FIREFIGHTER STAFFING MODEL IMPLICATIONS ON FIRE CASUALTIES AND FIRE LOSS: LIFE SAFETY AND SOCIO-ECONOMIC IMPACTS OF THE FIRE SERVICE

by

Jeffrey Daniel Shoffner

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Philosophy

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Abstract:

Fire and rescue services are considered a staple among services provided by governments to local communities. Local governments are often charged with providing these services, especially across the United States and Canada. As with any professional service, there are standards set forth in order to ensure services are adequate and provide equity to the citizens that they serve. The purpose of this dissertation will be to delve into the common staffing configurations of career fire departments across the United States and Canada, particularly related to staffing levels on fire engines and ladder trucks.

Fire departments utilize various staffing models, but commonly, fire engines and ladder trucks have complements of three or four firefighter crews in career departments in the United States and Canada. Industry standards suggests that a minimum of four firefighters should be staffed on each of these apparatus types. However, as a standard, there is flexibility for local departments to staff according to need, whether based on fiscal need or service demand. This dissertation examines correlations between staffing fire engines and ladder trucks with three personnel and higher property loss, as well as greater numbers of human casualties related to fire, verses communities that staff these apparatuses with four personnel.

Data was collected from career fire departments across the United States and Canada, then statistically analyzed to determine if there was a correlation of lower staffing and higher property loss and greater human casualties as the result of fire incidents. The results illustrated some surprise findings where it is questionable if staffing levels impact fire loss and human casualties.

Dedication:

I want to thank my family for their unwavering support of my pursuit of my studies and their sacrifices that have made it possible for me to reach the point of completion. I would not have completed this work without their support through this journey. Thank you, Courtney, Nate, and Elliott, I love you all more than you'll ever know. You guys are my daily inspiration and motivation. I want to dedicate this work to them for supporting me all the way through.

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Chapter One: Introduction

Overview and Background:

Government, in all its levels is dedicated to serving the needs of its citizens in order to provide for protection of the public welfare and a prosperous environment. In Paul's letter to the Romans, he describes that rulers are not a terror to good conduct, but only to bad, and therefore are instituted to protect citizens (Holy Bible NLT, Romans 13: 1-7). The fire service is often thought of as a government department that exist for the sole purpose of the protection of the population and its property. Therefore, the fire service plays a significant role in the structure and purpose of local governments across North America. There is a balance that must be maintained in government however, to not overburden the tax paying citizen, but yet provide adequate services and protection.

As with any public agency there has always been a question of what adequate staffing should be in order to balance service provisions with available funds. The fire service across the world is tasked with delivering property and life-saving services that are conducted by dedicated individuals from all walks of life, all with the dedication and calling to serve others. Fire Departments of all shapes and sizes serve global citizens and protect them from a variety of hazards, most notably, protection from fire, and more recently life-saving emergency medical intervention services. The National Fire Protection Association (NFPA) provides guidance to government managers and policy makers as to what their fire protection complement should be comprised of in terms of personnel numbers. This standard more specifically addresses the staffing on certain types of fire apparatus that most frequently respond to structure fire incidents. The types of fire apparatus most frequently responding to structure fires are most commonly referred to as fire engines, along with other apparatus depending on the nature of the fire

protection area (Stowell and Murnane 2013, p. 25). For the purposes of this study, fire engine and ladder truck staffing are evaluated as to any significant differences in property loss and human casualties where fire apparatus are staffed with three or four firefighters.

NFPA-1710 is the primary standard utilized by fire departments in the United States and Canada to determine what comprises adequate firefighter staffing to respond to single-family dwelling fires, which are one of the most common types of structure fires which also have the highest percentage of casualties due to fire (NFPA 2021). In the Decision Algorithm NFPA-1710 incorporates staffing recommendations for low risk/hazard incidents, such as single-family dwelling fires. It is suggested for both fire engines and ladder trucks to be staffed with four personnel each (NFPA-1710 2020, p. 1710-25). The NFPA however does not provide funding to local governments, nor does it provide the means for revenues to increase in order to support fire apparatus staffing. This sometimes presents challenging conditions for local governments and other public entities that fund fire protection in order to meet these staffing recommendations.

NFPA-1720 provides an outline to necessary staffing for structure fire incidents by describing how many personnel are required for each task. The basic staffing complement for a single-family dwelling structure fire consists of a total of sixteen firefighters, or seventeen if an aerial device, commonly referred to as a ladder truck is utilized (NFPA-1710 2020, p. 1710-12). However, this standard allows for individual departments to determine how many personnel would be on each type of responding fire apparatus (NFPA-1710 2020, p. 1710-11). The introduction of NFPA-1710 raised the anxiety level of both fire chiefs and city managers when it was originally passed due to fear that an organization such as the NFPA would require managers to fund, and fire chiefs hire, a certain number of firefighters that may exacerbate tight government budgets (Bryson 2020).

While NFPA-1710 recommends staffing fire engines and ladder trucks with a total of four firefighters each, many fire departments across the United States and Canada utilize three firefighters as their minimum staffing. As Cortez notes, fire companies typically operate with between two and five personnel on a fire apparatus, depending upon the needs of the community and what the specific fire department can financially afford (Cortez 2001, p. 200). While the NFPA standards make recommendations, these are voluntarily for fire departments to choose to adopt (*Staffing Levels Set for Firefighter Crews*, 2001). According to Cortez, many local government managers have often rebuffed the notion of increased staffing on fire apparatus due to the lack of research that supports staffing apparatus with four-person crews due to costs, as well as the increased liability placed upon municipalities if they do not conform to the standards (Cortez 2001, p.213). The Occupational Safety and Health Administration (OSHA) only mandates that for two firefighters to enter an atmosphere that is immediately dangerous to life and health, two additional firefighters must be on standby to assist them if the initial fire crew encounters trouble (Staffing Levels Set for Firefighter Crews 2001).

