Defining the Challenge:
Selecting Fire Scenarios for
Fire Protection System Design and Evaluation

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Background

A “fire scenario” is a detailed description of a fire, from ignition to extinction. Each scenario represents a possible fire to challenge the performance of a fire protection system, whether for detection or suppression. The system can be evaluated against the fire scenario in the laboratory, in which case the scenario is translated into a set of test conditions, or in the computer, in which case the scenario is translated into a mathematical description of fire-related conditions throughout the protected space.

Before you begin choosing fire scenarios, you need to decide on an evaluation framework or approach. One key choice is between a hazard-type assessment or a risk assessment. In a hazard-type assessment, you choose a diverse group of design fire scenarios, and you require the system to perform acceptably on each scenario. In a risk assessment, you choose a comprehensive group of scenario clusters, each weighted by its relative likelihood and each represented by a single scenario, and you require the system to perform acceptably on some overall measure that weights the scenario results by relative likelihood.

In either type of assessment, success or failure largely turns on the handling of challenging fire scenarios. A hazard-type assessment will be overly generous if it improperly excludes from the design scenarios a challenging scenario that would fail the system and would be regarded by the decision-maker or the affected parties as an important scenario to consider. A risk assessment will be overly generous if it assigns an improperly low likelihood weighting to a scenario cluster represented by a challenging scenario that would fail the system and again would be regarded by the decision-maker or the affected parties as an important scenario to consider.

Challenging scenarios

A scenario may be challenging because of one characteristic that by itself plays against the weaknesses or limitations of the system. A hazard-type assessment may be constructed against a group of these single-factor challenging scenarios, where each scenario is challenging for a different reason, but no scenario is challenging for multiple reasons. The several challenging scenarios used in the performance-based option of NFPA 101® are a good example of a group of design scenarios constructed primarily along the single challenging factor approach:

- Scenario 1: Typical and representative
- Scenario 2: Challenging because ultra-fast and in primary means of egress
- Scenario 3: Challenging because fire grows in normally unoccupied room before endangering a nearby large room or area with large number of occupants
- Scenario 4: Challenging because fire grows in concealed wall or ceiling space before endangering a large number of occupants in nearby area
- Scenario 5: Challenging because slow development (which may delay detection by fire protection systems) and shielded from systems; also near high occupancy area
- Scenario 6: Challenging because largest possible fuel load characteristic of normal operation, resulting in “most severe”, “rapidly developing” fire
- Scenario 7: Challenging because outside exposure fire
- Scenario 8: Challenging despite ordinary combustibles fire because one passive or active system is rendered ineffective; scenario not required if system reliability and design performance in absence of system are both acceptable to AHJ.

It is also possible to identify challenging scenarios that are “credible worst case” scenarios. These could be the most severe and challenging fires ever recorded – or the worst fires that have occurred with some regularity. They could easily be more severe than any of the NFPA 101 scenarios.

Beyond those scenarios are the theoretically possible scenarios that have not (so far) occurred anywhere. Such a scenario might combine a number of challenging conditions that have each occurred in real fires but have never occurred in combination. Alternatively, a challenging condition might be extrapolated in magnitude beyond any size yet encountered. For example, the fire might include the largest and most challenging fuel load the property is physically capable of holding.

Absent a risk assessment framework, it can be difficult to make a compelling argument against the inclusion of even the most severe and theoretical of these scenarios. Even if you are willing to do so, however, you will not be able easily to address reliability-related problems within a hazard-type approach. No system has perfect reliability, but no system worth having can be removed from a design without some impact on fire performance. At most, the deleted system can be justified as a backup.

*NFPA 101* addresses reliability-based challenging design fire scenarios by allowing the engineer to modify the criteria for acceptable performance, but there is no obvious basis for deciding what performance should be deemed acceptable under these conditions. Only a risk assessment, which weighs the increase in loss associated with system failure by the low likelihood of system failure, provides a mathematical basis within the analysis for evaluation.

Excluding reliability issues, the conditions that make a scenario challenging tend to fall into two types:
- Conditions that lead to a more rapid onset of unacceptable outcomes (such as death) or a more rapid onset of fire conditions that are taken as proxies of unacceptable outcomes (such as incapacitation, flashover, or structural collapse). This can involve characteristics of the fire (e.g., rapid growth, explosion or other unusually severe initial conditions) or characteristics of the exposed (e.g., proximity of high occupancy or high value to fire, unusual vulnerability of exposed).
Conditions that line up with system limitations, which primarily means uncovered or shielded fire locations.

