GEOGRAPHIC INFORMATION SYSTEM EMERGENCY SERVICES RESPONSE CAPABILITIES ANALYSIS

FINAL REPORT

International Association of Fire Fighters
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Washington, DC 20006

BEAVER DAM

FIRE AND RESCUE DEPARTMENT

Beaver Dam, WI

July 2020

Dedication

This Report is Dedicated to the Citizens of Beaver Dam, Wisconsin who Deserve the Most Efficient and Effective Fire, Rescue, and Emergency Medical Services Available.

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Executive Summary

The International Association of Fire Fighters (IAFF) Headquarters was engaged by the Beaver Dam Professional Firefighters, IAFF Local 3432, to provide information and resources to decision makers of the City of Beaver Dam regarding the deficiency of resources of the Beaver Dam Fire and Rescue Department (BDFRD).

The Beaver Dam Fire and Rescue Department provides fire suppression, rescue, non-emergency interfacility transfers, and emergency transport at the Advanced Life Support (ALS) level. The department provides coverage to the cities of Beaver Dam, Trenton, Calamus, and Westford for both fire and emergency medical service (EMS) response and EMS response only to Lowell Town and Lowell Village.

The department responds from one station and deploys one frontline engine, ladder and medic unit with a minimum staffing level of five firefighters. The department also maintains a number of additional vehicles, specifically, two engines, one rescue engine, four medic units, one tender truck, one brush truck, one fire boat, one hovercraft, a pickup truck and a van. At the minimum staffing level, the ladder truck is staffed by one firefighter while the engine and medic unit are staffed with two firefighters on each. These staffing levels do not meet the industry standards for a safe response, as outlined below. Career firefighters cross-staff the medic units, engine, the ladder truck and the other apparatus of the department. "Cross-staff" is a practice whereby the same crew is used to operate different units (e.g. medic unit or engine), dependent upon the type of incident. For example, when an EMS incident occurs, requiring more than one medic unit to respond, the firefighters of the fire engine staff one of the reserve ambulances, and overtime personnel or part time firefighters are called in, to maintain the minimum staffing level. Similarly, when a fire incident requires more than one engine, the personnel of the medic unit staffs one of the reserve engines. The use of overtime personnel increases the risk both for the firefighters and the community, as personnel working overtime might become fatigued, increasing the risk of injuries, and might not be able to efficiently complete critical emergency tasks. Local 3432 reports that part-time firefighters respond from home, which can cause delays and increases the risk for the community, as the other units would have to wait on scene for the part-time firefighters to arrive[1].

The practice of cross-staffing decreases the efficiency of the fire department and the safety of the community. For example, when a cross-staff crew is engaged on a medic unit, there are no

[1] This was the response model of the department until March 2020 and which was used during the time period covered by the data used in this report. In March 2020, the department modified its response: the engine is staffed with four firefighters. Part time firefighters respond to the station, staffing the ladder and additional apparatus as needed.

firefighters available to operate the fire suppression apparatus assigned to the same station. Similarly, when crews are operating the engines or the ladder, there is not a crew available to respond to an EMS incident requiring a medic unit. These incidents might need to wait for a crew to become available before receiving a response, increasing the risk of a negative outcome of the emergency.

The population of Beaver Dam and the other communities that are served by the fire department are expected to increase over the next years, and, with it, the number of both EMS and fire incidents will likely increase as well. The department does not have enough resources and apparatus to meet the current and future demand. Additionally, since engines are staffed with two firefighters and the ladder truck by one, the department does not meet the minimum staffing objectives for effective, efficient and safe emergency operations established by the National Fire Protection Association (NFPA®) Standard 1710: *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations and Special Operations to the Public by Career Fire Departments* and the Occupational Safety and Health Administration's (OSHA) "2 In/2 Out" Regulation. Studies[2] have shown that the smaller the crew size, the more tasks an individual must complete, which contributes to diminished efficiency and delays in initiating fire attack, containing fire. The failure to maintain enough resources to meet demand in a timely manner exposes civilians and firefighters to increased risk. It also furthers drains fire department resources and stresses the emergency response system by requiring additional apparatus to respond from farther distances.

This document will examine the department's incident demand levels and response capabilities in comparison to industry standard staffing and performance objectives. The current deficiencies within the BDFRD will be addressed by examining the call volume, the geographic characteristics and the risk factors existing in the department's jurisdiction. Through an analysis of computer-aided dispatch (CAD) data and the use of geographic information systems (GIS) mapping software, decision makers in Beaver Dam will be able to implement changes to the staffing level which will increase the safety of the population.

[2] NIST Report on Residential Fireground Field Experiments and NIST Report on High-Rise Fireground Field Experiments. < https://www.nist.gov/sites/default/files/documents/el/fire_research/Report-on-Residential-Fireground-Field-Experiments.pdf > and < https://www.nist.gov/publications/report-high-rise-fireground-field-experiments >

Key Findings

- The population of Beaver Dam is expected to increase in nearly every census tract[3] of the city in the next four years, with the highest growth rates expected in the central and west part of the city.

- The Centers for Disease Control found that the population in the central part of the city has the highest social vulnerability based on socioeconomics and demographic factors and is more exposed to the consequences of EMS and fire incidents. This area has also the highest density of fire and EMS incidents.

- The department can reach 15.4% of the city roads and 54% of the historical incidents' locations within 4 minutes of travel time from the station, assuming that the units are available and dispatched from the station.

- The department can assemble a minimum of four firefighters required by the "2 In/2 Out" regulation on 15.4% of the city roads, assuming that the units are available and dispatched from the station.

- The department does not have sufficient personnel to assemble the minimum response force of 17, 28, and 43 firefighters required for low, medium, and high-hazard fires[4].

- The number of incidents, including interfacility transfers, that the BDFRD responded to, increased by 8% between 2017 and 2018, from 2,540 to 2,745.

- A single incident often requires multiple units to respond. Demand must be assessed not only by considering the number of incidents, but also considering the number of units responding to the same incidents. The number of units' responses required to address the incidents increased by 15%, from 2,879 in 2017 to 3,306 in 2018.

- The number of units' responses required to address the incidents increased by 15%, from 2,879 in 2017 to 3,306 in 2018

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[3] A census tract is a geographic unit used by the US Census Bureau.

[4] A low-hazard structure fire is defined as a fire that occurs in a typical, 2000 square foot single-family residential home with no basement or exposures. Typical examples of medium-hazard structures include any shopping center ranging in size from 13,000 ft2 to 196,000 ft2 and 1,200 ft2 apartments in a three-story garden-style apartment building. Other examples include offices, mercantile, and industrial occupancies. NFPA 1710, §5.2.4.2.1, §5.2.4.3.1, and §A.5.2.4.1 (2). Examples of high-hazard fires are fires in large area buildings such as manufacturing centers, warehouses, grocery stores, schools, and other structures with a high fire load and populations.

- In 2017, 11% of the EMS incidents were non-emergency interfacility transfers, which increased to 16% in 2018.

- The department does not meet the NFPA 1710 travel time objective for EMS incidents: 63% of the EMS incidents received the first EMS unit within 4 minutes instead of the 90% required by NFPA 1710.

- The department does not meet the NFPA 1710 travel time objective for fire incidents: 49% of the fire incidents received an inadequately staffed engine, within four minutes, instead of the 90% required by NFPA 1710.

- Two or more of the four medic units were engaged at the same time for 297 hours in 2017 and 491 hours in 2018, which represents a 65% increase. This increase is due both to an increase of the time spent on emergencies and non-emergencies.

- Because of the practice of cross-staffing units, when multiple medic units are engaged in a response, the department does not have enough firefighters to staff the engines, unless overtime personnel are called in and arrive on station before another incident is dispatched. This increases the risk of excessive fatigue and injuries for the personnel, who might not have sufficient time to rest between shifts, as well as for the community, as the responses might be delayed.

Recommendations

The following recommendations will bring the department closer to meeting the NFPA 1710 objectives and will help reduce the travel times, the time required to assemble the minimum response force of four firefighters, and reduce the use of overtime personnel and the time when multiple medic units are engaged at the same time:

- increase the minimum staffing level to regularly staff one engine and the ladder truck with four firefighters each.

- Staff two medic units with two firefighters each, at all times.

Executive Summary Conclusion

The calls volume increased by 8% between 2017 and 2018, and the number of units needed to address these calls increased by 15%. The population of Beaver Dam and the nearby communities is expected to increase in the next four years and with it the number of emergency incidents.

The department does not meet the NFPA 1710 travel time and staffing objectives. Approximately 63% and 49% of the EMS and fire incidents received a first unit within four minutes, instead of the minimum of 90% required by NFPA 1710. In the time period analyzed in this report, the department was staffing the engine with two firefighters and the ladder truck with one, instead of the minimum of four firefighters on each fire suppression apparatus required by industry standards[5]. Additionally, the engine, the ladder truck and the medic units are cross-staffed, so that when multiple medic units are engaged at the same time there are no firefighters available to staff the engine and the ladder, and, similarly, when firefighters are operating the fire suppression apparatus, there is no personnel available to staff the medic units, unless overtime firefighters are called in.

At least two of the four medic units were engaged at the same time for 297 hours in 2017, and 491 hours in 2018, which represents a 65% increase. Because of the practice of cross-staffing units, when multiple medic units are engaged in a response, the department does not have enough firefighters to staff the engines.

In order to reduce response times, increase the safety of the firefighters, and meet the future demand, BDFRD should regularly staff both the ladder track and one engine with four firefighters. Two medic units should also be regularly staffed with two firefighters each.

The provision of fire protection and EMS response are essential services that governments must provide. However, for these services to be effective and efficient, they must be staffed and positioned appropriately to address emergencies in an equitable manner, as they occur. The findings in this report will provide the department and city officials with information on how the department's present response capabilities compare to industry standards and how the current lack of resources negatively affects the BDFRD ability to appropriately respond to incidents in the City of Beaver Dam. This information will demonstrate why the department should increase current resources to ensure that the demand can be met.

[5] In March 2020, the department modified its response: the engine is staffed with four firefighters. Part time firefighters respond to the station, staffing the ladder and additional apparatus as needed. However the department did not cease the practice of cross-staffing its units, and does not staff the ladder truck with four firefighters, as required by NFPA 1710.

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Risk Assessment of Beaver Dam

A significant part of planning for future fire department strategies is knowing the risks in the community. As such, risk characteristics within the City of Beaver Dam were examined for this report.

Demographic Profile

The City of Beaver Dam is located in Dodge County, Wisconsin. According to the 2010 US Census[6], Beaver Dam had a population of 16,214 people. The estimated population in July 2018 was 16,355 people. The GIS analysis conducted by the IAFF found that the population is expected to increase in nearly every census tract[7] of the city in the next four years, with the highest growth rates expected in the central and west part of the city. Nearby communities, where the department provides fire and EMS coverage, will also experience population growth, with the highest growth expected in the City of Madison and in Washington County. Since these communities belong to the department response area, the population growth in these cities will also increase the demand on the department.

The US Census reports that the fraction of people 65 years of age and older was 16.5% in 2018 and the fraction of people under the age of 5 was 5.4%. People in this category of age are considered more vulnerable and typically less able to anticipate, cope with, resist and or recover from the impacts of disaster. In total, 21.9% of the population of Beaver Dam is in a vulnerable category based on age. Additionally, in the period 2014-2018, 9.6% of the total population was represented by people under the age of 65 who were living with a disability.

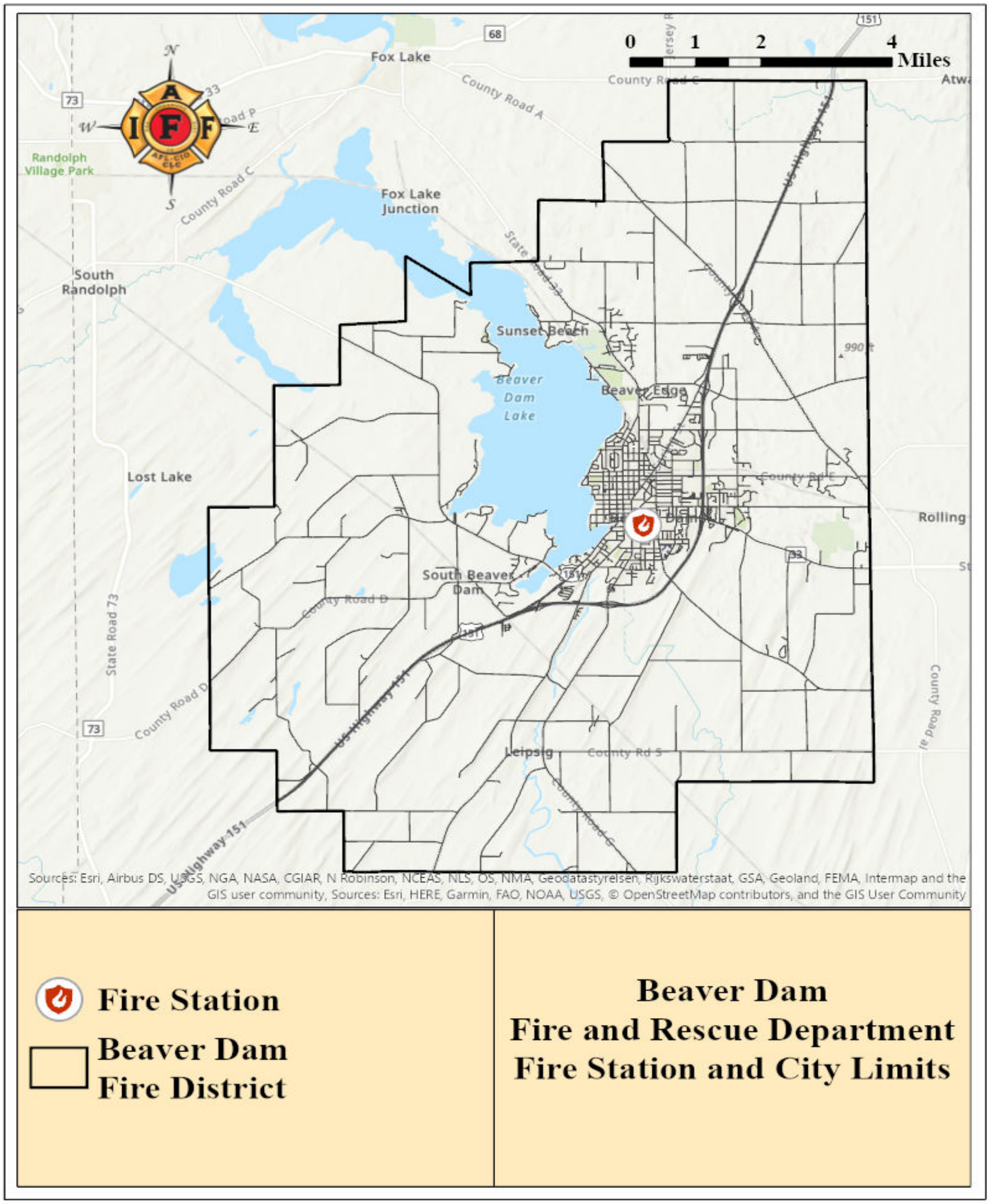
Poverty is another vulnerability factor. The US Census found that 11.3% of the Beaver Dam population lives at or below the poverty level. These are people that generally lack the means to properly maintain residences, which can lead to an increased risk for fire. Typically, people living within the demographics described above are at an increased risk for medical complications and hazard-related injury or death.

When assessing community risk, it is also important to consider housing characteristics. In 2019 the total number of housing units was estimated to be 10,136[8], and 844 units were vacant. Vacant units, lacking maintenance and fire protection features, are typically at a higher risk of fires and collapses, which increases also the risk of injuries and deaths for the firefighters. The buildings built in 1939 or earlier were 28% of the total, and those built in 1979 or earlier were 67% of the

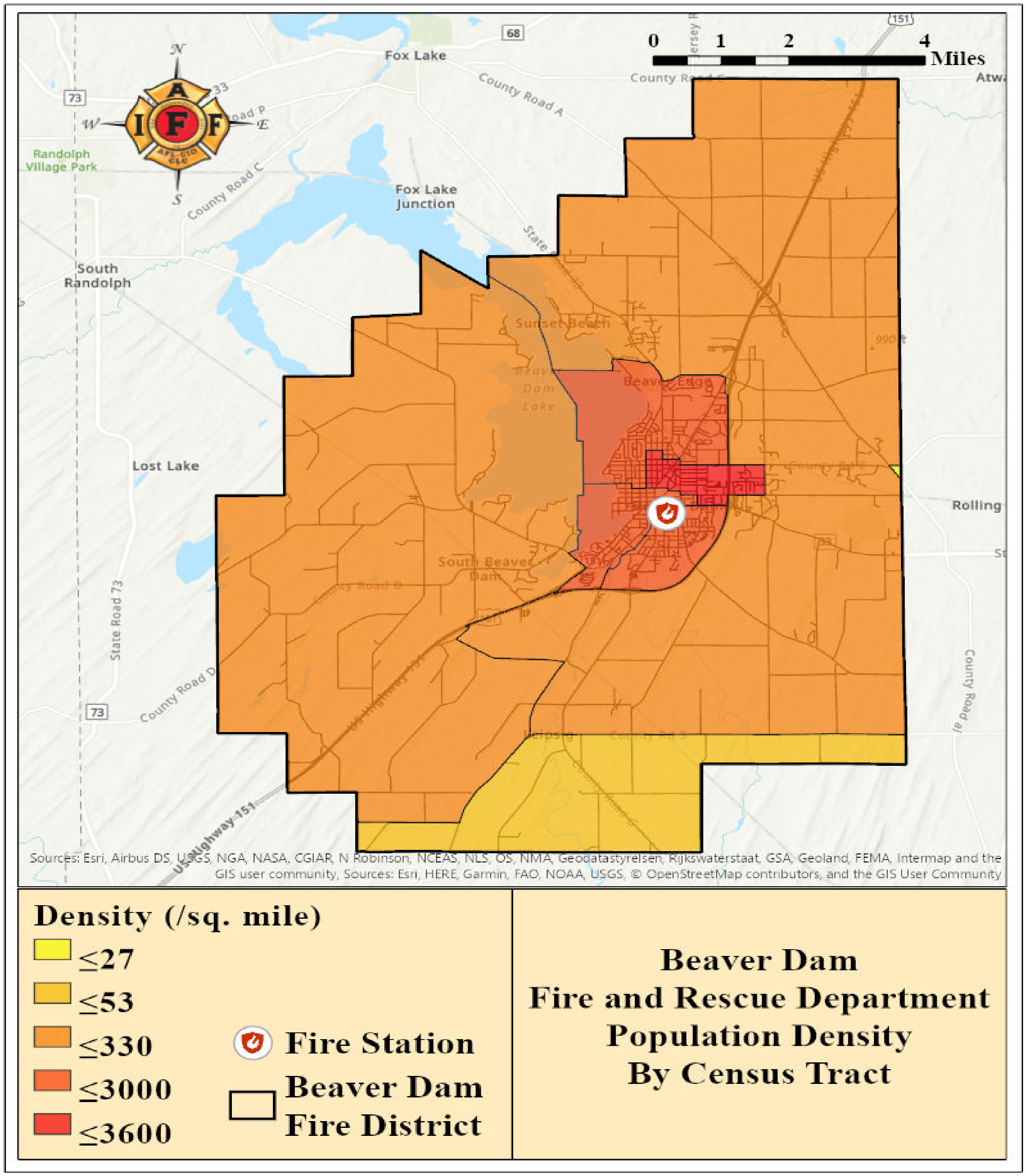
[6] https://www.census.gov/quickfacts/beaverdamcitywisconsin
[7] A census tract is a geographic unit used by the US Census Bureau.
[8] Esri Demographics: https://www.esri.com/en-us/arcgis/products/data-location-services/data/demographics

total buildings. Older structures are at an increased risk of fires, being constructed before modern day fire codes were developed, and often lacking proper maintenance.