There are many different reasons for NFPA 1710 to recommend staffing of at least four personnel on fire engines and ladder trucks, just as there are legitimate reasons that all communities do not staff their fire apparatus with the suggested four firefighters. The overstaffing of fire apparatus beyond the needs of the community contributes to higher costs of other local government services (Cortez 2001, p. 200). Coughlin states, however, that attempting to extinguish structure fires with smaller crews leads to greater fire loss and the greater likelihood of firefighter and civilian casualties (Coughlin 2016, p. 17).

One of the primary reasons the NFPA recommends engines and ladder trucks to be staffed with at least four firefighters each is to accomplish fireground tasks in the most efficient and safe

manner as possible. The National Institute of Standards and Technology (NIST) in partnership with the International Association of Fire Chiefs, the International Association of Firefighters, the Center for Public Safety Excellence, The Montgomery County, Maryland, Fire & Rescue Department, and the Fairfax County, Virginia, Fire and Rescue Department conducted a study in on the differences of efficiency of three-person and four-person crews responding to residential structure fires, which was published in April 2010 (Robinson 2010, p. 9).

The study assessed twenty-two different simulations of fireground tasks that were commonly conducted on the scene of single-family residential structure fires and utilized a variety of staffing arrays to simulate these tasks in live-burn situations. These tasks included, but were not limited to, overall scene operational time, time it took to apply water to a fire, establishing ladders to the roof or windows and ventilating a structure, conducting a primary search for fire victims, the time it took to deploy a stretch a fire hose for it to be ready to be utilized for a fire attack, and occupant rescue objectives, among others (Robinson 2010, p. 11). These tasks were evaluated utilizing staffing models ranging from two to five-person firefighting crews. The results from these simulations did demonstrate that the fireground tasks included in the study consistently were accomplished in shorter time and more efficient means with firefighter crews staffed with four crew members verses three or even two crew members (Robinson 2010, p. 10). In fact, all twenty-two fireground tasks that were measured during the simulations showed four-person crews completed all tasks faster than three-person crews (Robinson 2010, p. 11). These times varied dependent upon the task; however, on average all tasks were completed 25% faster using four-person crews verses using three-person crews (Robinson 2010, p. 10-11). This also included a 6% slower difference in the time crews of three, verses crews of four were able to get

water on the fires in the fire scenarios. Results also demonstrated that five-person crews did were not any more efficient or faster in the completion of tasks than four-person crews.

In a separate study conducted by the Underwriters Laboratories Inc., the University of Illinois at Urbana-Champaign, and the National Institute of Occupational Safety and Health the goal was to determine the effect of firefighter intervention on occupant tenability during a residential fire. This meant that the study focused on the practices and tactics of firefighters that impacted the potential for the survivability of an individual trapped in a residential fire. This study incorporated many of the tactics and tasks that were also incorporated into the NIST study, however, it went a step further by incorporating simulated victims that needed to be rescued (Kerber et al. 2019, p. 2290). The study examined two primary impacts to victims, temperature and gas concentrations that would be detrimental to the survivability of any occupant (Kerber et al. 2019, p. 2290). The simulations utilized live fire exercises involving the deployment of twelve firefighters on a simulated multiple room fire in a single-family residential structure (Kerber et al. 2019, p. 2293). The firefighting crews were from different geographic locations across the United States, but all were experienced firefighters who were familiar with live fire training conditions (Kerber et al. 2019, p. 2293). The deployment of twelve firefighters is less than the NFPA 1710 standard that recommends a minimum of sixteen firefighters (seventeen if an aerial device or ladder truck is utilized) (NFPA 1710 2020, p. 1710-12).

In this series of experiments fire attack crews consisted of two firefighters on a hoseline, which would be typical of engine or ladder staffing with three firefighters, where one firefighter remains with the apparatus for pump or ladder operations. Just as with the NIST simulations, the personnel participating in these studies arrived on the fire scene to conduct their tasks at staggered times to simulate true fire growth and actual dispatch and response delays (Kerber et

al. 2019, p. 2294). There were two distinct firefighter tactics tested for occupant tenability, one being a traditional interior fire attack where firefighters force their way into a burning structure to locate the seat of the fire and then extinguish it. The second method was called a transitional attack, where fire crews apply water from the exterior of a structure through an open window or door in an effort to cool the fire, then make entry and conduct an interior attack (Kerber et al. 2019, p. 2294). Twelve groups of firefighters participated in these experiments and according to Kerber et al. there was considerable variation in the time it took the teams to complete fireground tasks (Kerber et al. 2019, p. 2301). Some of the fireground tasks that were measured in the tenability experiment were hoseline deployment, hoseline advancement, forcing entry to the structure, and locating and removing victims from certain places inside the simulated home. The study noticed several variations in time and tactical preferences to accomplish the fireground tasks assigned which impacted the ability to reach victims, lower temperatures in the burning structure, and ventilate much of the smoke obscuring vision (Kerber et al. 2019, p. 2305).

The conclusion of the tenability study was that neither tactic had a major impact on the tenability of the simulated victim due to temperature and gas conditions in the structure. The outcomes were more influenced by the application of water on the fire and the immediate cooling of the atmosphere as well as the dispersion of smoke. There were other factors identified through the study that impacted the time to task completion, and these included the competency of the crews, the physical conditioning of the crews, and the speed in which they executed their activities (Kerber et al. 2019, p. 2305). Therefore, the tenability study which utilized two firefighters on each crew, with a maximum of twelve firefighters, demonstrated that the faster crews could put water on the fire and ventilate the structure, the better outcome for victims that were trapped within the structure. As illustrated from the tenability study there was also great

variation with the completion of the assigned tasks with the various crews. In addition, the tenability study also highlighted that there were instances were some crews of two firefighters were able to conduct tasks relatively quickly, however, it is also challenging for every firefighting crew of two in North America to be in prime physical condition and able to conduct fireground operations seamlessly every time a task is undertaken. This is where the benefit of added crew members is reflected in the NIST study which would reinforce the hypothesis of this staffing model research.

