Chapter 2
Risk, Fire Risk, and Fire Risk Assessment

Risk is the potential for realization of unwanted adverse conditions, considering scenarios and their associated likelihoods and consequences. Specifically, fire risk can be defined as a quantitative or qualitative measure of fire incident loss potential for fire protection engineering applications in event likelihood and aggregate consequences.

Fire risk assessment is the process of estimating and evaluating risks associated with fires affecting buildings, facilities, or processes. The method includes evaluating relevant fire scenarios with associated frequencies and consequences using one or more acceptance criteria. In practice, fire risk assessment is used for:

- Selecting an appropriate design considering the fire risk and cost associated with various alternatives
- Managing the fire risk in a building, facility, or process
- Informing resolutions of a regulatory process, such as evaluating the risk associated with code compliance, determining acceptable configurations in risk-informed/performance-based applications.

There can be several ways of assessing fire risk. Therefore, the way risk is defined in an application is based on the study's specific objectives. For example:

- If the objective is life safety and there is concern about human fatalities in a building, risk could be measured in terms of the potential number of deaths per year.
- If the objective centers on property protection, the risk should be measured based on the potential financial value of losses per year.

In general terms, the risk parameter is measured in "outcomes per unit of activity," where the "outcome" is the potential number of unwanted events (e.g., number of fatalities), and the unit of activity is often a measure of time (e.g., a year).

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2.1 The Concept of the Risk

The risk from a particular hazard associated with a building, facility, or process may be explained as the entire domain of potential scenarios. Each scenario is represented as:

- A description of the scenario (S_i).
- An estimation of the frequency (λ_i), which refers to the characterization of how often the scenario is expected to occur. This likelihood is often represented with a frequency or a probability depending on the application.
- Characterization of the consequences (C_i).

This combination of variables (λ_i and C_i) fully characterize each scenario (S_i). The total risk for the facility can then be determined by the sum of the risk of all scenarios [1]. Consistent with the definitions above, the total risk can be expressed quantitatively, as shown in Eq. 2.1.

$$Risk = \sum_{All\,S_i} \lambda_i \cdot C_i \tag{2.1}$$

where:

λ_I = frequency of the ith scenario
C_i = consequence of the ith scenario.

Sections 2.3 and 2.4 provide a practical interpretation of these parameters. Knowing the complete set of parameters, the risk may be expressed quantitatively in several ways. The simplest form of a quantitative risk expression is the sum of the products for each scenario according to Eq. 2.1. The benefit of expressing risk in this way is that hazards are easily comparable and evaluated using a risk matrix (described in Sect. 7.6). At the same time, this method of expressing the risk does not fully represent the nature of the risk for the facility. For example, it does not provide information about the magnitude of the consequences for each scenario concerning the individual frequency. In other words, without a description of risk, insights generated by the analysis supplementing the results, a resulting risk value will not distinguish between high likelihood/low consequence events and low likelihood/high consequence events. Risk can also be expressed semiquantitatively or qualitatively by characterizing the frequency and consequences to be compared and ranked.

2.2 Scenarios

For fire risk assessment purposes, a scenario is a term used to describe a series of events that may lead to an undesired consequence per the objectives used for the basis of the assessment. The set of elements characterizing a scenario often includes fire initiation, propagation, and mitigating fire safety features available in the building, facility, or process under evaluation. It may also include elements related to human behavior and evacuation. The scenario considers the fire causing the threat and the exposed items protected for a specific set of possible events. These elements typically include the frequency of occurrence of each scenario, the hazards associated with each scenario, and the mitigating fire safety features to provide prevention or protection against fire and the potential consequences of the event. The effect of mitigating fire protection features is typically considered by applying a conditional probability to the base frequency and modifying the expected consequences. The number of scenarios can often be extensive.

Scenarios can be grouped in "clusters." This is sometimes necessary to support meaningful assessment of frequency and consequences and permit the universe of possible fires in a building to be grouped into manageable scenarios to be included in the assessment [2].

