Fire Scenarios or Scenario Fires?
Can Fire Safety Science Provide the Critical Inputs for Performance Based Fire Sadety Analyses?

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ABSTRACT

Performance based codes promise to use modern engineering tools to satisfy the social goal of fire safety. Social fire safety goals can include life safety, property protection, or even requirements for redundant systems. But current proposals for performance based codes do not contain any technical method for connecting engineering designs to social goals. As a result, designers, not society, have been setting the key technical inputs, in particular designers have proposed that performance based solutions should only deal with a design fire, rather than providing the promised overall safety. This change allows designers substantial freedom, but at the cost of shifting key decisions on safety from public to private hands. Performance based codes will require a method for specifying the social requirements for fire safety in useable engineering terms, and enforcing those requirements on the building as completed.

KEYWORDS Performance based codes, fire risk, regulation, uncertainty

INTRODUCTION

Fire safety science is supported around the world largely because of its contribution to the scientific quality of fire safety regulation. Modern fire safety analyses often use complex fire modeling tools incorporating this scientific knowledge. It has been broadly suggested that these tools should spark a worldwide movement towards performance based codes.[1] However both the acceptance and questioning of performance based codes have taken place in an environment in which there may be fundamental confusion over the underlying scientific and technical support for performance based codes. Proposals for performance based codes can shift key policy making responsibility from the public to the private sector, so it is vital that any such codes be supported by unquestioned technical and scientific evidence.

All models are simplified abstractions. Decisions concerning the inputs and structure of a model are a function of both the real world situation and the tastes and preferences of the modeler. In the case of fire safety, the completeness of the model and the quality of the data used for inputs are critical questions in deciding whether the regulatory system can use the model. [2] Problems in evaluating the technical and scientific inputs can easily arise from differences in perspectives between policy makers (focused on the problem of acceptable building safety), and fire modelers (focused on the problem of predictable fire development).

Fire safety codes exist to protect public safety and are an exercise of fundamental government power. Traditional regulatory systems do not depend on scientific validation of legal requirements. Instead such codes are "politically" validated and decision-makers are politically responsible for their choices, even when the political decision is phrased in technical terms. Suggestions for performance based codes often involve transferring some portion of the decision making from political to technical spheres. Legal principles allow do allow delegation of public safety decision making to professionals only when the society can be assured that the socially mandated level of safety will be provided. This requires differentiating setting the level of safety from describing technical means for providing that level. While it may be appropriate to allow professionals wide discretion in devising the technical means for meeting public safety requirements, setting the safety level is a social decision and cannot be concealed in the technical exercise

WHAT IS A PERFORMANCE BASED CODE?

Performance based codes are normally presented as scientific, modern, efficient and professionally fulfilling. The term "performance based" codes is widely used, but it is not easy to relate how it is used in fire safety to use in other fields. Ken Richardson set down a widely accepted framework for performance based fire safety codes [3]:

> 1) *the outcome of the code is stated in terms of "lives and property saved" and generally specifies a "level of safety"*
> 2) *the codes specify verifiable performance requirements with demonstrated, quantifiable links to the objectives"*
> 3) *the codes permit any solution that meets the performance requirement*

This proposal claims that engineers have the ability to "verify" a connection between the "level of safety" of the design and "lives and property saved". If true it would have a substantial advantage over "prescriptive codes" that could not provide a measurable level of safety. Performance based codes tend to reflect this concept of "overall" fire safety. For example the UK statute states:

> *The building shall be designed and constructed so that there are means of escape in case of fire from the building to a place of safety outside of the building capable of being safely and effectively used at all material times*

Performance based codes also emphasize that they achieve safety outcomes:

"Fire safety goals are the overall outcomes to be achieved with regard to fire"[4]

But while the goals are often stated as lives and property saved, the engineering requirements are expressed in technical terms, not in life and property safety goals. Proponents claim to be able to connect the requirements to the goals by ***scientific*** methodologies:

> *Means to achieve compliance with the code begin through a rational thought process supported by scientific understanding of fire, followed by proven fire safety methods and calculations. This process lends itself to the use of computer models, which serve as tools to better implement these principles.*[5]

Can fire safety science establish scientifically that the building meets the social goals? Which are policy and which are technical decisions? How do societies make sure that engineers are not usurping the fundamental social role of determining the level of safety, under the guise of setting performance criteria?

