

Third Annual Dr. John Granito Award for Excellence in Fire Leadership and Management Keynote Address, **Dr. Lori Moore-Merrell**, Assistant to the General President of the International Association of Fire Fighters (lmoore@iaff.org)

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Report on Residential Fireground Field Experiments

Abstract

Service expectations placed on the fire service, including Emergency Medical Services (EMS), response to natural disasters, hazardous materials incidents, and acts of terrorism have steadily increased. However, local decision-makers are challenged to balance these community-service expectations with finite resources without a solid technical foundation for evaluating the impact of staffing and deployment decisions on the safety of the public and firefighters.

For the first time, this study investigates the effect of varying crew size, first-apparatus arrival time, and response time on firefighter safety, overall task completion, and interior residential tenability using realistic residential fires. This study is also unique because of the array of stakeholders and the caliber of technical experts involved. Additionally, the structure used in the field experiments included customized instrumentation; all related industry standards were followed, and robust research methods were used. The results and conclusions will directly inform the National Fire Protection Association® (NFPA®) 1710 Technical Committee, who is responsible for developing consensus industry-deployment standards.

This report presents the results of more than 60 laboratory and residential fireground experiments designed to quantify the effects of various fire department deployment configurations on the most common type of fire — a low-hazard residential structure fire. For the fireground experiments, a 2,000 ft² (186 m²), two-story residential structure was designed and built at the Montgomery County Public Safety Training Academy in Rockville, Maryland. Fire crews from Montgomery County, Maryland, and Fairfax County, Virginia, were deployed in response to live fires within this facility. In addition to systematically controlling for the arrival times of the first and subsequent fire apparatus, crew size was varied to consider two-, three-, four-, and five-person staffing. Each deployment performed a series of 22 tasks that were timed, while the thermal and toxic environment inside the structure was measured. Additional experiments with larger fuel loads as well as fire modeling produced additional insight. Report results quantify the effectiveness of crew size, first-due engine arrival time, and apparatus-arrival stagger on the duration and time to completion of the key 22 fireground tasks and the effect on occupant and firefighter safety.

Background

The fire service in the United States has a deservedly proud tradition of service to community and country dating back hundreds of years. As technology advances and the scope of service grows (e.g., more Emergency Medical Services [EMS] obligations and growing response to natural disasters, hazardous materials incidents, and acts of terrorism), the fire service remains committed to a core mission of protecting lives and property from the effects of fire.

Fire fighting is a dangerous business with substantial financial implications. In 2007, U.S. municipal fire departments responded to an estimated 1,557,500 fires. These fires killed 3,430 civilians (nonfirefighters) and contributed to 17,675 reported civilian fire injuries. Direct property damage was estimated at \$14.6 billion dollars (Karter, 2008). In spite of the vigorous nationwide efforts to promote firefighter safety, the number of firefighter deaths has consistently remained tragically high.

In both 2007 and 2008, the U.S. Fire Administration (USFA) reported 118 firefighter fatalities (USFA, 2008).

Although not all firefighter deaths occur on the fireground — accidents in vehicles and training fatalities add to the numbers — every statistical analysis of the fire problem in the United States identifies residential structure fires as a key component in firefighter and civilian deaths as well as direct property loss. Consequently, community planners and decision-makers need tools for optimally aligning resources with the service commitments needed for adequate protection of citizens.

Despite the magnitude of the fire problem in the United States, there are no scientifically based tools available to community and fire service leaders to assess the effects of prevention, fixed sprinkler systems, fire-fighting equipment, or deployment and staffing decisions. Presently, community and fire service leaders have a qualitative understanding of the effect of certain resource allocation decisions. For example, a decision to double the number of firehouses, apparatus, and firefighters would likely result in a decrease in community fire losses, while cutting the number of firehouses, apparatus, and firefighters would likely yield an increase in the community fire losses, both human and property. However, decision-makers lack a sound basis for quantifying the total impact of enhanced fire resources on the number of firefighter and civilian lives saved and injuries prevented.

Studies on adequate deployment of resources are needed to enable fire departments, cities, counties, and fire districts to design an acceptable level of resource deployment based upon community risks and service-provision commitment. These studies will assist with strategic planning and municipal and state budget processes. Additionally, as resource studies refine data-collection methods and measures, both subsequent research and improvements to resource-deployment models will have a sound scientific basis.

