David A. Charters, Ph. D. | *Fire Protection Engineering*

Jul. 1, 2013

WHY ASSESS FIRE RISKS?

For the vast majority of history, fire risks have not been assessed for the design of buildings, so why start now? There are a number of answers to this question, but the primary motivation is to avoid the many and varied multiple fatality fire disasters that have occurred in the past. These disasters are well known to fire professionals; to avoid the risk of omission, they are not listed here.

Paradoxically, one of the things that past disasters have in common is that they are all different. They are in different buildings types, with different causes and contributory factors. So it seems whatever is done to prevent the last disaster from happening again, the next disaster is likely to be almost completely different. Fire risk assessment provides the opportunity to address the potential risks from all foreseeable potential future disasters, not just the last one.

Occurrence Frequency, F	Range	Rating
Never	< 1 in 10,000 years	0
Remote	1 in 1,000 to 1 in 9,999 years	1
Rare	1 in 100 to 1 in 999 years	2
Infrequent	1 in 10 to 1 in 99 years	3
Occasional	1 in 1 to 1 in 9 years	4
Frequent	Once to 10 times per year	5
Common	> 10 times per year	6

Table 1. Example of Frequency Ratings for the Matrix Method

Another reason for undertaking fire risk assessment in building design is that risk (and its management) is at the heart of the engineering process, standards, testing, certification, etc. For example, a slightly tongue in cheek definition of engineering is that

> "Engineering is the art of modelling materials we do not wholly understand, into shapes we cannot precisely analyse, so as to withstand forces we can properly assess, in such a way that the public has no reason to suspect the extent of our ignorance."

That quote, by the way, was by the president of the Institution of Civil Engineers in 1946, so perhaps one of its other messages is that even mature engineering disciplines never stop questioning the basis on which they practice.

Closer to performance-based fire safety design practice, the principle of 'equivalency' is often used to determine whether an alternative design solution is adequate. Equivalency can be defined as:

> "...demonstrate that a building, as designed, presents no greater risk to occupants than a similar type of building designed in accordance with well-established codes."

Although the equivalency of most alternative solutions can be assessed at face value or by using deterministic performance-based analysis (such as smoke movement and evacuation analyses), the true metric of equivalency by this definition is risk.

Most fire risk assessments, however, are undertaken because it is a legal requirement. In some countries, it is a legal requirement to have a fire risk assessment that is suitable and sufficient. High hazard industries globally tend to have regime where a safety case is required to operate; often these safety cases are risk-based and include fire as a hazard. In many countries, legislation relating to corporate governance also requires boards of directors to manage the risks (including fire) that the organization faces.

QUALITATIVE FIRE RISK ASSESSMENT

Most people in society undertake risk assessments without realizing it – for example, when crossing the road. Sometimes fire protection engineers do likewise. For example, the review process at the start of any performance-based fire safety design process [known as Fire Protection Engineering Design Brief (FPEDB) or Qualitative Design Review (QDR)2] usually contains a list of tasks including:

- Review the structural design of the building
- Set fire safety design objectives
- Identify fire hazards and potential consequences
- Identify trial fire safety designs
- Agree upon acceptance criteria and method(s) of analysis
- Identify the fire/occupant scenarios for analysis
- Report

The process involved in qualitative fire risk assessment of existing buildings (in the UK3) identifies the following tasks:

1. Identify fire hazards
    - Sources of ignition
    - Sources of fuel
    - Sources of oxygen
2. Identify people at risk
    - People in and around the premises
    - People especially at risk
3. Evaluate, remove, reduce, and protect from risk
    - Evaluate the risk of a fire occurring
    - Evaluate the risk to people from fire
    - Remove or reduce fire hazards
    - Remove or reduce the risks to people
      – Detection and warning
      – Fire-fighting
      – Escape routes
      – Lighting
      – Signs and notices
      – Maintenance
4. Record, plan, inform, instruct and train

- Record significant findings and actions taken
- Prepare an emergency plan
- Inform and instruct relevant people; cooperate and co-ordinate with others
- Provide training

5. Review

- Keep assessment under review
- Revise where necessary

There is similarity between these and other qualitative risk assessment processes.[4,5,6,7,8] Qualitative assessments of risk alone may be sufficient for small and simple premises where fire risks are naturally low. However, qualitative methods may not be sufficient on their own for larger, more complex premises, where the risks from fire might naturally be higher.