While this particular research is not based solely upon single-family dwelling structure fires, but encompasses all fires where loss occurs, including commercial structure fires. The NIST study and the Kerber report do provide a meaningful contribution as it reinforces benefits of four-person crews verses three-person crews on the fireground. In addition, while the NIST study considered the impacts of staffing levels on fireground tasks, this was conducted in an experimental manner in an environment where tasks were simulated, as did the tenability study. This study examines data from actual fire incidents across the United States and Canada in order to identify any correlations between actual property loss, as well as fire casualties, that may support the data found from the NIST study. As noted, the NIST study utilized a burn prop on the site of a fire training facility and used simulations to determine the efficiency of fire crews of various sizes. This study will look at data from actual fire suppression activities involving single-family structures, commercial structures, and any other associated structures where actual fires occurred.

Property loss due to fire has ripple effects beyond just the loss to the individual property owner. This is exacerbated when fire loss occurs in a commercial structure where jobs are impacted. The loss of jobs due to fire can have substantial negative impacts on individual and

family incomes. The economic impact of fire loss can be significant to communities where job loss occurs, or production is interrupted due to loss of revenue to private businesses and tax revenue to local government units. Fire can also impact local and community amenities and resources which can temporarily or permanently degrade the quality of life for a locality. The link between fire apparatus staffing and human casualties along with property loss is to be determined in order to better understand the implications that staffing levels may have on local government expenditures and revenues. The link between fire casualties and fire apparatus staffing and the resultant economic impact of injuries or deaths caused by fire related incidents will also be explored. If there is a direct link between the investment of additional staffing of fire apparatus and the savings of property, jobs, and human casualties, then it could encourage communities to fund adequate staffing for long term savings. This could create an economic insurance policy by the addition of personnel resulting in more savings on local tax revenues as well as in local economies.

Theoretical Basis:

Considering the recommendations from the NFPA and the fireground experiments that have been conducted, it is assumed that fire departments that utilize greater staffing can be more effective in their approach to fire protection for communities. This includes reducing the amount of economic loss through the preservation of property and the reduction of deaths and injuries to both the public and firefighters. In turn, while the addition of extra staffing among fire departments can dig deeper into local government budgets, there can be savings realized in the long term by investing in increased staffing.

The problem in which this dissertation attempts to address is that while numerous experiments have been conducted to demonstrate the benefits of optimal fire apparatus staffing,

there have been no accounts of utilizing actual incident data to do so. The purpose herein is to attempt to correlate benefits of staffing specific types of fire apparatus with four personnel verses three. The significance of adding one additional firefighter to a fire engine or ladder truck could pay dividends to communities in terms of economic preservation through reducing job loss and property loss. Additionally, it would be expected that human casualties would be reduced with desired staffing of four firefighters. The human element and economic advantage of adding personnel would be very significant for public safety in local communities. While additional staffing would cost local governments more up front, there is potential that the investment in personnel could translate into a return on investment through preservation of the tax base and lives saved from fire. The specific research questions for this research are: does staffing fire engines and ladder trucks with four firefighters, verses three, provide more favorable outcomes in terms of human casualties and property preservation? Additionally, this research will also discuss what those benefits mean in terms of economic wellbeing to communities. Thus, not only is public safety addressed by certain staffing levels, but also the economic well-being of a community and the tax base of the local government that is charged with protecting it from fire and medical emergencies.

Local governments receive significant portions of their revenue from taxes of various forms. These include but are not limited to, general sales taxes, specific excise taxes, fees and charges, and local property taxes (Alm et al. 2011, p. 321). However, even with these various mechanisms, local government budgets often run very tight and operate with little leeway. Staley notes the fragility of local government revenues, and how various restraints on local government revenue across the United States can make it challenging for local entities to maintain budgets and provide services. Staley notes that local governments are experiencing the

most intense fiscal pressure of anytime in the last fifty years, which is largely due to changes in intergovernmental revenues, state mandates, and economic volatility (Staley 2018, p. 71). This makes the efficiency of the fire service even more important to local governments in modern times.

The fire service is tasked with the protection of the tax base, which also includes indirect economic inputs from income taxes, sales tax, and other revenues that may be generated from area businesses and economic activities. Delorme and Waterhouse note that the Phoenix Fire Department was the first fire department to conduct an economic impact study of a fire department's contribution to the economy. For instance, it was discovered through the Phoenix study that an estimated 6,951 jobs would have been lost over the course of the study year had it not been for the interventions of the Phoenix Fire Department (Delorme and Waterhouse 2018, p. 13). These were jobs unrelated to agriculture, but when factoring in agriculture related jobs, this number incased to 7,446 (Delorme and Waterhouse 2018, p. 13). The interventions by the Phoenix Fire Department thus contributed to preventing the GDP of the State of Arizona from decreasing by an estimate of $650 million. Therefore, fire departments provide a significant economic contribution to local economies, and in some instances even wider areas as noted. Any improvement in property preservation or fire prevention can offer dividends. It is for this reason that additional staffing, while costly, can provide sufficient contributions to preserve life and property that would otherwise be lost through fire incidents which could deliver sudden shocks to local economies through the sudden loss of jobs and production. Hence, an investment in firefighter manpower can likely produce savings long term through life and property preservation, the two main missions of fire departments across North America. Local governments must decide whether to invest up front to provide more protection for their tax base

through increased staffing or take the risk of fewer fire events, using low end staffing configurations in order to preserve tax revenue.

