NIST

Report on High-Rise Fireground Field Experiments

Executive Summary

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Executive Summary

Overall, the results of this study show that the number of fire service crew members in each company responding to a fire in a 30,000 square foot, thirteen-story structure had a dramatic effect on the crew's ability to protect lives and property. This conclusion can be summarized in three principal parts.

First, when responding to a medium growth rate fire on the 10th floor, 3-person crews ascending to the fire floor confronted an environment where the fire had released 60% more heat energy than the fire encountered by the 6-person crews doing the same work. Unfortunately, larger fires expose firefighters to greater risks and are more challenging to suppress.

Second, larger fires produce more risk exposure for building occupants. In general, occupants being rescued by smaller crew sizes and by crews that used the stairs rather than the elevators were exposed to significantly greater dose of toxins from the fire. While the exact risk exposure for an occupant will depend on the fire growth rate, their proximity to the fire, and the floor on which the fire is located, it is clear that on-scene deployment decisions can have a dramatic impact in determining the fate of building occupants.

Third, the study confirmed that a properly engineered and operational fire sprinkler system drastically reduces the risk exposure for both the building occupants and the firefighters. While this has been well understood for many years and most new high-rise buildings are constructed with fire sprinkler protection, NFPA estimates that 41 percent of U.S. high-rise office buildings, 45 percent of high-rise hotels, and 54 percent of high-rise apartment buildings are not equipped with sprinklers. Moreover, sprinkler systems fail in about one in 14 fires. Thus, fire departments should be prepared to manage the risks associated with unsprinklered high-rise building fires.

High-rise firefighting operations are considered high-hazard scenarios[1] because of the potential for extremely large fires and the potentially large number of building occupants who may be exposed to the resulting heat and smoke. Fires that are not contained by sprinklers or other fire protection measures may grow to consume large portions of available floor area due to the significant time that it takes for firefighters to reach and suppress the fire, as well as the large quantities of fuel load typical of modern office spaces. The fire in the scenarios considered in this report may grow to consume the majority of the contents of the east portion of the building.

Additionally, high-rise buildings may have large floor areas and many floors at or above the fire that need to be searched for possible victims or occupants

1. A low hazard occupancy is defined in the NFPA Handbook as a one, two, or three family dwelling and some small businesses. Medium hazard occupancies include apartments, offices, mercantile and industrial occupancies not normally requiring extensive rescue or firefighting forces. High hazard occupancies include schools, hospitals, nursing homes, explosive plants, refineries, high-rise buildings, and other high life hazard or large fire potential occupancies.

requiring assistance. Searching the fire floor is typically conducted in high heat and low visibility conditions due to the proximity of the fire. The remaining floors above the fire can take substantial resources and time to fully search.

Together, the tasks and hazards typical of the high-rise fireground combine to form a substantial operational challenge typical of the high-hazard class of response scenarios.

Firefighting continues to be a hazardous profession; the National Fire Protection Association (NFPA) reports over 70,000 firefighter injuries annually (Karter, 2012), with many occurring on the fireground. Residential fires, as examined in the NIST Report on Residential Fireground Experiments (Averill et al., 2010), typically dominate the fire loss statistics (property loss, civilian injuries and deaths, and firefighter injuries and deaths) due primarily to their frequency of occurrence. Independent of frequency, however, the residential fireground is considered a low hazard scenario in NFPA 1710, the national consensus standard for fire service deployment. High-rise fires, which are the subject of this report, pose unique operational challenges to fire service response, and represent a high hazard life safety scenario. Key challenges include the sheer scope and scale of conducting search and rescue operations, difficulty moving people and equipment vertically to the fire area, the size of the fire based on the time it takes to initiate firefighting operations, and logistical management of the significant number of firefighters and equipment required to complete critical tasks.

Despite the apparent hazards however, there are no scientifically-based tools available to community and fire service leaders to assess the effects of fixed sprinkler systems, fire suppression equipment or resource deployment and staffing decisions. Though community and fire service leaders have a qualitative understanding of the effect of certain resources allocation decisions, there is a universal lack of a sound basis for quantifying the total effects.

