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RISK AND PERFORMANCE STANDARDS

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Richard W. Bukowski, P.E.
NIST Building and Fire Research Laboratory
Gaithersburg, MD 20899-0001 USA

Abstract

Performance codes are replacing prescriptive codes in much of the world. As the form of the codes change, the form of standards which support those codes needs to evolve in concert. Thus, performance standards need to be explicit about the purpose(s) served by the standardized systems and to provide quantitative means to assess the degree to which they serve that purpose. Most of the engineering methods evolving to support performance based codes assess risk to life of building occupants relative to the risk to occupants in buildings which comply with the prescriptive code. Such *relative* risk assessment is cumbersome and unreliable, and should be replaced by absolute risk limits to enjoy all of the efficiencies of performance codes. Financial risk is easy to understand but is inappropriate to codes that exist to protect life. Risk to life is difficult to understand and communicate to the public. These risk analysis methods utilize scenarios as a bridge to experience and the means to quantify likelihoods. In the absence of incident data some systematic methods of identifying scenarios is needed. This paper deals with each of these issues in an attempt to stimulate research needed to find the answers.

1. BACKGROUND

The worldwide migration to performance-based fire and building codes has placed new demands on the engineering profession. One of the most challenging is for meaningful ways of assessing the degree to which specific designs meet the requirements which society places on its constructed facilities.

With regard to fire safety, it can be argued that society expects the risk of death or injury from fire to be held to some acceptable level that varies with occupancy. For example in residential occupancies, people are generally willing to accept higher risks in their own homes as compared to hotels. The general risk literature suggests that society expects the risk of multiple deaths or injuries per incident to be decreased, roughly in inverse proportion to the numbers (i.e., the risk of 10 deaths in an incident should be 1/10 that of a single fatality). What is not clear is how to communicate risk implications to policy makers and the public, and how to arrive at risk targets that society considers acceptable.

The fact that every draft performance evaluation system is risk based makes it clear that risk is the metric of choice for the performance-based safety regulations of the future. This fact raises certain issues which need to be addressed early so that this beneficial process is not unnecessarily delayed. Some such issues include:

1. The regulatory system is made up of codes and standards -- the former dictate *what* is required and the latter *how* to implement something that is required or provided voluntarily. When adopted, both have the force of law, but codes establish the fundamental requirements and standards expand on the details. In the debate over performance-based codes and standards, they are lumped together. How should standards change (if at all) to support the evolving performance-based codes?

2. Insurance has long used financial loss as the metric for risk decisions, as this can be compared against rates charged, and the customer can choose to lower the risk and reduce the premium. However, fire codes are concerned with life loss, raising the specter of the "value of a human life" problem. Use of the risk of death directly is no better since this is a difficult concept to understand, and people are willing to accept much higher risk of the death of strangers as compared to themselves or their family. Thus, what is the most appropriate unit for fire risk?

3. There are (at least) two ways of performing a fire risk analysis. One is to identify a small number of scenarios that are representative of a class of scenarios and do detailed (and time consuming) predictions with a complex set of models. The other is to identify a range of values for a number of independent variables which define the scenarios and do a Monte Carlo simulation of a large number of variations using simple (and very fast) calculations. Which provides a more reliable picture of the risk?

4. Risk analysis requires the likelihood and consequences of events, some of which may not be known in advance. Fire safety engineering analysis can address the consequences, given the event. This leaves us to determine the scenarios of concern and their likelihoods. Fire incident data can yield both, but these are uncommon in the world, and those that exist are not always reliable or don't provide all the needed data. Can scenarios and their likelihoods be generated by models of initiating events?

2. PERFORMANCE CODES

Much of the discussion to date has focused on performance-based codes. From those codes in place or under development around the world there is a clear consensus on their general characteristics[1]. These include first, a set of clear, quantitative objectives and second, a means to establish whether those objectives have been met. A performance code will usually also include "deemed to satisfy" provisions which codify approaches which experience has shown to provide acceptable solutions, such as the dimensions of egress stairs. These performance codes further include "Approved Documents" which are intended to catalog acceptable solutions for use in cases where a performance analysis is not needed. The first such approved document is generally the old prescriptive code.

In this way, the role of the code is to make clear the objectives which society desire for its constructed facilities. Examples from the fire regulations in the New Zealand Building Regulations of 1992[2] (which are typical of those being developed in other countries) include:

"Clause C2 - MEANS OF ESCAPE

OBJECTIVE

C.2.1 The objective of this provision is to:

(a) Safeguard people from injury or illness from a fire while escaping to a safe place, and

(b) Facilitate fire rescue operations."

