Chapter 30
Hazard Analysis and Risk Assessment Methodology for Safety and Security Problem Solving

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Abstract Safety is not defined as a total absence of hazards, it is a state in which hazards and conditions leading to physical, psychological or material harm are controlled in order to preserve (protect) the health and well-being of individuals and the community. Civil aviation sector is a huge system, contributing essentially in global and any national GDP, and any harmful event inside the system may decrease such a contribution sufficiently. Analytical modeling of the system safety is used to describe the relationships between the causes, dangers and effects of system states in its various operational scenarios. For activities, which characterized with a significant quantitative risk assessment, an approach can suggest for assessing the acceptability of risk. Risk is assessed according to the hazard identification, associated with the probability of adverse events and their consequences. The approach uses two types of risk: individual and societal. A number of events must occur if a main stressor should take place with conditional probability of their realization. Framework for risk assessment and reduction is considered also.

Keywords Risk · Aviation · Assessment and control

30.1 Introduction

Safety is not defined as a total absence of hazards and its objects are not to eliminate all the risks. Generally speaking the concept of safety is complex and difficult to understand in all its entire dimensions, physical, social, psychological, and, therefore, difficult to promote. Safety is a *state* in which hazards and conditions leading to physical, psychological or material harm are controlled in order to preserve (protect)

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health and well-being of individuals and the community. Risks can come from various sources – uncertainty in financial markets, threats from project failures (during their design, development or production), legal liabilities, financial credit, accidents, natural causes and disasters – and can cause a heavy damage. Safety is the result of a complex *process* where humans interact with their environments, including the physical, social, cultural, technological, political, economic and organisational environments, inside which the sources of hazard appear and exist (sometimes permanently) and, of course, should be controlled to limiting the risk for humans and communities at appropriate level. The effective safety (considering as a state or a process) improvement requires an integrated management approach, which takes into account several aspects in its framework that allows them to be viewed complicated and intelligibly [1].

Major accident investigations, particularly in transportation or/and energy sector, have identified a poor safety culture as a causal factor that increases the probability and severity of occurrence of the accidents and their consequences. A positive safety culture means first of all the readiness of the object under the risk to control personal or community vulnerability to the hazard(s) at appropriate level. Currently a proactive approach to integrate a safety culture at the organizational level of any kind of activities is required (focusing on troubleshooting just before the problems have a chance to emerge) in order to protect all safety-related functions against developing behaviors and practices that show themselves appropriate before an emergency happens. The safety culture explains conceptually and very pragmatically - how the vulnerability of an object at risk, especially defined by the lack of necessary knowledge and skills of as well as the priority placed on risk and safety among managers and employees can contribute to disasters that may expected in case of inadequacy of any element of the safety culture as such.

Transportation sector is one of the examples where terrorist attacks were found as a problem of highest sectoral importance, terrorist attacks on soft targets at airports, rail stations, seaports have increased during the last decade unfortunately. Transportation security, as a system, has been a major focus of transportation security policy since the terrorist attacks of September 11, 2001 involving the aviation. The events in New York World Trading Center exposed deep vulnerabilities in providing security of the aviation sector. As a result, the USA government adopted concrete policies and procedures to prevent aircraft hijackings in future and to keep prohibited items from getting into aircraft. However, since 2011, 14 airport attacks have occurred worldwide. The increase in attacks at airports demonstrates that rivals are continuously seeking new targets and not only in aviation sector. At the same time, a general increase in passenger travel has led to larger crowds at airports, rail stations, seaports, etc. Any attack on soft targets in their environment could cause not only the damage (mortality) in place, but even a significant disruption of the particular industry, leading to a large negative effect on the national economy, not to mention the social and psychological health of this nation's citizens. For example, a specific Annex 17 "Aviation Security" was adopted by ICAO (International Civil Aviation Organization) to its Chicago Convention on International Civil Aviation, which introduces the rules for protection of the people in airports and in aircraft from unlawful interference (hijacking). Originally, two terms – soft-target (a person who, due to specific vulnerability, provided by any actions and/or simply a lack of appropriate protection, is under the influence of existing risks and consequently turns into an *easy* target for terrorists) and hard-target (a person who, due to their specific actions and/or appropriate protection, is able to eliminate the existing risks and therefore most likely represents an *unattractive* target for terrorists) come from the military and relate to protected and unprotected targets. A glance at the world of people shows that most of them obviously defined as a category of soft targets. Such a category is largely characterized by the lack of personal security awareness and associated careless behavior.

