2.3 Integrating Physical Systems and Human Behavior Using Codes and Standards Requirements for Building Evacuation

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Summary

Codes need to be based on a fundamentally different approach to incorporating considerations of human behavior, especially where they regulate the production of performance-based designs. Codes have been based on traditional physical systems engineering approaches based on assumptions about occupants characteristics. The approach does not yield effective designs because (1) satisfactorily conservative assumptions cripple the design process, and (2) people are not credited for their abilities to adapt to dynamic scenarios. Instead, we need to integrate physical systems approaches with the goal-driven adaptive performance of people. Code-based designs need to specify realistic performance objectives for people as well as physical systems. Work by Groner and Williamson provides one possible approach towards integrating physical systems and human goal-directed behavior in a single holistic systems representation based on the achievement and preservation of desirable systems states.

What is the current state of knowledge from research and theory?

Building and fire codes are traditionally prescriptive, that is, they inflexibly specify the precise minimum requirements for buildings. Improvements to prescriptive codes occur incrementally, often based on incidents that provide evidence that existing provisions are based on faulty assumptions. Of considerable importance is the tendency of prescriptive requirements to protect against the repetition of historical events. Changes to prescriptive requirements that anticipate scenarios without historical precedence are difficult to institute.

Because they are reactive, prescriptive codes implicitly reflect historically prevalent naïve and unsubstantiated theories about human behaviors. As an example, the belief that people would "panic" or behave irrationally and selfishly was a predominant, but naïve and invalid theory. The *Life Safety Code*® included many references to "panic" that are still being weeded out. A few decades ago Stahl and colleagues (1982) conducted a National Bureau of Standard's sponsored survey of implicit assumptions about human behavior in the *Life Safety Code*®, along with evidence to the their validity, and concluded that most were unsupported by research. Pauls' research on movement down stairs revealed that code assumptions relating stairway width to flow rates were faulty.

In contrast to prescriptive codes, performance-based codes are intended to facilitate *engineered* solutions to design problems. As such, theory is central to the quality of performance-based designs. Unfortunately, performance-based code approaches retain a reliance on assumptions about occupant characteristics, making them vulnerable to the same unsubstantiated and naïve theories that underlie prescriptive provisions.

I believe that much of the problem results from the fire protection engineering design community's tendency to rely on a physical systems representation of human behavior. (Groner, 1998, 2002; Pauls and Groner, 2002) This physical systems-centered approach directs engineers to consider humans as systems components that should respond with *pre*determined behavior. "Traditional system-centered design treats users as just another resource to be assigned and optimized to meet operational goals." (Stanney, et. al, 1997; p. 639) The physical systems view is causally-based; human responses are "caused" by certain stimuli without relying on theory about the unobservable cognitive processes that people use to understand those stimuli. Not surprisingly, engineers are comfortable with this familiar paradigm.

In fire protection engineering, this view is exemplified by the idea that people are supposed to evacuate buildings when they hear alarm signals. Research and experience demonstrates that the approach fails in most settings. In reaction to this failure, we often call for more training in a problematic attempt to strengthen the causal association between stimulus and response. But this mechanical response runs counter to natural human tendencies. Training is an unreliable fallback to building designs based on faulty assumptions about human behavior.

The physical systems view mirrors the behaviorist perspective championed by B. F. Skinner wherein mental processes that can not be directly observed are excluded from theory. The behavioral sciences have rejected dogmatic behaviorism, and the manner in which codes incorporate human behavior will have to follow suit. Requirements must be based on the understanding that humans are information-processing adaptive agents that pursue goals aimed at protecting themselves, others and valued artifacts.

What is the current state of putting that theory into knowledge?

Performance-based design solutions are the best means for fully incorporating human behavior into code-complying designs. Unfortunately, current approaches still rely on the use of assumptions about "occupant characteristics." Taking the NFPA *Life Safety Code*® as an example, the performance-based design team is asked to specify "occupant characteristics" as a means to constrain design solutions. Because the design doesn't control "occupant characteristics," the engineer should assume the worst plausible set of characteristics that can characterize the building's occupants.

Further, in the *Life Safety Code* provision for the performance-based option, the design team engineer is asked to perform calculations like the following: "For each design fire scenario and the design specifications, conditions, and assumptions, the design team can demonstrate that each room or area will be fully evacuated… [And that] the timing of such an evacuation means that no occupant is exposed to fire effects. Such an evacuation requires calculation of the locations, movement, and behavior of occupants, because fire effects and occupants are kept separate by moving the occupants." (Section A.5.2.2, all references are to the 2004 edition.) An appendix note to *Life Safety Code* provisions explains that "The use and occupancy should not change to the degree that assumptions made about the occupant characteristics…and existence of trained personnel are no longer valid." (A.5.1.7) The *Code* recommends a list of "assumptions [that] can address a larger number of factors that are components of these basic performance characteristics." (A.5.4.5.2) Among these factors are commitment, role, social affiliation, alertness—all cognitively related factors about which the designers will have to make *conservative* assumptions to guarantee that people will be adequately protected.

