

# Survivability Profiling: How Long Can Victims Survive in a Fire?

BY STEPHEN MARSAR

In 2007, the United States suffered 118 firefighter line-of-duty-deaths (LODDs), 47 of which occurred in structure fires; two civilians were killed in those same fires. In 2008, there were 114 LODDs; 31 occurred in structural fires; three civilians were killed. In 2009, there were 89 LODDs, 24 in structural fires, and zero civilians were killed in those same fires.<sup>1</sup>

In my article “Survivability Profiling: Are the Victims Savable?” (*Fire Engineering*, December 2009), I defined survivability profiling as the art of examining a situation and making an intelligent and informed decision based on known events, or circumstances, to determine if civilians can survive existing fire and smoke conditions and to determine whether to commit firefighters to life-saving and interior operations. Based on the likelihood of civilian survivability, this concept goes beyond the tendency to justify risk whenever we respond to an occupied structure fire.

Survivability profiling asks—if people are suspected or known to be trapped—is there a reasonable assumption that they may still be alive? If not, we should slow down and attack the fire first and complete the searches when it is relatively safe for our operating forces to do so. Some will argue that using survivability profiling will kill people. No, fires and smoke kill people (many times before we even arrive on the scene). Survivability profiling *will* save firefighters’ lives.

The National Fire Protection Association (NFPA) states that the upper limit of human temperature tenability is 212°F, well below temperatures found in most significant structure fires that are beyond the growth (incipient) stage. In today’s fire environments, temperatures higher than 500°F can be easily obtained within three to four minutes. Flashover, which occurs at approximately 1,100°F, can develop well under five minutes.<sup>2</sup> If a space isn’t tenable for firefighters, trapped victims aren’t likely to survive either. Take the time to make it safe and prevent your firefighters from taking unnecessary risks.

Scientific research on human respiratory burns<sup>3</sup> and inhalation of hot gases in the early stages of fire<sup>4</sup> reveals that occupants trapped in structural fires have limited survival times. In the first experiment, which lasted 11 years, fire victims were tracked if they met three diagnosed criteria: (1) flame burns involving the face, particularly the mouth and nose; (2) singed nasal mucus membranes; and (3) burns sustained in closed-space, interior fires.

Twenty-seven patients were treated; 11 additional patients didn't meet all three of the test criteria or were dead on arrival. Of the 27 patients whose body surface burns ranged from 15 percent to 98 percent, 24 died (three in the first 24 hours and five within 36 hours). Respiratory burns directly accounted for 18 of those deaths (the others died of other burn injury complications). Factors that affected the fatalities included heat, toxic smoke, and humidity. (3)

Sixty percent of the victims were found to have been exposed to heat (most at temperatures above 200°F; some were below) and humidity for six to seven minutes (remote from the fire area). The fatality rate increased to 90 percent for those exposed to toxic smoke as well, even for only several minutes. The experiment concluded that human fire victims were most susceptible to respiratory burns from heat first, toxic smoke second, and humidity a distant third (victims found remote from the fire area died of smoke first and heat second, with heavy smoke conditions leading to immediate respiratory burn injuries). The time of exposure for all 24 fatalities was less than 10 minutes. (3)

The second experiment (using laboratory mice and human fire victims) (4) assessed the impact of inhaling hot gases during the early stages of fires. The researchers concluded: "Thermal injury takes place quickly," with death occurring at temperatures of 350°F within three minutes. The experiment notes that fire temperatures rise to more than 1,200°F within five minutes; therefore, the survival outcomes for victims are further limited. (4)

Lethal first-degree respiratory burns were found to occur in just 230 seconds (under four minutes). The experiment concluded that facing the fire causes more serious damage to the human respiratory tract, especially if the subject could not get away from the immediate fire area. It found that decreasing air velocity while increasing respiratory rates was helpful in minimizing thermal injuries of the respiratory tract. However, the experiment acknowledges that educating the public on this particular finding, coupled with the psychological and physiological reactions of civilians in fire situations, probably makes this conclusion unrealistic in helping to save lives.