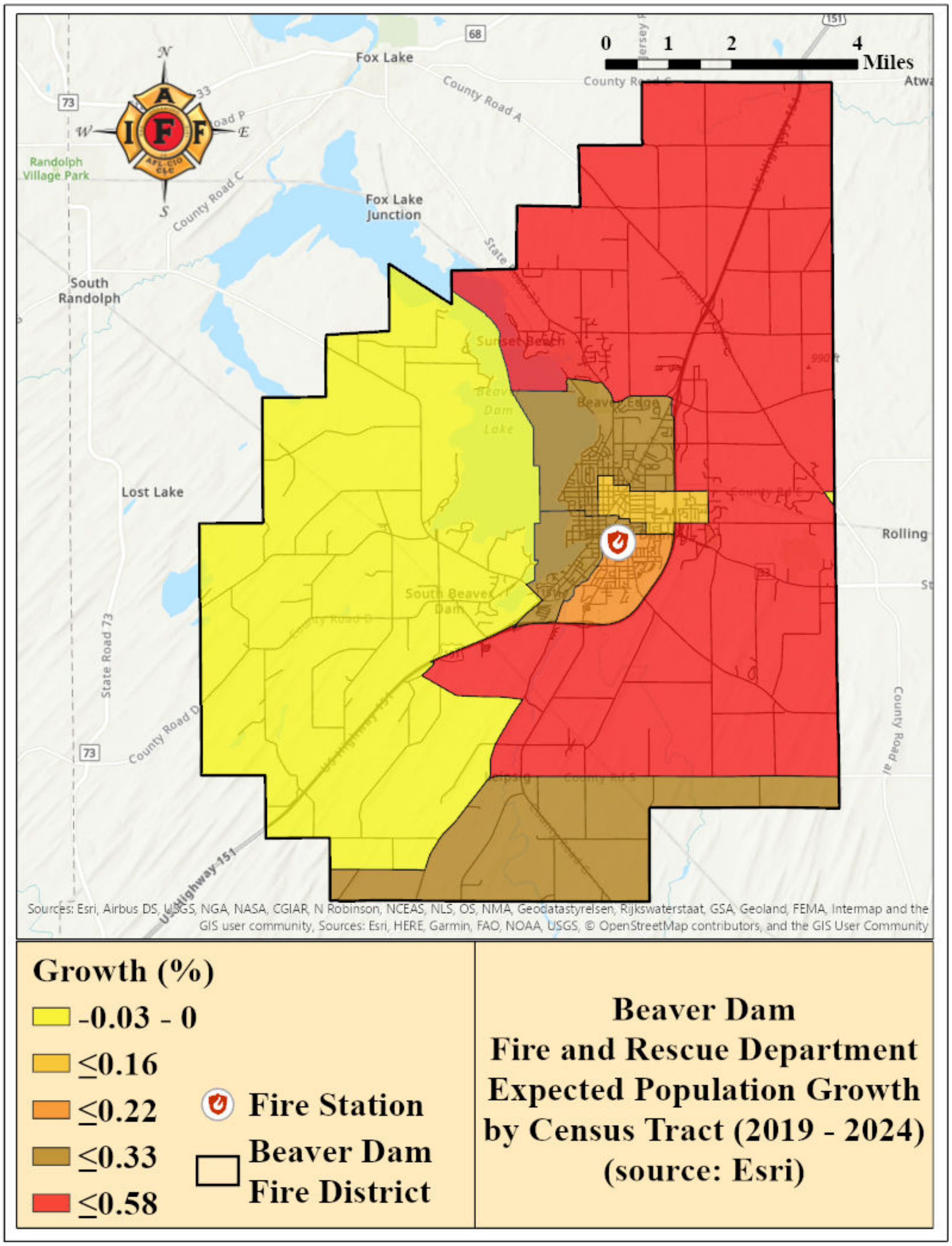
The maps on the following pages show the location of the Beaver Dam Fire and Rescue Department fire station, the concentrations of incidents, the population density, the population growth rate, and the social vulnerability index by census tract. The Centers for Disease Control social vulnerability index (SVI) score is determined by examining factors such as socioeconomics, housing composition, residents with disabilities, minority status, languages spoken, and housing and transportation. An SVI score assists in identifying areas in the community where citizens will most likely need assistance before, during, and after a hazardous event.



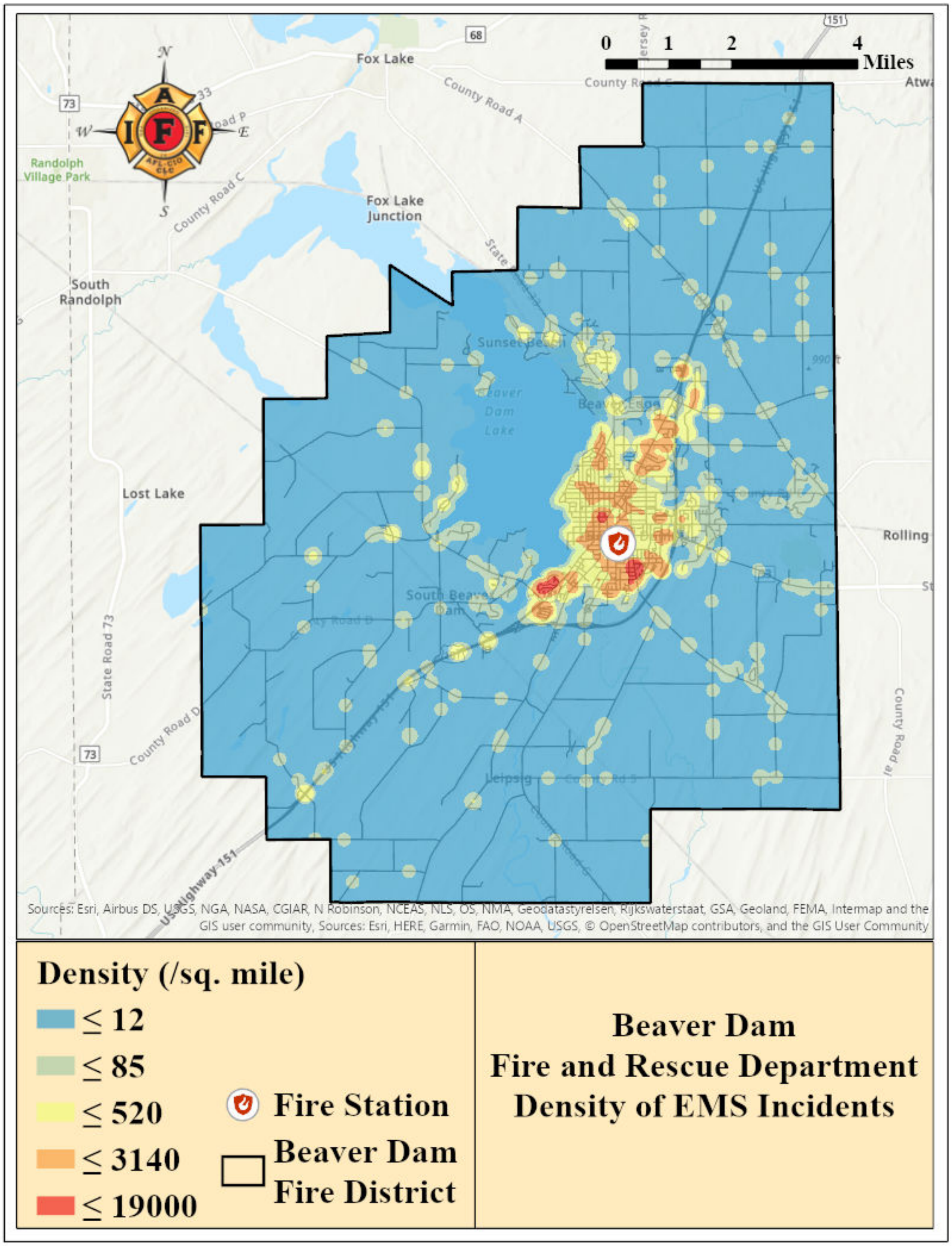
Map 1: Fire Station and Fire District. This map shows the location of the BDFRD fire station and the BDFRD fire district's boundary. Additionally, the department provides coverage to the cities of Trenton, Calamus, and Westford for fire and EMS response and Lowell Town and Lowell Village for EMS response only. Responses occurring in these municipalities cause the units of the department to be unavailable to respond to other emergencies for up to 3 hours.



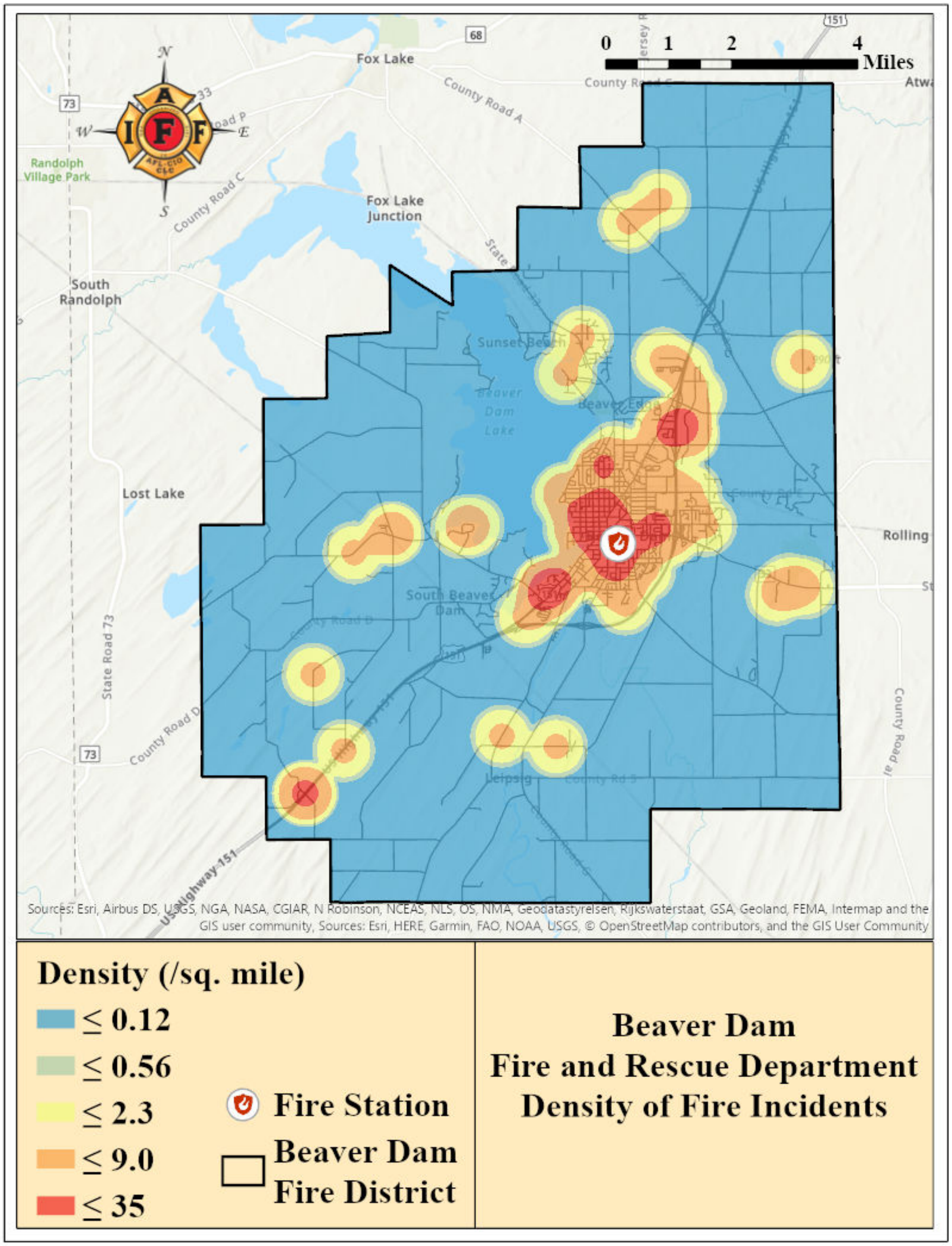
Map 2: Population Density by Census Tract. This map shows the population density of the Beaver Dam fire district, by census tract. Areas with higher density are typically associated with a higher number of fire and EMS incidents. Additionally, the department provides coverage to the cities of Trenton, Calamus, and Westford for fire and EMS response and Lowell Town and Lowell Village for EMS response only. For clarity, given the wide area that the department offers coverage to, this and the following maps will only focus on the Beaver Dam Fire District. However, the workload analysis will consider all the responses made by the department, including those towards the nearby communities.



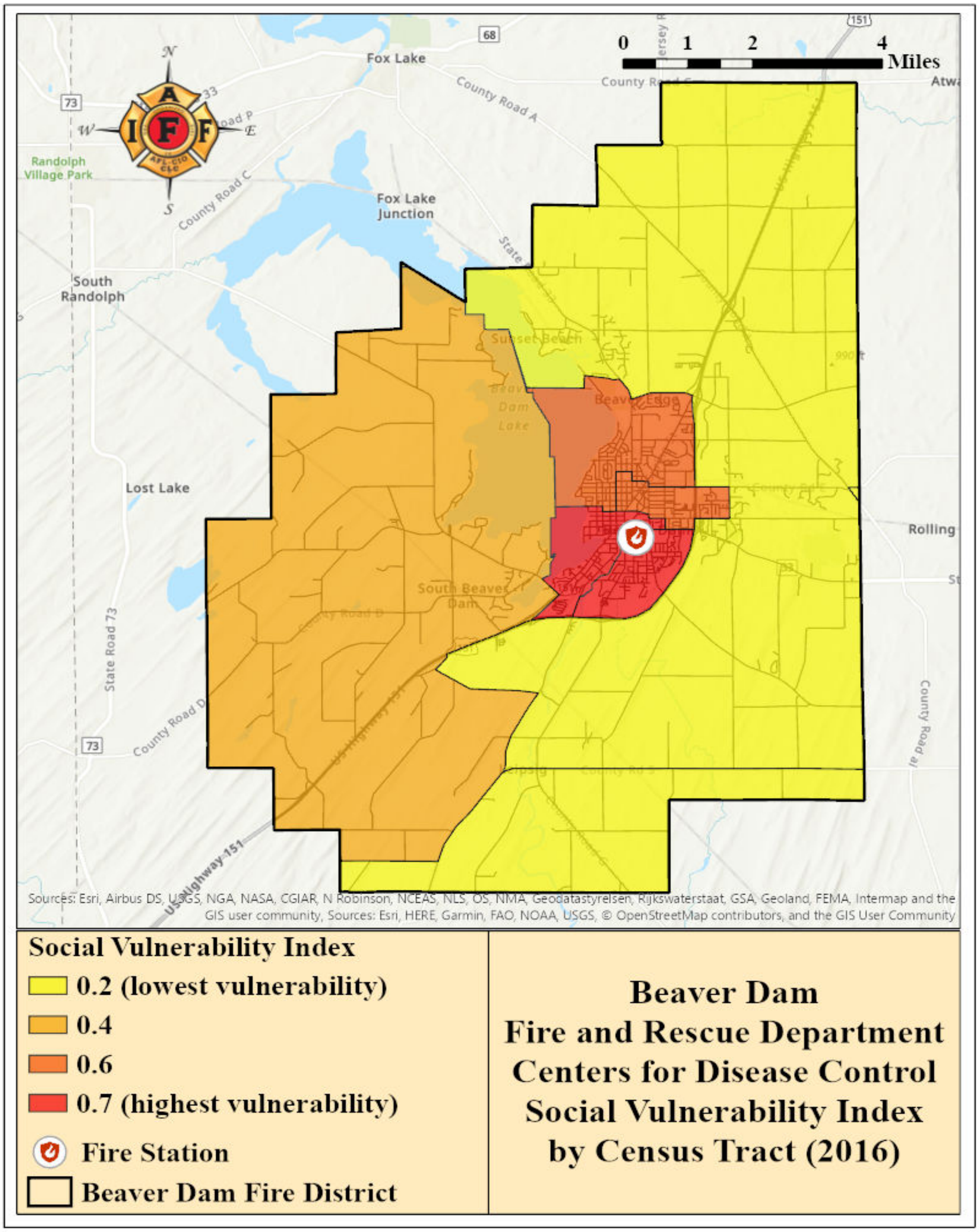
Map 3: Expected Population Growth by Census Tract (2019 - 2024). The population within the fire district is expected to grow in the next four years, especially in the central and west part of the jurisdiction which already have the highest concentration of incidents. The department should be ready to respond to an increasing number of incidents, which it cannot do with current resources. Additionally, the department provides coverage to the cities of Trenton, Calamus, and Westford for fire and EMS response and Lowell Town and Lowell Village for EMS response only (not shown on this map). The population is expected to increase in these communities as well.



Map 4: Density of EMS Incidents. This map shows the density of EMS incidents. Most of the incidents are located in central area of the city, which has the highest population density. Approximately 10% of the incidents occurred in other municipalities, out of the fire district boundaries. Despite being less frequent, these incidents cause the units of the department to be busy in responses for up to 3 hours.



Map 5: Density of Fire Incidents. This map shows the density of fire incidents. Most of the incidents are located in the central part of the city. However, several hot spots are spread through the entire jurisdiction.



Map 6: Centers for Disease Control, Social Vulnerability Index by Census Tract (2016). The central part of the city with the highest concentration of fire and EMS incidents is also the area with the highest vulnerability. The department needs to increase its staffing level to mitigate the risk and meet the current and future demand.

Fire Suppression Operations

The business of providing emergency services has always been labor intensive and remains so today. Although new technology has improved firefighting equipment and protective gear and has led to advances in modern medicine, it is the firefighters who still perform the time-critical tasks necessary to contain and extinguish fires, rescue trapped occupants from a burning structure, and provide emergency medical and rescue services.

A small flame can quickly burn out of control and become a major fire in a short period of time. This is because fire grows and expands exponentially as time passes. In the time frame of fire growth, the temperature of a fire rises to above 1,000° Fahrenheit (F). It is generally accepted in the fire service that for a medium growth rate fire,[9] flashover--the very rapid spreading of the fire due to super heating of room contents and other combustibles—can occur. Assuming an immediate discovery of a fire, followed by an un-delayed call to 9-1-1, and dispatch of emergency responders, flashover is likely to occur within 8 minutes of fire ignition. However, studies conducted by the Underwriters Laboratory (UL) and the National Institute of Standards and Technology (NIST) have proved that, due to new building construction materials and room contents that act as fuel, flashover may occur much sooner.

At the point of flashover, the odds of survival for unprotected individuals inside the affected area are virtually non-existent. The rapid response of an appropriate number of firefighters is therefore essential to initiating effective fire suppression and rescue operations that seek to minimize fire spread and maximize the odds of preserving both life and property.

This section will explain fire growth and the importance of fire department response to a low-hazard structure fire. A low-hazard structure fire is defined as a fire that occurs in a typical, 2,000 square foot, single-family residential home with no basement or exposures.[10]

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[9] As defined in the *Handbook of the Society of Fire Protection Engineers*, a fast fire grows exponentially to 1.0 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 MWs.

[10] NFPA 1710, 2020 ed. Pg. 1710-20 A.4.1.2.5.1

Fire Growth

The Incipient Phase

The first stage of any fire is the incipient stage. In this stage a high heat source is applied to a combustible material. The heat source causes chemical changes to the material's surface which converts from a solid and begins to release combustible gases. If enough combustible gases are released the material will begin to burn freely.

This process is exothermic, which means that it produces heat. The heat being generated raises the temperature of surrounding materials, which in turn begin to release more combustible gases into the environment and begins a chemical chain reaction of heat release and burning. At this point the fire may go out if the first object completely burns before another begins or the fire can progress to the next stage, which is called the Free Burning Phase.

The Free Burning Phase

The second stage of fire growth is the "free" or "open burning" stage. When an object in a room starts to burn, (such as the armchair in
Figure 1, following page), it burns in much the same way as it would in an open area. In this phase of the fire, oxygen in the air is drawn into the flame and combustible gases rise to the ceiling and spread out laterally. Simultaneously, the materials that are burning continue to release more heat, which heats nearby objects and materials to their ignition temperature, and they begin burning as well. Inside a room, unlike in an open area, after a short period of time confinement begins to influence fire development. The combustible gases that have collected on the ceiling will eventually begin to support fire and will begin to burn. Thermal radiation from this hot layer begins to heat the ceiling, the upper walls, and all the objects in the lower part of the room which will augment both the rate of burning of the original object and the rate of flame spread over its surface.

When this occurs, the structure fire reaches a critical point: either it has sufficient oxygen available to move on to the next stage or the fire has insufficient oxygen available to burn and it progresses back to the incipient stage. However, since structures are not airtight, there is a low likelihood of the fire depleting the available oxygen. During this stage of fire growth, toxic chemicals released by the fire and high heat are enough to burn people in the immediate area and disorient and/or incapacitate people in the structure. Without rapid response and aggressive intervention by an adequately staffed fire department, the fire will likely spread to the rest of the structure.