Project Overview

This project systematically studies deployment of fire-fighting resources and the subsequent effect on both firefighter safety and the ability to protect civilians and their property. It is intended to enable fire departments and city/county managers to make sound decisions regarding optimal resource allocation to meet service commitments using the results of scientifically based research. Specifically, the residential fireground experiments provide quantitative data on the effect of crew size, first-due engine arrival time, and subsequent apparatus stagger on time-to-task for critical steps in response and fire fighting.

The first phase of the multiphase project was an extensive survey of more than 400 career and combination fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The

results of this survey are not documented in this report, which is limited to the experimental phase of the project, but they will constitute significant input into future applications of the data presented in this document.

This report describes the second phase of the project, divided into the following four parts:

- **Part 1** — Laboratory experiments to design the appropriate fuel packages to be used in the burn facility specially constructed for the research project
- **Part 2** — Field tests for critical time-to-task completion of key tasks in fire suppression
- **Part 3** — Field tests with real furniture (room and contents experiments)
- **Part 4** — Fire modeling to apply data gathered to slow-, medium-, and fast-growth-rate fires

The scope of this study is limited to understanding the relative influence of deployment variables on low-hazard, residential structure fires, similar in magnitude to the hazards described in National Fire Protection Association® (NFPA®) 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. The standard uses as a typical residential structure a 2,000 ft² (186 m²) two-story, single-family dwelling with no basement and no exposures (nearby buildings or hazards such as stacked flammable materials).

The limitations of the study, such as firefighters' advance knowledge of the facility constructed for this experiment, invariable number of apparatus, and lack of experiments in extreme temperatures or at night, will be discussed in a later section of this report. It should be noted that the applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, and response to hazardous material incidents, acts of terrorism, and natural disasters, or other technical responses has not been assessed and should not be extrapolated from this report.

Literature Review

Research to date has documented a consistent relationship between resources deployed and firefighter and civilian safety. Studies documenting engine- and ladder-crew performance in diverse simulated environments as well as actual responses show a basic relationship between apparatus staffing levels and a range of important performance variables and outcome measurements such as mean on-scene time, time-to-task completion, incidence of injury among fire service personnel, and costs incurred as a result of on-scene injuries (Cushman, 1982; McManis Associates & John T. O'Hagan and Associates, 1984; Morrison, 1990; Phoenix [AZ] Fire Department, 1991).

Reports by fire service officials and consulting associates reviewing fire suppression and emergency response by fire crews in U.S. cities were the first publications to describe the relationship between adequate staffing levels and response time, time to completion of various fireground tasks, overall effectiveness of fire suppression, and estimated value of property loss for a wide range of real and simulated environments. In 1980, the Columbus (OH) Fire Division's report on firefighter effectiveness showed that for a predetermined number of personnel initially deployed to the scene of a fire, the proportion of incidents in which property loss exceeded \$5,000 and horizontal fire spread of more than 25 ft² (2.3 m²) was significantly greater for crews whose numbers fell below the set thresholds of 15 total fireground personnel at residential fires and 23 at large-risk fires (Backoff, 1980). The following year, repeated live experiments at a one-family residential site using modern apparatus and equipment demonstrated that larger units performed tasks and accomplished knockdown more quickly, ultimately resulting in a lower percentage of loss attributable to factors controlled by the fire department. The authors of this article highlighted that the fire company is the fire department's basic working unit and further emphasized the importance of establishing accurate and up-to-date performance measurements to help collect data and develop conclusive strategies to improve staffing and equipment utilization (Gerard & Jacobsen, 1981).