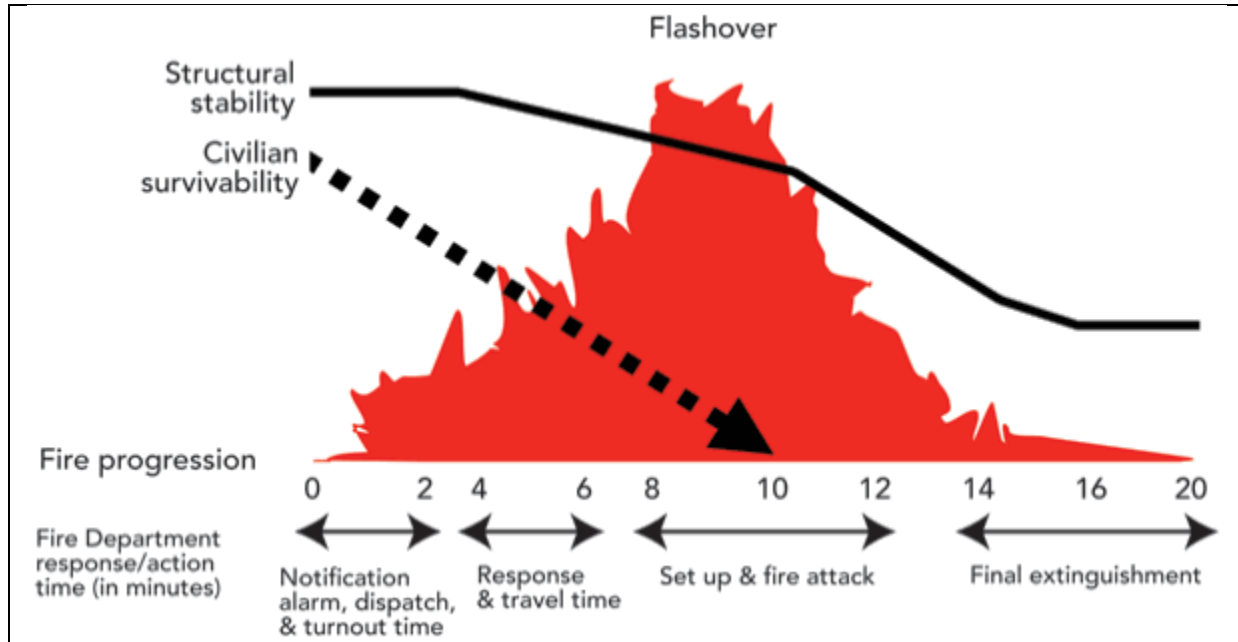
The clinicians found that it would be helpful to know the time that the patient was subjected to fire and smoke, along with the approximate temperatures encountered. This might be helpful in establishing an appropriate treatment protocol. Providing this information for firefighters may prove difficult to impossible, but perhaps noting the victim's location in relation to the proximity of the fire would be helpful.

Based on the work of Klaene and Sanders,<sup>5</sup> from a size-up point of view, you must carefully consider the potential benefit to life and property vs. the risk to firefighters, as the risks generally increase with time. The benefit to civilian occupants tends to decrease exponentially with time unless the fire is controlled quickly. As the probability of saving lives and property decreases, the degree of acceptable risk should also decrease.

Figure 1 illustrates how fire progresses from ignition through flashover. It shows flashover occurring in between two and six minutes. This is just as firefighters may be arriving on scene and entering the fire area. The structural stability and survivability lines in the illustration each start at 100 percent, when the building is at its maximum strength and occupants have the best

chance of escape. As the civilian survivability timeline moves toward the horizontal axis, the chance of survival nears zero, as the fire and deadly smoke conditions increase. At the same time, the structure is continuously losing strength and is proceeding toward catastrophic collapse.