Performance Based Codes In Other Areas

It is worth comparing alternative forms of performance based regulation. For example in environmental regulation the performance based regulatory requirement may be expressed as a limit on toxic gas release of so many parts per million (PPM). This is a true performance requirement, since there is no specific technical means is specified for compliance with the standard. However the goal of the regulation is not expressed in terms of how many cases of disease are prevented. The requirement is also specific to the pollutant. Pollution controls do not normally allow trade-off among pollutants based on a total number of injuries caused. PPM levels are simple to enforce.

Required testing is another kind of performance regulation. Such performance standards required specification of the test methodologies, such as those used for testing automobile crashworthiness, aircraft exit times, or aircraft icing resistance. Tests are generally considered valid only over a limited technological range. It is difficult to develop a single performance standard for widely different technologies or human responses, as shown by the recent controversy over air bags and short passengers. Traditional fire tests belong in this category.

Civil engineering performance standards which describe in detail the loads which structures carry, but not how to build the building. "Performance" is compliance with a legally set out engineering standard, such as 60 pounds per square foot. However there is no scientific statement of the actual level of safety, only that if the stress falls within the politically accepted level, the building will respond in a certain way.

In all of these cases the social risk evaluation is completed before the technical requirements are developed. The EPA says how much of a pollutant is acceptable, the DOT says what amount of crash resistance is required and building codes set out what load the building should carry. None of them say how safe the society is as a result of the regulation. Engineers are presented with a technical requirement, not a social goal. The requirement is created by a technically informed political judgement, stated in engineering terms.

The only regulated area that makes "absolute" claims of a level of safety for performance based engineering is nuclear power. [6] Probabilistic safety assessments for nuclear power claim to be able to predict the real risk of catastrophic loss and regulation can keep the plants at the socially acceptable level. But nuclear power plants are highly engineered; well-defined, heavily regulated industrial facilities not open to the public. The industry was willing to spend the many millions of dollars required to do the risk assessments, and had clear engineering support for most of the key points of the analysis. But in a very real sense nuclear power plants can do performance based analysis because the problems they face are rather simple compared to fire safety in ,for example, a low income housing project.

So why did fire engineers claim to be able to predict the level of safety in the first place? Why take on the extraordinary burden of proving scientifically that a given level of technical fire protection will produce a given level of social safety? The answer to this question may lie in the social process which gave rise to performance-based codes and the method by which the models were transferred from the laboratory to the field.

FRAMING THE QUESTION OF FIRE SAFETY

The important social questions in fire safety can be analyzed using the concept of "technological frame" as developed by Bijker.[7] Bijker describes the social treatment of technological "artifacts" e.g. fire risk models. Bijker suggests that the purpose or function of any technological artifact cannot be determined from examination of the artifact itself but must be described in terms of the social functions that the group around the artifact expects the artifact to perform. These include both technological and non-technological functions.

According to Bijker the creation of a new technological artifact creates a new "technological frame". The frame "leads to the attribution of meanings to technological artifacts". For performance based analysis, "meaning" describes the functions to be performed by the fire model. Performance based codes were an outgrowth of technological development in fire safety science, not a product of a social demand for a new kind of fire safety. The fundamental drive was a promise of cost reduction or architectural freedom. These are social, not really technical goals. Performance based codes were therefore not solely a technical movement but also had social components.

The original "technological frame" for performance based codes suggested total elimination of regulatory decision making in the code enforcement effort. The goal was to shift fire safety decision making from a "political" regulator to a "technical" engineer. There was little analysis as to whether fire protection engineers had a clearly better technological solution then the political regulators. Traditional codes were not disfavored because of specific fire safety requirements; they were disfavored because the political decision-makers created the technological requirements rather than fire protection engineers. Engineers claimed, in effect, that they had a high enough level of fire safety understanding that they could “tailor” fire protection to hazards and achieve the socially desired level of safety.