Subsequent reports from the USFA and several consulting firms continued to provide evidence for the effects of staffing on fire crews' ability to complete tasks involved in fire suppression efficiently and effectively. Citing a series of tests conducted in 1977 by the Dallas (TX) Fire Department that measured the time it took three-, four-, and five-person teams to advance a line and put water on a simulated fire at the rear of the third floor of an old school, officials from the USFA underscored that time-to-task completion and final level of physical exhaustion for crews markedly improved not after any one threshold, but with the addition of each new team member. This report went on to outline the manner in which simulated tests exemplify a clear-cut means to record and analyze the resources initially deployed and finally utilized at fire scenes (National Fire Academy [NFA], 1981). A later publication detailing more Dallas (TX) Fire Department simulations — 91 runs each for a private residential fire, high-rise office fire, and apartment house fire — showed again that increased staffing levels greatly enhanced the coordination and effectiveness of crews' fire-suppression efforts during a finite time span (McManis Associates & John T. O'Hagan and Associates, 1984). Numerous studies of local departments have supported this conclusion using a diverse collection of data, including a report by the National Fire Academy (NFA) on fire department staffing in smaller communities, which showed that a company crew staffed with four firefighters could

perform rescue of potential victims approximately 80 percent faster than a crew staffed with three firefighters (Morrison, 1990).

During the same time period that the impact of staffing levels on fire operations was gaining attention, investigators began to question whether staffing levels could also be associated with the risk of firefighter injuries and the cost incurred as a result of such injuries at the fire scene. Initial results from the Columbus (OH) Fire Division showed that "firefighter injuries occurred more often when the total number of personnel on the fireground was less than 15 at residential fires and 23 at large-risk fires" (Backoff, 1980). Mounting evidence has indicated that staffing levels are a fundamental health and safety issue for firefighters in addition to being a key determinant of immediate response capacity. One early analysis by the Seattle (WA) Fire Department for that city's Executive Board reviewed the average severity of injuries suffered by three-, four-, and five-person engine companies, with the finding that "the rate of firefighter injuries expressed as total hours of disability per hours of fireground exposure were 54 percent greater for engine companies staffed with three personnel when compared to those staffed with four firefighters, while companies staffed with five personnel had an injury rate that was only one-third that associated with four-person companies" (Cushman, 1982). A joint report from the International Association of Fire Fighters (IAFF) and Johns Hopkins University (JHU) concluded, after a comprehensive analysis of the minimum staffing levels and firefighter injury rates in U.S. cities with populations of 150,000 or more, that jurisdictions operating with crews of less than four firefighters had injury rates nearly twice the percentage of jurisdictions operating with crews of four-person crews or more (IAFF & JHU, 1991).

More recent studies have continued to support the finding that staffing per piece of apparatus integrally affects the efficacy and safety of fire department personnel during emergency response and fire suppression. Two studies in particular demonstrate the consistency of these conclusions and the increasing level of detail and accuracy present in the most recent literature by looking closely at the discrete tasks that could be safely and effectively performed by three- and four-person fire companies. After testing drills comprised of a series of common fireground tasks at several fire-simulation sites, investigators from the Austin (TX) Fire Department assessed the physiological impact and injury rates among the variably staffed fire crews. In these simulations, an increase from a three- to four-person crew resulted in marked improvements in time-to-task completion or efficiency for the two-story residential fire drill, aerial-ladder evolution, and high-rise fire drill, leading the researchers to conclude that loss of life and property increases when a sufficient number of personnel are not available to conduct the required tasks efficiently, independent of firefighter experience, preparation, or training. Reviews of injury reports by

the Austin (TX) Fire Department furthermore revealed that the injury rate for three-person companies in the 4 years preceding the study was nearly one-and-a-half that of crews staffed with four or more personnel. In a sequence of similar tests, the Office of the Fire Marshal of Ontario, Canada, likewise found that three-person fire companies were unable to safely perform deployment of backup protection lines, interior suppression or rescue operations, ventilation operations that required access to the roof of the involved structure, use of large hand-held hoselines, or establishment of a water supply from a static source without additional assistance and within the time limits of the study. Following these data, Fire Marshal officials noted that three-person crews were also at increased risk for exhaustion due to insufficient relief at fire scenes and made recommendations for the minimum staffing levels per apparatus necessary for suppression and rescue related tasks (Office of the Fire Marshal of Ontario, 1993).