SEMI-QUANTITATIVE FIRE RISK ASSESSMENT

Often, there is a need to identify a wide range of fire risks and then prioritize the way these risks are addressed. Semi-quantitative fire risk assessment provides a way of assessing and prioritizing a whole range of fire risks that may be present in a complex building.

The matrix method is one of the most popular and robust examples of these types of approaches to risk assessment. The matrix method defines a series of categories for how often things might go wrong (Table 1) and another series of categories for how bad unwanted fire events might be (Tables 2 and 3).

Severity (Life Safety), S	Rating
None	0
Minor Injuries	1
Major Injuries	2
One Fatality	3
Multiple Fatalities	4

Table 2. Example of Severity Ratings for the Matrix Method

Each rating in each series usually represents an order of magnitude range, and so no great precision is implied in the matrix method. With the assistance of a group of people familiar with the building under consideration and relevant historical information, one can assign each area an occurrence frequency and a severity rating. These ratings can then be combined to give a risk rating for each area (Table 3). This can be a powerful way of prioritizing risk reduction or more detailed analysis on risks that are highest.

Location	Risk Rating
Extension Site Works	7.0
Retail Outlets	6.0
Concourse and Forecourt	5.0
Platforms and Access Road	5.0
Clothes Store	4.0
Underground Station	3.0
Public Highway	3.0
Hotel Way	2.0

Table 3. Example of Combined Risk Ratings for the Matrix Method

Although these comparative risk ratings can be helpful in prioritizing risk reduction and identifying areas worthy of further analysis, they offer insufficient refinement for comparison between alternative life safety solutions or criteria or for investment appraisal of further fire safety investment. Better information is needed to perform these more detailed tasks.

THE LARGEST FIRE EXPERIMENT IN THE WORLD

In the quest for better information to predict levels of fire risk, and given that:

> "What can go wrong, will go wrong." – Disreali
>
> "If you can't measure it, you can't control it." – Lord Kelvin
>
> "If one would divine the future, then one must study the past." – Confucious

It might be worth considering the largest fire experiment in the world and its participants. Every time a building is used, in a philosophical sense it could be considered an experiment in fire safety. Almost always, the "experiment" ends safely and there is no fire. Every time a building has a fire presents an opportunity to measure fire risk by collecting data, with the intention of improving control over it. This data can be analyzed for information on areas of concern or types of buildings whose fire safety might need improving.

This can be a very powerful way of looking back at fire safety across segments of buildings or specific building types, but may not be very helpful when considering the future potential fire risks of a specific building under design.

QUANTITATIVE FIRE RISK ASSESSMENT

To consider the future potential fire risks of a specific building under design, full quantitative fire risk assessment might be necessary. This approach combines the probabilistic information from fire report data with predictions of the physical consequences of fire events.

Figure 1 shows the main tasks in a fully quantitative fire risk assessment where:

- Hazard identification – what can go wrong?
- Frequency analysis – how often is it likely to happen?
- Consequence analysis – how bad might it be?
- Risk acceptance – what should be done about it?