The purpose of conducting a series of high hazard, high-rise fireground experiments is to provide quantitative data on the effect of crew size, effective firefighting force assembly time, and vertical-response time on the intervention capability, effectiveness and safety of firefighters during a working high-rise, high risk building fire on an upper floor. The results of the project will inform the NFPA 1710 Technical Committee regarding the optimal crew size and total effective firefighting force for a first alarm assignment to a working high-rise or other high hazard fire. These high hazard response scenarios will also “bracket” the spectrum of fire response, acting as a complement to recently published low hazard Residential Fireground Deployment Study (Averill et al., 2010).

Satisfying several research objectives, this report focuses on the results of the high hazard high-rise fireground experiments. For these experiments, two stages of research were completed: (a) fireground time-to-task experiments in a 13 story high-rise building using simulated fire and smoke conditions, and (b) computer fire modeling to estimate the tenability conditions in the building as a function of the firefighter activities determined in part (a).

The following research question structured and guided the experimental design:

The following research question structured and guided the experimental design:

In the event of a fire on an upper floor of a high-rise building, what is the minimal fire service deployment configuration necessary to mitigate the event effectively and safely?

More specifically, data were sought to answer the following questions about the time required to carry out tasks on the fireground under a variety of conditions.

Time-to-Task Research Questions

1) How do crew size, ascent mode (stairs vs. elevator) and size of full alarm assignment (i.e., alarm size — low versus high) affect overall (i.e., start to completion) response timing?

   a. How do variations in crew size affect overall response timing?

   b. How much does ascent mode affect overall timing?

   c. How much does the size of a full alarm assignment affect overall response timing?

   d. How do overall response times vary by combinations of crew size, ascent, and alarm size?

Fire Modeling Research Questions

1) How do performance times resulting from different combinations of crew size, alarm size, vertical ascent, and fixed fire sprinkler systems affect the development of standard fire growth scenarios?

2) How do crew size, alarm size, vertical ascent, and fixed fire sprinklers affect the resulting interior tenability on the fire floor?

Based upon the research questions, 16 unique scenarios were considered, as shown in the table on page 4. Each of the scenarios assumes a fire on the 10th floor of a 13 story building with an open floor plan configuration measuring 100 ft by 300 ft (30 m by 91 m), for an area of 30,000 sq ft (2800 m^2) per floor). The fuel load is a standard cubicle configuration, with open-wall material, typical desk and drawer furniture, computers, printers and office chairs. Each scenario included two victims; one located on the fire floor and one located on the floor above the fire (Floor 11).

Scenario 1: High-alarm assignment[2] with 6-person crews dispatched to the building. Two fire service access elevators are available for fire service use. (Best case)	**Scenario 2:** Low-alarm assignment[3] with 6-person crews dispatched to the building. Two fire service access elevators are available for fire service use.
Scenario 3: High-alarm assignment with 5-person crews dispatched to the building. Two fire service access elevators are available for fire service use.	**Scenario 4:** Low-alarm assignment with 5-person crews dispatched to the building. Two fire service access elevators are available for fire service use.
Scenario 5: High-alarm assignment with 4-person crews dispatched to the building. Two fire service access elevators are available for fire service use.	**Scenario 6:** Low-alarm assignment with 4-person crews dispatched to the building. Two fire service access elevators are available for fire service use.
Scenario 7: High-alarm assignment with 3 person crews dispatched to the building. Two fire service access elevators are available for fire service use.	**Scenario 8:** Low-alarm assignment with 3-person crews dispatched to the building. Two fire service access elevators are available for fire service use.
Scenario 9: High-alarm assignment with 6-person crews dispatched to the building. Stairs are available for fire service use.	**Scenario 10:** Low-alarm assignment with 6-person crews dispatched to the building. Stairs are available for fire service use.
Scenario 11: High-alarm assignment with 5-person crews dispatched to the building. Stairs are available for fire service use.	**Scenario 12:** Low-alarm assignment with 5-person crews dispatched to the building. Stairs are available for fire service use.
Scenario 13: High-alarm assignment with 4-person crews dispatched to the building. Stairs are available for fire service use.	**Scenario 14:** Low-alarm assignment with 4-person crews dispatched to the building. Stairs are available for fire service use.
Scenario 15: High-alarm assignment with 3-person crews dispatched to the building. Stairs are available for fire service use.	**Scenario 16:** Low-alarm assignment with 3-person crews dispatched to the building. Stairs are available for fire service use. (Worst case)