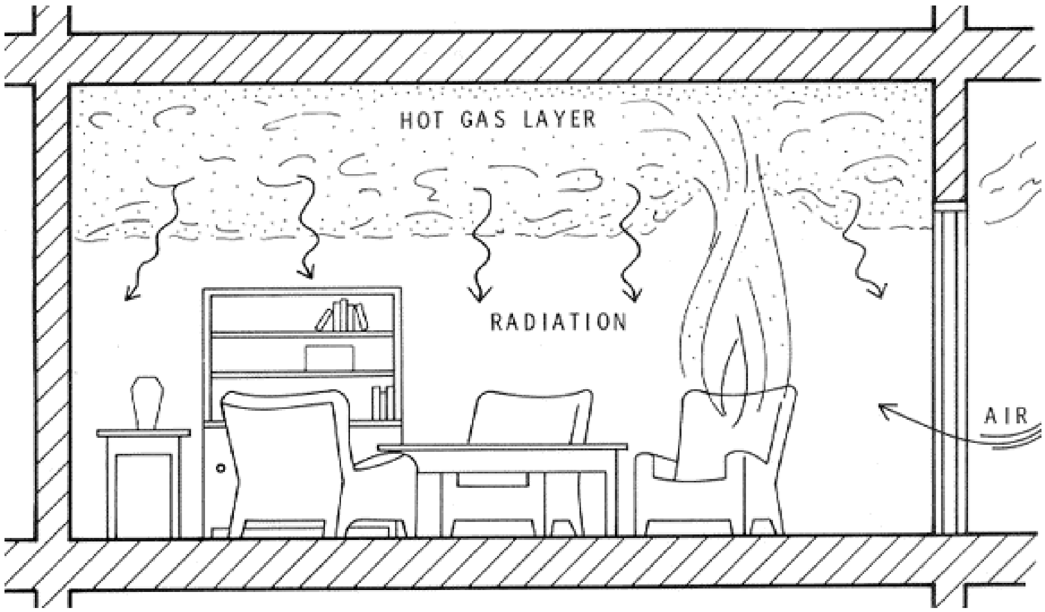

Figure 1:Fire Growth in a Compartment.[11] The above figure depicts the growth of fire in a compartment, which is an enclosed space or room in a building. In a compartment the walls, ceiling, floors, and objects absorb radiant heat produced by the fire. Unabsorbed heat is reflected back to the initial fuel source, which is depicted by the armchair above. This reflected heat continues to increase the temperature of the fuel source and therefore the rate of combustion. Hot smoke, combustible gases, and super-heated air will then rise to the ceiling and spread at first laterally across the ceiling, but later downward towards other fuel sources and the floor of the compartment. As this toxic, super-heated cloud touches cooler materials, the heat is conducted to them, thus increasing their temperature and eventually leading to pyrolysis, which is the process where a fuel source begins to release flammable vapor. This release of flammable vapor leads to further fire growth and eventually flashover. Flashover is the point at which all exposed fuel sources in a compartment ignite.

If there is sufficient oxygen, then the fire will continue to grow and the heating of the other combustibles in the room will continue to the point where they reach their ignition temperatures more or less simultaneously. If this occurs, all combustible materials in the room will spontaneously ignite. This transition from the burning of one or two objects to full room involvement is referred to as flashover. [12]

Flashover

Flashover, when it occurs, is the most significant event during a structure fire. As combustible gases are produced by the two previous stages, they are not entirely consumed and are therefore available fuels. These "available fuels" rise and form a superheated gas layer at the ceiling that continues to increase, until it begins to bank down to the floor, heating all combustible objects

[11] Image courtesy of University of California at Davis Fire Department
[12] J.R. Mehaffey, Ph.D., Flammability of Building Materials and Fire Growth, Institute for Research in Construction (1987)

regardless of their proximity to the burning object. In a typical structure fire, the gas layer at the ceiling can quickly reach temperatures of 1,200˚ F and higher. With enough existing oxygen at the floor level, flashover occurs, which is when everything in the room ignites at once. The instantaneous eruption of flames generates a tremendous amount of heat, smoke, and pressure. The pressure generated from this explosion has enough force to push fire beyond the room of origin and into the rest of the structure, as well as through doors and windows.

As has been noted, at the time of flashover, windows in the room will break. When these windows break, as a result of the increased pressure in the room, a fresh supply of air from the outside of the building is available to help the fire grow and spread. Based on the dynamics of fire behavior in an unprotected structure fire, any decrease in emergency unit response capabilities will correlate directly with an increase in expected life, property, and economic loss.

The Importance of Adequate Staffing: Concentration

NFPA 1500 and 1710 both recommend that a minimum acceptable fire company staffing level should be four members responding on, or arriving with, each engine and ladder company responding to any type of fire.

A prime objective of fire service agencies is to maintain enough strategically located personnel and equipment so that the minimum effective firefighting force can reach a reasonable number of fire scenes before flashover occurs.[13] Of utmost importance in limiting fire spread is the quick arrival of sufficient numbers of personnel and equipment to attack and extinguish the fire, as well as rescue any trapped occupants and care for the injured. Sub-optimal staffing of arriving units may delay such an attack, thus allowing the fire to progress to more dangerous conditions for firefighters and civilians.

Staffing deficiencies on primary fire suppression apparatus negatively affects the ability of the fire department to safely and effectively mitigate emergencies and therefore correlates directly with higher risks and increased losses, both physically and economically. Continued fire growth beyond the time of firefighter on scene arrival is directly linked to the time it takes to initiate fire suppression operations. As indicated in Table 1, responding companies staffed with four firefighters are capable of initiating critical fire ground operational tasks more efficiently than those with crew sizes below industry standards.

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[13] University of California at Davis Fire Department website; site visited June 7, 2004.
< http://fire.ucdavis.edu/ucdfire/UCDFDoperations.htm >

Engine Company Duties					Ladder Company Duties			
Fireground Tasks	**Advance Attack Line**	**% Change**	**Water on Fire**	**% Change**	**Primary Search**	**% Change**	**Venting Time**	**% Change**
4 Firefighters	0:03:27		0:08:41		0:08:47		0:04:42	
3 Firefighters	0:03:56	12% Less Efficient	0:09:15	6% Less Efficient	0:09:10	4% Less Efficient	0:07:01	32% Less Efficient
2 Firefighters	0:04:53	29% Less Efficient	0:10:16	15% Less Efficient	0:12:16	28% Less Efficient	0:07:36	38% Less Efficient

Table 1: Impact of Crew Size on a Low-Hazard Residential Fire.[14] The above table compares and contrasts the efficiencies of suppression companies in the completion of critical tasks for fire control and extinguishment. The smaller the crew size, the more tasks an individual must complete as a team member, which contributes to the delay in initiating fire attack and contributes to diminished efficiency in stopping fire loss. BDFRD staffs engines and the ladder respectively with two and one firefighters, exposing the personnel and the community to a significant risk.

First-arriving companies staffed with four firefighters are more efficient in all aspects of initial fire suppression and search and rescue operations compared to two- or three-person companies. There is a significant increase in time for all the tasks if a company arrives on scene staffed with only three firefighters compared to four firefighters. According to the NIST Report on Residential Fireground Field Experiments, four-person crews are able to complete time critical fireground tasks 5.1 minutes (nearly 25%) faster than three-person crews. The increase in time to task completion corresponds with an increase in risk to both firefighters and trapped occupants.

With four-person crews, the effectiveness of first-arriving engine company interior attack operations *increases* by 12% to 29% efficiency compared to three- and two-person crews respectively. The efficacy of search and rescue operations also *increases* by 4% to 28% with four-person crews compared to three- and two-person crews. Moreover, with a four-person company, because the first-in unit is staffed with a sufficient number of personnel to accomplish its assigned duties, the second-in company does not need to support first-in company operations and is therefore capable of performing other critical fireground tasks that are likely to improve safety and outcomes.

At the scene of a structure fire, the driver/operator of the first engine company on the scene must remain with the apparatus to operate the pump. This leaves one firefighter to assist the operator in securing a water source from a hydrant and two firefighters to deploy a hoseline and stretch it

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[14] Averill, J.D. et al. (2010). Report on Residential Fireground Field Experiments. NIST Technical Note 1661. National Institute of Standards and Technology; Gaithersburg, MD, April 2010.

to the fire. After assisting the operator, the third firefighter should begin to assist the other two firefighters with advancing the hoseline into the building and to the location of the fire. Before initiating fire suppression, the supervising officer of the first arriving engine company is also responsible for walking around the building to assess the situation, determine the extent of the emergency, and request any additional resources necessary to mitigate the fire.

Similarly, the driver/operator of the first arriving ladder company must remain with the apparatus to safely position and operate the aerial device while the other three firefighters also perform critical fireground tasks such as ventilation and search and rescue. Due to the demands of fireground activities, a fire attack initiated by companies with only three or fewer firefighters is not capable of effecting a safe and effective fire suppression and/or rescue operation until additional personnel arrive.

Insufficient numbers of emergency response units, or inadequate staffing levels on those units, exposes civilians and firefighters to increased risk. It also further drains already limited fire department resources and stresses the emergency response system by requiring additional apparatus to respond from further distances. Failing to assemble sufficient resources on the scene of a fire in time to stop the spread and extinguish the fire, conduct a search, and rescue any trapped occupants puts responding firefighters and occupants in a dangerous environment with exponential risk escalation such that it is difficult to catch up and mitigate the event to a positive outcome.

The Importance of Crew Size to Overall Scene Time

Studies have shown that the more personnel that arrive on engine and ladder truck companies to the scene of a fire, the less time it takes to complete all tasks associated with fire suppression, search and rescue, and other critical fireground activities. As dispatched units arrive with sufficient numbers of firefighters, the overall time on the scene of the emergency decreases since critical fireground tasks can be completed simultaneously rather than in sequence. This also results in the decrease of on-scene risk levels. In other words, the more firefighters available to respond and arrive early to a structure fire, the less time it takes to extinguish the fire and perform search and rescue activities, thus reducing the risk of injury and death to both firefighters and trapped occupants and reducing the economic loss to the property.

Overall Scene Time Breakdown by Crew Size		
Scenario	**Total Time**	**Efficiency**
4-Person Close Stagger	0:15:44	
3-Person Close Stagger	0:20:30	23% Less Efficient
2-Person Close Stagger	0:22:16	29% Less Efficient
4-Person Far Stagger	0:15:48	
3-Person Far Stagger	0:21:17	26% Less Efficient
2-Person Far Stagger	0:22:52	31% Less Efficient

Table 2: The Relationship between Crew Size and Scene Time.[15] The above table displays how companies staffed with larger crew sizes will be on the scene of an emergency for a shorter time than smaller sized companies. This lag on scene could be translated to mean that emergency resources will be unavailable longer to address other emergencies that may arise.

As Table 2 shows, units that arrive with only two firefighters on an engine or ladder truck are on the scene of a fire almost 7 minutes longer than units that arrive with four firefighters on each crew. Responding units arriving with only three firefighters on an apparatus are on the scene of a fire 5 to 6 minutes longer than units that arrive with four firefighters on each apparatus. In addition to crew size, the time between the arriving crews matters to overall effectiveness and total on scene time.

In the NIST study on the low hazard residential fire, close stagger was defined as a 1-minute time difference in the arrival of each responding company. Far stagger was defined as a 2-minute time difference in the arrival of each responding company.[16] [17] The results show a consistent pattern of units arriving with four firefighters in a close stagger or far stagger will decrease the overall time at the scene of the emergency compared to units that arrive with two or three firefighters, and are more efficient in fire suppression tasks as well.

[15] Ibid.
[16] Ibid.
[17] One-minute and two-minute arrival stagger times were determined from analysis of deployment data from more than 300 U.S. fire departments responding to a survey on fire department operations conducted by the International Association of Fire Chiefs and the International Association of Firefighters.

Physiological Strain on Smaller Crew Sizes

The same NIST study also examined the relationship between crew size and physiological strain. Two important conclusions were drawn from this part of the experiments.

- Average heart rates were higher for members of small crews.
- These higher heart rates were maintained for longer durations.[18]

In 2018 alone, 44% of all firefighter fatalities were related to overexertion.[19] There is strong epidemiological evidence that heavy physical exertion can trigger sudden cardiac events.[20] Smaller crews are responsible for performing a number of tasks that are designed to be performed by multiple people and frequently in teams of two. This means that firefighters on smaller crews are required to work harder than larger crews to accomplish multiple tasks. Additionally, as discussed earlier, firefighters on smaller crews will also be working longer than larger sized crews. Working harder and longer in high heat and dangerous, stressful environments increases the likelihood of firefighters suffering an injury, or worse dying, as a result of overexertion.

Charts 1 and 2, on the following pages, highlight the cardiovascular impact on firefighters based on crew size for the first arriving engine and truck company. The heart rates of firefighters of crew sizes ranging from 2 to 5 firefighters were measured as they participated in the NIST study. The study was able to conclude that not only do smaller crews work harder and longer than larger crews, their heart rates are also more elevated for longer periods of time as well. This increases the risk of firefighters suffering an injury or death from overexertion. A firefighter suffering a medical emergency on the scene of a working fire, EMS, or rescue incident negatively impacts outcomes and increases the risk to the community, the citizen requiring assistance, and the firefighter.

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[18] Averill, J.D. et al. (2010). Report on Residential Fireground Field Experiments. NIST Technical Note 1661. National Institute of Standards and Technology; Gaithersburg, MD, April 2010.
[19] Fahy, R.F., Molis, J.L. (June, 2019) Firefighter Fatalities in the United States-2018. NFPA.
[20] Albert, C.A., Mittleman, M.A., Chae C.U., Lee, I.M., Hennekens, C.H., Manson, J.E. (2000) Triggering Sudden Death from Cardiac Causes by Vigorous Exertion. N Engl J Med 343(19):1355-1361

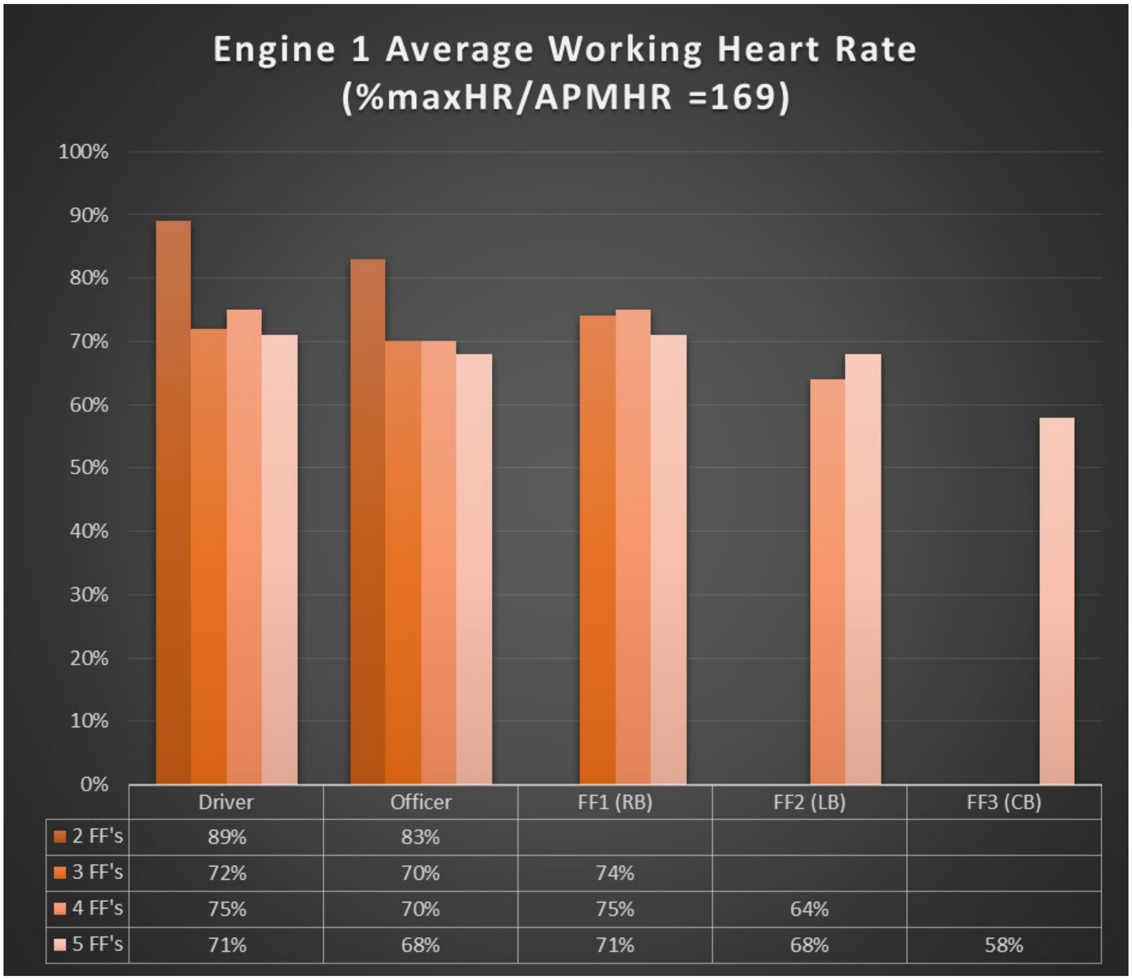

Chart 1: Average Peak Heart Rate of First Engine (E1) with Different Crew Sizes by Riding Position.[21] *In this chart, heart rates are expressed as a percent of maximal age-predicted maximal HR.* The average heart rates for firefighters on the first engine company were above 80% of age-predicted maximum values when only 2 firefighters were working. When staffing was at 2 firefighters, the driver of the apparatus had an average peak heart rate of nearly 90% of the age-predicted maximum. This is largely due to the number of additional tasks the driver must perform to prepare the engine to pump water to the fire and then join the officer to stretch hose to the fire. As can be seen, the larger the crew size, the lower the heart rate.[22] Decision makers could potentially reduce their liability for firefighter injury and death by ensuring staffing is compliant with the minimum recommended industry standards of four firefighters per apparatus.

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[21] Riding position for Chart 1 are as follows: Driver, Officer, Firefighter 1-Right Bucket (RB) seat, Firefighter 2-Left Bucket (LB) seat, Firefighter 3- Center Bucket (CB) seat. A fire company that is staffed with 2 will consist of a Driver and an "Officer."