Security awareness itself is not enough in usual case. In most of the cases, people also demand on necessary tools and measures to be able to realize any activity safely. In fact, soft targets mean a great threat for society – however, the problem is mostly local. If a person does not prepare himself/herself in a qualified way and does not take appropriate preventive measures, it contributes to the uncertainty of themselves, affects others, and increases the probability of an emergency. The problem in reality is much more complex than a simple lack of funding (for preventive measures). Contemporary terrorism does not consider any moral limits. The rate of violence and mortality resulting from the crimes appears to be rising. We're all human, we're all vulnerable – it is an important condition, which needs to be considered everywhere and every time. Obligation from the states and from any person exists – to transform the soft targets to be "harder" and to diminish their vulnerability [2]. For that the States should establish a specific safety policy and safety objectives and facilitate the promotion of a positive safety culture in a community, for example like aviation security or/and aviation safety policy must be declared State, any airline and/or airport to promote security and safety inside the area of their responsibility.

30.2 Safety First

30.2.1 Safety as a State and a Process

Transportation is critical to the lives of people and the global economy. The aviation sector has been among the most frequent targets of terrorist attack and the level of aviation security should be used to assess the *state* and ability of the sector to be protected and kept safe. As demonstrated by number of case studies, airport (aircraft) attacks disrupt the aviation system network as a whole and cause cascading effects inside the system and sometime even going outside. Such attacks may cost for airport and/or airline millions of dollars in lost airline revenues, business continuity operations, emergency response, infrastructure damage/renovation, crowd management, injuries, and deaths. For example, aviation alone accounts for more than 5% of USA GDP contributing over $1.6 trillion to the total market economy [3]. The attacks impact both the local and national economy. An airport attack could result in damage up to $17 billion in GDP from lost air travel [4]. In Brussels for example, the attack cost the Belgian economy an estimated four billion Euros [5]. To progress with the emerging threat, a specific national systematic approach is required and should be launched as a specific *process* to address the protection of people in the airport environment.

30.2.2 Risk Methodology in General

In accordance with the UN International Strategy for Disaster Reduction (UNISDR) terminology [10] the risk is defined as the probability of harmful consequences, or expected losses (any damage to human health, livelihoods or property, injuries, fatality, economic activity disrupted or environment damaged, etc.) resulting from interactions between natural or human-induced hazards and vulnerable conditions.

Under the standard [11] the definition of “risk” is no longer a “chance or probability of loss”, but an “*effect of uncertainty on objectives*”. The purpose of risk assessment is to provide evidence-based information and analysis to make informed decisions on how to treat particular risks and how to select between options to provide an activity. Principal benefits of a performing risk assessment include a wide set of positive outcomes for person, group or/and community. In general the risk (R) and hazard (H) ratio can formally be expressed in simple form as:

$$R = f\ (H \times E) \qquad (30.1)$$

where H – hazard, in our case terroristic attack against soft target, which may lead to a number of effects, E – type and value of exposure of the hazard (depending on number of terrorists involved, their level of training for that, their type of arms and tactics against violent people used, etc.) on subject of impact (for example, on population), f – function of their interdependence.

This simple conceptual dependence between risk and hazard in Eq. (30.1) does not consider the contribution of vulnerability of the object-at-risk (or elements-at-risk) to the hazard under consideration – “the conditions determined by physical, social, economic and environmental factors or processes, which increase the *susceptibility* of a community to the impact of hazards” [6]. Elements-at-risk has a certain level of vulnerability usually, which can be defined in a number of different ways. The general definition is that vulnerability describes the *characteristics* and *circumstances* of a community, system or asset that make it susceptible to the damaging effects of a hazard [7]. There are many aspects of vulnerability exist, related to a number of inter-related conditions (see for example [8]), which may increase the susceptibility of a community to the impact of any hazard under consideration, they can be generally classified as shown in Table 30.1.

In relation to hazard (H), vulnerability (V) and amount of elements-at-risk ($A_{elements\text{-}at\text{-}risk}$) (or consequences to them from hazard impact) the risk (R) can be presented conceptually with the following basic equation:

Table 30.1 General classification of vulnerability, modified from [9]