The most comprehensive contemporary studies on the implications of fire-crew staffing now include much more accurate performance measures for tasks at the fireground in addition to the basic metric of response time. They include environmental measures of performance, such as total water supply, which expand the potential for assessing the cost-effectiveness of staffing not only in terms of fireground personnel injury rates but also comparative resource expenditures required for fire suppression. Several examples from the early 1990s show investigators and independent fire departments beginning to gather the kind of specific, comprehensive data on staffing and fireground tasks such as those suggested and outlined in concurrent local government publications that dealt with management of fire services (Coleman, 1988). A report by the Phoenix (AZ) Fire Department laid out clear protocols for responding to structure fires and response evaluation in terms of staffing, objectives, task breakdowns, and times in addition to outlining the responsibilities of responding fire department members and the order in which they should be accomplished for a full-scale simulation activity (Phoenix [AZ] Fire Department, 1991). One attempt to devise a prediction model for the effectiveness of manual fire suppression similarly reached beyond response-time benchmarks to describe fire operations and the step-by-step actions of firefighters at incident scenes by delineating the time-to-task breakdowns for size-up, water supply, equipment selection, entry, locating the fire, and advancing hoselines, while also comparing the predicted time-to-task values with the actual times and total resources (Menker, 1994). Two separate studies of local fire department performance, one from Taoyuan County in Taiwan and another from the London Fire Brigade, have drawn ties between fire crews' staffing levels and total water demand as the consequence of both response time and fire severity. Field data from Taoyuan County for cases of fire in commercial, business, hospital, and

educational properties showed that the type of land use as well as response time had a significant impact on the water volume necessary for fire suppression, with the notable quantitative finding that the water supply required on-scene doubled when the fire department response increased by 10 minutes (Chang & Huang, 2005).

Response time as a predictor of residential fire outcomes has received less study than the effect of crew size. A Rand Institute study demonstrated a relationship between the distance the responding companies traveled and the physical property damage. This study showed that the fire severity increased with response distance, and therefore the magnitude of loss increased proportionally (Rand Institute, 1978). Using records from 307 fires in nonresidential buildings over a 3-year period, investigators in the United Kingdom correspondingly found response time to have a significant impact on final fire area, which in turn was proportional to total water demand (Sardqvist, 2000).

Recent government and professional literature continue to demonstrate the need for more data that would quantify in depth and illustrate the required tasks, event sequences, and necessary response times for effective fire suppression in order to determine with accuracy the full effects of either a reduction or increase in fire-company staffing (Karter, 2008). A report prepared for National Institute of Standards and Technology (NIST) stressed the ongoing need to elucidate the relationship between staffing and personnel injury rates, stating that "a scientific study on the relationship between the number of firefighters per engine and the incidence of injuries would resolve a long-standing question concerning staffing and safety" (TriData Corporation, 2005). While not addressing staffing levels as a central focus, an annual review of fire department calls and false alarms by the NFPA® exemplified the need to capture not only the number of personnel per apparatus for effective fire suppression but also to clarify the demands on individual fire departments with resolution at the station level (NFPA®, 2008).

In light of the existing literature, there remain unanswered questions about the relationships between fire service resource deployment levels and associated risks. For the first time, this study investigates the effect of varying crew size, first-apparatus arrival time, and response time on firefighter safety, overall task completion, and interior residential tenability using realistic residential fires. This study is also unique because of the array of stakeholders and the caliber of technical advisors involved. Additionally, the structure used in the field experiments included customized instrumentation for the experiments; all related industry standards were followed; robust research methods were used; and the results and conclusions will directly inform the NFPA® 1710 Technical Committee as well as public officials and fire chiefs.¹

Discussion

Both the increasing demands on the fire service — such as the growing number of EMS responses, challenges from natural disasters, hazardous materials incidents, and acts of terrorism — and previous research point to the need for scientifically based studies of the effect of different crew sizes and firefighter-arrival times on the effectiveness of the fire service to protect lives and property. To meet this need, a research partnership of the Commission on Fire Accreditation International (CFAI), International Association of Fire Chiefs (IAFC), IAFF, NIST, and Worcester Polytechnic Institute (WPI) was formed to conduct a multiphase study of the deployment of resources as it affects firefighter and occupant safety. Starting in FY 2005, funding was provided through the U.S. Department of Homeland Security/Federal Emergency Management Agency (DHS/FEMA) Grant Program Directorate for Assistance to Firefighters Grant Program — Fire Prevention and Safety Grants. In addition to the low-hazard residential fireground experiments described in this report, the multiple phases of the overall research effort include development of a conceptual model for community risk assessment and deployment of resources, implementation of a generalizable department incident survey, and delivery of a software tool to quantify the effects of deployment decisions on resultant firefighter and civilian injuries and on property losses.