[22] Smith, D.L., Benedict, R. Effect of Deployment of Resources on Cardiovascular Strain of Firefighters. April, 2010. Pp 5-7

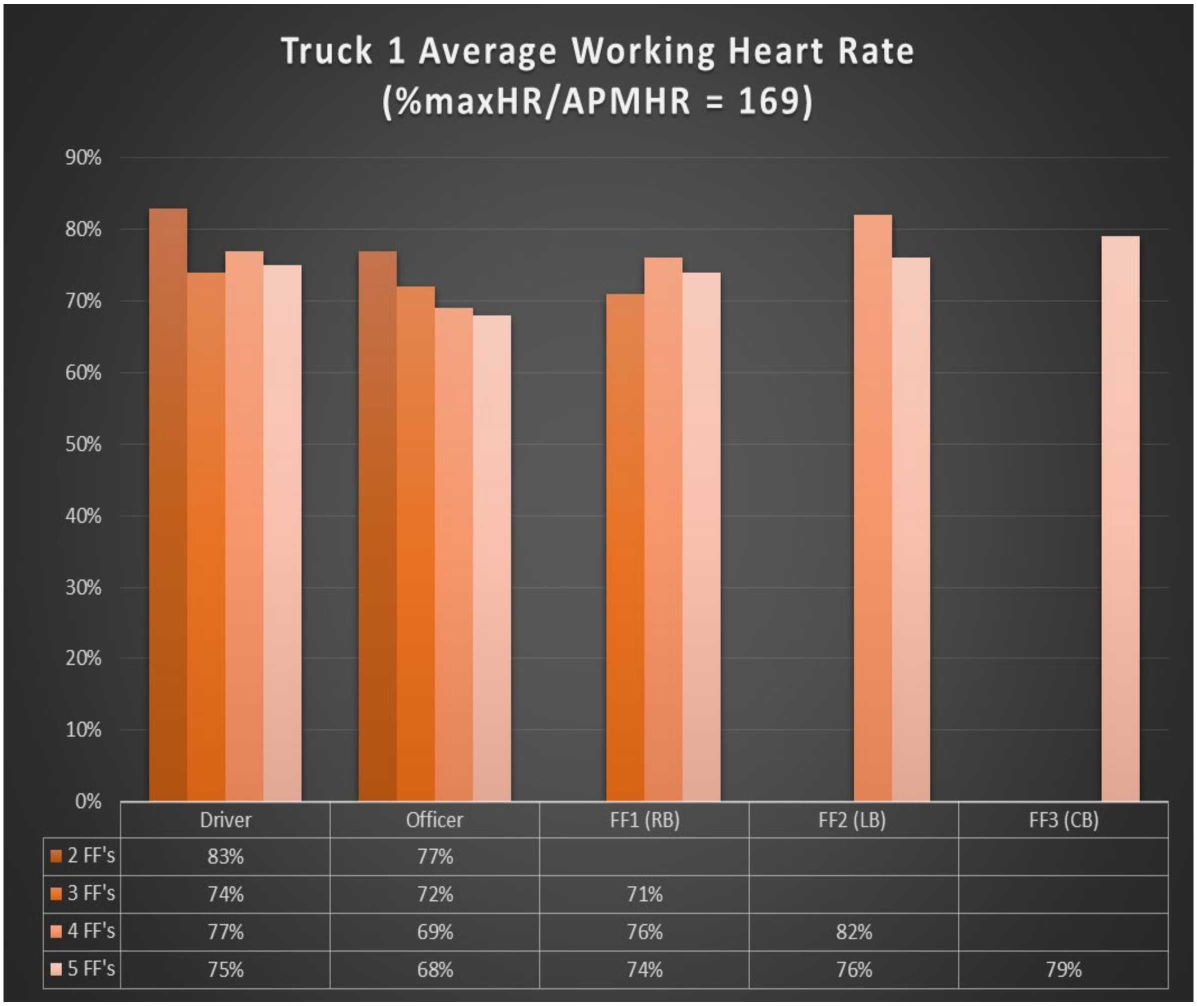

Chart 2: Average Peak Heart Rate of First Truck (T1) with Different Crew Sizes by Riding Position.[23] In this chart, heart rates are expressed as a percent of maximal age-predicted maximal HR. The average heart rates for firefighters on the first truck company were above 80% of age-predicted maximum values when only 2 firefighters were working.[24] Decision makers could potentially reduce their liability for firefighter injury and death by ensuring staffing is compliant with the minimum recommended industry standards of four firefighters per apparatus.

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[23] Riding position for Chart 2 are as follows: Driver, Officer, Firefighter 1-Right Bucket (RB) seat, Firefighter 2-Left Bucket (LB) seat, Firefighter 3- Center Bucket (CB) seat. A fire company that is staffed with 2 will consist of a Driver and an "Officer."

[24] Smith, D.L., Benedict, R. Effect of Deployment of Resources on Cardiovascular Strain of Firefighters. April, 2010. Pp 5-7

The Importance of a Rapid Response

Uncontained fire in a structure grows exponentially with every passing minute. Any delay in the initiation of fire suppression and rescue operations, such as the 5- to 7-minute delay that results from smaller sized crews of firefighters, translates directly into a proportional *increase* in expected property, life, and economic losses as is shown in Table 3, following page. It warrants emphasizing that if a structure has no automatic suppression or detection system, a more advanced fire may exist by the time the fire department is notified of the emergency and is able to respond. Fires of an extended duration weaken structural support members, compromising the structural integrity of a building and forcing operations to shift from an offensive to defensive mode.[25] As with inadequate staffing, this type of operation will continue until enough resources can be amassed to mitigate the event.

In the NIST study on the low-hazard residential fire, researchers also used fire modeling to mark the degree of the toxicity of the environment for a range of growth fires (slow, medium, and fast). Occupant exposures were calculated both when firefighters arrive earlier to the scene, and when arriving later. The modeling showed that the longer it takes for firefighters to rescue trapped occupants, the greater the risk posed to both the firefighters and occupants by increasing atmospheric toxicity in the structure.

[25] According to the NFPA, "it's important to realize that every 250 GPM stream applied to the building can add up to one ton per minute to the load the weakened structure is carrying."

Rate Per 1,000 Fires			
Flame Spread:	**Civilian Deaths**	**Civilian Injuries**	**Average Dollar Loss per Fire**
Confined fires (identified by incident type)	0.00	8.7	$200
Confined to object of origin	0.4	11.1	$1,200
Confined to room of origin, including confined fires by incident type[26]	1.8	23.8	$4,000
Beyond the room, but confined to floor of origin	16.2	76.3	$35,000
Beyond floor of origin	24.6	55.0	$65,900

Table 3: The Relationship between Fire Extension and Fire Loss.[27] The above table displays the rates of civilian injuries and deaths per 1,000 fires, as well as the average property damage. Following the far-left column from top to bottom, each row represents a more advanced level of fire involvement in a residence. Typically, the more advanced the fire, the larger the delay in suppression. Assuming an early discovery of a fire, companies staffed with larger crew sizes help to minimize deaths, injuries, and property loss. This highlights why a 5- to 7- minute delay in suppression activities by smaller sized crews results in higher economic losses to a residence.

OSHA's "2 In/2 Out" Regulation

The "2 In/2 Out" Regulation is part of paragraph (g)(4) of the United States Occupational Safety and Health Administration's (OSHA) revised respiratory protection standard, 29 CFR 1910.134. The focus of this important section is the safety of firefighters engaged in interior structural firefighting. OSHA's requirements for the number of firefighters required to be present when conducting operations in atmospheres that are immediately dangerous to life and health (IDLH) also covers the number of persons who must be on the scene before firefighting personnel may initiate an interior attack on a structural fire. An interior structural fire (*an advanced fire that has spread inside of the building where high temperatures, heat and dense smoke are normally occurring*) would present an IDLH environment and, therefore, require the use of respirators. In those cases, at least two standby persons, in addition to the minimum of two persons inside

[26] NFIRS 5.0 has six categories of confined structure fires, including cooking fires confined to the cooking vessel, confined chimney or flue fire, confined incinerator fire, confined fuel burner or boiler fire or delayed ignition, confined commercial compactor fire, and trash or rubbish fire in a structure with no flame damage to the structure or its contents. Homes include one- and two-family homes (including manufactured housing) and apartments or other multifamily housing. These statistics are national estimates based on fires reported to U.S. municipal fire departments and so exclude fires reported only to federal or state agencies. National estimates are projections. Casualty and loss projections can be heavily influenced by the inclusion or exclusion of one unusually serious fire. Property damage has not been adjusted for inflation.
[27] National Fire Protection Association, NFPA 1710 (2020), Table A.5.2.2.2.1 Fire Extension in Residential Structures, 2012-2016.

needed to fight the fire, must be present before firefighters may enter the building.[28] [29] This requirement is mirrored in NFPA 1500, which states that "a rapid intervention team shall consist of at least two members and shall be available for rescue of a member or a team if the need arises. Once a second team is assigned or operating in the hazardous area, the incident shall no longer be considered in the 'initial stage,' and at least one rapid intervention crew shall be required."

NFPA Standard 1710 also supports the OSHA regulation by requiring a minimum of four personnel on all suppression apparatus. Portions of the 1710 Standard recommend that "fire companies whose primary functions are to pump and deliver water and perform basic firefighting at fires, including search and rescue… shall be staffed with **a minimum of four on-duty members**,"[30] while "fire companies whose primary functions are to perform the variety of services associated with truck work, such as forcible entry, ventilation, search and rescue, aerial operations for water delivery and rescue, utility control, illumination, overhaul and salvage work… shall [also] be staffed with **a minimum of four on-duty members**."[31]

However, the number of personnel required per fire suppression apparatus increases with risk and demand. NFPA 1710, 2020 edition states that engine and ladder companies that are assigned to first-due districts that have a high number of incidents, geographic restrictions[32], geographic isolation[33], or areas considered to be urban[34] with regards to population density, all as identified by the AHJ, should be staffed with a minimum of five firefighters. First-due districts that have tactical hazards, high hazard occupancies, or densely populated urban areas[35], as identified by the AHJ, shall have companies that are staffed with six firefighters.[36]

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[28] According to NFPA standards relating to fire fighter safety and health, the incident commander may make exceptions to these rules if necessary, to save lives. The Standard does not prohibit fire fighters from entering a burning structure to perform rescue operations when there is a "reasonable" belief that victims may be inside.

[29] Paula O. White, letter to Thomas N. Cooper, 1 November 1995 (OSHA)

[30] NFPA 1710, § 5.2.3.1 and §5.2.3.1.1.

[31] NFPA 1710, § 5.2.3.2 and §5.2.3.2.1.

[32] Geographic Restriction is a defined condition, measure, or infrastructure design that limits response and/or results in predictable response delays to certain portions of the jurisdiction.

[33] Geographic Isolation is a first-due response zone or jurisdiction with staffed resources where over 80% of the response area is outside of 10-minute travel time from the next closest staffed suppression apparatus.

[34] An urban area is an incorporated or unincorporated area with a population over 30,000 people and /or a population density over 1,000 people per square mile but less than 2,999 people per square mile.

[35] A dense urban area is an incorporated or unincorporated area with a population density of over 200,000 people and/or a population density of over 3,000 people per square mile.

[36] NFPA 1710, § 5.2.3.1.2, §5.2.3.1.2.1, §5.2.3.2.2, and §5.2.3.2.2.1.

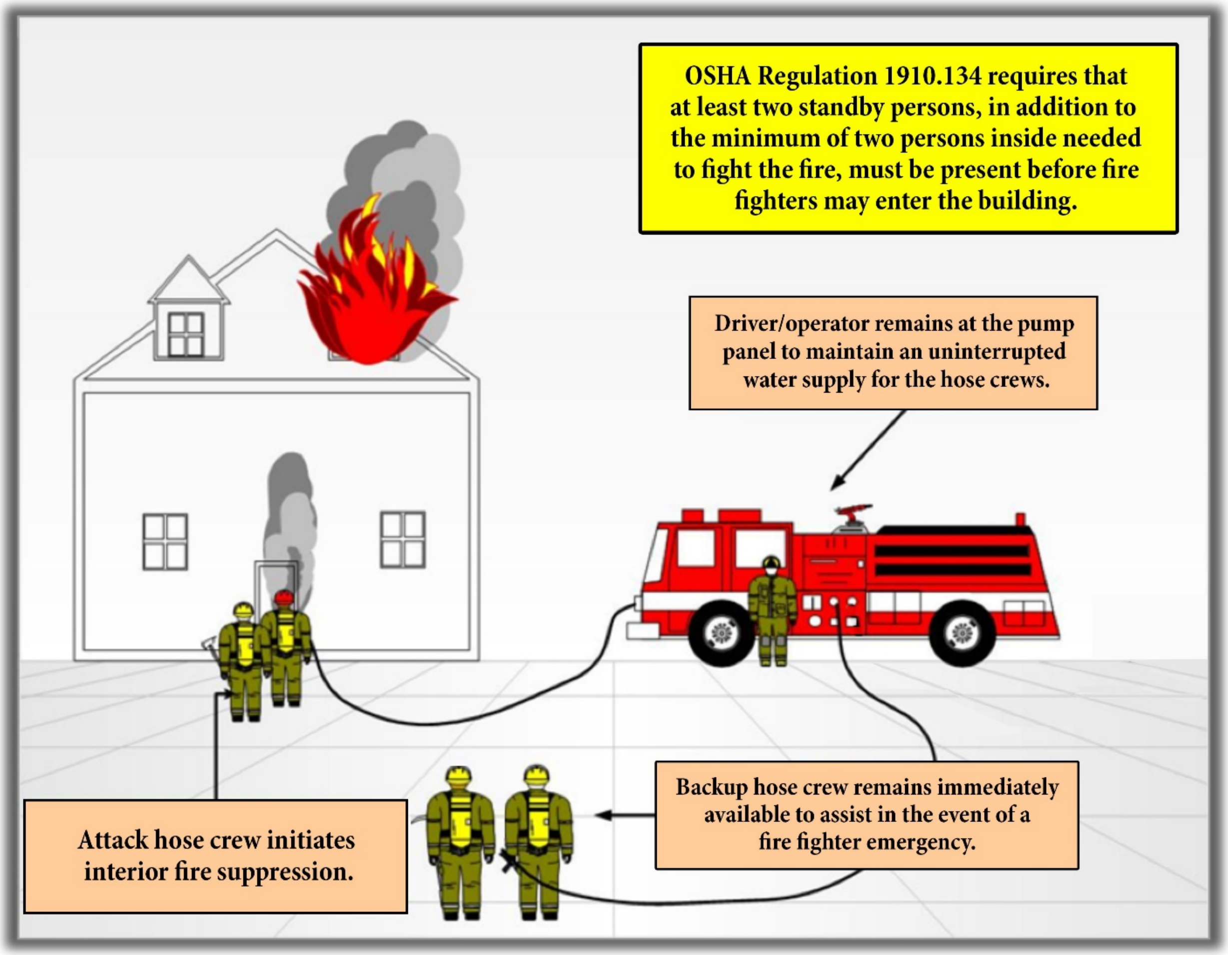

Figure 2: The OSHA "2 In/ 2 Out" regulation. The above figure depicts the number of firefighters required to meet OSHA regulation 1910.134, which demands one firefighter outside for every firefighter inside. The firefighters outside can support a secondary attack line and facilitate the rescue of trapped or disabled firefighters should the need arise. In this scenario the driver/operator of the apparatus is not counted towards the total number of firefighters.

Several examples of incidents exist in which the failure to follow the "2 In/2 Out" regulation have contributed to firefighter casualties. For example, in Bridgeport, Connecticut in July 2010, two firefighters died following a fire where NIOSH later found that although a "Mayday" was called by the firefighters, it wasn't responded to promptly as there was no Incident Safety Officer or Rapid Intervention Team (RIT) readily available on scene. In a second case, two firefighters were killed in a fire in San Francisco, California in June 2011. The initial RIT was re-assigned to firefighting duties, and the back-up RIT did not arrive on scene until after the victims were removed.

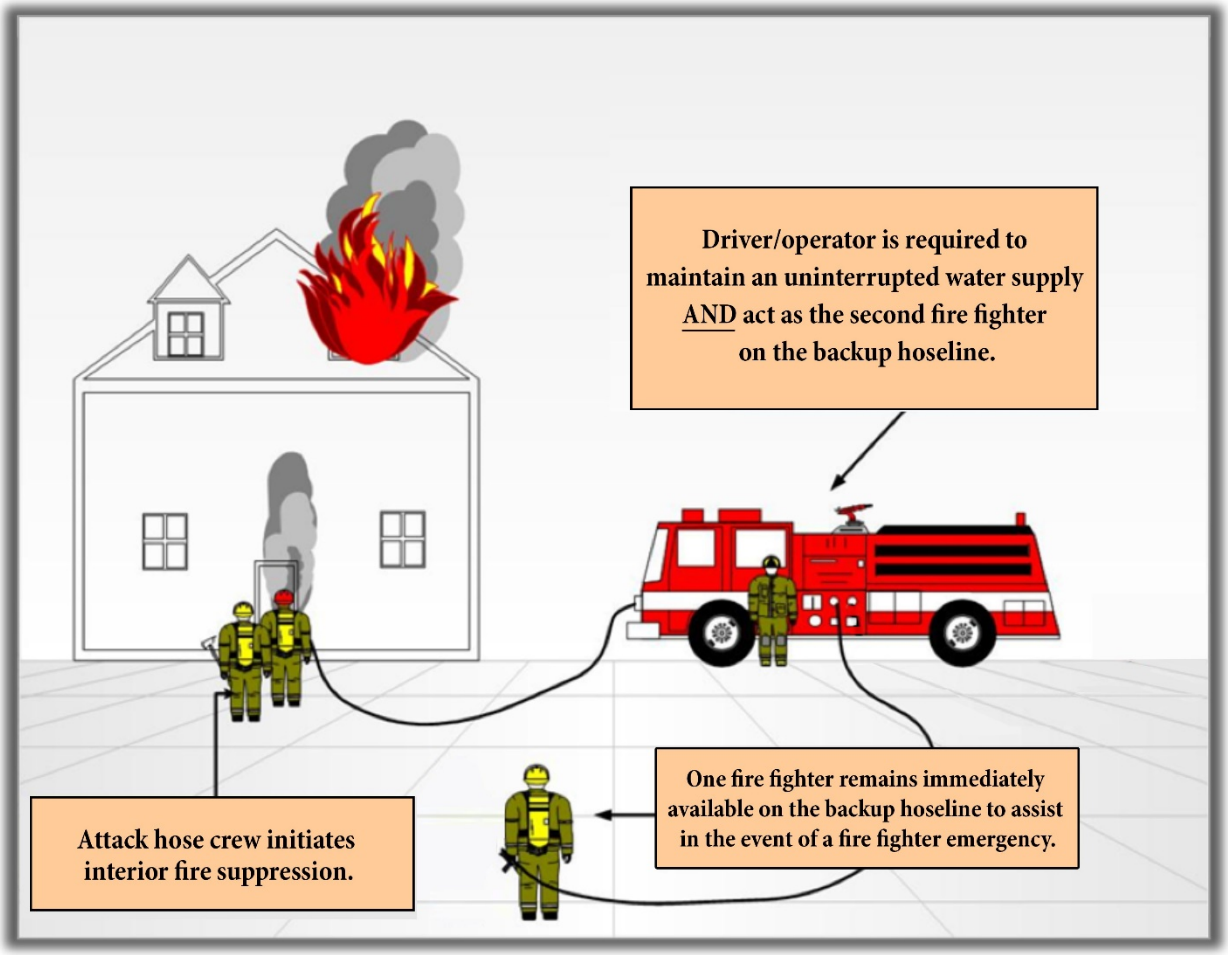

Figure 3: Emergency "2 In/2 Out" Operations. In the emergency model depicted above, the arriving fire apparatus is staffed with a crew of 4 personnel and operates under emergency conditions. In this case the driver/operator of the fire apparatus is also counted as a firefighter, which means that firefighter must be dressed in personal protective equipment (PPE) and be ready to participate in rescue if the need should arise.

When confronted with occupants trapped in a burning structure and a single fire company is on scene, only a company staffed with four firefighters can initiate emergency search and rescue operations in compliance with the "2 In/2 Out" Regulation. As indicated in the previous graphic, this requires the complete engagement of every firefighter from the first-in fire company, staffed with four, to participate in the effort, and means that the driver-operator of the apparatus must tend to the pump to ensure the delivery of water to the firefighters performing the initial attack and search and rescue operations and be prepared to make entry with the remaining firefighter should the crew operating inside become trapped.

Regardless, when there exists an immediate threat to life, only a company of four firefighters can initiate fire suppression and rescue operations in compliance with "2 In/2 Out" Regulation, and in a manner that minimizes the threat of personal injury. In crews with fewer than 4 firefighters, the first-in company must wait until the arrival of the second-in unit to initiate safe and effective fire suppression and rescue operations. This condition underlines the importance and desirability of fire companies to be staffed with a minimum of four firefighters and stresses the benefit of four-person companies and their ability to save lives without having to wait for the second-in company to arrive.

Initial Full Alarm Assignment

Initial Full Alarm Assignment Capability, as outlined in NFPA Standard 1710, recommends that the "fire department shall have the capability to deploy an initial full alarm assignment within a 480-second travel time to 90 percent of the incidents… [and that the] initial full alarm shall provide for the following:

Assignment	***Required Personnel***
Incident Command	1 Officer
Uninterrupted Water Supply	1 Pump Operator
Water Flow from Two Handlines	4 Firefighters (2 for each line)
Support for Handlines	2 Firefighters (1 for each line)
Victim Search and Rescue Team	2 Firefighters
Ventilation Team	2 Firefighters
Aerial Operator	1 Firefighter
Initial Rapid Intervention Crew (IRIC)	4 Firefighters
Required Minimum Personnel for Full Alarm	**16 Firefighters & 1 Incident Commander**

Table 4: NFPA 1710, §5.2.4.1.1. This breakdown of the expected capabilities of a full alarm assignment, in compliance with NFPA 1710, requires a minimum contingent of 17 fire suppression personnel

In addition, NFPA 1710, §5.2.4.6.2 states, "The Fire Department shall have the capability for additional alarm assignments that can provide for additional command staff, members, and additional services, including the application of water to the fire; engagement in search and rescue, forcible entry, ventilation, and preservation of property; safety and accountability for personnel; and provision of support activities…"

The ability of adequate fire suppression forces to greatly influence the outcome of a structural fire is undeniable and predictable. Each stage of fire extension beyond the room of origin directly increases the rate of civilian deaths, injuries, and property damage.