The theory of government to provide protection has been longstanding. For instance, Johnson notes that from the middle ages there has existed a notion that government had the responsibility to protect the citizenry for the common good (Johnson 2014, p. 137). Johnson further notes that the notion of government protecting the populace had origins in respect to protecting the people from harm from military interventions. However, the concept is still relevant at the local level as well in that the intent is to protect citizens from "human suffering" (Johnson 2014, p. 143). Policies at the local level that optimize the protection of local populations are important to the viability of communities. Policy decisions that impact staffing of essential public safety services for the common good in order to protect lives and property cannot be underscored enough. As fire protection is a public good and service provided by local governments, both big and small, it is important that the service provided for the good of the people is optimized to make the most positive difference (Helpap 2022, p. 110). Therefore, are policy makers willing to place their populations and tax bases more at risk by staffing fire apparatus with levels below NFPA1710 recommendations? This research should provide an indication if this is the case, or if staffing of fire apparatus with three personnel is equally as effective as staffing with four personnel.

Problem & Research Question:

As noted, the purpose of this dissertation is to examine if there is a correlation between staffing levels of certain types of fire apparatus and the number of injuries of civilians and firefighters, and property loss due to fire. Fire engine and ladder truck staffing will be analyzed using data obtained through surveys and requests made to individual fire departments, examining any correlations between staffing with three and four firefighters on each type of apparatus and

resultant property loss and casualty counts in each community where information is obtained. Therefore, the primary research question for this study is does staffing of three firefighters verses four firefighters on fire engines and ladder trucks contribute to higher property loss and higher number of fire casualties, both with civilians and firefighters?

In 2020 alone, there were 1.4 million fires in the United States according to the NFPA. This includes residential and commercial structure fires. These 1.4 million fires resulted in 3,500 civilian deaths and 15,200 civilian injuries. In addition, property loss was estimated at approximately $21.9 billion (Ahrens and Evarts 2021, p. 2). These numbers represent significant economic and emotional losses for thousands of people and local communities. Any reduction in these numbers is priority for the fire service. Staffing models are part of the equation of adequate fire protection. If it is discovered that crew staffing has an automatic positive impact on the amount of property lost to fire, as well as to human casualties as a result of fire, it provides ample evidence on the merits of increased staffing despite the upfront costs associated with adding additional fire personnel.

Personnel costs are significant to any fire department and can have a substantial range based upon the local economic environment. For example, if a locality has a higher cost of living than another it can be assumed that personnel costs will be higher than in other communities. For the purposes of this study, the average cost of one firefighter position was obtained from different municipal fire departments across North Carolina. These departments serve cities that range in population from 60,000 people to in excess of 300,000 people. For instance, the annual expense for one firefighter position for the Greensboro Fire Department, a department that serves approximately 300,000 residents, is $77,968.08 (USD). This includes salary and benefits, as well as necessary items to equip a firefighter, such as personal protective equipment, radios, and

uniform items (Church 2022). The Town of Cary Fire Department which serves approximately 177,000 residents has similar costs for a single firefighter position, with annual costs at $81,991.20 (Jacoby 2022). The City of Burlington, which lies geographically between Greensboro and Cary, and has a population of approximately 56,000, has an annual expense of a first-year firefighter approximately at $75,000 which includes salary, benefits, equipment, and training costs (Handy 2022).

As noted in the Fry et al. study that many fire department shifts consist of working one twenty-four-hour shift, followed by forty-eight hours, or two days, off duty (Fry et al. 2006, p. 353). This translates into three different shifts that must be staffed. Therefore, when incorporating the aforementioned staffing costs for one firefighter position, multiplied over three shifts, this presents significant staffing costs just for one extra firefighter on each shift of any given department. If two apparatus need to be staffed with one additional firefighter, then this figure multiplies by six. Therefore, if a municipality has three stations with three engines and one ladder truck, the costs could easily approach $1 million just to add staffing from three to four personnel on each apparatus. In order to accomplish this, most policy makers, city managers, and local boards would desire to see a cost savings at least equivalent to these increased staffing costs to make it feasible.

Further, the intent of this research is to provide a better understanding of the economic implications of property loss and fire casualties and how this relates to fire apparatus staffing. Fire loss is much more than just property lost to an individual or an individual business, as it has multiplier effects. For instance, for fires in commercial structures, these buildings hold value as places of employment which in many cases also generate revenue and tax income for localities. Fire Departments provide a clear economic benefit to communities, not just in property saved,

but the number of jobs preserved, which in turn relates to income to employees and the spinoff from their economic output in their respective communities. This is in addition to the tax base preserved by the fire departments (Delorme & Waterhouse 2018, p. 5).

Human capital also holds value. In the Book of Matthew, Jesus said, "Who then is the faithful and wise servant, whom his master has set over his household, to give them their food at the proper time?" (Holy Bible NLT, Matthew 24:45). As the verse describes those who work faithfully provide for their families and others, and it is the role of the fire service to protect the citizens to minimize interruptions in individual and collective productivity. For example, if an individual is severely injured or even suffers fatal injury due to a fire event, there is frequently an economic impact to the immediate household or family of the individual, as well as to the greater community due to a person's economic contribution. Dublin and Lotka define the value of a human life "as the present value of an individual's future net income" (Delorme and Waterhouse 2018, p. 38). This calculation is determined by attributing a specific individual's economic contribution to society. For instance, this is determined using an individual's gross income minus what they would spend on themselves, thus their financial contribution to support others and the economy are what is important (Delorme and Waterhouse 2018, p. 38). An injured person may only have a temporary interruption in their economic contribution to society and a household, however a fire fatality would have a longer lasting and more substantial impact.

Delorme and Waterhouse further note that there is a willingness of an individual to pay a certain amount to reduce the exposure to a particular risk, as well as a willingness to accept a certain level of risk (Delorme and Waterhouse 2018, p. 38). This willingness to accept a certain level of risk as well as to pay to mitigate a certain level of it, provide evidence that if the public

understands the cost of risks, there may be an acceptance to fund additional resources to decrease a specific type of risk that can be detrimental to health, safety, and property.