	Human – social	Physical	Economic	Cultural/ environmental
Direct losses	Fatalities Injuries Annoyance Activity (for example sleep, rest, learning) disturbance and/or disruption Loss of income or employment Homelessness	Structural damage or collapse to buildings Non –structural and damage to contents Structural damage infrastructure(especially critical infrastructures)	Interruption of business due to damage to buildings and infrastructure Loss of productive workforce through fatalities, injuries and relief efforts Capita costs of response and relief	Destruction of cultural heritage/ Sedimentation Pollution Endangered species Destruction of ecological zones
Indirect losses	Diseases Permanent disability Psychological impact Loss of social cohesion due to disruption of community Political unrest	Progressive deterioration of damage buildings and infrastructure which are not repaired	Economic losses due to short term disruption of activities Long term economic losses Insurance losses weakening the insurance market Less investments Capital costs of repair Reduction in tourism	Loss of cultural diversity/ Loss of biodiversity

$$R = H * V * A_{elements-at-risk} \qquad (30.2)$$

or taking into account the capacity (C_c) (opposite term to vulnerability) to cope the hazard consequences [10]:

$$R = H * V * A_{elements-at-risk}/C_c. \qquad (30.3)$$

All these Eqs. (30.1, 30.2, and 30.3) would not be taken literally as a mathematical formula in most of the cases, but rather a model to demonstrate a concept. The first part of the formula for risk, Hazard (or somewhere Threat) x Vulnerability, can also be looked at as a probability [10]. This likelihood is a rough measure that describes the chances a given vulnerability will be discovered and used by a hazard actor. The last part of the formula ($A_{elements\text{-}at\text{-}risk}$) describes the consequences, or impact to elements-at-risk itself, of an impacting attack by hazard actor. The combination of the likelihood and the impact describes the severity of the risk, Fig. 30.1.

Recently, various disciplines investigated the concept of interaction of danger, vulnerability and coping capacity for risk assessment and control, it has considerably

Risk=	Hazard	xVulnerability	/Capacity	x Impact	Conceptual formulation
Risk =	Probability of Hazard Event	x Likelihood of impact		x Severity of consequences	Mathematical formulation
Data sources:	Statistics of historical data for exposure analysis and assessment	Description of the factors of vulnerability and coping capacity		Individual risks, social risks, monetary values, etc	Data presentation for analysis and assessment

Fig. 30.1 Scheme for risk calculation

expanded to a number of new applications. Its conceptual risk assessment formula has changed over time as follows [10]:

$$R = f[H(V, C_c).V(H, C_c)/C_c(H, V)], \tag{30.4}$$

where a number of complex interactions between attributes hazard (H), vulnerability (V) and capacity (C_c) is considered for any possible kind of element-at-risk. For example, the response of the human ear to acoustic spectral frequency of noise event may be considered as vulnerability property of the humans under the risk of noise impact or as it is used currently – to correct the noise exposure level on a value of human ear response, in such way to change the impacting exposure (or hazard) of this disturbing noise including human susceptibility to sound frequency.

If the humans will be provided with ear plugs to prevent them from disturbing noise (for example during their sleep) or if the disturbing noise source will be outside of the sleeping room and a simply closed windows may provide less vulnerable conditions – once again a complex interdependency between H, V and C_c will take place (for example, closed windows in a room may be considered as coping capacity of the location for noise protection purposes or as vulnerability conditions of this location), their account on noise impact will be quite complicated. As a result any kind of community engagement may influence a problem of aircraft noise impact assessment dramatically due to such complex interdependency between H, V and C_c, as shown in general scheme in Fig. 30.2.

In general case the severity of the hazard impacts depends strongly on the level of exposure and vulnerability in the affected area, and evidence indicates that risk has increased worldwide largely due to increases in the exposure of population and its assets, so understanding vulnerability and exposure are fundamental to our understanding of risk [6]. But the given above Eqs. (30.1, 30.2, 30.3, and 30.4) are not only conceptual ones, sometimes they can also be actually calculated (for example, with spatial data in a GIS to quantify risk from geo-distributed hazards [6]). First, while the concepts of “threats” and “vulnerabilities” are clearly relevant to determining the probability of a possible outcome of an event, they are not equivalent to the probability of a possible outcome of an event.