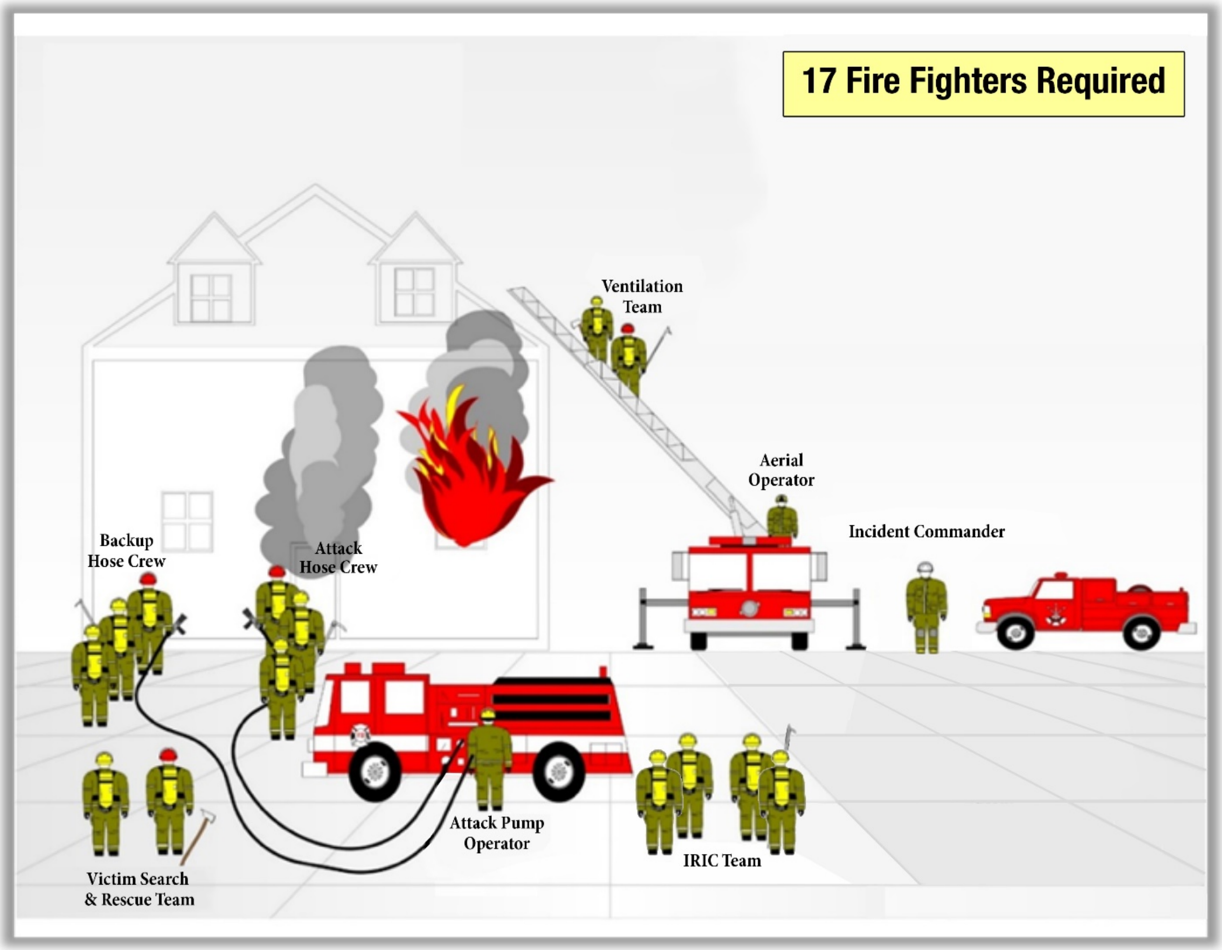

Figure 4: Initial Full Alarm Assignment Deployed Within 8 Minutes, 17 Firefighters Required. The above figure depicts the full alarm assignment required by NFPA 1710 as discussed in Table 4.

Fire growth is exponential, growing in a non-linear manner over time. Extending the time for crew assembly by waiting for additional crews to arrive causes on-scene risk to escalate. The higher the risks at the time firefighters engage in fire suppression, the greater the chance of poor outcomes including civilian injury or death, firefighter injury or death, and increased property loss.

High-Rise Operations

Although this section specifically addresses fire response to high-rise buildings, it is important to note that the discussion can be extrapolated to large area buildings such as manufacturing centers, warehouses, grocery stores, schools, and other structures with a high fire load and populations.

Overview of High-Rises

High-rise buildings were once found exclusively in urban cities. However, today they are commonly found in small and mid-sized suburban communities as well. Many high-rise buildings in suburban areas are newer, shorter, and protected by automatic sprinkler systems, although this is not always a guarantee. NFPA 101, Life Safety Code, 2015 Edition and the International Code Council's International Building Code both define a high-rise structure as a building more than 75 ft. (23 m) in height, measured from the lowest level of fire department vehicle access to the bottom of the highest occupied floor. High-rises, which are described in NFPA 1710 §A.3.3.36 as high-hazard occupancies, represent an extraordinary challenge to fire departments and are some of the most challenging incidents firefighters encounter.

High-rise buildings may hold thousands of people above the reach of fire department aerial devices and the chance of rescuing victims from the exterior is greatly reduced once a fire has reached flashover. The risks to firefighters and occupants increase in proportion to the height of the building and the height of the fire above grade level.[37] This is especially true once firefighters are operating above the reach of aerial ladders on truck companies. In these situations, the only viable means of ingress or egress is the interior stairs. Therefore, a sound fire department deployment strategy, effective operational tactics, and engineered fire protection systems cannot be separated from firefighter safety. As in any structure fire, engine company and truck company operations must be coordinated.

High-rise buildings present a unique threat to the fire service. Multi-floor fires such as the Interstate Building Fire, One Meridian Plaza Fire, World Trade Center collapse, Cook County Administration Building Fire, and Deutsche Bank Building Fire each represented serious challenges to the operational capabilities of a modern fire department. According to the NFPA, between 2007 and 2011, there were an estimated 15,400 reported high-rise structure fires per year that resulted in associated losses of 46 civilian deaths, 520 civilian injuries, and $219

[37] Klaene, B. and Sanders, R. (2007). Structural Firefighting: Strategies and Tactics- High-Rise. Jones and Bartlett 2007.

million in direct property damage. Office buildings, hotels, apartment buildings, and health care facilities accounted for nearly half of these high-rise fires.[38]

Although the frequency of fires in high-rise structures is low, they pose a high consequence of loss with regards to injury, loss of life, and property damage. Even if a department does not respond to high-rise buildings at present, it may in the future as urban sprawl continues and/or jurisdictional border restrictions and population growth require taller buildings to meet residential needs.

High-Rise Firefighting Tactics

As has been stated, in a high-rise fire the risks to firefighters and occupants increases in proportion to the height of the building and the height of the fire above ground level. As the level of the fire floor gets higher, firefighters are required to carry more equipment further and must rely more on the building's standpipe system. A standpipe system is a piping system with discharge outlets at various locations usually located in stairwells on each floor in high-rise buildings that is connected to a water source with pressure supplemented by a fire pump[39] located in the building and/or a fire apparatus with pumping capabilities.

A fire in a high-rise building can threaten occupants and responding firefighters. Because of the amount of time it takes firefighters encumbered with equipment to access the involved floors, the fire may have expanded well past the area of origin. This means that firefighters can encounter a large volume of fire and darkened conditions when they arrive on the involved floors. This can be further complicated if the building is not equipped with a sprinkler system. Additionally, open-layout floor plans such as office buildings with cubicle farms can challenge both the standpipe's flow capacity and fire department resources regarding search, rescue, and hoseline deployment. The most effective way to extinguish a high-rise fire is by mounting an offensive attack as early as possible, because in most historic high-rise fires, the best life safety tactic is extinguishing the fire. Good high-rise firefighting tactics and firefighter/occupant safety cannot be separated. As with a residential structure fire, the first arriving suppression apparatus should be on the scene within four minutes of travel time.

Like residential structure fires, there are several critical tasks that must be accomplished. However, unlike residential firefighting in a 2,000 square foot residence, firefighters working at a high-rise fire must travel upwards of more than three stories and carry additional equipment beyond the normal requirements. Additionally, as it takes longer to assemble an effective firefighting force and to access the fire floor, firefighters are likely to encounter a large volume of fire and will therefore have an extended fire attack. Because of this, it is necessary to establish an equipment supply chain to transport equipment and resources up and down the building.

[38] Hall, J.R. (2013), High-Rise Building Fires. NFPA.
[39] Structural Firefighting Strategy and Tactics 2nd Edition. Klaene B., Sanders R. NFPA 2008

Search and Rescue

Search and rescue are critical fireground tasks that comprise a systematic approach to locating possible victims and removing those victims from known danger to a safe area. In a residential structure fire, searches are normally conducted by a crew of two firefighters, supplemented by an attack or ventilation crew. However, high-rise structures pose challenges regarding search and rescue that are not typically encountered in residential housing. For commercial high-rises and wide-area structures, large open areas and cubicle farms require additional search and rescue teams so that thorough searches can occur over a larger area than found in most residences. In addition to these larger areas, search and rescue can be further complicated because conscious victims may retreat to areas to find shelter from heat and smoke. These areas may differ from places where they are typically seen by coworkers, making locating them difficult if they are unaccounted for.

In residential high-rises, apartments typically lack two exits and usually share a common hallway for egress. Doors left open by victims fleeing fire can allow fire and smoke to spread into the hallway and impact escape attempts. Firefighters will be slowed in their search since they will be required to force their way into numerous apartments to search for victims. For this reason, regardless of commercial or residential, it is essential for there to be multiple search and rescue teams operating per involved floor to quickly locate victims in large surface areas. It is also necessary for additional search and rescue teams to search the floors above the fire and the highest floor of the building, due to how fire and smoke spread to the rest of the building. Search and rescue teams should also be supplemented with evacuation management teams to assist injured or disabled victims down the stairwells so searching can continue. It should be noted that in regard to high-rise fire suppression, crews larger than four performed searches faster than crews of four, thus minimizing a person who is trapped exposure to fire and toxic gases.

Fire Extinguishment

Fire extinguishment is a critical factor, since the intensity and size of the fire will determine the extent to which combustion gases are heated and how high they will rise inside the building. Building suppression systems, both active and passive, can impact fire growth, occupant safety, and firefighter safety and effectiveness. Such features include active fire detection and automatic sprinkler systems that are designed to either extinguish the fire or contain it until firefighters arrive.

Once firefighters are on scene, they will complete a series of fire confinement and extinguishment tasks. Firefighters access the structure, locate the fire, locate any avenues of spread, place hoselines, and establish a water supply. Once a water supply is established, water should be placed at the seat of the fire or in the compartment containing the fire to extinguish it. Unlike residential structure fires where hoselines can be stretched from the fire apparatus into the structure, high-rise structures require the use of standpipe systems to combat fire. This requires firefighters to carry multiple sections of hose to the affected floors and connect into the system to fight fire. Minimally, firefighters must deploy two hoselines to the involved floor and one hoseline to the floor above the fire. The third hoseline supports a number of critical tasks in the suppression effort. Principally, it is used to protect search and rescue teams, but also to stop the spread of fire as a result of conduction and convection through exposed pipes, metal framing, and ventilation systems.

Ventilation

Ventilation affects both search and rescue and fire extinguishment. Coordinated ventilation may be implemented at any time during the operation, but it should be coordinated with suppression and interior rescue activities. Ventilation is used to channel and remove heated air, smoke, fire gases, and other airborne contaminants. Applying proper ventilation at the right time and place is key to firefighter and occupant safety. Venting at the wrong time or place can draw active fire toward fresh air, which will injure or kill anyone in its path. In instances of high-rise fire suppression, adequate and appropriate ventilation is important to keep stairways free of smoke and noxious gases for victims who are evacuating.

Support

As has been discussed, fire suppression in a high-rise or high-hazard structure requires the establishment of a supply chain to shuttle equipment to different locations. Additionally, with increased resources and personnel, there is an increased need for additional supervision and accountability.

One critical support variable in high-rise fire operations is the availability of reliable elevators. If firefighters can safely use the elevators to move people and equipment, fire-ground logistics may be significantly improved. When the fire is located several floors above ground level, there is a strong inclination to use the elevators. However, fire service access elevators[40] may not be available in all buildings. Therefore, adequate stairways are necessary for firefighters to transport equipment and reach the fire floor for suppression.

Moving supplies and staff up 10, 20, 30, or more stories is an arduous task. If it is not properly managed, firefighters may be exhausted and unable to fight the fire or rescue trapped occupants. Additionally, joint use of stairways by firefighters moving upward and occupants attempting to evacuate may increase the overall evacuation time of the occupants, as well as delay the firefighters' efforts to begin critical tasks such as fire suppression or search and rescue

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[40] A fire service elevator is engineered to operate in a building during a fire emergency and complying with prescriptive building code requirements and the American Society of Mechanical Engineers (ASME) A 17.1 safety standard for elevators.

operations. As such, it is important to have multiple firefighters to help carry equipment upstairs and manage resource distribution.

To accomplish the critical fireground tasks associated with high-rise firefighting and meet the minimum staffing objectives for task completion, NFPA 1710 recommends the following company sizes for the first arriving unit(s) on the scene within four minutes of travel time for response to high-hazard structure:

- In first-due response areas with a high number of incidents, geographical restrictions, geographical isolation, or urban areas, as identified by the AHJ, these companies shall be staffed by a minimum of five on-duty members.[41]
- In first-due response areas with tactical hazards, high-hazard occupancies, or dense urban areas, as identified by the AHJ, these fire companies shall be staffed with a minimum of six on-duty members.[42]

As indicated by the tasks that must be accomplished on a high-rise fireground, understanding the required resources is critical. The number of firefighters needed to safely and effectively combat a high-rise fire may be large. Although an offensive fire attack is the preferred strategy whenever conditions and resources permit, a defensive attack that limits operations to the outside of a building and generally results in more property damage must be considered when risks to firefighter safety are too great and benefits to building occupants are negligible. The offensive vs. defensive decision is based on several factors: fireground staffing available to conduct an interior attack, a sustained water supply, the ability to conduct ventilation, and risk vs. benefit analysis regarding firefighter and occupant safety. Table 5, on the next page, displays the minimum number of firefighters required to arrive in the first full alarm assignment to a high-rise fire.

[41] NFPA 1710. §5.2.3.1.2 and §5.2.3.2.2
[42] NFPA 1710. §5.2.3.1.2.1 and §5.2.3.2.2.1.

Assignment	Required Personnel
Incident Command	1 Incident Commander 1 Incident Command Aide
Uninterrupted Water Supply	1 Building Fire Pump Observer 1 Fire Engine Operator
Water Flow from Two Handlines on the Involved Floor	4 Firefighters (2 for each line)
Water Flow from One Handline One Floor Above the Involved Floor	2 Firefighters (1 for each line)
Rapid Intervention Crew (RIC) Two Floors Below the Involved Floor	4 Firefighters
Victim Search and Rescue Team	4 Firefighters (2 per team)
Point of Entry/Oversight Fire Floor	1 Officer 1 Officer's Aide
Point of Entry/Oversight Floor Above	1 Officer 1 Officer's Aide
Evacuation Management Teams	4 Firefighters (2 per team)
Elevator Management	1 Firefighter
Lobby Operations Officer	1 Officer
Trained Incident Safety Officer	1 Officer
Staging Officer Two Floors Below Involved Floor	1 Officer
Equipment Transport to Floor Below Involved Floor	2 Firefighters
Firefighter Rehabilitation	2 Firefighters (1 must be ALS)
Vertical Ventilation Crew	1 Officer 3 Firefighters
External Base Operations	1 Officer
2 EMS ALS Transport Units	4 Firefighters
Required Minimum Personnel for Full Alarm	**36 Firefighters** **1 Incident Commander** **6 Officers**

Table 5: Number of Firefighters for an Initial Full Alarm to a High-Rise Fire. Fighting fire in high-rise structures poses many unique obstacles and challenges other than are found in a residential structure fire. Hose cannot be deployed directly from fire apparatus and needs to be carried, with other equipment, to the location of the fire. Search and rescue is impacted by large areas and accessibility concerns. Additionally, because of delays in access, firefighters are likely to encounter a high volume of fire which will necessitate a supply chain to equip ongoing suppression efforts. A single alarm response to a high-rise building minimally requires 43 responders, consisting of 36 firefighters, 1 incident commander, and 6 officers.

Fire Department EMS Operations

In recent years, the provision of emergency medical services has progressed from an amenity to a citizen-required service. More than 90% of career and combination fire departments provide some form of emergency medical care, making fire departments the largest group of prehospital EMS providers in North America. In many fire departments that deliver prehospital care, EMS calls can equate to over 75% of total call volume.

There are six main components of an EMS incident from start to finish.[43] These are (1) detection of the incident, (2) reporting of the incident to a 9-1-1 center, (3) response to the incident by the appropriate emergency resources, (4) on scene care by emergency response personnel, (5) care by emergency personnel while in transit to a medical care facility, and (6) transfer of the patient from emergency response personnel to the medical care facility. Not all EMS events will necessitate all six components, as when a patient refuses treatment, or is treated at the scene and not transported.

In an analysis of data from over 300 fire departments in the United States, first responder units, which are typically fire engines, arrived prior to ambulances approximately 80% of the time.[44] This is likely due to the fact that fire stations housing first responder units, which are equipped and staffed with dual-role firefighter/emergency medical service technicians and supplies, are more centrally located and are able to effect a quicker response and provide life-saving procedures in advance of an ambulance. This reinforces why it is in the best interest of the public good for the fire department to provide EMS transport as well as first response.

The benefit of supporting EMS transport within fire department operations is that fire departments are already geared towards rapid response and rapid intervention. Strategically located stations and personnel are positioned to deliver time critical response and effective fire suppression and are therefore equally situated to provide effective response to time critical requests for EMS service. Both fire suppression and EMS response are required by industry standards to have adequate personnel and resources operating on scene within 4 minutes. In both fire suppression and EMS incidents, time is directly related to the amount of damage, either to the structure or the patient.

When ambulance response is prolonged, a patient will be further delayed in reaching a medical facility to receive definitive care. This is especially dangerous for incidents of chest pain, stroke,

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[43] The Star of Life, designated by Leo R. Schwartz, Chief of EMS Branch, National Highway Traffic Safety Administration (NHTSA) in 1997.
[44] Moore-Merrell, L. et al. (2010) Report on Residential EMS Field Experiments, Fire Fighter Safety and Deployment Study; Washington, DC, September 2010.

and survivable cardiac arrest. Many times, patients experiencing symptoms associated with these events may not recognize the onset indicators and immediately call for assistance.[45] [46] [47] [48] Acute Coronary Syndrome (ACS), or heart attack, is the number one leading cause of death in the United States. Experts agree that an ACS event should receive definitive care from a hospital within one hour of onset of symptoms. One study found that definitive care for ACS within one hour of onset improves survivability by 50% and 23% if definitive care was given within 3 hours.[49]

Strokes, which are the number three cause of death in the U.S., as well as a leading cause of disability, also benefit from expedient treatment in definitive care. Ischemic stroke, which is a stroke caused from a blood clot, can be effectively treated if definitive care is received within 3 to 4.5 hours[50] of onset of symptoms. The sooner a patient receives definitive treatment from onset of symptoms, the less likely a patient is to suffer disability from this type of stroke. However, it is important to emphasize that before the time critical treatment can be administered to the patient in the hospital, there is a time intensive assessment that must be performed to ensure the patient is qualified to receive the treatment. The current benchmark for an ischemic stroke patient "door to needle"[51] is less than or equal to 60 minutes. However, Steps Against Recurrent Stroke (STARS) registry shows that the median door to needle time is 96 minutes or 1 hour and 36 minutes.[52]

In two-tiered EMS systems that deploy with sufficient resources, there is an increased likelihood that a patient will receive an ambulance and a first responding fire apparatus in not only a timely manner, but also frequently at the same, or close to the same time. This is extremely beneficial to the patient as most EMS responses, particularly the previously mentioned conditions, are labor intensive. Patients suffering from ACS should not perform any form of exertion as to minimize any damage that is occurring. Patients suffering from strokes are frequently unable to exert due to physical disabilities caused by the incident. An adequately sized crew is able to provide simultaneous interventions while assessment is being performed, thereby reducing the on-scene

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[45]American Heart Association, *Heart Disease and Stroke Statistics-2005 update,* Dallas, TX: AHA 2005

[46] Time from Symptom Onset to treatment and outcomes after thrombolytic therapy. Newby LK, et al. *J Am Coll Cardiol.* 1996:27:1646-1655

[47] An International Perspective on the Time to Treatment of Acute Myocardial Infarction. Dracup, K. et al. *J Nurs Scholarsh* 2003;35:317-323

[48] Prehospital and In-hospital Delays in Acute Stroke Care. Evanson, KR, et al. *Neuroepidemiology* 2001;20:65-76

[49] Association of patient delays with symptoms, cardiac enzymes, and outcomes in acute myocardial infarction. Rawles, JM. Et al. *Eur Heart J.* 1990; 11:643-648.