2. Low Alarm Assignment is defined as 3 Engines, 3 Trucks, 2 Battalion Chiefs (with Aides), 2 Ambulances
High Alarm Assignment is defined as 4 Engines, 4 Trucks, 2 Battalion Chiefs (with Aides), 3 Ambulances

Primary Findings

Of the 38 fireground tasks measured during the experiments,[3] certain tasks were deemed critical, having he most significant impact on the success of firefighting operations. All differential outcomes described below are statistically significant at the 95 % confidence level or better.

Overall Time To Task Completion

Overall scene time is the time that firefighters are actually engaged in tasks on the scene of a structure fire. During the experiments, this time included all operational tasks with the exception of overhaul[4] and salvage[5]. The time to completion of all tasks decreases as crew size increases. On average, 3-person crews took nearly an hour to complete their fire response, while crews of 6 firefighters required a mean time of just under 40 min for completion. The performance of crews sized 4 and 5 were in-between, with crew size 5 taking about 2 min longer than crew size 6, and crew size 4 taking about 9 min longer than crew size 5 but 12 min less than crew size 3. Therefore, the time to complete all task times are substantially reduced for crew size of 6 compared to 5, 5 compared to 4, and 4 compared to 3.

Advance Attack Line

As firefighters engage on a fireground, putting water on the fire is one of the most important tasks. Extinguishing the fire is necessary to reduce the continuously escalating risks from fire and the toxic products of combustion. Before water can be put on a fire, however, a hose line must be stretched from the standpipe in the stairwell to the compartment where the fire is burning. In a more specific analysis comparing each crew size to a 3-person crew, the time differences increase as crew size increases. From the initiation of on-scene firefighting activities, a 3-person crew took 1 min 43 s (8.5 %) longer than a 4-person crew to stretch the hose line. A 3-person crew took 2 min 47 s (13.9 %) longer than a 5-person crew to complete the same task. Finally, the most notable comparison was between a 3-person crew and a 6-person crew, with a 4 min 28 s (22.3 %) difference in task completion time.

Advance Second Line

The size of the fire required two 2 ½ inch lines to fully suppress; therefore, a second hose line had to be advanced from the standpipe in the stairwell to the fire. A 3-person crew took 4 min 4 s (17.4 %) longer than a 5-person crew to stretch the second line. A 4-person crew took 2 min 43 s (12.3 %) longer than a 5-person crew to complete the same task. Finally, the most notable comparison was between a 3-person crew and a 6-person crew, with a 5 min 38 s (24.1 %) difference in task completion time.

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3. In addition to the tasks denoted in this report, salvage and overhaul operations on the fireground are major tactical priorities that require significant time and resources in order to minimize loss. These tasks however, were not included in the study scenario.
4. Overhaul is used to ensure the fire is out completely and that the environment is safe for others to enter. Firefighters may use thermal imaging cameras to look at walls and ceilings to find hot spots, or they may tear out sections of walls and pull sections of ceilings to assure there has been no fire spread.
5. Salvage is the firefighters' attempt to save property or reduce the damage from water and smoke. Salvage operations are typically performed immediately after a fire by removing unharmed property from the fire area and covering it with canvas tarpaulin or other heavy protective material.