The first phase of the project was an extensive survey of more than 400 career and combination (both career and volunteer) fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the experimental phase of the project. The survey results will constitute significant input into the development of a future software tool to quantify the effects of community risks and associated deployment decisions on resultant firefighter and civilian injuries and property losses.

The following research questions guided the experimental design of the low-hazard residential fireground experiments documented in this report:

1. How do crew size and stagger affect overall start-to-completion response timing?
2. How do crew size and stagger affect the timings of task initiation, task duration, and task completion for each of the 22 critical fireground tasks?
3. How does crew size affect elapsed times to achieve the following three critical events that are known to change fire behavior or tenability within the structure?

- a. Entry into structure
 - b. Water on fire
 - c. Ventilation through windows (three upstairs and one back downstairs window and the burn-room window)
4. How does the elapsed time to achieve the national standard of assembling 15 firefighters at the scene vary between crew sizes of four and five?

In order to address the primary research questions, the research was divided into the following four distinct, yet interconnected parts:

- **Part 1** — Laboratory experiments to design appropriate fuel load
- **Part 2** — Experiments to measure the time for various crew sizes and apparatus stagger (interval between arrival of various apparatus) to accomplish key tasks in rescuing occupants, extinguishing a fire, and protecting property
- **Part 3** — Additional experiments with enhanced fuel load that prohibited firefighter entry into the burn prop — a building constructed for the fire experiments
- **Part 4** — Fire modeling to correlate time-to-task completion by crew size and stagger to the increase in toxicity of the atmosphere in the burn prop for a range of fire-growth rates

The experiments were conducted in a burn prop designed to simulate a low-hazard fire in a residential structure described as typical in NFPA® 1710. NFPA® 1710 is the consensus standard for career firefighter deployment, including requirements for fire department arrival time, staffing levels, and fireground responsibilities.

Limitations of the study include firefighters' advance knowledge of the burn prop, invariable number of apparatus, and lack of experiments in elevated outdoor temperatures or at night. Further, the applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, terrorism/natural disaster response, hazardous materials, or other technical responses has not been assessed and should not be extrapolated from this report.

Primary Findings

Of the 22 fireground tasks measured during the experiments, results indicated that the following factors had the most significant impact on the success of fire-fighting operations. All differential outcomes described in the following sections are statistically significant at the 95-percent confidence level or better.

Overall Scene Time

The four-person crews operating on a low-hazard structure fire completed all the tasks on the fireground (on average) 7 minutes faster — nearly 30 percent — than the two-person crews. The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster — nearly 25 percent — than the three-person crews. On the low-hazard residential structure fire, adding a fifth person to the crews did not decrease overall fireground task times. However, it should be noted that the benefit of five-person crews has been documented in other evaluations to be significant for medium- and high-hazard structures, particularly in urban settings, and is recognized in industry standards.²

Time to Water on Fire

There was a 10-percent difference in the *water on fire* time between the two- and three-person crews. There was an additional 6-percent difference in the water on fire time between the three- and four-person crews. (i.e., four-person crews put water on the fire 16 percent faster than two-person crews). There was an additional 6 percent difference in the water on fire time between the four- and five-person crews (i.e., five-person crews put water on the fire 22 percent faster than two-person crews).

Ground Ladders and Ventilation

The four-person crews operating on a low-hazard structure fire completed laddering and ventilation (for life safety and rescue) 30 percent faster than the two-person crews and 25 percent faster than the three-person crews.

Primary Search

The three-person crews started and completed a primary search and rescue 25 percent faster than the two-person crews. The four- and five-person crews started and completed a primary search 6 percent faster than the three-person crews and 30 percent faster than the two-person crew. A 10-percent difference was equivalent to just over 1 minute.

Hose Stretch Time

In comparing four- and five-person crews to two- and three-person crews collectively, the time difference to stretch a line was 76 seconds. In conducting more specific analysis comparing all crew sizes to the two-person crews, the differences are more distinct. Two-person crews took 57 seconds longer than three-person crews to stretch a line. Two-person crews took 87 seconds longer than four-person crews to complete the same tasks. Finally, the most notable comparison was between two-person crews and five-person crews — more than 2 minutes (122 seconds) difference in task completion time.