**Figure 1. Fire Progression, Structural Stability, and Survivability Comparison**



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Of course, no two fires act the same or follow an exact timeline. Some fires may progress more slowly, and some may grow more quickly, depending on many factors and conditions. (2)

According to the Phoenix (AZ) Fire Department’s “Safety and Risk Management Profiles”<sup>6</sup> standard operating procedure, when considering the “SURVIVAL” of any victim in any emergency, members must consider the conditions that are present in the “compartment or area,” or the fire and/or hazardous atmospheric conditions affecting the victim’s viability. As examples, the procedure includes the following:

A fire in a rear bedroom of a house, with smoke throughout the house, may allow a survivable environment if a search and rescue effort is initiated quickly. We may extend risk, in a calculated manner, in these conditions. A significant fire in a residence with dense smoke under pressure to floor level throughout the building likely means victims could not survive. A very cautious, calculated rescue and fire control operation would be warranted. A well-involved building would likely represent a zero survivability profile. Similar conditions in an abandoned building would indicate little survivability and little property to be saved. Members should avoid an offensive firefight. Victims buried by a trench collapse or under water for 10 minutes or more would be unlikely to survive; therefore, an extremely cautious and well-planned, safe recovery operation is required.

The key to the concept of survivability profiling is for firefighters to stop for a few seconds, get the big picture of the incident they are facing, gather as much information as possible, and make an educated decision as to the probability (*not* possibility) of victim survival. As posed by Gary Klein,<sup>7</sup> “Firefighters should rely on their intuition and gut feelings to assist them in making these most difficult of decisions. What might be the hardest decision for a firefighter to make is to not enter a burning structure or hazardous area where people might or even are known to be trapped without the possibility of survival.”

Focusing on the civilian survivability timeline as shown in Table 1, you must examine the relationship of oxygen levels for both humans and the fire. According to the New York State Office of Fire Prevention and Control, “The human body and fire are similar in that they both require oxygen to survive. Fire, for example, consumes oxygen and produces toxic gases that may displace, absorb, or dilute the remaining available oxygen. At 16- to 17-percent oxygen levels, a fire will start to die out or smother due to oxygen deprivation. Atmospheres below 19.5 percent are considered oxygen-deficient atmospheres.”<sup>8</sup>

**Table 1. Effects of Hypoxia<sup>8</sup>  
(Reduced Oxygen)**

<b>Oxygen Percentage Available</b>	<b>Symptoms</b>
21	Normal conditions, no effect.
19.5	OSHA oxygen-deficient atmosphere.
17	Muscular impairment, rapid breaths.
12	Dizziness, headache, rapid fatigue.
9	Unconsciousness.
7 to 6	Death within a few minutes.

Table 1 also shows the effect of decreased oxygen on the human body—that is, below 19.5 percent, the human body, particularly the brain, will start to feel the effects. Below 16 to 17 percent, physical and emotional impairments will be exhibited, and below 9 to 10 percent, unconsciousness and eventually death will occur. These low oxygen levels do not include the toxic by-products found in smoke during a fire.

When the by-products of fire—that is, smoke and toxic gases—are added to the oxygen-deficient atmospheres found in most enclosed structure fires, you can readily identify the harmful effects and the speed at which they can incapacitate and kill humans. These toxic by-products and

oxygen-deficient atmospheres have been well documented and extensively researched. One example of this documentation is the article “CO Rx: A Safety Prescription,” which chronicles the near-death experience of one Fire Department of New York fire officer and the tragic deaths of 10 others over the past 30 years.<sup>9</sup> Each of those deaths resulted from carbon monoxide (CO) poisoning.

The article states: “More fire deaths occur from CO poisoning than from any other toxic product of combustion.” It demonstrates the speed with which CO can incapacitate an individual (within minutes). It also describes CO as “an odorless, colorless, tasteless, and non-irritating gas that is present in all fires ... it is an extremely flammable gas that can travel great distances.” CO crowds out oxygen from the blood, poisoning the brain and tissues. Several factors that can lead to CO poisoning include (1) the level of CO in an area, (2) the length of time exposed, and (3) the physical condition and activity of the individual during the exposure.