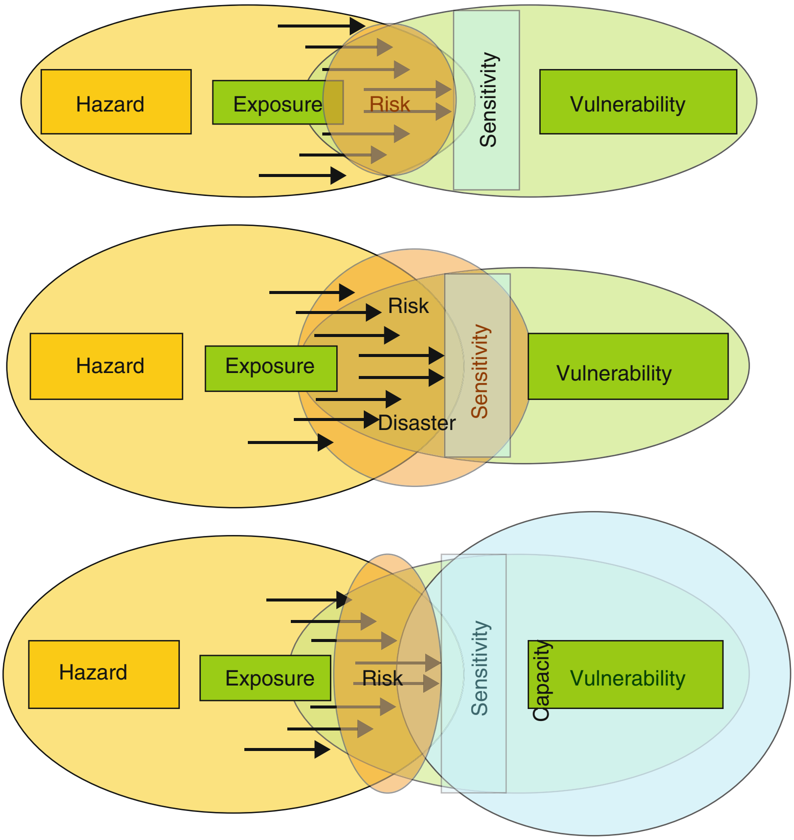

Fig. 30.2 General scheme for hazard, vulnerability and coping capacity inter-influence in risk assessment and control [10]

Mathematically the 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), Fig. 30.1:

$$\mathrm{R} = \mathrm{P} * \mathrm{C}. \tag{30.5}$$

For individual risk this basic condition may be expressed by the formula [11]:

$$\mathrm{R} = \mathrm{P_f} * \mathrm{P_{d/f}}, \tag{30.6}$$

where P_f – the probability of harmful event (eg, aircraft accident); $P_{d/f}$ – the likelihood of the consequences (effect or damage), particularly the fatal consequences caused to individuals in the absence of protection from (or resistance to) a danger.

Individual risk R_i is an averaged over the year probability of death, injury and illness for an individual who may be located (lives or performs any kind of activities) near the source of hazard (eg airport or power plant or any other critical object), as a result of hazard existence/occurrence/exposure (eg, airplane crash into power plant or into residential area) and regardless presence of the people at all. The purpose of R_i estimating is to ensure that individuals, who may be affected by a threat from critical object (source of hazard), are not exposed to excessive risks. It is a characteristic of the source of hazard or property of lands around this object (which is location specific, for example like Noise Zone around the airport in accordance with aircraft noise levels or Public Safety Zone around the airport in accordance with Third Party Risk assessment), thus R_i may be shown by contours around the object on a map and to be used further for land use planning and corresponding zoning purposes to control the impact of this hazard on population.

Also a societal risk R_S may be used for assessment, which represents the risk to a (large) group of people. It is an annual probability that N or more people may die, being injured and/or ill due to the danger occurrence/exposure. R_S is not person and location specific, but usually used for national and international normative limits and standard values for any kind of hazard control and safety promotion. Societal risk is difficult to apply to the task of risk reduction, specifically because it is multidimensional. It is therefore adequate to look at both R_S and R_i to achieve a full risk picture to be effective with risk management in following steps.

Severity of a hazard (risk of consequences of a danger, Fig. 30.1) is combined with an estimate of its probability (or consequence). First needs to be determined, how often there may be a danger. Usually a function of probability combinations of causes (factors) should be considered. Then a likelihood of the worst state of the system must be assessed. This evaluation can also be quantitative or qualitative (if statistical data for quantity assessment is absent or not enough). Inaccuracy of the data used (Fig. 30.1) and confidence intervals of the results are the same important results of assessment for the following analysis and decision making, because their values often the same as for main results of risk assessment.