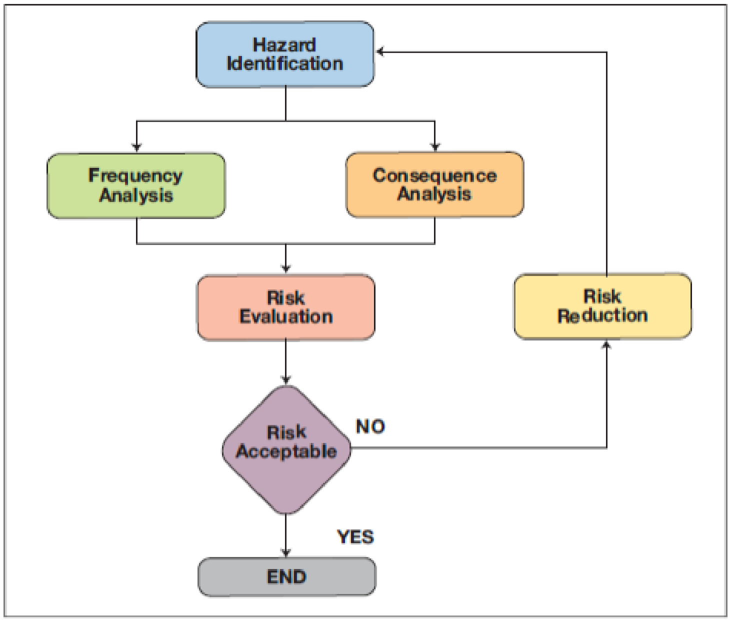

Figure 1. Quantitative Fire Risk Assessment Process[6]

One of the major challenges to quantifying future fire risk for a specific building design is that the events of greatest concern are very rare, and in many cases may not have happened yet and are not recorded in fire report data. Therefore, there is a need to break the fire event process down into many sub-events (for which there is data) so that they can be reconstructed to predict the probable frequency of fire events that have not happened yet.

Typically, the way this is done is through event trees and fault trees (Figures 2 and 3).