Richardson proposed that society could set a level of safety in terms of lives lost. Fire engineers could then use "any technology" that promised not to kill more than the allowed number of people. As a result the only role for regulators was to check whether the methodology was sufficient. In this environment it was essential to claim that the technology could guarantee a social level of safety. The ability to guarantee a level of safety restated the "social" fire problem as a fire protection "engineering" problem

Some economists in the 1970s made similar claims that benefit/cost analysis would allow the replacement of political decision making with “scientific” decisions based on economic analysis. The problems was that scientific tools developed for economic analysis of the return on investment of public utilities did not function well in the non-marketplace environment of personal injuries. The net result was to make sure that policy makers were given economic analysis of regulatory programs, but the final decisions were still made on policy grounds.

At least three different social movements were used to "frame" the proposals for performance based codes. Performance based codes are clearly part of a "regulatory reform" movement which developed in the mid’70s. Much of this reform urged replacement of political with technological decisions. Many statutes in the United States required safety regulations to be stated in "performance" standards. Structural engineering developed performance based regulation. Proponents often rested on the claim that "performance based" was a "good thing" compared to those old fashioned "prescriptive" codes

The second social issue, which is much more specific to fire safety, is the suggestion that fire safety should only mean life safety, rather than property safety. Proponents claimed that "property protection" is not a social issue. The attraction of course is that protecting lives from fire is conceptually much easier than protecting property.

A third social issue was the repeated claim that existing prescriptive codes contained "redundancies" i.e. required a variety of safety systems to provide the desired protection. Performance based code advocates routinely referred to codes having "excessive redundancy" with the clear implication that excessive redundancy is a clear technological error.

While all three of these social factors were used to promote performance based codes, in each case there were countervailing arguments. In the case of regulatory reform performance based fire codes were proposed before there were clear models or case studies to support these codes. The reality that existing codes are a complex mix of performance and prescriptive requirements was often lost in the shuffle. In many areas it was much easier to demand performance standards than to write them. [8] Unless regulatory agencies are given an astounding level of regulatory autonomy, it can be fairly difficult to write enforceable performance standards.[9] This is especially true when widely differing technologies perform similar functions. E.g. how do you create "performance standards" for exit signs?

In the case of property damage, countries vary widely in terms of the acceptability of such damage. In the United States local jurisdictions compete for industrial development, and depend heavily of property tax revenue, so it is much more difficult to convince regulators to accept the "life safety only" concept than in a country with a different social or tax system. Focussing only on life safety also allowed some obfuscation of the reality that performance based fire safety design could result in destruction of the building. This was hardly good public relations, especially when using civil engineering as an analogy. Civil engineering performance based regulation does not consider a building a success simply if the people can be evacuated before the building collapses.

Finally the required level of redundancy is clearly a social, not a technical decision. There is no social consensus that redundant systems are bad. Cars are required by law to have dual braking systems, aircraft have multiple safety systems, nuclear power plants have defense in depth. Societies may simply choose not to have all the technological eggs in one basket.

Regulators began to understand that systematic elimination of redundancy was often concealed in the risk models themselves, usually by assumptions that all systems worked or that the fire load, or the possibilities of system failure were within arbitrary bounds. Some regulators, such as the Nuclear Regulatory Commission began demanding specific proof of redundancy as part of the modeling process.

REGULATING USING FIRE SAFETY SCIENCE DATA

Many authors point out that performance based fire regulation began as a management tool by the US General Services Administration. But a key difference between management and regulation is the need to express a regulatory goal in sufficiently concrete terms to evaluate whether the regulator is performing and the regulated party is complying. Regulation requires a precise technical system for measuring compliance with the social requirements. But in the process of developing performance based codes this key step was omitted. Even assuming that the actual hazard or risk could be evaluated, no one developed a comprehensive method for expressing social judgements about fire safety or fire hazards in useful regulatory terms. There is no fire safety unit really comparable to pounds per square foot of load. A performance based analysis may use a 5 MW fire as a scenario, but furniture and other combustibles do not come labeled in megawatts, so there may be no clear way for a regulator to keep a fire load within the assumptions of a fire safety analysis. This is the critical difference between fire safety analysis as a scientific or analytical method and a useful regulatory tool. Unless and until fire safety science can express social requirements in a technical language, it will be difficult to integrate the science into the regulatory process

It became obvious that total elimination of the regulators as proposed by Richardson proved to be impossible, both for technical and political reasons. The rhetoric of performance based codes shifted to the vocabulary of "objective based codes". More detailed technical processes were proposed. But the underlying claim remained that engineers could provide a desired level of safety using engineering methodologies. Performance based fire safety codes continue to make the claims of a providing the socially required level of safety. But how good is the connection between fire science and fire safety?