In summary, does staffing of three firefighters verses four firefighters on fire engines and ladder trucks contribute to higher property loss and higher number of fire casualties, both with civilians and firefighters? If this is indeed the case, what are the human and economic implications of such staffing models and does impact of funding four-person crews off set economic impacts of greater fire loss and subsequent interrupted economic activity, as well as the impact of loss of human life or hardship incurred through injuries? As Taylor et al. note, cost-effectiveness is used widely to inform policy makers regarding allocation of public tax dollars (Taylor et al. 2019, p. 419). The question then becomes is whether it is more cost effective to spend funds on additional staff in order to preserve tax income from both people and property if additional staffing does show a correlation in property and life preservation.

Research Design:

In order to compile data that is relevant to the research, municipal and other career departments were contacted for annual data which included staffing levels, specifically targeting three verses four firefighter crews, for fire engines and ladder trucks, annual department budgets, populations served, and the number of human casualties from fires. The casualties included both civilians and firefighters, but were evaluated separately. Given that the data came from departments of various sizes and populations served, the data was normalized in an effort to place it on a level plain. In order to do this, data was normalized in order to determine how many casualties occur per 100,000 people, as well as departmental budgets will also be divided in a similar fashion in order for data to be relevant across the spectrum of department and population size (Holden and Holden 2016). It was demonstrated that larger populations had

higher numbers of casualties, as well as higher property loss, therefore these numbers needed to be normalized in order to compare data with much smaller departments.

Once the data was normalized it was statistically analyzed to ascertain if there were specific differences in the occurrence and frequency of casualties, as well as the amount of property loss due to fire, based upon the actual staffing models of various jurisdictions. It was not necessary to know what department submitted data, as much as it was important to understand the data gathered from individual survey and department responses. The objective was for this collection of data to paint an unbiased picture of property loss and fire casualty figures across the United States and Canada with associated staffing configurations. Therefore, there was a significant quantitative component in order to draw conclusions and outcomes that sought to examine if there was a difference in the mean or median of property loss where staffing levels vary. Other statistical tests will also be utilized using SPSS statistical software in order to test the resultant data and verify its validity. Therefore, this research will be quantitative in nature seeking a statistical correlation between staffing, property loss, and casualties.

Following the analysis of data gathered, economic impact data was also incorporated to understand the impacts of a structure fire on a commercial property where job loss occurs, which then impacts personal income and government revenue. The difference in human casualties as it relates to staffing levels was also be analyzed to determine the monetary difference in the community to determine if fewer casualties could translate into cost savings to a community.

In addition to comparing data from fire departments with various staffing levels, the NFPA also provides data regarding the rate of civilian casualties per 1000 fires, as well as the average dollar loss per fire, based upon the intensity of the flame spread. Fire spread is how far a fire progresses in a structure, whether it is contained to its object of origin or on the opposite

spectrum of spreading beyond the floor of origin (National Fire Incident Reporting System Reference Guide).

Hypothesis and Potential Outcomes:

The alternate hypothesis is that there will be a statistical difference in the number of injuries to civilians and firefighters, as well as property loss when comparing staffing levels, with greater numbers of injuries and property loss occurring where departments staff these apparatuses with three firefighters. The null hypothesis will be that there is not a statistical difference, or the null hypothesis is rejected where there are negative results with greater staffing. While there has been a great deal of discussion surrounding staffing models for fire apparatus, there is limited data on the utilization of real incident data which has been used in determining a relationship. As Gavigan et al. note, there are two types of business logistics, with one of them being the study of human capital and studying the efficiency of the number of employees needed to operate a particular business or service (Gavigan et al. 2016, p. 59). There has been limited academic research focused on the field of emergency services with much of public safety research focused on law enforcement (Henderson and Charbonneau 2016, p. 561). This paper attempts to answer some of the questions as it relates to human capital of firefighters and their benefit to the communities they serve as well as expand academic research in the fire services field.

There are potentials for multiple outcomes through this research. One potential outcome is that there is relatively no correlation between fire apparatus staffing and property loss, and human casualties. This would reject the null hypothesis. In order for this to occur research may indicate that property loss is higher in many instances with staffing of four firefighters verses three on both fire engines and ladder trucks. There is also the potential that staffing for one type of apparatus such as ladder trucks staffed with four firefighters, while engines staffed with three

firefighters makes the difference in lower property loss instead of both apparatuses being staffed with the recommended four firefighters each.

In addition to various outcomes with property loss and various staffing models, there is also the possibility that there will be no correlation between fire casualties and staffing levels. Fire casualties will be split between civilian casualties and firefighter casualties. The expected result is that lower staffing levels will translate into higher numbers of civilian and firefighter casualties. The theory is that if the results of the NIST Residential Dwellings study holds true on actual fire incidents, then the additional personnel can accomplish fireground tasks much more quickly, which would provide more opportunities for victims to be rescued or fires extinguished when time is of the essence.

If there is a statistical correlation between greater staffing levels and an improvement in property savings, as well as better outcomes with human casualties this may provide financial incentive for local governments to fund needed positions on fire apparatus if the economic benefit can be demonstrated. As noted, each firefighter position can be quite costly for municipalities. Extra positions can be difficult for public managers to justify when services and work can be accomplished with present-day staffing levels. While there are national standards for staffing, these standards are not laws or set requirements, and still offer some variability in how they are applied. Thus, government managers who may not be intimately familiar with the fire service, may be reluctant to divert funding towards positions which they may see as having no economic or financial benefit. The fire service, unlike some other government divisions, typically does not generate revenue and many government administrators may find these functions burdensome on budgets, not understanding the role they play in tax and revenue preservation. Gurdal et al. acknowledge that taxes are the most important finance tool for

government expenditures, and therefore, it is critical for local governments to be able to preserve their tax base and tax revenues (Gurdal et al. 2020, p. 306).

Assumptions and Limitations:

As noted in the general hypothesis of this research there is a general assumption that lower staffing levels on fire engines and ladder trucks in career and municipal fire departments will correlate to higher property losses and higher numbers of human casualties, with both civilians and firefighters. The assumption is that due to previous studies, such as the National Institute of Standards and Technology Residential Fireground Experiments study, demonstrated critical residential fireground tasks could be completed faster with optimal staffing of four firefighters on a crew. This, in theory, would suggest that due to the importance of time when encountering fire and damage sustained from it, the less time fire has to spread, the lesser the damage and thus property loss. In the same thought, reduced time to conduct tasks, such as rescue, should also reflect in lower human casualties.