[50] Thrombolysis with Alteplase 3 to 4.5 Hours after Acute Ischemic Stroke. Hacke, W. et al. *N Engl J Med*. 2008;359:1317-1329

[51] "Door to Needle" is an industry specific term that refers to the time the patient entered the emergency department to the time the received the treatment. A drug named recombinant tissue plasminogen activator (rt-PA) is utilized to dissolve the thrombosis causing the stroke. Current FDA approvals limit this drug's use to 3-4.5 hours from initial symptoms and require a CT scan and labs before administration.

[52] Improving Door-to-Needle Times in Acute Ischemic Stroke: The Design and Rational for the American Heart Association/American Stroke Association's Target: Stroke Initiative. Fonarow, Gregg, et al. *Stroke* 2011;42:00-00

time. Following completion of critical tasks, the crew can then facilitate a safe removal of the patient to the ambulance and minimize the risk of injury to patient and provider.[53]

One of the most labor intensive and time critical requests for EMS response is cardiac arrest, which globally affects 20-140 out of every 100,000 people. Traditionally, the American Heart Association (AHA) taught a method of cardiac resuscitation that involved single rescuer performance of prioritized action.[54] However, there was a gap between instruction and practice which led to confusion and may have potentially reduced survival. In reality, providers respond and function in teams larger than two.

The AHA's guidelines for cardiac resuscitation focus on a team-centric approach. Evidence-based research suggested that the manner in which CPR was being performed was inherently inefficient and only provided 10-30% of the normal blood flow to the heart and 30-40% to the brain.[55] [56] This was linked to provider fatigue from administering chest compressions, and as such, these studies indicate that providers should be rotated to ensure effective depth and rhythm of chest compressions. Consensus documents from the AHA recommend that providers should rotate with every two-minute cycle of CPR. It is also recommended that requests for EMS service for cardiac arrest also have a team leader to organize priorities and direct resources as they arrive or are needed. The team leader would also be responsible for identifying symptoms of fatigue and making appropriate assignment adjustments to ensure maximally efficient CPR.

Although the AHA and other researchers have not identified what an optimally sized crew for effective team-centric CPR should be, some consensus literature from AHA has mentioned that five providers were best suited to perform resuscitation. However, providers may be required to perform multiple tasks. Industry best practices, through the guidance of Medical Directors, have suggested six providers would be most successful in minimizing confusion and redundancy.

An EMS crew consisting of six personnel would require four personnel arriving with the first responding fire apparatus and two with the ambulance.[57] For an all-ALS system, two of the six should be Paramedics, with a minimum of one assigned to each of the responding apparatus. Some ALS systems require two Paramedics on the ambulance and a minimum of one on the first responding fire apparatus. However, these deployment options are determined by State directive

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[53] Moore-Merrell, L. et al. (2010) Report on Residential EMS Field Experiments, Fire Fighter Safety and Deployment Study; Washington, DC, September 2010.
[54] Highlights of the 2010 American Heart Association Guidelines for CPR and ECC
[55] Determinants of Blood Flow during Cardiac Resuscitation in Dogs. Halperin, HR et al. *Circulation* 1986;73:539-550
[56] Increased Cortical Cerebral Blood Flow with LUCAS, a New Device for Mechanical Chest Compressions Compared to Standard External Compressions during Experimental Cardiopulmonary Resuscitation. Rubertson S, et al. *Resuscitation*. 2005;65:357-363
[57] NFPA 1917: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments

or Medical Director's discretion. Regardless of the make-up of the EMS certification level of the providers on scene, an ALS integrated cardiac arrest response should provide for the following: a lead provider, an airway manager, two providers to interchangeably deliver chest compressions, a provider to establish an intravenous medication line and administer medications, and a provider to operate the monitor.

Fire Department Deployment

Before discussing the staffing and deployment analysis of the BDFRD resources, it is imperative to understand the intricacies of distribution and concentration.

The Importance of Adequate Resources: Distribution

Distribution involves locating geographically distributed, ideal first-due resources for all-risk initial intervention. Distribution describes first due arrival. Station locations are needed to assure rapid deployment for optimal response to routine emergencies within the response jurisdiction. Distribution can be evaluated by the percentage of the jurisdiction covered by the first-due units within adopted public policy service level objectives.[58] In this case, distribution is measured by the percentage of roads that are covered from each fire station within 4-[59], 6-[60], 8-minute[61] and 10-minutes and 10-seconds[62] travel times to adhere to NFPA 1710, 2020 edition. Four minutes of travel time is the allowable maximum travel time for the first arriving apparatus at the scene of a fire, first responding unit to an EMS incident, and BLS ambulance if there is not a first responding unit already on the scene.

Distribution study requires geographical analysis of first due resources. Distribution measures may include:[63]

- Population per first-due company
- Area served per first-due company (square miles)
- Number of total road miles per first-due company (miles)
- Dwelling unit square footage per first-due company

[58] Commission on Fire Accreditation International, 5th Edition. 2008. Page 52.
[59] Four minutes of travel time is the allowable maximum travel time for the first arriving apparatus at the scene of a fire, first responding unit to an EMS incident, and BLS ambulance if there is not a first responding unit already on the scene.
[60] Six minutes of travel time is the maximum amount of travel time permitted for the second arriving apparatus. Although not explicitly stated, it is recommended that this apparatus be the ladder truck or a company that will be assigned to ladder duties.
[61] Eight minutes of travel time is the maximum amount of travel time permitted for a low-hazard alarm assignment and the arrival of an ALS resource, assuming a BLS unit is already on the scene within 4 minutes of travel time.
[62] Ten minutes and ten seconds of travel time is the maximum amount of travel time permitted for a high-hazard alarm assignment.
[63] Commission on Fire Accreditation International, 5th Edition. 2008. Page 52.

- Maximum travel time in each first-due company's protection area

- Catchment areas (4-minute road response from all fire stations) to determine gap areas and overlaps of first-due resources

- Areas outside of actual performance
    1. Population not served
    2. Area not served (square miles)
    3. Road miles not served (miles)
    4. Dwelling unit square footage not served

- First-due unit arrival times (Engine, Truck, ALS unit, etc.)

A major item to be considered in the distribution of resources is travel time. It should be a matter of public policy that the distribution of fire stations in the community is based on the element of travel time and the response goal. Travel time should be periodically sampled and analyzed to determine whether the fire department is achieving a reasonable response performance to handle emergencies.[64]

Evaluating a small number of incidents for response time performance also does not reflect the true performance of the department. Analyzing tens of thousands of incidents measured over 3-5 years will provide a more accurate assessment of the delivery system performance. Completing the same analysis over a period will allow for trend analysis as well.[65]

Distribution strives for an equitable level of outcome: everyone in the community is within the same distance from a fire station. Distribution is based on the probability that all areas experience equal service demands, but not necessarily the same risk or consequences as those demands for service in other areas. For example, suburban communities in a jurisdiction may have the same service demand as an industrial factory area, but the level of risk is very different. This can have an impact on fire station locations as placement would probably put the stations near high risk areas to provide shorter travel times. Additionally, EMS response times based on medical emergencies will drive equal distribution in the community and negate distribution based on risk, as the risk is equal.

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[64] Commission on Fire Accreditation International, 5th Edition. 2008. Page 53
[65] Commission on Fire Accreditation International, 5th Edition. 2008. Page 53

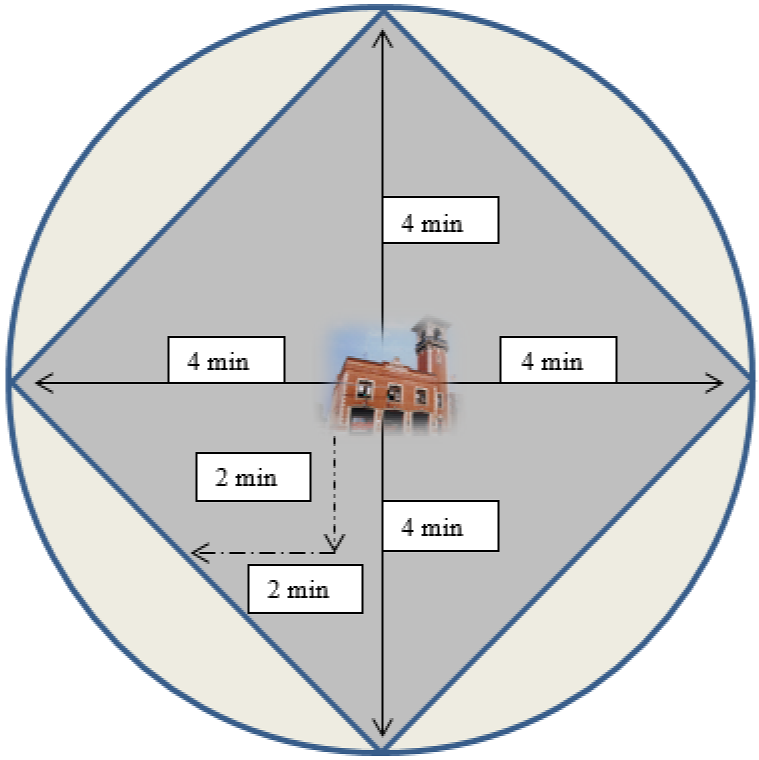


Figure 5: Normal Distribution Model for an Initial 4-Minute Response Area.[66] As depicted in the above figure, fire stations and emergency resources should be distributed throughout a community so that citizens receive equitable coverage and protection. However, there are additional points of concern when modeling a response district such as road network, traffic patterns, and building occupancies.

First unit arrival times are the best measure of distribution. It should be noted that if an area experiences fire unit arrival times outside the adopted performance measure, in this case 4-minute travel time per NFPA 1710, it does not necessarily mean it has a distribution issue.[67] Other issues occur such as reliability, call processing times and turnout times, and traffic which can affect the overall performance of response times.

An effective response force for a fire department is impacted not only by the spacing of fire stations but also by the type and amount of apparatus and personnel staffing the stations. To assemble the necessary apparatus, personnel, and equipment within the prescribed timeframe, all must be close enough to travel to the incident, if available upon dispatch. The placement and spacing of specialty equipment is always challenging.[68] Specialty units tend to be trucks, rescue units, hazmat, or Battalion personnel. Most often there are less of these types of equipment and personnel compared to the first-line response of engines and medic units. Selecting where to put

[66] Derived from Commission on Fire Accreditation International, 5th Edition. 2008. Page 53
[67] Commission on Fire Accreditation International, 5th Edition. 2008. Page 55
[68] Commission on Fire Accreditation International, 5th Edition. 2008. Page 62

specialty units requires extensive examination of current and future operations within the fire department and a set goal of response time objectives for all-hazards emergencies within a jurisdiction.

Distribution vs. Concentration

Major fires have a significant impact on the resource allocation of any fire department. The dilemma for any fire department is staffing for routine emergencies and also being prepared for the fire or emergency of maximum effort. This balancing of distribution and concentration staffing needs is one that almost all fire agencies face on an ongoing basis.

The art in concentration spacing is to strike a balance with respect as to how much overlap there should be between station areas. Some overlap is necessary to maintain good response times and to provide back-up for distribution when the first-due unit is unavailable for service or deployed on a prior emergency.

Concentration pushes and pulls distribution. Each agency, *after risk assessment and critical task analysis,* must be able to quantify and articulate why its resource allocation methodology meets the governing body's adopted policies for initial effective intervention on both a first-due and multiple-unit basis.[69]

[69] Commission on Fire Accreditation International, 5th Edition. 2008. Pages 62-63

Mapping Analysis of the Beaver Dam Fire and Rescue Department

In creating this document, it was important to ascertain where stations were located and if they were located to provide fair and equitable coverage to the citizens. In order to make this assessment, the IAFF created maps of the Department's response area and plotted the fire station.

Computer modeling was then used to determine the distance apparatus could travel in 4 minutes. The following table specifies the current location of the station, the apparatus of the department and the minimum staffing level.

Station	Address	Apparatus	Min. Staffing
\Station 1	205 S. Lincoln Avenue	Ladder 1271 Engine 1261 Medic 1251 Medic 1252	1 FF/Medic 1 Captain, 1 FF/Medic 2 FF/Medic Cross-Staffed

Table 6: Current Fire Station Locations and Staffing. This table displays the minimum staffing level of the department. In addition to those reported in this table, the department cross-staffs two engines and two additional medic units, as well as one tender truck, one brush truck, a boat, one hover craft unit and a diver trailer. When the demand requires multiple units to be engaged on responses, the department resorts to overtime personnel to guarantee that the station is staffed with at least two firefighters.

Travel times were modeled using ESRI ArcGIS Pro 2.4.2. Fire stations were identified on Geographic Information System (GIS) maps as starting points with vehicles traveling at posted road speeds.

When generating the maps, several assumptions needed to be addressed prior to drawing conclusions from the analysis. These assumptions are as follows:

- Modeled travel speeds are based on reasonable and prudent historical traffic speeds using the typical traffic on Wednesday at 5.00 pm. Actual response speeds may be slower, and the associated travel times greater, with any unpredictable impedances including, but not limited to:
  - Traffic Incidents: Collisions and vehicle breakdowns causing lane blockages and driver distractions.

- Work Zones: Construction and maintenance activity that can cause added travel time in locations and times where congestion is not normally present.
- Weather: Reduced visibility--road surface problems and uncertain waiting conditions result in extra travel time and altered trip patterns.
- Special Events: Demand may change due to identifiable and predictable causes.
- Traffic Control Devices: Poorly timed or inoperable traffic signals, railroad grade crossings, speed control systems, and traveler information signs contribute to irregularities in travel time.
- Inadequate Road or Transit Capacity: The interaction of capacity problems with the aforementioned sources causes travel time to expand much faster than demand.[70]

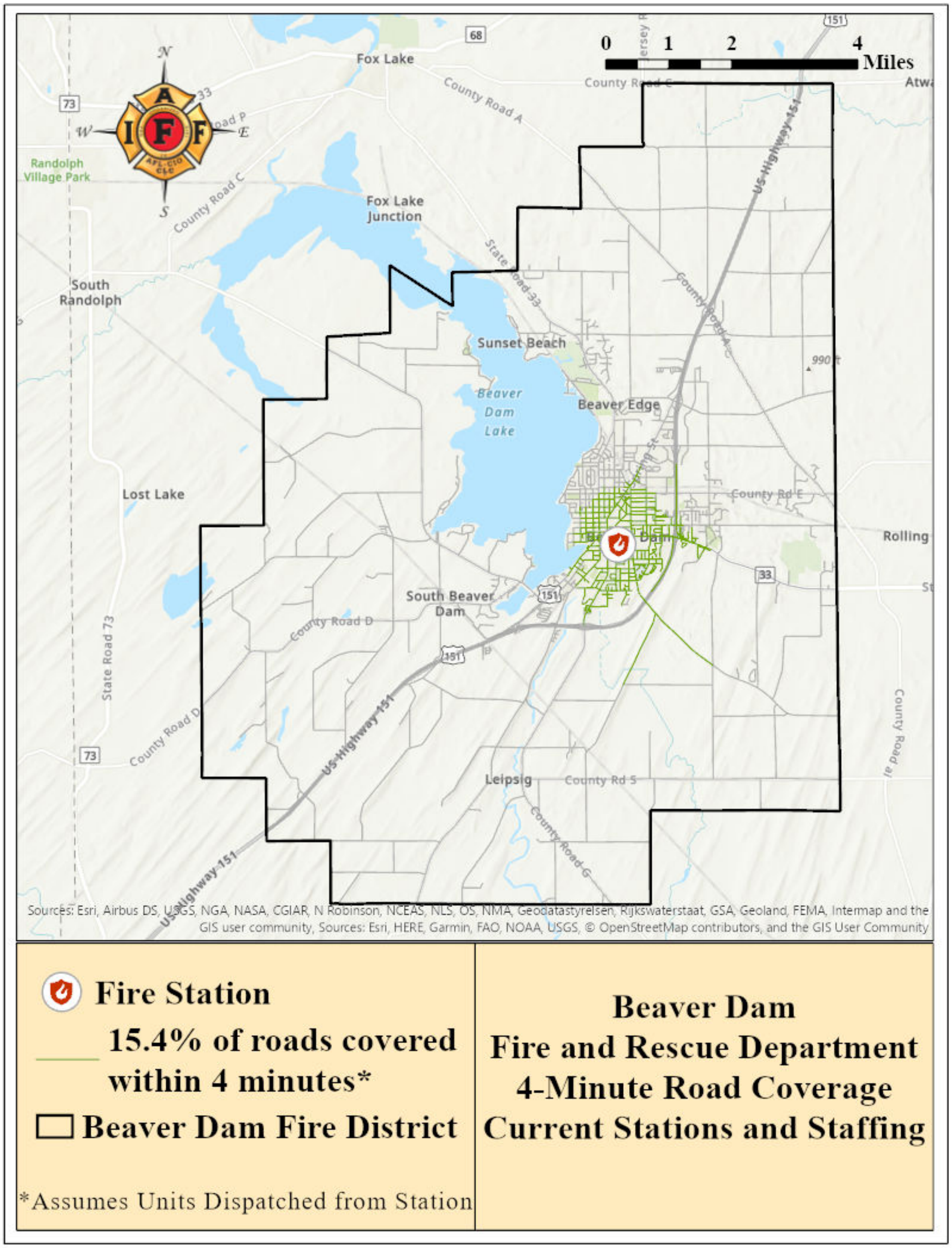
In addition, it is reasonable to suggest that because larger emergency vehicles are generally more cumbersome and require greater skill to maneuver, their response may be more negatively affected by their weight, size, and in some cases, inability to travel narrow surface streets.

As discussed, computer modeling only considers travel time of apparatus. Decision makers should understand that once apparatus and personnel arrive on the incident scene there are other essential tasks that must be completed which require additional time before access, rescue, and suppression can take place. Tasks such as establishing a water supply, forcible entry (access), and deployment of an attack line are not considered in the computer modeling. Other additional factors also include:

- The time from arrival of the apparatus to the onset of interior fire operations (access interval) must be considered when analyzing response system capabilities.
    - The access interval is dependent upon factors such as distance from the apparatus to the task location and the elevation of the incident and locked doors or security bars which must be breached.
    - Impediments like these may add to the delay between discovery of a fire and the initiation of an actual fire attack.
- The reliability of a community's hydrant system to supply water to fire apparatus.

- Weather conditions

[70] David Shrank and Tim Lomax, The 2003 Urban Mobility Report, (Illinois Transportation Institute, Illinois A&M University: September 2003).



Map 7: 4-Minute Road Coverage, Current Stations and Staffing. This map shows the roads that the department can reach within four minutes of travel time from the current station. These are also the roads where the department can assemble a minimum of four firefighters within four minutes assuming all units are available at the time of dispatch. However, since the fire suppression apparatus are staffed with two or one firefighters, multiple units are needed to assemble the minimum force of four firefighters, which might increase the actual travel times.

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Workload Analysis of the Beaver Dam Fire and Rescue Department

The workload analysis presented in this section is based on the CAD data provided by the IAFF Local 3432 covering the time period from January 1st, 2017 through December 31st, 2018. The CAD data include an incident identifier number, responding apparatus, location of incident, dispatch time, en route time, arrival time, the times corresponding to when apparatus and personnel have cleared the incident, and the National Fire Incident Reporting System[71] (NFIRS) codes, which allows to identify the type of emergency.

The timestamps reported in the CAD include date, hour and minute of dispatch, en route, arrival and clear times. The seconds are not reported, so that there exists a one-minute uncertainty on each timestamp. As shown in the sections below, this uncertainty does not affect the conclusions of this report, because the travel time performance of the department exceeds the NFPA 1710 objectives by an amount larger than the uncertainty associated with the lack of information on the seconds. However, the department should make an effort to improve the precision in the collection of data.