Fire Out

Extinguishing the fire out is critical to reducing risk to both firefighters entering the structure and to trapped occupants. Fire Out, in the study, was defined as having both the attack line and the second hose line in place. There was a 2 min 14 s difference (8.1 %) in the Fire Out time between the 3- and 4-person crews. There was an additional 1 min 15 s difference (5.0 %) in the Fire Out time between the 4- and 5-person crews. (i.e., 5-person crews extinguished the fire 3 min 29 s faster than 3-person crews). Finally, there was a 7 min 2 s difference (25.6 %) in the Fire Out time between the 3- and 6-person crews.

Search and Rescue 10th Floor

The fire floor was an open floor plan and contained 96 cubicles. In the high hazard high-rise commercial building, the 4-person crew started the search 1 min 23 s (7.8 %) faster and completed the search and rescue 11 min 21 s (18.4 %) faster than the 3-person crews. In the same structure, the 5-person crews started the search 1 min 4 s (6.7 %) faster than the 4-person crews and 2 min 27 s (14.1%) faster than the 3-person crew. Additionally, 5-person crews completed the search faster than the 4- and 3-person crews by 13 min 34 s (29 %) and 24 min 55 s (42 %) respectively. Six-person crews had the best times, starting the search 1 min 19 s faster and completing the search 2 min 57 s (8.0%) faster than 5-person crews. The greatest difference in search times was between 6- and 3-person crews. Six-person crews started the search on the fire floor 3 min 46 s (22 %)faster and completed the search 27 min 51 s (47 %) faster than the 3-person crews.

Victim #1 Rescued

There was a single victim located on the fire floor that was found and rescued by all crews. A 5-person crew located the victim on the fire floor 25 min 19 s (50.6 %) faster than a 3-person crew and 12 min 7 s (32.9 %) faster than a 4-person crew. Likewise, a 6-person crew located the victim on the fire floor 28 min 33 s (57.1 %) faster than the 3-person crew, 15 min 21 s (41.7 %) faster than the 4-person crew, and 3 min 14 s (13.2 %) faster than a 5-person crew.

Four-person crews also removed the victim from the IDLH[6] environment and facilitated the victim's exit from the building 13 min 11 s (25.1 %) faster than a 3-person crew. Likewise, 5-person crews were able to remove the victim from the fire environment and get them out of the building 11 min 39 s (29.7 %) faster than the 4-person crews, while 6-person crews removed the victim from the environment and got them out of the building 14 min 58 s (38.1 %) faster than the 4-person crews and 3 min 19 s (12.0 %) faster than the 5-person crews. Additionally, victim descent occurred 4 min 42 s more quickly for crews using elevator rather than stairs to get the victim out of the building.

6. IDLH — Immediately Dangerous to Life and Health. IDLH conditions can be due to high levels of heat, smoke, or toxic gases, which rapidly threaten a person's ability to effect their own escape.

Advance Line Above the Fire (11th Floor)

In a high-rise structure, it is essential to place a hose line on the floor above the fire floor in the event of vertical fire spread. A 3-person crew took 2 min 58 s (11.5 %) longer than a 5-person crew to complete this task while, a 4-person crew took nearly 2 min (7.8 %) longer than a 5-person crew. The most notable comparison was between a 3-person crew and a 6-person crew, with a 3 min 38 s (14.0 %) difference in task completion time.

Search and Rescue 11th Floor

The floor above the fire was separated into a number of conference rooms and offices that had to be searched by each crew. During the experiments, the 4-person crews completed the search 9 min 31 s (18.6 %) faster than the 3-person crews. Meanwhile, the 5-person crews started a primary search/rescue 1 min 34 s (6.8 %) faster than the 4-person crews and completed the search 2 min 37 s (6.3 %) faster than the 4-person crews. In the same structure, the 6-person crews also started the search 1 min 30 s (6.6 %) faster than the 4-person crews but completed the search 5 min 8 s (12.3 %) faster than the 4-person crews.