The cumulative effects of CO and the bonding of CO to the blood’s hemoglobin (known scientifically as COHb) have a “half-life of about five hours.” That means that it will take approximately five hours for COHb in a human’s body to drop to half of its current level after the CO exposure has ended. (9)

Carbon monoxide effects are first felt by the parts of the body with high metabolic rates, with the brain and heart being the most sensitive. Firefighters who are hard at work during a fire will be more susceptible than a more sedentary, unconscious, or moderately active person. The inability to control muscle movements is a symptom of severe exposure and is quickly followed by unconsciousness. Tables 2 and 3 show how the percentage of COHb affects humans. The letter “K” represents “a factor related to exertion level.” The value of K = 3 for resting or an unconscious state, = 8 for moderate exertion, and = 11 for strenuous exertion. (9)

**Table 2. COHb Levels and Effects<sup>2</sup>**

<b>COHb</b>	<b>Symptoms and Medical Consequences</b>
10%	No symptoms.
15%	Mild headache.
25%	Nausea and serious headache.
30%	Symptoms intensify.
45%	Unconsciousness.
50%	Death.

## Table 3. Comparing Similar Exposures Under Rest and Exertion<sup>9</sup>

COHb	CO ppm*	CO% in air	K factor	Exposure time
45%	200,000 ppm	20%	3	45 seconds
45%	200,000 ppm	20%	8	16.9 seconds
45%	200,000 ppm	20%	11	12.3 seconds

At rest, it would take 45 seconds to develop 45% COHb levels; strenuous exertion reduces this time to 12.3 seconds. At 45% COHb, a person is unconscious. **A firefighter will not have time to react.** Note. \* ppm = parts per million in air

Table 4 shows the human response to CO at different concentrations.

## Table 4. Human Response to Carbon Monoxide at Different Concentrations<sup>2</sup>

Carbon Monoxide (CO) in Air	Human Response
0.2 %	Headache after 10 minutes, collapse after 20 minutes, and death after 45 minutes.
0.3 %	Maximum "safe" exposure for five minutes and danger of collapse in 10 minutes.
0.6 %	Headache and dizziness in 1 to 2 minutes and danger of death in 10 to 15 minutes.
1.28 %	Immediate effect, unconsciousness after 2 to 3 breaths and danger of death in 1 to 3 minutes.

## CYANIDE

In a more recent study, the People's Burn Foundation<sup>10</sup> expands on the above CO information by citing a 2006 NFPA study that reveals 87 percent of people who died in fires had a toxic blood concentration of cyanide as well as CO.

As the president of the Cyanide Poisoning Treatment Coalition, Robert Schnepf, an assistant chief in the Alameda County (CA) Fire Department, laments: [These findings are] “critical to firefighters, as researchers are now finding that job-related deaths once thought to be related to lack of oxygen, over-exertion, or heart attack in some cases can instead be directly linked back to cyanide poisoning.” (10) He further states that “these victims died from breathing the smoke long before the fire killed them.” (10) Items in the home that are burning and being heated will give off deadly poisonous and toxic gases. According to the Macomb (MI) Fire Department’s public education flyer, these gases will confuse and disorient people still in the home, making the simplest task (and hence, escape) seem difficult to impossible. Very quickly, smoke will obscure the lights and the daylight coming through the windows. Rooms will become black. The heat will be unbearable. The combination of poisonous gases and smoke will be choking, blinding, and lethal.

The flyer answers a common question from civilians: “How much time do I have to escape a fire?” The answer: “To survive a fire in your home, you must act immediately; your time is measured in seconds—not minutes.”

In the *Toxic Twins* video presentation, (10) Schnepf contends: “Today fires burn hotter, grow faster, and are more toxic than fires of the past,” as we all know.

