps of the risk analysis process.

2.8 Questions

(1) How is risk analysis defined?

(2) The broadly acceptable level of risk in the UK is the individual annual risk of fatalities:$10^{-6}a^{-1}$ (Proske 2008).

 (a) How can this information be used in a risk management process?
 (b) In which step of the 14-step risk management process can it be used?

(3) Must the steps of the 5-step risk management scheme happen in the presented order? If yes, why is this necessary? If no, why would one go back to a previous step?

(4) For what type of building could the scenario-based assessment be interesting?

(5) Which boxes in Fig. 2.5 can be related to which of the steps of the 5-step risk management scheme of Fig. 2.4?

(6) Which of the steps of the 14-step risk management scheme in Fig. 2.10 are covered by the scheme in Fig. 2.7?

(7) Which definition of risk do you use at your work place? Which other definitions can you find in the literature? Discuss the differences and advantages or disadvantages.

2.9 Answers

(1) See Sect. 2.2.4.
(2) (a) As R_{crit} in (2.2).
 (b) In step (10), see Sect. 2.4.
(3) No, the incremental optimization and monitoring process might ask for a reconsideration of a previous step, see Sect. 2.3.3.
(4) E.g. an embassy, bank building, headquarter of a company, house of a public person, …
(5) Scenario definition -> 1, hazard analysis -> 2, consequence analysis, probability analysis and risk analysis -> 3, accept scenario yes, no -> 4, risk minimization -> 5.

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