Fire Models: Hard and Soft Inputs

Fire models originated in the explanation of specific fires, whether in the laboratory or the real world. These were fires in which the modeler knew virtually all the key environmental variables contributing to the fire. In these fires the "hard" part of the task was reliably modeling the thermodynamics, mass loss, ventilation etc. Engineers who were successful in "explaining" these real or laboratory fires began to believe that they had defined the problem of engineering for fire safety and had the ability to "predict" fire development. Explaining past fires soon led to claims that these models were accurate enough predictors for the regulatory environment. The caveat was that the engineers may only be able to predict a fire if all the relevant environmental variables are known to the same degree of precision as in the explained fire, and if at that level fires are deterministic entities.

Fire safety risk analysis uses many different types of inputs. It is possible to identify both "hard" and "soft" inputs. “Hard” inputs are usually based on precise laboratory findings, but data on human behavior and similar variables, for which no standards exist, is often very “soft”. The mathematical models seemed so powerful it may have seemed trivial to "nail down" the soft variables and be able to "engineer" a building for fire safety. The laws of thermodynamics, mass loss and combustion products seem to be dominate the analyses, compared to the "soft" data related to of human behavior, fire load, building condition or initial fire. A value for a "soft" variable can be produced for use in the model, without analysis as to whether the value of the variable is real, a point, or a point estimate on a continuum. Even the most determined advocate of fire models accepts that the "hard" part of a fire safety model represents only a partial solution to the fire safety-engineering problem. Where they may disagree with regulators is whether the "hard" part can be used without adequate data in the "soft" part.

In some ways the distinction follows the dichotomy between ***Epistemic*** and ***Aleatory*** uncertainty. Epistemic uncertainty refers to the actual "rules" of a process, which in the case of thermodynamics is fairly well understood. Aleatory uncertainty refers to the quality of data used in the process, which in the case of future fires may not be well documented at all. Aleatory issues such as the input fire, fire load or human behavior are often described with words like "assumptions", "Art" and "expert judgment". Dubious suggestions are even made such as "code compliance can be routinely assumed", "sprinkler systems are always functioning" or that "fire alarms result in instant purposeful movement".

The problem of arbitrary data appears to be aggravated if the goal is confidential regulatory approval rather than published engineering analysis. Dr. Hall of the NFPA sensibly cautions users of fire risk models.

> *If only a few scenarios are modeled explicitly, then each one is implicitly required to be representative of a much larger and more varied collection of other scenarios. There may be no good evidence to support this.*[10]

In the SFPE Handbook Hall also stated

> *A fire risk analysis without a long list of stated assumptions is bound to be a model with many hidden assumptions, which are almost certain to be less well founded, if examined, then a list of "shaky" but explicit assumptions.* [11]

This caution has not prevented people from making detailed predictions of the fire risk of proposed buildings despite lack of detailed knowledge of the soft variables. But are these predictions the product of a "scientific understanding of fire"? Or are they simply more or less what Hall calls a "series of guesses?" More importantly, how are the uncertainties in the process resolved? For example Assuming that the sprinklers are always working may be convenient for the model developer, but what does it say about what happens when they are not? A highly refined engineering analysis that is totally dependent on conjectural initial values for the "soft" variables may be useless as a regulatory tool. [12] For example when considering a fire door, exactly how does a fire protection engineer develop a "the probability that the door will be open and the probability that the fire will spread"? If the engineer uses national or international data on whether fire doors open or closed, how is the fire safety is being "designed for a specific application rather than for a general occupancy".[4] How is such a universal analysis any different from the occupancy categories of traditional codes?