Calculation of individual risk R_i basically involves the multiplication of the probability of hazard event and the damage given by this event. As the damage fraction is never larger than 1, it is therefore logical that R_i can never become larger than the probability of hazard event inside a system. By integrating the individual risk R_I and the population density m the expected value of the number of people with damages for their health $E(N)$ inside population N can be determined:

$$\mathrm{E(N)} = \iint_{\mathrm{A}} \mathrm{R_j(x, y)\ m(x, y)\ dxdy}, \tag{30.7}$$

where all the contributing values are defined at location (x,y) and number of damaged people inside area A per year. The number of people exposed (N_{EXP}) to a certain event can be found by integrating the population density over the exposed area A:

Table 30.2 General classification of damage, modified from [12]

Damage	Tangible	Intangible
Direct	Residences Airport/transportation facilities and inventory Vehicles Agriculture grounds Industrial/occupational facilities Infrastructure and other public facilities Business interruption (inside effected area) Evacuation and rescue operations Clean up costs	Fatalities Injuries and illnesses Annoyance of the humans Animals Utilities and communication Historical and cultural losses Environmental losses
Indirect	Damage for business outside effected area Substitution of business/production outside effected area Temporary housing of evacuees	Societal disruption Societal depression Damage to government

$$N_{EXP} = \iint_A m(x, y)\, dxdy. \qquad (30.8)$$

In more general form probability of harmful event P_f may be divided to the probability of scenario p_{Sc}, leading to such event, and the probability of hazard exposure p_{Ex} due to this scenario:

$$P_f = p_{Sc}\, p_{Ex}. \qquad (30.9)$$

The effects are usually described in terms of various type of damage k (eg, fatality, injury, physical damage, environmental losses, loss of income, etc. depending what are the elements-at-risk and what type of assessment is under consideration) and their vulnerability v_k (for example, describing a third party risk around the airport in case of aircraft accident a person's vulnerability can be defined as mortality):

$$P_{d/f} = k\, v_k. \qquad (30.10)$$

An overview of different types of consequences due to technological accident is given in Table 30.2. The damage is divided into tangible and intangible types, depending on whether or not the losses can be assessed in monetary values. Another distinction is made between the direct damage, for example caused by physical contact with aircraft crash just on site of the accident, and damage indirectly following from the crash (fire, air or ground surface pollution outside the accident site, so on). Indirect damage can be defined as damage that occurs outside the affected area [12]. For example any kind of business can lose supply and demand from the affected area.

Risk assessment needs to be used in framework of its regulation [13]. To investigate the effects of hazards correctly there are important factors of vulnerability – physical, social, economic, cultural and environmental conditions and processes that

Risk management	**Hazard exposure** management: monitoring and control	**Vulnerability factors** management: detection and preparedness	**Protection measures** management: policy, measures and procedures	**Response and emergency** management: response and emergency plans	Management
Risk=	**Hazard**	**xVulnerability**	**/Capacity**	**x Impact**	Conceptual formulation
Risk =	**Probability of Hazard Event**	**x Likelihood of impact**		**x Severity of consequences**	Mathematical formulation
Data sources:	Statistics of historical data for exposure analysis and assessment	Description of the factors of vulnerability and coping capacity		Individual risks, social risks, monetary values, etc	Data presentation for analysis and assessment

Fig. 30.3 Scheme for risk calculation and management [9]

tend to increase the damage from the effects of the hazards impact on the person or society as a whole (Fig. 30.3). There is necessary a *coping capacity* – capabilities of a human, system, society, nature to confront the consequences of emergencies, dangers and threats, i.e. resources are needed that may reduce the negative effects.

For activities which characterized with a significant quantitative risk assessment a framework can suggested for assessing the acceptability of risk. Limit of risk acceptability is determined by the level above which the risk cannot be justified except of extraordinary circumstances. Below the limit of acceptability a risk may be allowed only in response to the advantages associated with the activity, but it should be analyzed for the requirements of ALARP (As Low as Reasonably Practicable). With the improvement of risk management practices it can reach the point at which the cost associated with further risk reduction is high enough to justify the further advantage of its reduction.

30.3 Conclusions

The widespread use and important advantages of risk assessments does not mean that they are the sole determinants of management decisions; risk managers are considering a number of factors. Although risk assessments provide critical information to managers, it is only a part of the decision making process. Reducing the risk to the lowest level can be very expensive or technically unfeasible.

The field of education offers numerous advantages for giving more explicit attention to hazard reduction awareness. Other side – lack of knowledge and skills is a subject of human vulnerability, especially in case of emergencies. Their appropriate level is a subject of coping capacity of the people under the impact of hazard. At higher levels of education and in professional training, more efforts are needed to integrate risk management into other subjects related to the environment, natural resources and sustainable development [14]. Teachers are widely recognized leaders; learning and educational facilities are highly valued in local communities around the world. However, specific disaster risk issues have been incorporated into curricula slowly, and explicit programmes of risk education remain the exception rather than the norm in most countries. A gap exists between the growing recognition of the importance of teaching about disaster risks and actually doing it.

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