To evaluate the department's workload, several measures were considered, including the number of individual apparatus responding to the same incidents, travel times for the responding apparatus, overlapping responses, and the personnel needed to operate the apparatus in any given hour.

Call Volume Analysis

In the time period evaluated in this analysis, the number of incidents that the BDFRD responded to, increased by 8%, from 2,540 to 2,745. Both fire and EMS emergencies, as well as other kinds of emergencies, often require more than one unit to respond. Demand must be assessed not only by considering the number of incidents, but also considering the number of units responding to the same incidents. The number of units' responses required to address the incidents increased by 15%, from 2,879 in 2017 to 3,306 in 2018.

[71] https://www.nfirs.fema.gov/

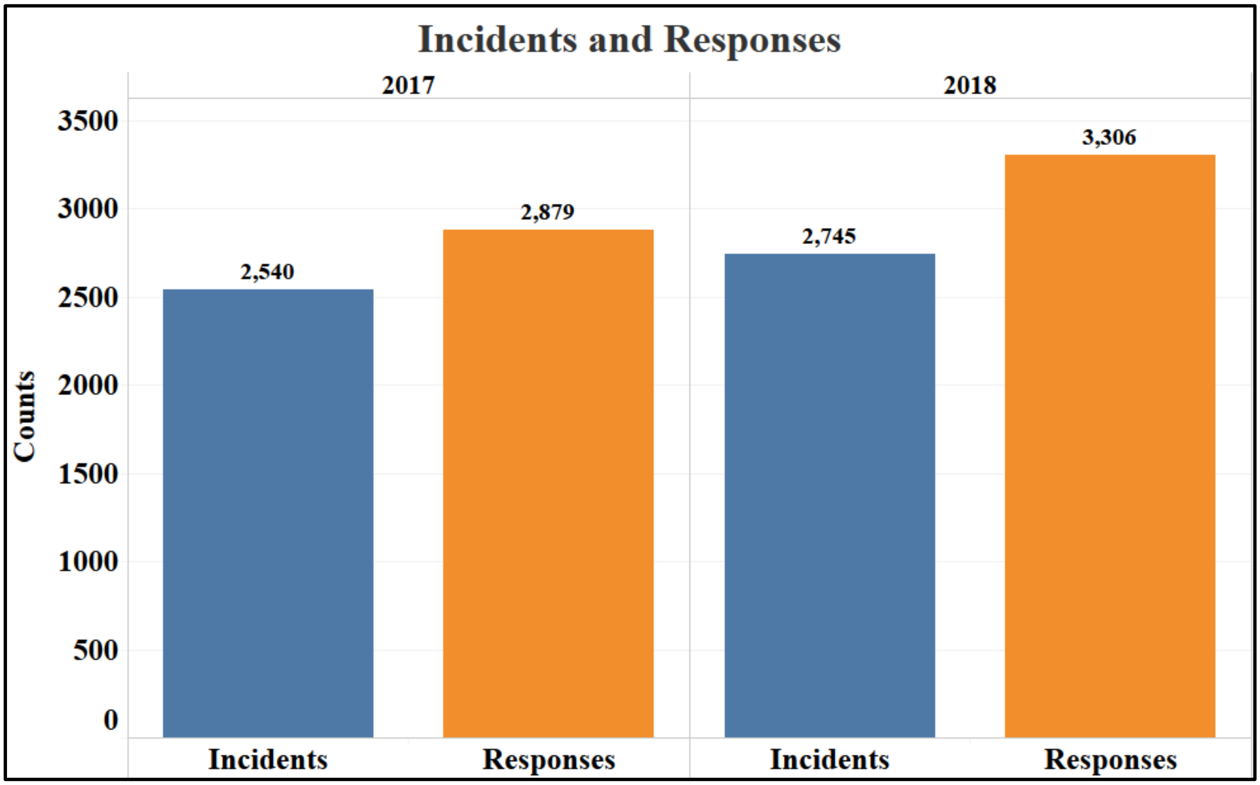

Chart 3: Incidents and Responses. The number of incidents that the BDFRD responded to, increased by 8%, from 2,540 to 2,745. The number of units' responses required to address the incidents increased by 15%, from 2,879 in 2017 to 3,306 in 2018.

Approximately 91% of the incidents that the department responded to were EMS incidents, 2% were fire incidents, and the remaining 7% was represented by other type of emergencies[72]. Despite being less frequent than EMS incidents, fire calls are more time consuming. Although fire incidents were only 2% of the total, they accounted for 10% of the total time that the apparatus of the department spent on incidents in 2017, which increased to 15% in 2018. The average time that the apparatus of the department spent on fire incidents was 111 minutes, the 90th percentile[73] was 185 minutes. In comparison, the average time spent on EMS incidents was 54 minutes, and the 90th percentile was 71 minutes.

[72] Such as public service calls and HazMat calls.

[73] The 90th percentile is the value below which 90% of the values fall. For example, in this case, a 90th percentile of 185 minutes means that for 90% of the fire incidents, the time spent on scene was less than or equal to 185 minutes.

Travel Time Analysis

The travel time analysis examined the en route and arrival on scene times included in the CAD data to calculate the travel times for apparatus responding to incidents. NFPA 1710 requires a travel time of four minutes (240 seconds) or less to at least 90% of incidents for the first arriving engine company to the scene of fire incidents and for the first arriving EMS company with BLS capability, or higher, at the scene of EMS incidents. Travel times that are consistently higher than these benchmarks pose a risk for the community and suggest that the department needs additional resources.

The 90th percentile of the travel time for the first arriving unit at the scene of EMS emergency incidents[74] was 420 seconds both in 2017 and 2018. The travel time of the first arriving engine at the scene of fire incidents was 528 seconds in 2017 and 594 seconds in 2018. Both or fire and EMS incidents the department does not meet the NFPA 1710 travel time objectives. Approximately 63% of the EMS incidents and 49% of the fire incidents received the first unit, respectively an EMS unit for medical emergencies and an engine for fire incidents, within four minutes, instead of the 90% required by NFPA 1710.

The timestamps reported in the CAD include date, hour and minute of dispatch, en route, arrival and clear times. The seconds are not reported, so that there exists a one-minute uncertainty on each timestamp, and, potentially, up to two minutes (120 seconds) on the travel time. However, this uncertainty is irrelevant, because even if the 90th percentiles of the travel time were 120 seconds lower than those reported above and shown in the next chart, the department would still not meet the NFPA 1710 objectives[75]. This can clearly be seen in the chart below, where the 90th percentile performance of the department is more than 120 seconds above the NFPA 1710 threshold.

[74] This statistic excludes non-emergency interfacility transfers and focuses on emergency calls only.
[75] Additionally, it is statistically unlikely that the 90th percentiles are overestimated by 120 seconds. For this to happen, every single travel time for every first arriving unit at the scene of an incident would have to be overestimated by 120 seconds, which is unlikely.

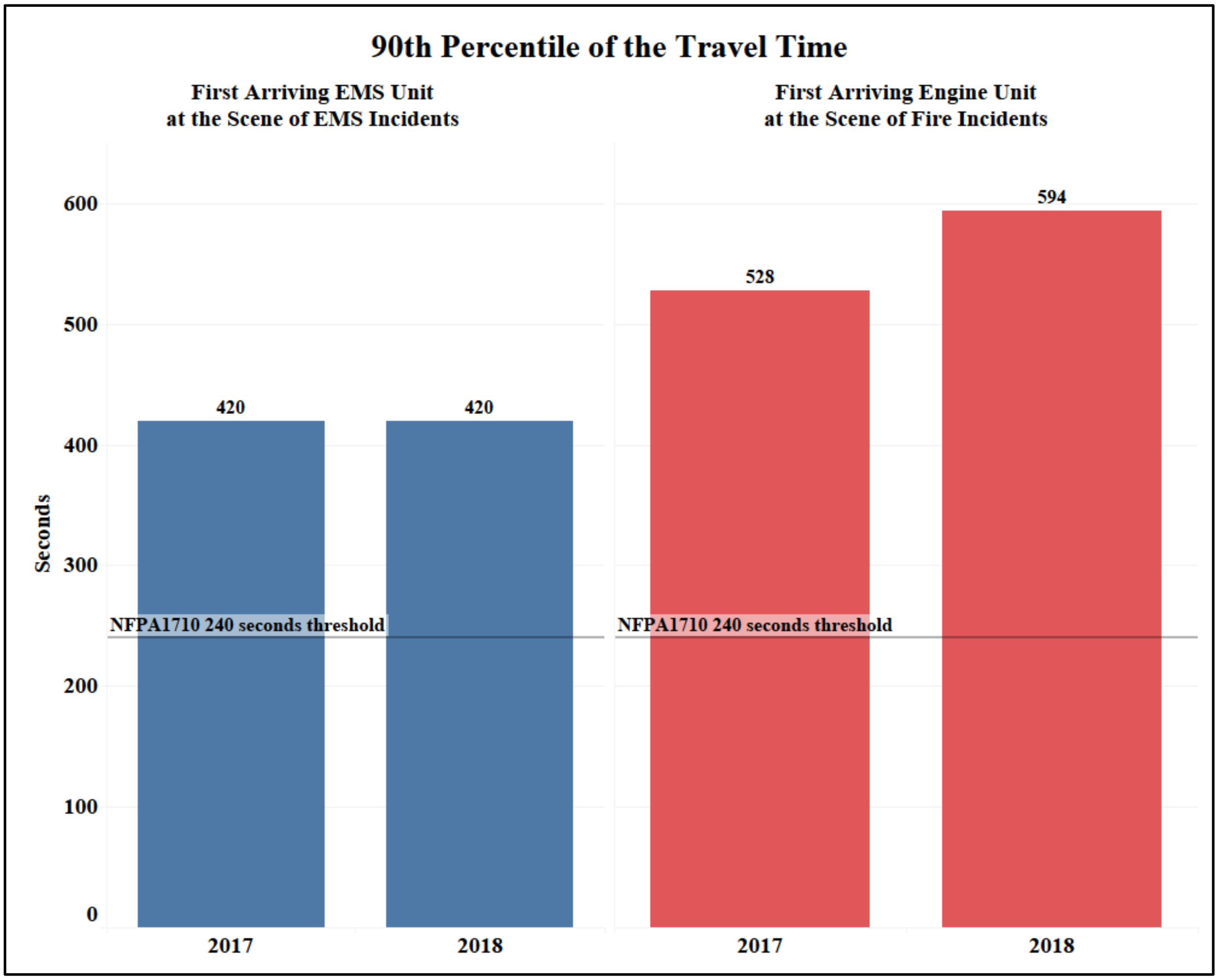

Chart 4: 90th Percentile of the Travel Time. The 90th percentile of the travel time for the first arriving unit at the scene of EMS emergency incidents was 420 seconds both in 2017 and 2018. The travel time of the first arriving engine at the scene of fire incidents was 528 seconds in 2017 and 594 seconds in 2018. Both or fire and EMS incidents the department does not meet the NFPA 1710 travel time objectives.

The Occupational Safety and Health Administration's (OSHA) "2 In/2 Out" Regulation requires at least four personnel to be on scene before beginning interior fire suppression operations. BDFRD staffs fire engines with 2 firefighters and the ladder truck with one firefighter. As a result, crews must wait for additional resources to arrive, delaying critical fireground tasks. Chart 5 shows the 90th percentile of the total travel time[76] for the effective response force of four firefighters for fire incidents. Both in 2017 and 2018 the 90th percentile of the minimum response force of four firefighters was 540 seconds, which is 300 seconds (five minutes) higher than the 240 seconds NFPA 1710 objectives. This poses a significant danger for the community and for the firefighters, should they start the fire suppression operations before the minimum force is

[76] For every incident, this travel time is calculated as the time interval between the earliest en route time of all the units dispatched to the incident, and the arrival on scene time of the unit which completes the effective response force of four firefighters.

assembled. In order to reduce this risk, the department needs staff the fire suppression apparatus with four firefighters, as detailed later in this report, and cease the practice of cross-staffing engines, the ladder, and the medic units, so that when the medic units are engaged in responses the fire suppression apparatus are still fully staffed and available.

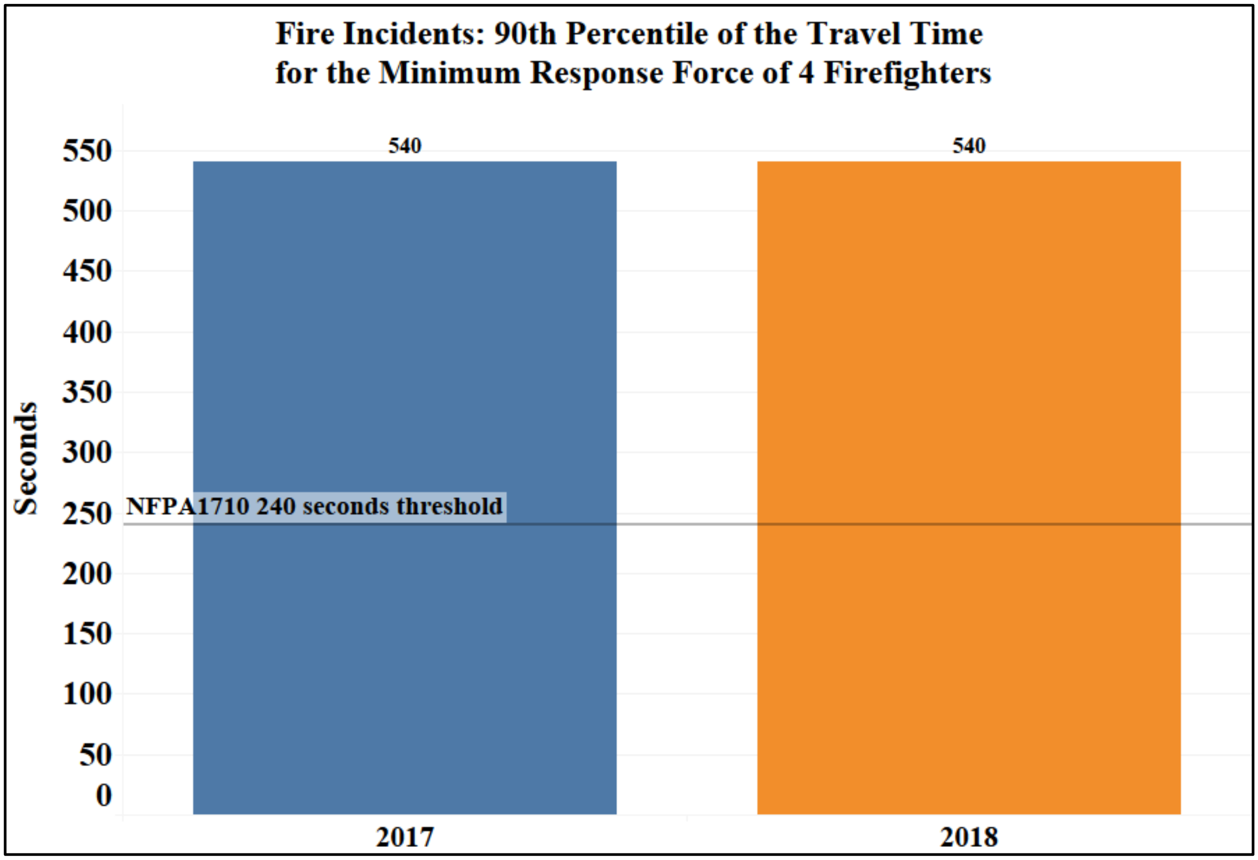

Chart 5: Fire Incidents: 90th Percentile of the Travel time for the Minimum Response Force of four Firefighters. Both in 2017 and 2018 the 90th percentile of the minimum response force of four firefighters was 540 seconds, which is 300 seconds (five minutes) higher than the 240 seconds NFPA 1710 objectives. This poses a significant danger for the community and for the firefighters, should they start the fire suppression operations before the minimum force is assembled.

Overlapping responses for medic units

The previous section considered the number of firefighters needed to operate the apparatus in a given hour, not necessarily on responses occurring at the same time. This section focuses on the medic units only and considers the occurrences of multiple medic units engaged at the same time, either responding to the same or to different incidents. The total time that multiple units were engaged at the same time is a useful indicator of the workload of a department. The more units are engaged on assignment at the same time, the more difficult is for the department to provide a timely response to a new, incoming call. Additionally, because the department cross-staffs its medic, ladder and engine units, when multiple medic units are engaged at the same time, the department might not have sufficient personnel to operate the engines and the ladder and to respond to fire emergencies.

The following chart considers the total amount of time, in each year, when at least two medic units were engaged at the same time responding to the same or to different incidents. It is important to note that the minimum staffing level of the department is five firefighters. With two medic units engaged at the same time, staffed with two firefighters each, the department has one to two firefighters left to operate the rest of the apparatus and might need to resort to overtime personnel to guarantee that a minimum of two firefighters is present in the station. With three medic units engaged at the same time, the department is deploying its entire typical daily staff and must resort to overtime personnel[77]. When all the four medic units are engaged at the same time, besides having to call in firefighters working overtime, the department does not have medic units available to respond to medical emergencies.

The chart shows that the total time with two, three or all the four medic units engaged at the same time increased from 2017 to 2018. Three of the four medic units (and, therefore, the full typical staffing level) were deployed at the same time for 37 hours in 2017, which nearly doubled (+89%) to 70 hours in 2018. In 2017, the total time with all the four medic units engaged at the same time was 5 hours, which increased to 8 hours in 2018. In total, two or more of the four medic units were engaged at the same time for 297 hours in 2017 and 491 hours in 2018, which represents a 65% increase. With the increasing population and demand, the time with multiple medic units engaged on overlapping responses will also increase. The department should cease the practice of cross-staffing its units, so that when the demand requires multiple medic units to be engaged at the same time, the engines and the ladder of the department will be still ready to respond to fire emergencies and motor-vehicle incidents.

[77] However, the numbers in the chart should not be confused with the total overtime hours that the department had to use. This analysis considers only the cases when two or more medic units of the department were engaged at the same time and it is not an estimate of the amount of overtime hours used by the department. The information about the overtime hours used by the department cannot be estimated from the CAD and was not available for this analysis.

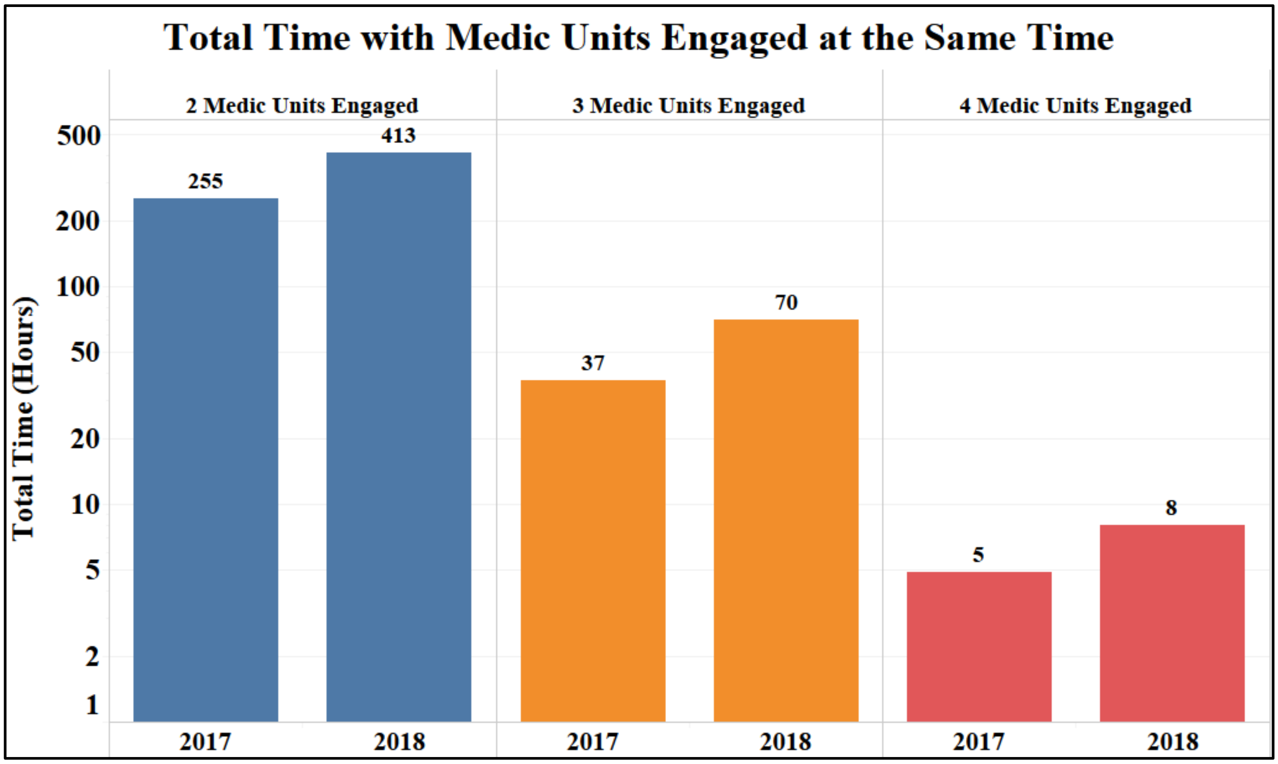

Chart 6: Total Time with Medic Units Engaged at the Same Time. The chart shows that the total time with two, three or all the four medic units engaged at the same time increased from 2017 to 2018. With two medic units engaged at the same time, staffed with two firefighters each, the department has one to two firefighters left to operate the rest of the apparatus, unless personnel working overtime is called in the station. With three and four medic units engaged at the same time, the department is deploying its entire daily staff and must resort to overtime personnel. When four medic units are engaged at the same time, there are no medic units left to respond to medical emergencies.