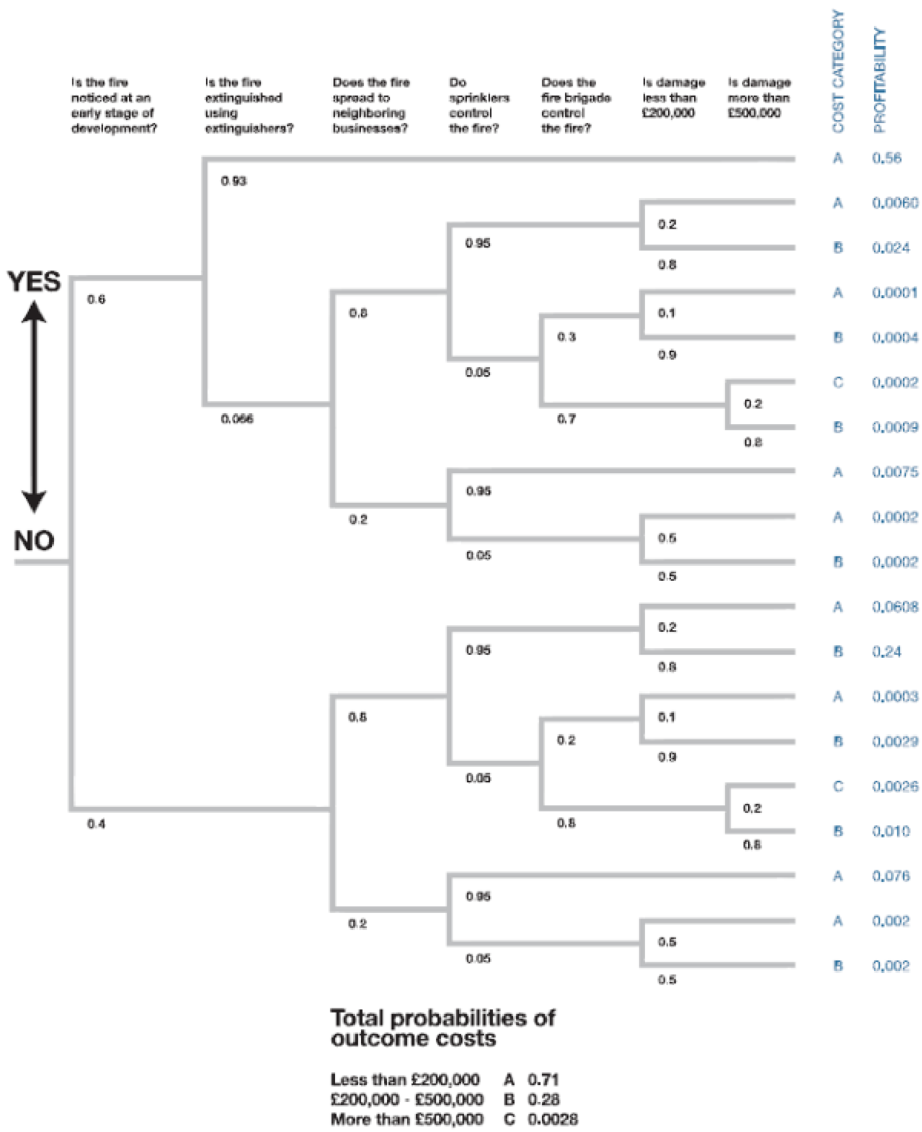

Figure 2. Example of an Event Tree[9]

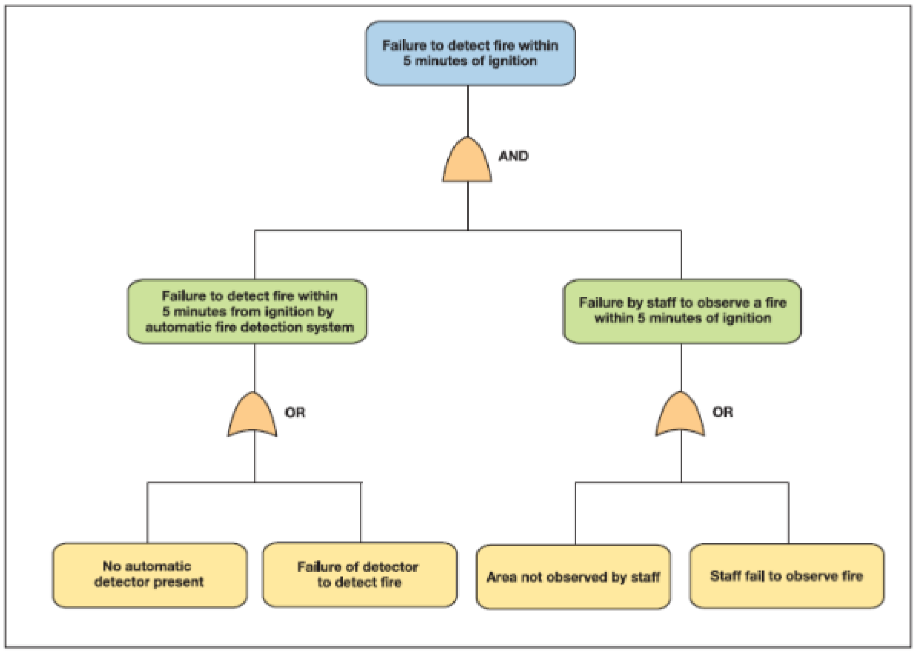

Figure 3. Example of a Fault Tree[10]

Event trees are helpful in considering all the possible outcomes (on the right-hand side) from an initiating event (on the left-hand side), which is usually ignition for fire risks. The frequency of the initiating event can be estimated from fire report data, and the conditional probabilities of the sub-events can be quantified from fire report data or fault trees.

Fault trees are helpful in quantifying the probability of a top event of concern (such as the failure of a fire protection system) from all the potential root causes (at the bottom), again quantified from fire report data.

It is not uncommon for concerns to be raised over the quality of data used in this analysis. However, the reasons why quantitative risk assessments are undertaken, in spite of the limitations of the available data, include:

- A lot can be learned about the failure modes of (and so improve) a design by simply constructing fault and event trees.
- The numerical outcome should never be treated as a precise prediction; it is just another way of better informing a design decision, in the same way that prescriptive standards and deterministic performance-based analysis are used to improve design decisions.

So quantitative assessment of fire risk should not be treated as an accurate prediction – any more than a fire test on a new item can guarantee the performance of all subsequent items in all applications throughout a product's life. However, they can both improve the risk outcome of a design.