Nearly everyone would agree that this is the fundamental intent of fire regulations -- to allow for safe egress. With prescriptive codes it was implied that buildings which provided all of the features and arrangements required would be "safe," and in a performance code this is an explicit objective. It can be argued, however, that this is still not sufficiently clear. For example, does society intend that *everyone* be able to exit without injury? Does this include those with physical limitations, infants, persons intimate with the ignition, and under all conditions and at all times of the day or night? Are even minor injuries which do not result in lasting deficits prohibited? Is society willing to accept the cost implications of fully protecting everyone all of the time? We certainly need to do a better job of understanding what society expects and at what cost.

3.0 PERFORMANCE STANDARDS

As the world transitions to performance codes, standards will still be needed to provide the detail of how to meet the intent of the code. However, since the form of the code has changed, the form of the standard should be re-thought so as to best complement the performance oriented nature of the system. Specifically, what form should a standard take relative to that generally agreed for a performance code?

Since the code is built around explicit objectives, the standard needs to clearly state its intent regarding the purpose of the system or feature covered. For example, alarm systems are intended to provide early detection of an unwanted fire, notification to the occupants of the need to evacuate or relocate, and notification of the fire service of the need for their assistance and, in large buildings, direct them to where they need to go. Further, an alarm system should **not** respond to conditions not associated with an unwanted fire and should **not** direct the fire service to areas other than where the fire is to be extinguished. Finally, alarm systems should be reliable and able to meet their stated objectives (or some subset thereof) during any single fault condition from a specified set.

Thus, the form of a performance standard is first, to explicitly state its purposes and second, to provide a means to establish quantitatively what constitutes meeting those purposes. In addition, any quantitative measure of the ability of the system to fulfil its purpose needs to include the reliability of systems. This refers to the likelihood that such protective systems will perform as intended when called upon to do so. Like the code, the performance standard will have "deemed to satisfy" provisions which describe arrangements which are known to meet the intent. Current prescriptive standards are likely to comprise early "Approved Documents" for standards as well.

3.1 Purposes of Standards

Fire safety standards cover a myriad of topics, but can be considered to fall into several, broad categories. Standards on fire protection systems and components such as fire alarm, sprinkler systems, fire pumps, emergency power systems, etc., are all intended to assure the reliable operation of critical equipment in the event of a fire. They detail the proper installation, maintenance, and use of the equipment or systems covered which are deemed necessary to assure reliable operation. Here, the purpose statement would include the function provided by the system, such as notification of occupants and emergency services for an alarm system, extinguishment of the fire for a sprinkler system, provision of sufficient pressure and flow for a fire pump or voltage, current, and frequency for an emergency power system.

Another category of fire standards covers the safe installation and operation of equipment and systems needed to prevent fires from starting or to limit their size or impact. Examples would include standards on ovens and furnaces, chimneys and fireplaces, power plants (nuclear or fossil fueled), and various standards on the safe storage and handling of combustible or hazardous materials. In this case, the statement of purpose needs to include quantitative performance measures such as the maximum heat release rate which would be allowed from the maximum quantity of material which can be stored in a given fire area, or the maximum temperature which is allowed on a surface under the most severe conditions of operation.

A third category of fire standards relate to test or measurement methods or standard guides on methods for the collection of information or to define a process such as the investigation of fires or the conduct of fire hazard or fire risk assessments. These standards attempt to provide reliable and consistent information on which decisions can be made with confidence.

3.2 Quantitative Measures of Performance

The first category of standards might talk of detection of fires before they constitute a threat to occupants and while there is sufficient time for safe egress, or of sprinkler activation and fire extinguishment before tenability limits are exceeded in the room of fire origin. In these cases, the quantitative measures of performance are the fire size at detection or activation and the "worst case" exposure to occupants before extinguishment. In addition, an estimate of the system reliability in terms of the likelihood that the system will perform its function when called upon if the provisions of the standard are followed, must be included.

For those standards intended to prevent fires or limit their impact or size, the measure of performance is the assumed rate of ignitions or the limiting conditions that can be assumed if the standard is followed. Where standards are intended to provide uniform procedures for making measurements or testing performance, techniques of assessing repeatability and reproducibility exist and should be used as both the measure for performance and reliability.