The NIST residential dwelling experiment does have its share of limitations as the report readily admits. This study will work towards filling in the gaps from the identified limitations from the NIST residential dwelling study. First, the report does not consider the nature of crew size for other emergencies that fire crews routinely respond to including hazardous materials incidents, terrorist events, or technical rescue emergencies, all of which generally require a multi-company response (Robinson 2020, p. 51). Additionally, as the study readily admits, all of the experiments were simulations and findings were not taken from actual emergency incidents where fire crews responded (Robinson 2020, p. 51). Smith states that "a study that leaves out data is waving a big red flag" and while data may not be left out of these experiments, given they are not based on real incidents that occurred, this does leave the report results open for debate as

to what real incident data would demonstrate (Smith 2020, p. 199). Other factors that must be taken into consideration on the time it takes crews to act are often factors of the construction of the structure they are responding to, as well as the structure's fuel loads, and how the fires were first ignited (Buffington and Ofodike 2019, p. 2370). This also can include the nature of the environment surrounding structures, whereas dense urban development as dense urban environments can produce completely different results from fire loss as do more suburban development (Li and Davidson 2013, p. 217). This particular study was conducted on a fire training ground in structures designed for live fire training and not actual inhabited single-family residential dwellings.

While the hypothesis and assumptions are that the concluding evidence will suggest a direct correlation between staffing levels and less property loss, and lower casualty figures, there are several limitations to the data that was gathered. For instance, data was gathered from municipal and career departments from a spectrum of sizes and service areas. Larger departments had exponentially higher property loss values as well as higher casualty figures than departments in smaller communities, not because these localities have suffered greater fire damage, but the larger populations mean more fires were more likely to have occurred. This is why data was normalized in order for it to be analyzed and relevant. Data from jurisdictions that serve almost three million people to jurisdictions that serve just under seven thousand people were evaluated. In addition, departments of various sizes regarding budgets and firefighters also was examined. Therefore, it was imperative to base conclusions on data that is valid to the research question.

Another limitation of this particular study is that it did not evaluate the fire prevention practices of the fire departments from where data was obtained. Fire prevention activities may involve significant efforts such as inspecting properties throughout a jurisdiction, where the

primary goal is to identify and correct particular fire hazards, or even provide education to the community about methods to reduce the risk posed by fire. A study in the United Kingdom that assessed a ten-year period of fire prevention efforts, including increased spending on these efforts demonstrated that increased spending correlated with a decrease in fires (Taylor et al. 2019, p. 424). However, this same study also concluded that there was not a decrease in fire casualties with increased expenditures towards fire prevention efforts (Taylor et al. 2019, p. 424). If significant fire prevention efforts do reduce the number of fires, then in theory, it is possible for fewer fires to translate into fewer casualties. While this may not have been the case with the study in the United Kingdom referenced by Taylor et al., it is certainly conceivable that this could occur if other fire data was analyzed. Therefore, it is entirely possible that fire departments may allocate significant portions of their budgets towards fire prevention efforts in lieu of staffing apparatus at suggested levels per the NFPA in order to reduce their local fire problem.

Another assumption that was hinted at with the tenability study was that even with two firefighters on a fire attack crew, which would likely be representative of a three-person engine or ladder complement (as the driver typically remains with the apparatus in order to operate the ladder, pump, etc.), the fireground tasks could still be undertaken rapidly. This is especially true if the crew of firefighters were in top physical condition as well as being particularly adept at the fireground tasks required of them. This would likely involve significant training as well as highly skilled and motivated personnel. While firefighters such as these do exist, it is also unlikely that every municipal and career fire department will be completely staffed with individuals of this motivation and skill level. The tenability study to its credit sought experienced firefighters and did not incorporate those individuals with little experience. Even if

departments were staffed completely with the most skilled and physically abled firefighters it could be argued that four of them on a crew would still be more efficient and effective than just having crews of three.

Technical Terms Explained:

There are many technical terms that are applicable to this study and in order to provide a better understanding of their meaning throughout this research key terms will be identified below. This list is not all inclusive and other terms may be identified throughout the document as pertinent. NFPA standard 1710 provides much of the framework which inspired this work. As such, a number of terms and definitions that are pertinent to this research originate within the NFPA document depository. They are as follows:

1. *Fire Apparatus:* A vehicle designed to be used under emergency conditions to transport personnel and equipment, and to support the suppression of fires and mitigation of other hazardous situations (NFPA 1710 2020, p. 1710-6)

The primary fire apparatus that are relevant to this study are fire engines which typically are staffed with anywhere from one to four personnel depending upon staffing models and budget constraints. Engines are the mainstay of the fire service and generally are focused on quick response for fire suppression activities and emergency medical response (Norman 2019, p. 39).

The other fire apparatus that is applicable to this study is a ladder truck or aerial truck. This type of apparatus is generally assigned duties to rescue trapped individuals and provide necessary fireground tasks such as search and ventilation (Norman 2019, p. 157). All of the general tasks both apparatuses undertake are best performed in quick succession or even in tandem to be most effective and provide the best results in minimizing casualties and fire loss.

2. *Career Fire Department:* A fire department that utilizes full-time or full-time equivalent (FTE) station-based personnel immediately available to comprise at least 50 percent of an initial full alarm assignment (NFPA 1710 2020, p. 1710-7).

As noted earlier in this text, full-time career departments are being evaluated for this study. The fire service in North American is typically modeled in either the career fire department model, the volunteer fire department model, or the combination fire department, which is a department that has a staffing array that utilizes both volunteers and paid staff, either of which can comprise less than 85 percent of the membership (NFPA 1720 2020, p. 1720-6). Due to the inconsistencies with staffing associated with volunteer departments or even combination departments, full-time career departments are the best fit for this study to determine the effectiveness of crew size on fire scenes.