Victim #2 Rescued

In addition to the victim on the fire floor, a second victim was located on the floor above the fire. Each crew operating on this floor was tasked with locating and rescuing the victim. The 5-person crews located the victim 17 min 23 s (34 %) faster than the 3-person crews and 2 min 41 s (7.4 %) faster than the 4-person crews. Likewise, 6-person crews located the victim on the floor above the fire 2 min 48 s (7.7 %) faster than the 4-person crews.

Four-person crews removed the victim from the IDLH environment and got them out of the building 14 min 33 s (27.2 %) faster than 3-person crews. Likewise, 5-person crews were able to remove the victim from the fire environment and get them out of the building 17 min 9 s (32.1 %) faster than 3-person crews and 2 min 36 s (6.7 %) faster than the 4-person crews. Similarly, the 6-person crews rescued and removed the victim from the building 2 min 48 s (7.1 %) faster than 4-person crews. Additionally, victim descent occurred nearly 6 min more quickly for crews using elevator rather than stairs.

Summary of Regression Analysis

The effects of crew size, vertical ascent mode, and alarm size on the timing of critical firefighter tasks were studied using standard regression analysis. The analysis compared the times at which each task was started, the time to complete the task, and the time the task was completed. These timing values were given the labels begin time, duration, and end time, respectively.

Crew Size

Going from 3-person to 4-person crews had a large impact on advancing the attack line, advancing the second line, and begin times for search and rescue. Reductions in times to begin these tasks were in the range of 1 min to 2 min. Going from 4-person to 5-person crews reduced the times to begin all critical tasks by 1 min to 2 min. Increasing crew size from 5-person to 6-person crews showed significant reductions in begin time, just over 1 min, to advance the attack and second lines and for search and rescue on the fire floor (10th floor).

When assessing task end times and incrementally increasing crew size by a single firefighter (i.e., 3 to 4, 4 to 5, and 5 to 6), the largest time improvements are seen when going from crew size 3 to 4. As firefighter crews navigate the later tasks, the improvements cumulatively reach the 10 min to 15 min range. Very large time improvements are seen for the 10th Floor Search and Victim #1 Rescue tasks (over 11 min) when incrementing crew size from 4 to 5. The improvements in the times to complete all tasks are substantial (9 min to 12 min) when incrementing crew size from 3 to 4 or from 4 to 5.

Fire Service Access Elevators

All tasks were completed more than 4 min faster when the elevators were utilized compared to stairs. Begin times for nearly every critical task above ground level and nearly all end times were reduced compared to stair ascent. This is because using fire service access elevators dramatically reduced times associated with upward and downward transport of people or equipment. Using elevators to transport air bottles and other equipment from the lobby to Staging allowed completion of Establishment of Stairwell Support[7] over 10 min more quickly than moving the equipment up the stairs. Additionally, the transport of both Victim #1 and Victim #2 from Staging to the outside of the building was faster when using the elevators (compared to the stairs), by 2 min 41 s and 3 min 19 s, respectively.

Alarm Size

Tasks assigned to engine 4 and truck 4, including Advancing the Line Above the Fire, Primary Search on Floor 11 and Rescuing Victim #2, had begin time and end time reductions since those crews were dispatched in the first rather than the second alarm assignment.

Combining Alarm Size and Crew Size

Given the findings from the crew size analysis that adding one or two firefighters to a crew could generally achieve substantial task performance increases, a logical question is whether the meaningful benefits of a higher crew size could be realized by implementing a larger alarm response (additional engines and trucks) at a smaller crew size (e.g., high/4 compared to low/5). Another hypothesis is that a high response with lower crew size might yield similar results in task timing to that of a low response with higher crew size.

In summary, the analysis of the alarm response and crew size combinations suggests that the benefits of higher crew size exceed those of higher alarm assignment. Low alarm response with a higher crew size tends to be more favorable in critical task timings than the corresponding timings for a high alarm response with a crew size of one less firefighter.

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7. Stairwell Support is also known as Ground Support, according to NFPA Standard 1561: Standard on Emergency Services Incident Management System.

Combining Alarm Response and Ascent Mode

In comparing different combinations of alarm response (high, low) and ascent mode (stairs, elevator), results contrasted several combinations of alarm size and ascent mode.