4. ASSESSING RISK

Once the Performance Codes and Performance Standards are in this format, the use of risk assessment as the method to determine compliance becomes possible. The Codes will express for any occupancy, the consequences of fire which society is willing to accept as its objectives, and the types of analysis or "acceptable solutions" which demonstrate compliance.

From these, an engineering analysis will identify what approaches can satisfy the list of acceptable consequences. Each approach requires that certain functions are performed, and these are associated with Standards that explain how the equipment, systems, or procedures are to be implemented and maintained in order to assure the function, and an associated reliability by which the function must be discounted.

This method identifies the complementary aspects of systems such that if one fails to provide its function, another will provide it, perhaps at a reduced level (in the absence of common failure modes). This allows redundancy without unnecessary duplication, allowing cost optimization without sacrificing safety.

However, what has been described so far (avoidance of specified consequences) is not risk, but rather hazard assessment. Design fires may be specified in the codes by occupancy along with the ability of the engineer to suggest alternatives for specific applications, based on an analysis of the fuels and ignition sources present. If probability distributions for these as well as some other parameters such as occupant loadings and characteristics (e.g., age, sex, physical and mental capabilities) are provided, a risk assessment can then be performed.

4.1 Relative Risk

In all but one of the engineering methods proposed in support of performance codes the risk assessment is for *relative* risk. This requires that the risk of the subject building be assessed and that the risk for a similar building (same occupancy and general characteristics) but designed in accordance with the prescriptive code also be calculated so the two can be compared. This doubles the computational burden and discourages the calculated solution in all but those few cases where no alternative exists.

Justification of the relative risk approach usually takes a form similar to statements made by Australia's Building Regulatory Review Task Force (BRRTF) which said,[3]

> "... with a few exceptions the Australian community appears to be reasonably satisfied with the safety levels achieved by our current regulations."

This leads to their conclusion that,

> "... the risk levels achieved by buildings designed to the current regulations can be used for the time being, as convenient benchmarks of the risk levels which must be achieved by any alternative fire safety system arrangements."

But relative risk poses some potential pitfalls which need to be considered. For example, Brannigan argues,[4]

> "The statement that the public is satisfied with the level of fire safety is debatable, but even if true it does not necessarily support the statement of equivalence (to buildings built to current regulations) for at least four reasons:"

Paraphrasing Brannigan's points: First, the equivalence statement assumes that the public is satisfied with an expected risk to life rather than a safety level. Fire, especially disastrous fires are rare events. When dealing with rare events the public may believe that the risk to life is actually zero.

Second, the claim that society is "satisfied with the level of safety achieved by our current regulations" assumes that the current regulations are the sole cause of this socially acceptable level of safety. Codes specify minimum requirements which are often exceeded in the recognition of liability or public image (e.g., significant improvements in fire safety were implemented by the lodging industry following the fires of the 1980's, well in advance of changes to the codes). If the performance level is set as equivalent to the minimum code, the result may be an increase in losses when compared to the code compliant building.

Third, they assume that the engineering methods accurately reflect the expected risk to life in different buildings. It may not be possible to predict accurately loss rates in the future due to the fact that stochastic elements are based on past materials and lifestyles which may change (e.g., smoking materials are among the most commonly cited ignition sources in fatal fires, and the rate of smoking is rapidly declining in many countries).

Fourth, they assume that both the buildings and society's views of risk are static. Fire disasters often point out flaws in the code which are subsequently corrected. If such a flaw were uncovered, the performance method would allow buildings to continue to be built with that aspect of risk uncorrected as long as that hazard goes unrecognized by the prescriptive code. Most societies would not accept such a practice.

4.2 Absolute Risk

The draft Code of Practice from the British Standards Institution (BSI)[5] is the only method which has attempted to set acceptable levels of risk. The proposed values are based on current fire losses in the UK. The authors suggest

> "... that the public broadly tolerates the average risk of death from fire provided that the number of deaths in any one incident is small."

They suggest a value for the risk of death per individual per year at home (1.5×10^{-5}) or elsewhere (1.5×10^{-6}), and for the risk of multiple deaths per building per year (>10 deaths, 5×10^{-7}; and >100 deaths, 5×10^{-8}). Of course, the comments made in the previous section concerning any assumption that society is satisfied with current losses apply here as well. Thus, some better method of making public policy decisions about acceptable levels of risk is needed.