3. *Company:* A group of members: (1) under the direct supervision of an officer; (2) trained and equipped to perform assigned tasks; (3) usually organized and identified as engine companies, ladder companies, rescue companies, squad companies, or multi-functional companies; (4) operating with one piece of fire apparatus (pumper, aerial fire apparatus, elevating platform, quint, rescue, squad, ambulance) except where multiple apparatus are assigned that are dispatched and arrive together, continuously operate together, and are managed by a single company; (5) arriving at the incident scene on fire apparatus (NFPA-1710 2020, p. 1710-7).

The research focused in this study is based upon the staffing of company level apparatus and thus the term company or companies may appear regularly throughout the text. It is important to understand that various fire departments utilize different models of staffing their companies, particularly as it relates to the type of apparatus. This study will offer insight into ideal company

size for engines and ladders as it relates to maximum job performance measured through property preservation and reducing casualties related to fire.

4. *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 (NFPA-1710 2020, p. 1710-11).

Engine companies, as defined by NFPA are one of the two primary types of apparatus utilized in this study. As identified, previously, each type of apparatus has a primary role to play on fire scenes. It should be noted though that frequently specific apparatus types can find their crew members performing any number of tasks as needed.

5. *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 (NFPA-1710 2020, p. 1710-11).

As mentioned previously, ladder companies are the second type of apparatus being utilized in this study due to their role and usage by most career fire departments in the United States and Canada, playing specific roles in fire incident mitigation.

6. *NFPA:* "The National Fire Protection Association is a global non-profit organization based in Quincy, Massachusetts with the goal of eliminating death, injury, property, and economic loss due to fire, electrical, and related hazards" (National Fire Protection Association).

The National Fire Protection Association, or NFPA as it is referred to throughout this work, is the organization that governs the standards associated with fire service deployment and

operations. This includes but is not limited to, standards associated with minimum staffing standards for various types of fire incidents, fire service training standards, as well as other relevant standards regarding fire prevention and suppression activities (National Fire Protection Association).

7. *NFPA 1710:* NFPA 1710 is the Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Departments (NFPA 1710 2020, p. 1710-5).

NFPA 1710 is the primary standard that provides guidance for career departments as to their appropriate apparatus and personnel deployment to structure fires, fire alarms, and other emergency incidents (NFPA 1710 2020, p. 1710-12, p. 1710-13). It is the intent through this research, this standard will be proven effective more greater property preservation and lower human casualties have resulted from staffing prescribed in this standard.

8. *Fire Spread:* The extent of fire spread in terms of how far the flame damage extended (National Fire Incident Reporting System Complete Reference Guide p. 5-7)

Fire spread and its subsequent property damage is used to compute the value in property loss following a fire. These figures are sometimes distinguished between the value of the contents of a structure fire and the value of the structure itself. The measurement and extent of fire spread can also be an indicator of the efficiency of the fire suppression crews who respond to fire incidents.

9. *Casualty (Fire):* A person who is injured or killed at the scene of a fire. (Includes injuries or deaths from natural or accidental causes sustained while involved in the activities of fire control, rescue attempt, or escaping from the dangers of the fire.) (National Fire Incident Reporting System Complete Reference Guide, p. C-2).

One of the primary themes of this research focuses on human casualties as the result of fire, including both civilian and fire personnel casualties who have been injured or suffered death in the wake of a fire incident.

10. *Losses:* Rough estimation of the total loss to the structure and contents, in terms of cost replacement in like kind and quantity. This estimation of the fire loss includes contents damaged by fire, smoke, water, and overhaul. This does not include indirect loss, such as business interruption (National Fire Incident Reporting System Complete Reference Guide, p. 3-41).

In addition to human casualties being examined closely with staffing models, fire loss is also incorporated. As the definition above infers, fire loss only represents the actual physical loss of property and its subsequent cost and value. This research will take this a step further when discussing staffing models and fire loss as it relates to business interruption and further economic consequences.

11. *Human Capital:* The economic concept of the contributions of the financial contributions to society through work, as well as through attributes that "facilitate the creation of personal, social, and economic well-being" (Okumura and Deguchi 2020, p. 46).

The topic or theme of human capital is important in this research due to the ultimate goal to determine if staffing configurations impact injuries sustained by the public as well as the number of deaths. Due to the individual contributions, both monetarily and social, it is important to understand benefits to additional staffing if it contributes to the preservation of human life and minimizes injuries to citizens.

Summary:

Fire has always held a certain degree of danger to mankind and to this day continues to produce events that cause property loss as well as human injury and death. The modern fire service has evolved greatly over the years to meet the challenge of uncontrolled fires that may strike residences and businesses. In summary, the following study will undertake research focusing on actual fire incident data from a variety of departments found throughout the United States and Canada and examine the staffing configurations of the fire departments that responded to these events. As identified, the staffing of fire apparatus for career departments is a matter of public policy as it relates to the protection of property and lives, as well as emergency services that tax payers expect to be provided through their contributions to public coffers. There are also industry accepted standards that guide policy makers, city managers, and fire chiefs as to how these services will be provided. These best practices have been based off of simulations and drills that demonstrated optimal staffing levels to conduct specific fireground tasks. Fire Departments throughout the United States and Canada have been demonstrated to be capable to carry out most fireground tasks with less than recommended staffing, however, there is a question as to how effective these tasks are with less staffing. The results of this study will illustrate whether these staffing configurations have an impact on actual property loss and human casualties and their resultant economic impacts which have wider public policy implications.

American government and democracy has strived to provide the best governing model for the people, providing basic services for the protection of the public at minimal cost through taxation. Fiscal responsibility also requires adequate services to be provided for the money spent in order to model responsible government. In doing this, public managers must look to serve their populations, providing necessary services for the protection of populations and local tax bases.