When ignited, one pound of wood releases 8,000 British thermal units (Btus). A Btu is defined as the scientific measurement of the amount of heat required to raise one pound of water 1°F. Conversely, one pound of plastic from today’s environment has been shown to release as much as 19,900 Btus when it is ignited. Household items once made out of wood are now fashioned out of plastics. The toxic smoke produced by the proliferation of synthetic materials and the extreme temperatures reached in very short duration has high levels of hydrogen cyanide that is 30 times deadlier than that of CO alone. That can lead to chronic health hazards with accumulative effects. The effects of cyanide and CO together have been named “The Toxic Twins.” (10)

According to Schnepf, cyanide disables the body’s ability to absorb oxygen. The human body has an affinity for CO approximately 250 times to one compared with oxygen. Cells begin to die, and the body’s ability to function and move is quickly impaired. Cyanide impairs the human’s ability to think and move. Schnepf uses the analogy: “Cyanide kills your organs, CO kills your blood, and it only takes a matter of seconds.” At a relatively low concentration of 135 parts per million (ppm), cyanide and CO will kill a person in approximately 30 minutes. At 3,400 ppm (as is found in most enclosed structure fires), survival time is cut to less than one minute.

Brian A. Crawford, chief of the Shreveport (LA) Fire Department, has examined and introduced the “Firefighter Duty to Die Syndrome (FDTDS).” He examines the relationship between line-of-duty fatalities and the psychological factors that create a cultural belief that dying in the line of duty is part of the job. Crawford, acknowledging that firefighting is inherently dangerous, admits that some firefighters will die despite every precaution, safe workplace practices, and healthful lifestyle changes meant to minimize such risks. However, looking at the U.S. average of 100 LODDs annually, he feels the fire service must begin to look beyond the traditional explanations and practical recommendations.

The fire service “must expand discussions to more aptly include psychological components such as those found in the FDTDS,” Crawford says. Without serious discussion as to why some fire department cultures, groups, or individuals believe that unnecessary risk and unsafe behaviors are an acceptable part of the occupation, “the fire service is missing the mark and possibly a chance to save the life of one or more of its own,” he explains.

As Crawford sees it, the syndrome is a “firefighter’s behavior that reflects a sense of obligation and duty to unnecessarily risk personal and others’ safety above what is appropriate or required.” The problem of FDTDS comes, he notes, when firefighters venture beyond safe limits and escape unhurt. This increases their belief that since the behavior did not result in an injury, it must be acceptable. Crawford further examines how firefighters who undertake unsafe actions often rely on the ends to justify the means and often feel that the dangers of their actions are irrelevant if a victim (dead or alive) is rescued or recovered and the fire is extinguished, “even if performing the task in a safer manner would have produced the same result.”

Sooner or later, according to Crawford, the end will not justify the means, as when a firefighter is seriously injured or killed. “The odds of tragedy are increased by the syndrome’s snowballing effect,” he says. If a firefighter is allowed to perform dangerous actions without consequence or, worse, the actions are met with praise, the chances are increased that the behavior will be repeated until a negative result ultimately occurs. Regarding the investigations into LODDs, Crawford suggests that the mental developments that led the firefighter to being in that tragic place at that tragic time should be the focus of reducing deaths and “not a sidebar.” Crawford notes that currently, national firefighter fatality investigations, discussions, and recommendations all focus on practical actions, policy, and procedures and all but ignore the “cognitive processes leading up to and occurring during line-of-duty incidents.”

The bottom line is that there is a challenge before the firefighters in the United States. That challenge is to develop a culture and attitude that do not accept LODDs as part of the job. Risking lives to save others is a noble calling. It must be done in a calculating manner and as safely as possible within the hostile environments in which we are forced to work. Survivability profiling and the recognition of the very limited time that occupants have to survive, dependent on the fire and smoke conditions found, *must* be a conscious thought in our minds. With national average response times of four to six minutes—in some instances, when there *are* civilians trapped—we may have only an additional two to four minutes to search, locate, remove, and revive them. These are facts, not conjecture.

Will we be able to look in the faces of parents on the front lawn of their burning home and tell them that their loved ones inside are not savable? I don’t know. But, what I *do* know is that if survivability profiling is telling us that, in reality, their loved ones are not savable, we hopefully have learned to put out the fire first and perform the searches as quickly as possible when it is relatively safe to do so. We will be doing “everything we can,” including saving the lives of firefighters.

## **Endnotes**

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