The alarm size had virtually no effect on critical task timings, with the exception of Primary Search of the Floor Above the Fire (Floor 11) and Victim #2 Rescue. High alarm response realized a mean reduction in the range of 1 min to 4 min for these tasks. The Overall Time to Task Completion was also significantly smaller for high alarm response by 3 min. No other task timing comparisons were statistically different.

In the elevator scenarios, high alarm response led to eight significantly lower timings than did a low alarm response. Results show 45 s reductions in begin time for Fire Out, Primary Search of Fire Floor 10, and Victim #1 Found. Small reductions of just over a minute were noted in begin times for Search of the Floor Above the Fire (Floor 11) and Victim #2 Found. Small reductions of 30 s to 2 min were also noted for times related to Advance the Line Above the Fire. No other task timing comparisons were statistically different.

Fire Modeling Results

In order to assess the hazard to occupants and firefighters as a consequence of different deployment configurations, computer fire modeling was performed. Three different 'standard' fires were simulated using the NIST Fire Dynamics Simulator (FDS) model. The three fires, characterized in the Handbook of the Society of Fire Protection Engineers (SFPE) (Hadjisophocleous and Mehaffey 2008) as slow, medium, and fast,[8] grew non-linearly with time and had burning characteristics similar to the experimental results of typical office cubicle fires (Madrzykowski et al. 2004).

An Fractional Effective Dose (FED)[9] value of 1.0 is defined as the toxic exposure at which 50 % of the population would be incapacitated. The detailed probabilistic relationship between FED and the percentage of people incapacitated is unknown. However, an FED of 0.3 can be related qualitatively to a level that affects vulnerable members of the population, while an FED of 3.0 will incapacitate all but the least sensitive people.

Computer fire modeling using NIST's FDS demonstrated the effectiveness of a working fire sprinkler system for medium growth rate fires; the FED values remained well below a value of 0.3 for all crew sizes and ascent methods, while FED values for non-sprinkled structures typically exceeded 1.0 at some point

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8. As defined in the SFPE Handbook, a fast fire grows to 1 MW in 2 min 30 s; a medium fire grows to 1 MW in 5 min; a slow fire grows exponentially to 1 MW in 10 min. A 1 MW fire can be thought of as a typical upholstered chair burning at its peak. A large sofa may produce a fire with a peak HRR value of 2 MW to 3 MW.
9. To characterize the accumulated hazard associated with inhalation of gases typical of combustion products, a time-integrated value known as the fractional effective dose (FED) was used. FED is an international standard, maintained by the International Standards Organization (ISO) and documented in ISO document 13571. FED is a probabilistic quantity used to estimate the impact of toxic gases on humans (ISO 2007). For this study, FED accounted for the effects of excess carbon monoxide and carbon dioxide inhalation and oxygen depletion.

during fire development. Thus, the overall hazard is greatly improved compared to the non-sprinklered fires for both firefighters and occupants. According to the NFPA, a working sprinkler system is 96 % effective at controlling the growth and spread of fires in structures (NFPA 2006). Due to a number of high-profile fires in high-rise buildings, and considering their demonstrated effectiveness, sprinkler systems are often required in new high-rise buildings and many jurisdictions have required existing high-rise buildings to be retrofitted with sprinkler systems.

However, sprinkler systems are not installed or functional in all high-rise buildings. According to the NFPA (NFPA 2011), 41 % of high-rise office buildings are not protected by sprinkler systems (compared to 25 % of high-rise "care of sick" facilities, 45 % of high-rise hotels and 54 % of high-rise apartment buildings). Therefore, much of this report is focused on analysis of fire department deployment configurations responding to fires in an unsprinklered high-rise building.