How Bad Could It Be?

Having estimated how often it might go wrong, to predict levels of fire risk, it is also necessary to consider how bad the outcome of a range of fire events might be. The most potentially accurate way of estimating how bad a fire might be is through full-scale fire experiments.

While this might be the most interesting way to predict consequences, for the wider range of fire events under consideration in quantitative risk assessment, it would quickly become prohibitively expensive and time consuming. Therefore, most quantitative fire risk assessments use computer models to predict consequences.

What Should Be Done About It?

Having quantified the fire risks from a building design based on the frequency and consequence analysis, the crucial question then becomes what should be done about it. To inform this decision, it is worth considering why people accept or tolerate risk.[11]

The most common reason that people accept or tolerate risk is simply that they are not aware of it. The risks associated with asbestos and smoking used to fit into this category. Simply undertaking a fire risk assessment should help reduce the number of fire risks.

The next most common reason that people tend to accept risks is that the risk is so small to be of little or no (negligible) concern. People also tolerate risks where there is a significant benefit as a result of the activity associated with the risk. An example of this is travelling by road, which continues to be popular even when many people are injured and killed in road accidents each year.

Risk acceptance also identifies some interesting paradoxes. For example, why are most people who have a fear of flying happy to drive? Flying is much safer than driving, yet people tend to have more of a fear of flying. The difference can usually be explained by the insight that people are happy to accept a higher level of risk in an activity if they feel they have some control over the level of risk. So people feel they have a large degree of risk control when driving (voluntary risk) and little risk control (involuntary risk) when flying. This might also explain why societies are generally more tolerant of fire risks in single dwellings than they are in public buildings.[12]

For fire risk assessment in design, acceptance criteria can vary:

- For life safety (in the absence of absolute risk criteria), fire risks are usually compared to the fire risks for a similar type of building designed in accordance with well-established codes;
- For financial fire safety objectives, there is usually some financial cost/benefit or rate of return on investment criteria.

EXAMPLES OF THE APPLICATION OF FIRE RISK ASSESSMENT TO BUILDING DESIGN

In the following cases, quantitative fire risk assessment was used in conjunction with, not instead of, prescriptive guidance and deterministic performance-based fire safety design to give additional insights and more complete perspective on the fire safety design of the buildings.

Fields Shopping Center, Denmark

Fields was the first shopping center to be built in Denmark. While its design might be considered standard in some countries, the development was in the context of a general concern surrounding fire safety in retail premises. The Authority Having Jurisdiction (AHJ) asked for a quantitative fire risk assessment to supplement the code compliant and performance-based design aspects of the project.

Due to its general concerns surrounding retail fire safety, the AHJ developed some absolute fire risk criteria. The fire risk assessment indicated that the fire risks in all retail areas of the development were below the risk criteria. The predicted level of risks (similar to Figure 4) also showed a difference between small units and large units (with risks in the latter being higher). At this early stage in the design, the system designers were able to reduce the level of fire risk in the large units at minimal additional cost by increasing the redundancy and reliability of some of the key fire protection systems.