The term "fire scenario" describes how the fire develops, including ignition, growth, and extinguishment. It also considers the context, for example, the fire location and other factors needed to describe the exposure to the items to be protected for estimating the consequences (C_i) (see Sect. 3.6).

2.3 Frequency

In the context of this guide, frequency captures the likelihood of a fire occurring as the number of events that occur within a specific time interval. Frequency is the ratio of the number of times an event occurs in a time period (e.g., the number of fires per year).

The frequency can be further characterized in the analysis with a set of applicable conditional probabilities ($P_i^{''}$) for each scenario (i). As such, the frequency can be expressed as follows:

- Initiating event frequency (λ_{init}) is the frequency of ignition for scenario i.
- The scenario frequency can be expressed as ($\lambda_i = \lambda_{init} \cdot P_i$) where the conditional probability represents events affecting the fire scenario progression, often associated with fire growth, detection, and suppression activities.

Conditional probabilities are necessary to describe how events may result in potential consequences. At the same time, conditional probabilities are not always required. For example, the tolerable or acceptable risk levels associated with scenarios with relatively low frequencies or consequences may not need to be further refined with conditional probabilities (i.e., conditional probabilities are assumed to be a value of 1.0).

In addition to the frequency and consequences of the postulated fire scenario, conditional probabilities are used in the context of fire risk to account for factors explicitly included in the quantification process. For example, a conditional probability may be included to characterize the failure of a suppression system given a fire, the variation of egress outcomes, etc. As such, these parameter(s) are multipliers to the initiating event frequency characterizing each scenario. This concept is further discussed later in Chaps. 10 and 11.

2.4 Consequences

In a fire risk assessment, the term "consequences" involves determining the potential impacts of a fire scenario. Depending on the objective of the risk assessment, the consequences may be expressed differently (i.e., using different units). Examples of consequences used in fire risk assessments include monetary loss per accident, numbers of injuries or fatalities, damaged building floor area, and business downtime.

2.5 Interpretation of the Risk Parameters

Consider a typical scenario consisting of the following progression of events: ignition, fire growth/propagation, detection, suppression, and resulting consequences. Each of these elements can be associated with a parameter in the risk equation described earlier as follows:

- Ignition can be quantitatively captured in the frequency term (e.g., a fire ignition frequency). This can be expressed in terms of the "number of ignitions" per unit time.
- Fire growth or propagation can be expressed in terms of a conditional probability (i.e., the probability of fire growth given ignition). This may be modified by compartmentalization strategies or limitations on available fuel load (e.g., limiting the use of combustible building materials).
- Detection and suppression can also be represented with a conditional probability (i.e., probability of detection or suppression at a point in time given fire ignition and growth).
- Given the use of conditional probabilities, an event starting with ignition may have several outcomes (i.e., different consequences). For example, successful suppression will result in a specific consequence. On the other hand, failure of suppression will result in a different set of consequences.

The conceptual example was limited to detection and suppression features. The concept of conditional probabilities can be expanded to capture most of the critical elements in the fire safety program for a facility, including fire prevention, passive fire protection, egress strategies, etc. These conditional probabilities have the practical effect of reducing the frequency of ignition events that may eventually progress to higher consequences, resulting in a lower fire risk depending on the effectiveness of the fire safety features included.

In semiquantitative or qualitative assessments, each term in the risk equation is similarly interpreted. The frequency refers to the likelihood of fire initiation. The conditional probabilities capture the scope and effectiveness of a fire safety program (i.e., mitigative strategies). The consequences refer to the expected damage or losses generated by the fire. As such, the risk equation provides a comprehensive framework for treating quantitatively, semiquantitatively, or qualitatively all elements of a fire scenario.

References

1. S. Kaplan, B. Garrick, On the quantitative definition of risk. Risk Anal. **1**(1), 11–27 (1981)
2. ISO, *ISO 16733-1:2015: Fire Safety Engineering—Selection of Design Fire Scenarios and Design Fires—Part 1: Selection of Design Fire Scenarios* (ISO, Geneva, 2015)