Note, further, that sprinkler systems are designed to control fires, rather than suppress them. Fire department response is still required even in fully-sprinklered high-rises in order to extinguish the fire, to search for and rescue occupants requiring assistance, and to control the sprinklers (limiting water damage). Additionally, NFPA estimates that sprinkler systems fail to operate in 7 % of structure fires (one of every fourteen fires) primarily due to human error. "Two-thirds (65 %) of the sprinkler failures to operate were because the system had been shut off before the fire. Another one-sixth (16 %) occurred because manual intervention defeated the system, for example, by shutting off the sprinklers prematurely. Lack of maintenance accounted for 11 % of the sprinkler failures and 5 % occurred because the wrong type of system was present. Nearly all failures were therefore entirely or primarily problems of human action. Only 3 % involved damage to system components." (NFPA 2006) Therefore, even when a large proportion of high-rise buildings within a jurisdiction are protected by sprinkler systems, the fire department should be prepared to deploy resources to hazards consistent with unsprinklered fires.

For unsprinklered scenarios, the time advantages gained by larger engine crew sizes and by using elevators versus stairs. allowing crews to complete tasks more quickly, improving the interior conditions, including temperature, visibility, and toxicity on the fire floor. For medium growth rate fires, firefighters entering the environment were found to encounter fires between 5 MW to 11 MW in size, depending on crew configuration and ascent method. This range in fire size can be visualized as the equivalent of two cubicles on fire for a 6-person crew versus five cubicles on fire for a 3-person crew.

Crew size and vertical ascent mode can significantly affect the likelihood of a successful rescue of victims on the fire floor. For victim rescue times discussed above, FED values in the cubicle where the victim was located ranged from 0.14 (6-person crew using the elevator) to 1.22 (3-person crew using the stairs). The FED, based on the biological effects of toxic gases, was used to assess the tenability of the fire environment. Consistently, smaller crew sizes resulted in greater exposure of victims and firefighters to combustion products compared to larger crew sizes. Additionally, using the stairs delayed rescue and resulted in higher toxic exposures when compared to using the elevators.


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Limitations

The scope of this study is limited to understanding the relative influence of deployment variables to the critical outcomes associated with a working high-rise structure fire. The applicability of the conclusions from this report to low hazard residential fires, outside fires, terrorism/natural disaster response, HAZMAT or other technical responses has not been assessed and should not be extrapolated from this report. Additionally, some important tasks, such as secondary search, property salvage, utility control, water mitigation, building overhaul, and returning firefighting equipment were not considered in these experiments. These tasks delay the return of units to service and should be considered in the design of fire department coverage. Other limitations that affect the interpretation of the data or conclusions are discussed in the report.

Conclusions

A total of 48 field experiments and complementary fire modeling simulations were conducted to determine the impact of crew size, alarm size and vertical response mode on firefighter safety and effectiveness at a high hazard high-rise commercial structure fire. This report quantifies the effects of changes to crew size, alarm size and/or vertical response mode for high hazard high-rise commercial firefighting operations in both sprinklered and non-sprinklered buildings. While resource deployment is addressed in the context of a high-rise structure type and high risk level, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many factors including geography, available resources and community expectations, as well as local hazards and risks. Though this report contributes significant knowledge to community and fire service leaders in regard to effective resource deployment for fire suppression, other factors contributing to policy decisions are not addressed.

The results provide a technical basis for the effectiveness of company crew size, alarm size and vertical response mode to be added to NFPA Standard 1710. The results also provide valid measures of total effective response force assembly on scene for high-rise fireground operations, as well as the expected performance of time-to-critical-task measures for high hazard high-rise commercial structure fires. Additionally, the results provide tenability measures associated with the occupant exposure rates to the range of fires considered by the fire model. The results of the project will also inform code provisions in the national model building codes which require fire service access elevators in new construction over 120 ft (36 m).

Future research should extend the findings of this report in order to quantify the effects of crew size and apparatus arrival times for moderate/medium hazard or other high hazard events, such as fires in mercantile establishments consisting of a row of stores and restaurants, warehouse facilities, responses to large-scale non-fire incidents, or technical rescue operations.

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FIRE FIGHTER SAFETY AND DEPLOYMENT STUDY

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