As discovered by the nuclear power industry, the problem is that risk to life is too abstract to be understood by the public. Risk acceptance is highly variable, depending on to whom the risk applies (individual vs. society), the perceived value of the activity, whether the risk is assumed voluntarily, and whether the people at risk are considered especially deserving of protection (e.g., children, elderly, handicapped, or involuntarily confined). Perhaps if the risk were expressed in a way which had meaning to the public it would be easier to obtain policy decisions on what is acceptable.

5. EXPRESSING RISK

5.1 Risk to life

Expressing risk to life in a way which can be understood by the public is a problem which has been addressed for years by the nuclear power and air transport industries with limited success. At the most basic level risk to life is a small number generally expressed in scientific notation, which itself is not understood by most people. The risk is normally compared to events or activities such as the risk of being struck by lightning or the risk of death during skydiving. While the public impression is that these are rare events, they really have no good feel for how rare.

5.2 Risk of financial loss

This leads to the consideration of other metrics for risk. The general unit of value in society is money, and the insurance industry has expressed risk in monetary terms for most of its history. Risk of financial loss is easy to understand and allows direct evaluation of offsetting benefits of investment in reducing risk or in the costs of insurance against the loss.

Financial loss is thus the perfect metric for risk but for one problem. The primary focus of fire codes is life safety, requiring that risk to life must then include a measure of the value of human life. Numerous (at least partially) objective measures of such value have been proposed -- earning potential over the remaining expected life, potential contributions to society, costs of insurance or legal settlements, costs associated with regulation intended to reduce accidental fatalities, to name just a few. In each case the concept that some people have less "value" to society than others is met with great objection, especially by those whose value is deemed lower.

6. ESTIMATING RISK

Traditional risk analysis has involved probabilistic techniques for both the likelihood estimates and the consequences of the events. These techniques may use experience (generally the case in most fire analysis) or may involve expert judgement and failure analysis methods where there is little or no experience (such as in the nuclear power industry). Regardless of how it is approached, one of the strengths of risk analysis is its ability to deal with distributions of outcomes based on variations in conditions which affect these outcomes. For example, doors may be open or closed, systems may be out of service, people may be present or not, and so forth. When major fire incidents are examined, it is generally recognized that a number of unfavorable conditions needed to be present for the accident to proceed to the observed condition.

In recent years the evolution of deterministic fire models and other predictive techniques has led to the desire to assess the consequences of events in a more objective manner. An early attempt to develop methods to quantify the fire risk of products met with limited success[6,7]. Since then, other risk assessment methods have been developed which have followed a different philosophy. The early method cited identified a limited number of scenarios, each representing a larger number of scenarios in a class, and used detailed physical models to estimate consequences. A more recent risk model[8] limits the level of detail included in the physical models to minimize execution time, and identifies much larger numbers of scenarios (by establishing distributions for most input variables). It then uses a Monte Carlo technique to determine distributions of outcomes.

This difference raises an interesting question. Is the fire risk affected more by the distribution of possible conditions of the scenarios or by the physical and chemical processes present in the fire itself? Or more directly, how important is it that the simplified models may predict the wrong consequences because of their simplicity, or that the Monte Carlo approach may miss a dominant case? The former can be addressed by validation studies and the latter by parametric studies. Some of both have been done, but more work is needed.

7. SCENARIO GENERATORS

Most of the research effort in the development of risk assessment methods has been in the estimation of the consequences of events. But the quantification of risk is equally dependant on the ability to describe detailed scenarios and their likelihood of occurrence. In a few countries fire incident data are collected that can be used for this purpose, but often we find that not all the needed information is collected[6]. The most recent national fire incident data system was initiated in Australia to provide such data for risk assessment in support of their new performance codes.

But these are the exception. Most countries do not collect incident data in any comprehensive way. Instead, risk methods use scenario descriptions and frequency estimates obtained from experts such as the fire service or insurance interests. This approach suffers from numerous shortcomings not the least of which are data skewed by the perception of the expert and lack of representativeness in sampling.

In 1989 NIST sponsored some work at UCLA on the feasibility of modeling initiating events for the purpose of making improved scenario descriptions and ignition frequencies, based on techniques developed for use in nuclear power plants[9]. While the techniques show some promise, limited resources has resulted in a halt to this line of research.

8. CONCLUDING REMARKS

The world community is clearly moving toward performance codes as replacements for both building and fire codes of a more prescriptive nature. Standards support codes in the building regulatory process and the format of performance standards needs to change in a way which is consistent with their need to support performance codes. Since the codes specify objectives it would seem that the standards need to specify the functions to be performed and the reliability with which these functions are provided.