Staff Demand Analysis

This section analyzes the demand on the time of the personnel of the BDFRD, regardless of the type of unit. The staff demand is defined as the number of firefighters needed to operate the BDFRD apparatus in any given hour[78]. When calculating the staff demand, the number of firefighters needed to staff the cross-staffed units are counted as if those units were each staffed by a crew of the same size. For example, a crew of two firefighters cross-staffs the engines and the medic units of the department. If, in one hour, one crew of two firefighters is dispatched on the engine and later in the same hour the same crew is dispatched on the medic unit, the number of firefighters needed in that hour is considered to be four. If, in the same hour, a second crew of two firefighters is dispatched on any apparatus, the number of firefighters which was needed in that hour is considered to be six. For this calculation, the responses occurring in one hour are not necessarily occurring at the same time (*overlapping*). Overlapping responses will be discussed in the following section. This calculation provides an indication of the number of firefighters needed in every hour of the year to operate the apparatus of the department and respond to emergency calls.

When the number of firefighters needed in one hour approaches or exceeds the minimum staffing level of the department, it is more likely that either the same crews are being dispatched on multiple calls in the hour, or that the department is resorting to overtime personnel to staff units that do not have a dedicated crew. In both cases, personnel may not have adequate rest and recovery time, which poses a risk to the safety of the community and the personnel. The frequent need for overtime personnel or dispatching the same crew multiple times in one hour, is a symptom that the department does not have sufficient on-duty staffing levels to meet the demand. In addition to rest periods needed between calls, personnel frequently working overtime also do not have time to recuperate properly between shifts.

It is important to emphasize that this staff demand analysis is not a calculation of the amount of overtime hours worked by firefighters. The goal of this analysis was to estimate the number of hours in each year when the number of firefighters needed to staff the units required to meet call demand was close to, or exceeded, the number of firefighters on duty.

BDFRD has a minimum staffing level of five firefighters. The chart below shows the total number of hours in each year when a number of firefighters equal to or exceeding this minimum staffing level was needed to operate the apparatus of the department. The total number of hours requiring five or more firefighters increased from 180 in 2017 to 258 in 2018, which represents a 58% increase.

[78] Here *hour* refers to the 60-minute period between whole numbers on a clock, for example, 1:00 to 2:00 or 15:00 to 16:00

This result shows that the number of firefighters needed to meet call demand was equal to or exceeded the minimum staffing level for an increasing number of hours each year. With the expected increasing population and associated demand, it is likely that the number of hours requiring five or more firefighters will increase as well. The BDFRD needs to increase the minimum daily staffing level in order to reduce the risk of personnel becoming fatigued, which could pose a risk both for the citizens and firefighters.

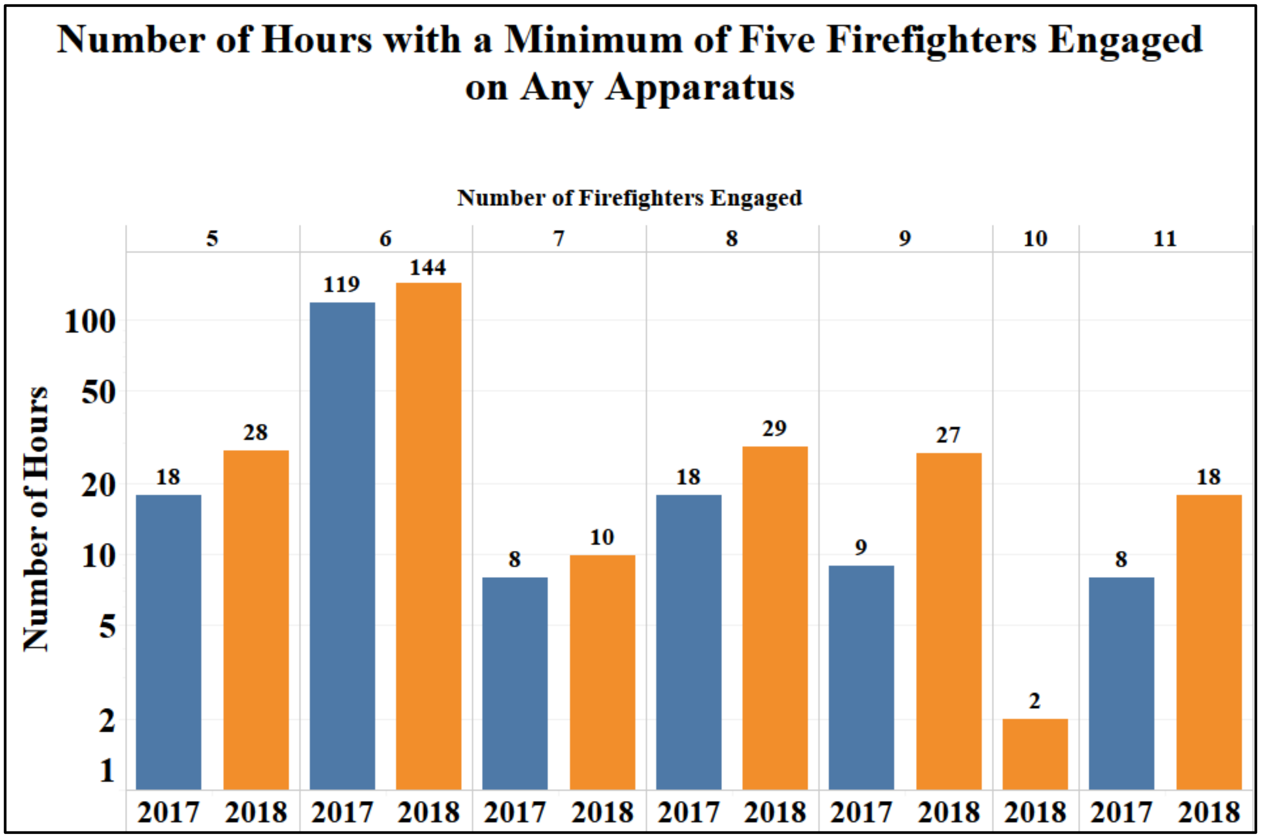

Chart 7: Number of Hours with a Minimum of Five Firefighters Engaged on Any Apparatus. The total number of hours requiring five or more firefighters increased from 180 in 2017 to 258 in 2018, which represents a 58% increase. With the expected increasing population and associated demand, it is likely that the number of hours requiring five or more firefighters will increase as well. The BDFRD needs to increase the minimum daily staffing level in order to reduce the risk of personnel becoming fatigued, which could pose a risk both for the citizens and firefighters.

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Emergency Response Capabilities, Recommended Stations and Staffing

The GIS and workload analysis conclude that, in order to help meeting the NFPA 1710 objectives regarding the travel time and to be able to respond to the increasing demand in an efficient and safe way, the BDFRD should increase its minimum staffing level and cease the practice of cross-staffing the engines, the medic units and the ladder. The department should regularly staff one engine and one ladder truck with four firefighters at all times, as required by NFPA 1710, and two medic units with two firefighters each.

These recommendations will increase the ability of the department to meet the demand, as more units would be available at any given time. The roads that the department could reach within a travel time of 4 minutes from the current station would not change compared to the current coverage[79], however, by staffing the fire suppression apparatus with four firefighters, the department will no longer need multiple units at the scene of an incident in order to assemble the minimum response force of four firefighters.

The following table summarizes the recommended minimum staffing level. The changes compared to the current staffing level are highlighted.

Station	Address	Apparatus	Min. Staffing
Station 1	205 S. Lincoln Avenue	Ladder 1271 Engine 1261 Medic 1251 Medic 1252	4 FF/Medic 1 Captain, 3 FF/Medic 2 FF/Medic 2 FF/Medic

Table 7: Recommended Staffing. This table displays the recommended staffing level of the department. The recommended changes are highlighted. The department should regularly staff the ladder truck and one engine with four firefighters, and two medic units with two firefighters.

[79] Therefore, this map is not shown, as it would be the same as Map 7**.**

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Conclusion

In conclusion, regardless of the type of response, fire suppression companies are not staffed in compliance with industry standards for safe, efficient, and effective response to fires or rescue situations. In the time period evaluated in this analysis, the number of incidents that the BDFRD responded to, increased by 8%, from 2,540 in 2017 to 2,745 in 2018. The population of Beaver Dam is expected to increase in the next four years, and, with it, the number of emergency calls.

Approximately 63% of the EMS incidents and 49% of the fire incidents received the first unit, respectively an EMS unit for medical emergencies and an engine for fire incidents, within four minutes, instead of the 90% required by NFPA 1710. Both in 2017 and 2018 the 90th percentile of the travel time for the minimum response force of four firefighters was 540 seconds, which is 300 seconds (five minutes) higher than the 240 seconds NFPA 1710 objectives. This poses a significant danger for the community and for the firefighters, should they start the fire suppression operations before the minimum force is assembled.

The total number of hours requiring the entire minimum staff of five firefighters, or more, to respond to emergencies increased from 180 in 2017 to 258 in 2018, which represents a 58% increase. The total time with two, three or all the four medic units engaged at the same time increased from 2017 to 2018. Three of the four medic units (and, therefore, the full staffing level) was deployed at the same time for 37 hours in 2017, which nearly doubled (+89%) to 70 hours in 2018. In 2017, the total time with all the four medic units engaged at the same time was 5 hours, which increased to 8 hours in 2018. In total, at least two of the four medic units were engaged at the same time for 297 hours in 2017, and for 491 hours in 2018, which represents a 65% increase. With the expected increasing population and associated demand, it is likely that the number of hours requiring five or more firefighters to be engaged in responses will increase, as well as the amount of time with multiple medic units engaged at the same time.

In order to reduce the travel times, the time required to assemble the minimum response force of four firefighters, the use of overtime personnel and the time with multiple medic units engaged at the same time, the BDFRD should increase the minimum daily staffing level, cease the practice of cross-staffing medic units, engines and the ladder truck and regularly staff one engine and the ladder truck with four firefighters. The department should also staff two medic units with two firefighters. This recommendation will reduce the risk for the firefighters and for the citizens of Beaver Dam and the nearby communities and will increase the efficiency of the department's operations and the ability to meet the future demand.

While it is impossible to predict where most of a jurisdiction's fire and medical emergencies will occur, the BDFRD should examine where emergencies have typically occurred in the past and make efforts to ensure these areas continue to enjoy the same level of coverage, while adjusting resources and deployment as needed in an effort to achieve complete compliance with industry standards. Areas with accelerated development and population growth will require additional coverage in the future. Any projected increase in emergency response demands should also be considered before changes are implemented, focusing on associated hazard types and planned response assignments.

As explained by the Commission on Fire Accreditation International, Inc. in its Creating and Evaluating Standards of Response Coverage for Fire Departments manual, "If resources arrive too late or are understaffed, the emergency will continue to escalate…What fire companies must do, if they are to save lives and limit property damage, is arrive within a short period of time with adequate resources to do the job. To control the fire before it reaches its maximum intensity requires geographic dispersion (distribution) of technical expertise and cost-effective clustering (concentration) of apparatus for maximum effectiveness against the greatest number and types of risks." Optimally, there needs to be a balance between both elements.

The ramifications of low staffing levels, as they pertain to the loss of life and property within a community, are essential when considering a fire department's deployment configuration. A fire department should be designed to adequately respond to several emergencies occurring simultaneously in a manner that aims to minimize the loss of life and the loss of property that the fire department is charged to protect. Any proposed changes in staffing, deployment and station location should be made only after considering the historical location of calls, response times to specific target hazards, compliance with departmental Standard Operating Procedures, existing industry standards, including NFPA 1500 and NFPA Standard 1710, and the citizens' expectation of receiving an adequate number of qualified personnel on appropriate apparatus within acceptable time frames to make a difference in their emergency.

Appendix

Performance Standards

The National Fire Protection Association (NFPA) produced NFPA 1710 *Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. NFPA 1710 is the consensus standard for career firefighter deployment, including requirements for fire department arrival time, staffing levels, and fireground responsibilities.[80]

Key Sections included in the 1710 Standard that are applicable to this assessment are:

- **4.1.2.1** The fire department shall establish the following performance objectives for the first-due response zones that are identified by the AHJ:
  - (3) 240 seconds or less travel time for the arrival of the first engine company at a fire suppression incident[81]
  - (4) 360 seconds or less travel time for the arrival of the second company with a minimum staffing of 4 personnel at a fire suppression incident
  - (5) For other than high-rise, 480 seconds or less travel time for the deployment of an initial full alarm assignment at a fire suppression incident
  - (6) For high-rise, 610 seconds or less travel time for the deployment of an initial full alarm assignment at a fire suppression incident
  - (7) 240 seconds or less travel time for the arrival of a unit with first responder with automatic external defibrillator (AED) or higher-level capability at an emergency medical incident
  - (8) 480 second or less travel time for the arrival of an advanced life support (ALS) unit at an emergency incident, where this service is provided by the fire department provided a first responder with an AED or basic life support (BLS) unite arrived in 240 seconds or less travel time.
- **4.3.2** The fire department organizational statement shall ensure that the fire department's emergency medical response capability includes personnel, equipment, and resources to deploy at the first responder level with AED or higher treatment level.

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[80] NFPA 1710, 2020

[81] All travel time objectives are to be achieved 90% of the time

- **5.2.3 Operating Units**. Fire company staffing requirements shall be based on minimum levels necessary for safe, effective, and efficient emergency operations.

- **5.2. 3.1 Engine Companies.** Fire companies, whose primary functions are to pump and deliver water and perform basic firefighting at fires, including search and rescue, shall be known as engine companies shall be staffed with a minimum of four on-duty personnel.
  - 5.2.3.1.1 These companies shall be staffed with a minimum of four on-duty personnel.
  - 5.2.3.1.2 In first-due response zones with a high number of incidents, geographical restrictions, geographic isolation, or urban areas, as identified by the AHJ, these companies shall be staffed with a minimum of five on-duty members.
  - 5.2.3.1.2.1 In first-due response zones with tactical hazards, high-hazard occupancies, or dense urban areas, as identified by the AHJ, these fire companies shall be staffed with a minimum of six on-duty members.

- **5.2.3.2 Ladder/Truck Companies.** Fire companies whose primary functions are to perform the variety of services associated with truck work, such as forcible entry, ventilation, search and rescue, aerial operations for water delivery and rescue, utility control, illumination, overhaul and salvage work, shall be known as ladder or truck companies… shall be staffed with a minimum of four on-duty personnel.
  - 5.2.3.2.1 These companies shall be staffed with a minimum of four on-duty personnel.
  - 5.2.3.2.2 In first-due response zones with a high number of incidents, geographical restrictions, geographic isolation, or urban areas, as identified by the AHJ, these companies shall be staffed with a minimum of five on-duty members.
  - 5.2.3.2.2.1 In first-due response zones with tactical hazards, high-hazard occupancies, or dense urban areas, as identified by the AHJ, these fire companies shall be staffed with a minimum of six on-duty members.

- **5.2.3.4 Fire Companies with Quint Apparatus**
  - 5.2.3.4.1 A fire company that deploys with quint apparatus designed to operate as either an engine company or a ladder company, shall be staffed as specified in 5.2.3.
  - 5.2.3.4.2 If the company is expected to perform multiple roles simultaneously, additional staffing, above the levels specified in 5.2.3, shall be provided to ensure that those operations can be performed as required.

- **5.2.4.1** The initial full alarm assignment to a structure fire in a typical 2000 ft^2 … two-story single-family dwelling without basement and with no exposures shall provide for the following

Assignment	*Required Personnel*
Incident Command	1 Officer
Uninterrupted Water Supply	1 Pump Operator
Water Flow from Two Handlines	4 Firefighters (2 for each line)
Support for Handlines	2 Firefighters (1 for each line)
Victim Search and Rescue Team	2 Firefighters
Ventilation Team	2 Firefighters
Aerial Operator	1 Firefighter
Initial Rapid Intervention Crew (IRIC)	4 Firefighters
Required Minimum Personnel for Full Alarm	**16 Firefighters & 1 Incident Commander**

- **5.2.4.2 Open-Air Strip Shopping Center Initial Full Alarm Assignment Capability**
  - 5.2.4.2.1 The initial full alarm assignment to a structure fire in a typical open-air strip shopping center ranging from 13,000 ft^2 to 196,000 ft^2 (1203 m^2 to 18,209 m^2) in size

- **5.2.4.3 Apartment Initial Full Alarm Assignment Capability**
  - 5.2.4.3.1 The initial full alarm assignment to a structure fire in a typical 1200 ft^2 (111 m^2) apartment within a three-story, garden-style apartment building shall provide for the following:

Assignment	***Minimum Required Personnel***
Incident Command	1 Incident Commander 1 Incident Command Aide
Uninterrupted Water Supply (2)	2 Firefighters
Water Flow from Three Handlines	6 Firefighters (2 for each line)
Support for Handlines	3 Firefighters (1 for each line)
Victim Search and Rescue Teams	4 Firefighters (2 per team)
Ladder/Ventilation Teams	4 Firefighters (2 per team
Aerial Operator	1 Firefighter
Rapid Intervention Crew (RIC)	4 Firefighters
EMS Transport Unit[82]	2 Firefighters
Required Minimum Personnel for Full Alarm	**27 Firefighters** **1 Incident Commander**

[82] The Standard further states, "Where this level of emergency care is provided by outside agencies or organizations, these agencies and organizations shall be included in the department plan and meet these requirements."

- **5.2.4.4 High-Rise Initial Full Alarm Assignment Capability.**
    - 5.2.4.4.1 Initial full alarm assignment to a fire in a building with the highest floor 75 ft. (23 m) above the lowest level of fire department vehicle access shall provide for the following:

Assignment	*Required Personnel*
Incident Command	1 Incident Commander 1 Incident Command Aide
Uninterrupted Water Supply	1 Building Fire Pump Observer 1 Fire Engine Operator
Water Flow from Two Handlines on the Involved Floor	4 Firefighters (2 for each line)
Water Flow from One Handline One Floor Above the Involved Floor	2 Firefighters (1 for each line)
Rapid Intervention Crew (RIC) Two Floors Below the Involved Floor	4 Firefighters
Victim Search and Rescue Team	4 Firefighters
Point of Entry/Oversight Fire Floor	1 Officer 1 Officer's Aide
Point of Entry/Oversight Floor Above	1 Officer 1 Officer's Aide
Evacuation Management Teams	4 Firefighters (2 per team)
Elevator Management	1 Firefighter
Lobby Operations Officer	1 Officer
Trained Incident Safety Officer	1 Officer
Staging Officer Two Floors Below Involved Floor	1 Officer
Equipment Transport to Floor Below Involved Floor	2 Firefighters
Firefighter Rehabilitation	2 Firefighters (1 must be ALS)
Vertical Ventilation Crew	1 Officer 3 Firefighters
External Base Operations	1 Officer
2 EMS ALS Transport Units	4 Firefighters
Required Minimum Personnel for Full Alarm	**36 Firefighters** **1 Incident Commander** **6 Officers**

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