When basing designs on assumptions about occupant characteristics, how conservative is conservative enough? The answer is that the assumptions will need to be so conservative that the design process will be blocked. Take, for example, the problem of making an assumption about the amount of time that people take before responding to an alarm. We know that in many settings, people won't quickly respond to an alarm in the absence of additional cues, so it is conservative to assume the no one will respond to a simple alarm signal in the absence of confirming cues. We know that people respond to additional information provided by emergency response teams, but in many buildings, emergency response teams don't respond reliably, so the designer conservatively should assume that it won't happen at all. When all such conservative assumptions about human responses are taken together, performance-based design becomes impossible.

What is the gap between that and where we need to be?

The approach of exclusively relying on assumptions about occupant characteristics is a faulty method for incorporating human behavior into building designs, regardless of whether the approach is prescriptive or performance-based. We know that such needed conservatism does not accurately reflect human response because people actively work to understand situations and adapt according to the manner in which the incident evolves. An approach that credits people with this capability is needed.

A design approach is needed whereby designers establish performance goals for both the built features *and* the people occupying the building. The design then enables not only the design of physical components that contain and suppress the fire, but also the design of a cognitive task environment that enables people to respond adaptively to the evolving event. Performance-based code approaches need to establish "performance objectives" for people that enable human adaptive capabilities (Groner, 1996). By designing buildings that support performance objectives for people, we will also enable more accurate and reliable predictions of human actions and reaction times. Prescriptive codes are already missing important opportunities to support people in their efforts to adapt to building emergencies (Groner, 1998).

There are two principle gaps to our writing code provisions that incorporate performance objectives for people:

We must learn how to devise human performance objectives that are compatible with the goals that people normally try to pursue during building emergencies. We have learned the hard way about using a performance objective that is *not* compatible with natural human responses—expecting people to immediately respond to uninformative alarm signals. We need a more sophisticated approach.

We must learn how to integrate human performance objectives into a holistic representation of how protective systems, including building layouts, both active and passive fire protection systems, occupant characteristics, and designed procedures work together to achieve high level design objectives like those specified by the *Life Safety Code* (4.1; 4.2).

What activities and resources are needed to close this gap?

The "first gap," devising good human performance objectives, can be achieved using two complementary approaches:

Relevant theory and empirical research needs to be reviewed for its relevance and guidance. Some of the research is specific to human behavior in building fires, but most of the relevant theory and research can be found in fields such as disaster sociology, cognitive science, organizational theory, and cognitive ergonomics. Returning to the example of human responses to simple alarm signals, each of these fields contributes theory and findings that would lead designers to avoid this as a performance goal.

Additional empirical research into real incidents should be conducted with the intent of capturing data about the goals that people naturally pursue given their "occupant characteristics" and the types of situations in which they find themselves during building emergencies. This type of information has rarely been collected, although data that specifically related occupants' behaviors to perceived situations and goals has been collected as part of the NIST investigation of evacuations during the WTC building disaster. (Averill, et al., 2003)

In response to the "second gap" of integrating human performance objectives into a holistic representation of systems performance, we need modeling approaches that facilitate the design of protective systems for buildings that include human performance objectives. Better yet, the models will fully integrate human and building performance into a holistic systems representation. In my view, the development of such models requires real design problems and collaborations designers (e.g., fire protection engineers) and behavioral science or human factors specialists.

First and foremost, to account adequately for the goal-seeking information-processing reality of human behavior, building design needs to change from systems-centered design to user-centered design. "User-centered design…considers users' roles and responsibilities as the key design objective to be met and supported by advancing technologies." (Stanney, et. al, 1997; p. 639)

In collaboration with R. Brady Williamson at University of California Berkeley, I developed an approach that provides a formal systematic approach towards integrating human adaptive behaviors into fire protection engineering design (Groner and Williamson, 1997; Groner and Williamson, 1998). The approach is based on desirable systems states, a construct that can be used to both characterize engineering design goals and the goal-driven adaptive behavior of people. In fire protection engineering, the behavior and development of fires is often characterized as discrete states. The practice of fire engineering largely involves the design of systems intended to prevent fires from transitioning to less desirable states (e.g., flashover, spread beyond the room of origin). Stated differently, design goals for both the built environment and human occupants involve the preservation or restoration of desirable system states. Active and passive building systems and people pursue these goals independently or in concert.

The approach has been used to qualitatively model problems related to fire scenarios in a university library and the effects of hardening natural gas supply lines during an earthquake. While the few attempts to use the approach to integrate physical systems and human performance have been qualitative, there is no inherent reason why the approach cannot be used to as a basis for quantified risk analysis by calculating the probabilities of transitions between different states.

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