For public safety related objectives, risk seems to be the method of choice on which to base judgements of acceptable performance. Most fire safety engineering methods currently under development use relative risk based on the hypothesis that society is satisfied with the current fire risk in buildings. Some, such as in New Zealand, Japan, and Australia do so implicitly by accepting relative risk assessment against buildings which comply with the prescriptive code. One, developed for England and Wales, has established explicit risk targets equal to current loss experience. However, arguments have been raised which may mean that either approach might not withstand legal challenges. Further, no regulatory bodies other than in Japan have accepted either approach in practice. Hazard based approaches that measure performance in a prescribed set of scenarios avoid these problems, but these generally do not consider the most rare events which still may incur public outrage. Deterministic models have a seminal role in fire safety engineering analysis to support this process, but the engineering community has yet to sort out the best approaches to estimating risk and communicating the results.

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Discussion

Patrick Pagni: Dick, I've got a real problem with that idea of minimizing the physics. It's crucial, I think, when we start making these performance-based analyses, that we get it right. If we get it wrong, people are going to throw us away with the bath water and we won't have a chance to come back and do it right later. So, while it may be important to have a fairly broad range of scenarios and while picking those is a key problem, being willing to throw away the physics in order to broaden the range of scenarios is a path down in which we ought not go.

Richard Bukowski: I certainly agree with that. That's why I said we have to find the right balance. We can't throw away all the physics, but at the same time, I think we want to look, for example, to see if there is some easy way to make an estimate. There's parts of it, I think, we can finesse and save a certain amount of time. The approach that David Young took was to go to a simple reactor model instead of two.

Howard Emmons: I was interested in Pat's remark because I have always thought, as you might expect, in terms of the ultimate future, when we have a program that is so complete that we can compute any fire with any accuracy we please. But when we look at the big building, there are at least dozens of places a fire might start. There are probably thousands of combinations of open doors and closed doors and windows, and goodness knows what. I have never though in terms of your present statement in which by reducing the physics, we might examine these thousands of possibilities quickly, but not very accurately. However, by looking at the results, we could pick out the four or five combinations that are essential because they are the worst possible ones. Then we could run those with the ultimate model, if and when we get one, so that we really can say this building is safe.

Discussion cont.

Edward Zukoski: I sort of agree with Howard. There are so many physical combinations of the building, and there are so many different-sized fires, and the thing your worried about most, as far as life safety, is often what happens a long way from the fire. But it seems to me what you suggest is a very reasonable way to approach it, particularly given the wide range of fuel types and everything else you have to worry with.

Takeyoshi Tanaka: I also agree with the comments made by the two previous speakers. If we can come up with simpler models, then that would be better. And if it takes the form of an equation, it will be even better because by doing so, we can see the effect of changing the parameters or changing the size of the fire. We would know how much the size of fire would impact the results. I think that would be a very convenient thing for designers to use. So, I believe such simple model would be very useful to get an estimate of the risk at the first stage, and I think we should do more work in developing such simple models.

John Hall: In statistics, we're accustomed to stratifying random samples to put our power where the leverage is greatest. In computational fluid dynamics, we're accustomed to making the grid sizes smaller in areas where we want more leverage. I take your presentation, whether it's talking about the public's checkered view of risk or the balance between physics and scenarios, as a call for a more comprehensive approach to managing and minimizing the overall error in our analysis and our decision making procedures, and I think it's great.

Makoto Tsujimoto: When risk evaluation was discussed about ten years ago, there was not much interest expressed. However, this time there is a lot of interest in risk evaluation and I welcome this trend. I would like to make a few comments because I have been involved in risk assessment in a very serious way in Japan for a long time. In this kind of research, we have to find out where acceptable risk is. We conducted a survey using a questionnaire to compare the level of acceptable risk and what people perceive as absolute risk. Of course, there are not many methods to correctly calculate absolute risk, but with the use of many methods, we compared absolute risk verses the perceived risk, and we didn't find any correlations. So when we conduct such risk assessment, I think it's important for us to pay attention to what kind of risk environment we are in.

John Rockett: This pertains to Howard Emmons's comment. The model that I published in 1968, which was a horrible model, had somewhat the idea in mind that was just expressed. However, after I had been doing that for a while, I began to be very sensitive to what is now referred to as chaos theory in the highly non-linear nature of fire and the fact that even though you have surveyed a lot of cases with a simple model and you think you have identified some extreme cases for further detailed analysis, you may have completely missed the point.