Industry Standard Achieved

As defined by NFPA® 1710, the *industry standard achieved* time started from the first-engine arrival at the hydrant and ended when 15 firefighters were assembled on scene.³ An effective response force was assembled by the five-person crews 3 minutes faster than the four-person crews. Based on the study protocols modeled after a typical fire department apparatus deployment strategy, the total number of firefighters on scene in the two- and three-person crew scenarios never equaled 15; and therefore the two- and three-person crews were unable to assemble enough personnel to meet this standard.

Occupant Rescue

Three different standard fires were simulated using the Fire Dynamics Simulator (FDS) model. Characterized in the *Handbook of the Society of Fire Protection Engineers* as slow-, medium-, and fast-growth rate,⁴ the fires grew exponentially with time. The rescue scenario was based on a nonambulatory occupant in an upstairs bedroom with the bedroom door open.

Independent of fire size, there was a significant difference between the toxicity, expressed as fractional effective dose (FED), for occupants at the time of rescue, depending on arrival times for all crew sizes. Occupants rescued by early-arriving crews had less exposure to combustion products than occupants rescued by late-arriving crews. The fire modeling showed clearly that two-person crews cannot complete essential fireground tasks in time to rescue occupants without subjecting them to an increasingly toxic atmosphere.

For a slow-growth-rate fire with two-person crews, the FED was approaching the level at which sensitive populations such as children and the elderly are threatened. For a medium-growth-rate fire with two-person crews, the FED was far above that threshold and approached the level affecting the general population. For a fast-growth-rate fire with two-person crews, the FED was well above the median level at which 50 percent of the general population would be incapacitated.

Larger crews responding to slow-growth-rate fires can rescue most occupants prior to incapacitation along with early-arriving larger crews responding to medium-growth-rate fires. The result for late-arriving (2 minutes later than early-arriving) larger crews may result in a threat to sensitive populations for medium-growth-rate fires. Statistical averages should not, however, mask the fact that there is no FED level so low that every occupant in every situation is safe.

Conclusion

More than 60 full-scale fire experiments were conducted to determine the impact of crew size, first-due engine arrival time, and subsequent apparatus arrival times on firefighter safety and effectiveness at a low-hazard residential structure fire. This report quantifies

the effects of changes to staffing and arrival times for residential fire-fighting operations. While resource deployment is addressed in the context of a single structure type and risk level, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many other factors, including geography, local risks and hazards, and available resources as well as community expectations. This report does not specifically address these other factors.

The results of these field experiments contribute significant knowledge to the fire service industry. First, the results provide a quantitative basis for the effectiveness of four-person crews for low-hazard response in NFPA® 1710. The results also provide valid measures of total effective response-force assembly on scene for fireground operations as well as the expected performance time-to-critical-task measures for low-hazard structure fires. Additionally, the results provide tenability measures associated with a range of modeled fires. Future research should extend the findings of this report in order to quantify the effects of crew size and apparatus arrival times for moderate- and high-hazard events such as fires in high-rise buildings, commercial properties, certain factories, or warehouse facilities and responses to large-scale nonfire incidents or technical-rescue operations.

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Endnotes

¹NFPA® is a registered trademark of the National Fire Protection Association®, Quincy, Massachusetts. NFPA® 1710 defines minimum requirements relating to the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by substantially all career fire departments. The requirements address functions and objectives of fire department emergency services delivery, response capabilities, and resources. The purpose of this standard is to specify the minimum criteria addressing the effectiveness and efficiency of the career fire department fire suppression operations, emergency medical services, and special operations delivery in protecting the citizens of the jurisdiction and the occupational safety and health of fire department employees. At the time of this experiment, the 2004 edition of NFPA® 1710 was the current edition.

² NFPA® 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*: Section 5.2.1 Fire Suppression Capability and Section 5.2.2 Staffing.

³ As defined in the *Handbook of the Society of Fire Protection Engineers*, a fast fire grows exponentially to 1 MW in 150 seconds. A medium fire grows exponentially to 1 MW in 300 seconds. A slow fire grows exponentially to 1 MW in 600 seconds. A 1 MW fire can be thought of as a typical upholstered chair burning at its peak. A large sofa might be 2 to 3 MW.

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