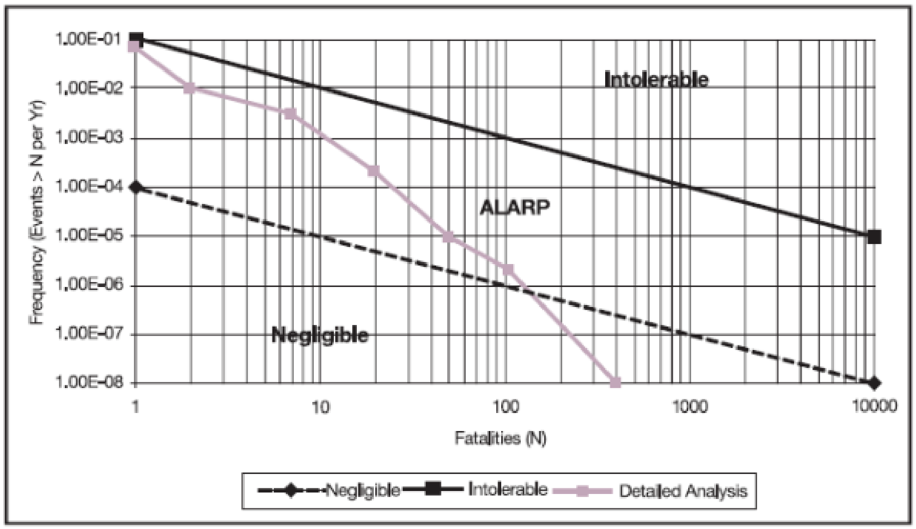

Figure 4. Example of F-n Curve Showing Different Levels of Risk[7]

Rail Infrastructure

Although life risks from fire were historically and consistently low, a major rail infrastructure operator was concerned about the number of fires, unwanted fire signals and their financial consequences for the business.[13] Therefore, a series of risk workshops using the matrix method was undertaken to prioritize the areas of highest fire risk and identify potential risk reduction measures for consideration.

The risk cost/benefit of these risk reduction measures was then quantified, and they were all presented on a graph in order of cost/benefit ratio (similar to Figure 5).

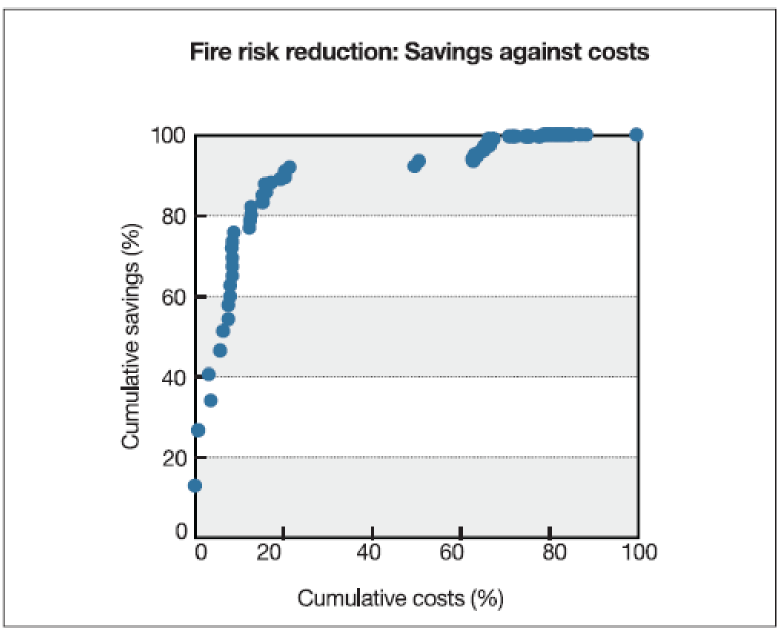

Figure 5. Example of Risk/Cost Benefit Ratios for A Range of Fire Safety Investment Options[12]

What the graph showed was that 80% of the risk reduction benefit could be realized from just 15% of the potential investment. This meant that for a £3million investment, there would be a return of £14million year on year (no payback or discounted cash flow analysis); in addition, a poor investment of £22million could be avoided. There was also a benefit for the users of the rail infrastructure, in that many of the risk reduction measures improved punctuality, while maintaining fire safety.

Fire Safety Guidance

Much of the current prescriptive guidance is now informed by statistical analysis of fire report data, and in some cases, no changes are made unless it is risk/cost beneficial. For example, in the UK, the proposal to discount an additional staircase in high-rise buildings following 9/11 was found not to be risk/cost beneficial. That is, the increased cost in prescribing the provision far outweighed any likely reduction in risk. Therefore, the prescription also includes the alternative of upgrading the lift provision for use during evacuations.

David A. Charters is with BRE Global.

References:

1. *SFPE Engineering Guide - Performance-Based Fire Protection*, National Fire Protection Association, Quincy, MA, 2007.
2. BS 7974, *Application of Fire Safety Engineering Principles to the*