FIRE SCENARIOS OR SCENARIO FIRES?

Fire protection engineering has technical and scientific problems in claiming that performance based codes will provide the socially required level of safety. There is no engineering method to predict the building's fire load or the condition of the structure, no easily available methodology for society to specify the level of safety, and no easy way to regulate buildings in accordance with the engineering assumptions.

Instead of directly addressing the technical problems, some advocates of performance based codes have taken a different tack. They have proposed an entirely new form of regulation in which key social safety decisions are made by engineers, instead of regulators. **The centerpiece of this effort is to suggest that the "fire scenarios" used to test a performance-based design should be developed by the fire protection designer, rather than the authority having jurisdiction.** This is a remarkable proposal, since without a technical specification of the fire safety goal, the designer is self-regulating.. Reducing the size of a design fire or changing its location or changing the condition of the building or occupants can have an enormous effect on the evaluation of the fire protection. Without a proven connection to social goals, there are no standards for technical development of fire scenarios. [12] Regulation becomes a process of the designer trying to see what assumptions can be pushed past a regulator.

Resolving this issue requires exploring how scenarios came to be part of performance based codes. In the original performance based code proposals there was no explicit mention of scenarios. "Fire Scenarios" were later introduced as part of the performance based code structure and explicitly included the entire fire hazard:

> *The fire scenario describes factors critical to the outcome of the fire such as ignition source, nature and configuration of the fuel, ventilation, characteristics and location of the occupants, and conditions of the supporting structure and other equipment.... Each fire scenario should be considered to represent a larger family of similar scenarios and the associated documentation should recognize this representation* [13] see also [14]

This original use of the term "scenario" is the same as that used by the Nuclear Regulatory Commission, i.e. a comprehensive statement of the target environment's overall safety. The scenario would represent a technical description of the social expectation of safety. Scenarios would include all the potential elements of the fires, the building and the human response.

The critical step was not merely to leave scenario development to the designer, the scenario itself was redefined. **Scenarios stopped including the entire hazard, and became instead just a specified design fire**. Control of that fire under assumed conditions became compliance with the code. For example in a draft Performance Based Code proposed by the NFPA Task Group the regulatory criteria include:

> *2-11 A sprinkler system shall achieve the performance objectives of section 1-5 for the fire scenarios in section 2-2* [15]

But the "fire scenarios" listed were simply a set of specific "scenario fires". To comply with the Performance Based Code the sprinkler system design now only has to perform in response to these design fires. The "fire scenario" is limited to the fire itself, not the environment:

> *Fire scenarios specify the fire conditions under which a proposed fire safety solution is expected to meet the fire safety goals...*
>
> *A fire scenario can be considered as the "fire load" that an occupant or building would be likely subjected to without interference from the fire safety system* [4]

The "fire scenario" is now just the "fire conditions". The building is now the "fire safety solution". In other words the building satisfies the code if it copes with the scenario fire. There is no longer any requirement that the scenario fire must represent the range of real world conditions that might occur in the building. The fire scenario is also explicitly subordinated to the data needs of the fire models:

> *Fire scenarios describe the specifications needed for a fire test or the input for a fire modeling run.* [4]

But fire models have relatively limited forms of inputs and outputs. There is no fundamental reason why real world conditions appear in a form that the fire models can use. The real fire hazard is being subordinated to the need for data to fit the model. The portions of the earlier fire scenarios that describe the occupants and most of the other soft characteristics, (including the condition of the fire safety systems) are now treated as designer's "assumptions".