Rapid fire growth involves far more than rate of flaming fire growth (such as the parameter for a $t^2$ fire). The proximity and nature of nearby combustibles may have more to do with the rate of overall fire growth than the burning rate characteristic of the first ignited item. The room size and room linings may be more important to the onset of flashover, and the wall coverings may be more important to fire growth via flame spread. Compartmentation or its absence may be the most important factor in fire growth beyond the first room. And room corner effects are yet another location-related factor that may be decisive in the challenge posed by a fire scenario.

A sufficiently severe initiating event may make all of this moot. Or, it may make it moot within a zone around the point of origin, but there may be far more building, population, and property outside that zone. The criteria for acceptable outcomes should be set differently for such an event, but the scenario is not inherently and completely outside the system design scope.

Because so many challenging factors are driven by fire location, it is worth considering patterns of fire origin in different types of areas of origin. For example, reported 2004-2008 structure fires in properties other than homes (that is, excluding dwellings, duplexes, apartments, and manufactured homes) showed the following patterns:

<table>
<thead>
<tr>
<th>Area of Origin Grouping</th>
<th>Fires</th>
<th>Civilian Deaths</th>
<th>Civilian Injuries</th>
<th>Direct Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normally occupied rooms</td>
<td>35%</td>
<td>56%</td>
<td>55%</td>
<td>32%</td>
</tr>
<tr>
<td>Exterior areas and surfaces</td>
<td>25%</td>
<td>16%</td>
<td>25%</td>
<td>14%</td>
</tr>
<tr>
<td>Normally unoccupied rooms (e.g., closet, other storage area, heating or machinery room)</td>
<td>24%</td>
<td>10%</td>
<td>7%</td>
<td>34%</td>
</tr>
<tr>
<td>Service/structural area excluding exterior areas but including concealed spaces</td>
<td>9%</td>
<td>7%</td>
<td>8%</td>
<td>15%</td>
</tr>
<tr>
<td>Inside means of egress</td>
<td>2%</td>
<td>5%</td>
<td>3%</td>
<td>2%</td>
</tr>
<tr>
<td>Unclassified or multiple areas</td>
<td>5%</td>
<td>5%</td>
<td>2%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Nearly half of all civilian deaths and injuries and two-thirds of direct property damage in non-home structure fires are caused by fires that begin somewhere other than a normally occupied room. Many of these areas are left out of coverage for at least some automatic detection or suppression system designs.

Factoring Reliability into the Evaluation

In addition to posing a severe complication to the mathematics of system evaluation, reliability issues are at the heart of a number of controversy-filled current arguments about the need for and the sufficiency of different fire protection systems. For example, is it reasonable for requirements for structural fire resistance to ignore the effectiveness and reliability of sprinklers, the less than perfect reliability of fire resistance, and the fact that not all building collapses are entirely unacceptable?
However, it is easier to identify the problems created by ignoring reliability than it is to identify valid, practical ways to incorporate reliability issues in context. Setting a separate standard for reliability creates all kinds of problems, and even then, you need to set different, less ambitious goals for design performance when a system or feature does not work, or else nothing is acceptable that is not perfectly reliable. And of course nothing is perfectly reliable.

Summary

An acceptable fire protection system must be able to achieve defined fire safety goals under the full range of fire challenges it may face. But no system can achieve the same fully satisfactory goals under all challenges.

Scenarios provide a way of grouping fire challenges into a manageable analysis task. Typical scenarios are not much of a test for a design. Typical scenarios can be handled by good systems, or bad systems, or even no system in many cases.

Challenging scenarios are where you really find out what the system can and can’t do. The challenging scenarios that no design can address may be excluded from the selection of design scenarios in a hazard-type evaluation or low-weighted into irrelevance by likelihood weights in a risk assessment. But some of those challenges are not really improbable enough to be dismissed in this way. And this approach is particularly unsatisfactory in dealing with reliability issues.

One way or another, it is not possible to really evaluate a design or a system without some attempt to quantify the likelihood of failure to achieve the fire safety goals (which is never zero). And the acceptability of a particular likelihood of failure to achieve the goals is very bound up with quantification of how badly you will miss the goals when you fail. Those two elements fit neatly into a risk assessment but not at all well into a hazard-type evaluation.