In the performance based code proposal in the NFPA Handbook, there is no step of verifying that the scenario is a realistic real world fire situation. The "Verification" step does not include any step of making sure that the social goals are met. Instead verification means:

> *1) Verification that the proposed solution shows the building will meet the fire safety goals for the assumptions and fire scenarios established* [4]

The proposal also states:

> *"The effectiveness of the proposed solution for occupants who fall outside the scope of these assumptions would be much less certain".* [4]

The proposed Performance Based Life Safety Code is similar. First the Fire Scenario is defined as including "*characteristics and locations of occupants, and conditions of supporting structure and other equipment" But* later they are described as "*Ordinary fire in occupied room", "Fire Originating in means of egress" and Fire with initial smoldering stage*". Soft inputs are described as "*assuming common degradation in design assumptions*" [16]

It is not clear that the proponents of proponents of performance based codes fully understand the implications of the shift from fire scenarios to scenario fires. The change is enormous. Instead of a system where "*the codes specify verifiable performance requirements with demonstrated, quantifiable links to the objectives*", the building is supposed to comply if it meets the designer's choices of "*the characteristics or assumptions of who or what is to be protected and under what conditions*" [4]

"Fire scenarios" were originally developed to represent the real world situation of the building. Switching to a "scenario fire" leaves the regulator guessing at the connection between the scenario fire and reality. How would the regulator know that the chosen design fires are the most important fire stresses? How does the regulator interpolate data from other fires or locations? What happened to all the other fire hazard variables not represented in the scenario fire?

WHO IS SETTING THE LEVEL OF SAFETY?

The "scenario fire" switch turns the regulatory process on its head. In the original "fire scenario" proposal the performance objectives were a ***product*** of the fire safety goals, and "fire scenarios" described the ***entire fire hazard.*** Under the "scenario fire" approach the only criterion is the capability of the design, under specified assumptions, to resist the chosen scenario fire. Instead of scientific proof that a design provides the level of safety specified by the social goals, the fire safety analysis only indicates that the building will provide a limited protection against a test fire chosen by the designer.[17] .

"Quantifiable connection" between the technical solution and the social goal has simply been eliminated. The justification for the switch is presumably that it is extremely difficult to actually anticipate all the possible fire scenarios. But that was known all along. The performance based code approach was sold on the grounds that the fire safety community had the "scientific" ability to state that a given building design met a specific social goal. But when it came to making good on the promise, engineers reverted to the same system used in prescriptive codes. Engineers test the building design under laboratory conditions, and if it complies with those specified conditions it is acceptable. But without comprehensive scientific support for the chosen scenarios, it is impossible to state what level of safety is generated. This is true even if the only claim is a equivalence to a building built under the existing code. The claim is still a comparison using a laboratory fire and a defined set of assumptions.

This type of "scenario fire" based regulation represents no conceptual change at all from a traditional test based "performance" fire standard. Both involve a test method, and an assumption that the test method reflects the reality of fire and the socially desired level of safety. Instead of putting a wall in a furnace, performance based codes use a digital model of a hypothetical fire. The only change is that building owners and fire protection engineers are defining the required level of safety, instead of the society.

IMPLICATIONS FOR FIRE SAFETY SCIENCE

This analysis highlights a gap between the promise of fire safety science and the regulation of social fire hazards. As we have stated elsewhere, one of the key methods for reducing the uncertainty in the performance based code process is to substitute regulation for prediction.

> *Any risk model which purports to describe the reaction of a technical system in a future environment that includes unpredictable human action must be accompanied by a regulatory system capable of keeping the human decisions within the conditions of the model or simulation.* [18]

Many highly uncertain predictions can actually be resolved using regulation, if the regulator has the needed information. If the model says the safe capacity of a room is 200 people, we can develop methods for keeping the occupancy at that level. The key is whether the fire safety science community can specify their outputs in a format that regulators can actually use. Performance based regulation requires several key technical inputs:

1) There must be a clear-cut method for engineers to specify the range of available levels of safety in a form that can be transformed into in useable social policy. Inputs to models must be specified in a form that lends itself to the regulatory process, rather than being specified by the requirements of the models.

2) Engineers cannot expect to specify the form in which public policy must be made. Society must be free to protect property, vulnerable populations or insist on redundancy or margins of safety.

3) Social safety levels and technical requirements have to be developed in tandem. At all stages engineers should avoid concealing social decisions in technical models.

4) There must be clear technical measures adequate for regulating the compliance of a building with the assumptions in a fire safety analysis..

CONCLUSION

Performance based analyses are still unable to meet the claim that they can document that buildings meet a specified level of public safety. Improvements are possible but the process should be driven by the social needs, not the engineering requirements. .

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