Philippians 2: 1-4 states “In humility count others more significant than yourselves. Let each of you look not only to his own interests, but also to the interests of others” (Holy Bible, Philippians 2: 1-4). In honoring the verse from Philippians, policy makers must allocate necessary funds to the proper places within their governments and be responsible in their allocations, specifically in protecting their citizens.

Chapter Two: Literature Review:

Fire Apparatus Staffing and Public Policy:

As mentioned earlier there has been a significant amount of study and literature regarding fire apparatus staffing and the funding required to achieve various configurations. A reason typically stressed for the staffing of four personnel on fire engines and ladder trucks is for the safety of the fire department crews as well as the individuals impacted by the fires. Firefighting is frequently a physically demanding profession which increases the firefighter's risk of musculoskeletal injuries and physical overload, including premature death. The nature of short and frequent energy loads are often culprits for the injuries and illnesses that afflict firefighters (Bos et al. 2004, p. 446-447). During calendar year 2010, 71,875 firefighter injuries were recorded in the United States, with 45.5% of these injuries occurring on the fireground (Burgess et al. 2014, p. 1043).

Both fire chiefs and city managers would agree that fire protection is financially costly for communities. Additionally, fighting fires has been overtaken by other emergency responses as the primary calls for service by firefighters. The introduction of stricter building codes, the installation of more fire suppression systems, and increased public fire safety education have all played a role in the decreasing number of fires in the United States (Benest and Grijalva 2002, p. 7). However, fire suppression is still a needed service and requires significant funding for infrastructure and adequate personnel. In addition to these needs, as Benest and Grijalva note, fire department unions have become more aggressive in their demands for staffing and pay (Benest and Grijalva 2002, p. 7). The compromises to provide higher pay may sometimes come with less staffing in order to compensate the firefighters employed at their respective departments.

In a 1998 study on firefighter staffing conducted by Dennis Tharp, who was then in the National Fire Academy's Executive Fire Officer Program, surveyed 53 fire departments across the United States on their staffing models. Tharp discovered that out of those 53 departments there was limited purposeful decisions made when considering having more than minimum staffing on duty (Fry et al. 2006, p. 363). For instance, 19 fire departments indicated they utilized a minimum staffing policy, while 30 had policies that allowed them to hire additional firefighters, and only five departments considered overtime costs when hiring firefighters (Fry et al. 2006, p. 363).

In addition to firefighter injuries, firefighter fatalities have also been investigated by various agencies throughout the years. The National Institute for Occupational Safety and Health conducted firefighter fatality investigations for the years 2006 through 2014. While they found many factors upon which to make recommendations to improve the safety of firefighters, adequate staffing was included in their top ten recommendations in order to decrease firefighter fatalities (Hard et al. 2019, p. 23-24).

Literature Related to the Theoretical Framework:

As Thoreson and Svara note that citizens feel fire protection and related public safety services, such as emergency medical services, are some of the most important services provided by local governments (Thoreson and Svara 2010, p. 6). The public expects rapid responses with adequate personnel and equipment to mitigate whatever emergency that they might be experiencing when they summons fire department assistance (Thoreson and Svara 2010, p. 6). Given the public has this mind frame it is in the best interest to provide for the public's safety and for policy to provide for these expected services.

While the investment in public safety is important to local governments and their constituents, the rise in funding for the fire service has had a flatter rate of increase compared to that of law enforcement (Glass 2009, p. 31). Glass illustrates that regarding local government funding of public safety, the prison systems, police force, and the court systems have all seen a much sharper increase in funding compared to the fire service (Glass 2009, p. 31). Glass reports that during the period of 1990's there was a 22% increase in law enforcement officers in the United States, while crime actually fell. This begs the question that if public policy makers felt that increases in staffing for law enforcement officers was important for community safety, shouldn't staffing increases in firefighters be strongly considered as well if there can be a benefit shown?

A large hindrance to the increase in firefighter staffing to see benefits is that there has been relatively little scholarly research related to the fire service, while there has been much more in law enforcement. Henderson and Charbonneau report that in a review of 93 scholarly articles published in public administration journals, only 9% were related specifically to the fire service, with even fewer related to emergency medical services at 5% (Henderson & Charbonneau 2016, p. 570). The framework of this dissertation rest on the need for more scholarly work to be conducted regarding the fire service and its ability to provide guidance to public administrators in order to better protect their communities. This includes examining whether different staffing configurations, such as three or four firefighters provide the optimal benefit to the public. This guidance is sorely needed for public officials to make informed budgetary decisions for the sake of public safety and welfare. The aim behind providing adequate staffing for the public safety and welfare closely relates to Walzer's theory of distributive justice and providing equal fire and rescue services for the common good (Reiner 2016) and (Walzer 1983).

Economic Implications of Firefighter Staffing:

Property loss due to fire can be very impactful, if not detrimental to the local tax base and surrounding communities. Anderson et al. state that understanding and quantifying property loss fire risk is extremely important in making decisions of how to best protect their communities from fire (Anderson et al. 2018, p. 715). This burden is not only on the shoulders of fire service leaders alone, but also those of city managers and other governing officials of local communities. As part of evaluating the fire risk, these local leaders must account for their level of fire protection services and what is required to meet the challenge they may face.

There is much more to property loss than just the value of structures lost or damaged to fire as well, but there are economic ripple effects if property is damaged by fire. As Delorme and Waterhouse explain firefighters have a great financial impact by considering everything they save, whether it is life or property (Delorme and Waterhouse 2018, p. 11). Delorme and Waterhouse provide examples from Montreal, Quebec, where a study on the economic impact of the fire service was conducted in 2017. During the year 2015, the Montreal Fire Department responded to 110 commercial fires where over $1.55 (CAD) billion in value was saved, much of it through the preservation of 20,903 jobs that were sustained due to fire extinguishment activities. In addition, the value of 43 individuals that were resuscitated following cardiac arrest events and had full recoveries was estimated at an additional $348 (CAD) million, thus totaling $1.89 (CAD) billion preserved in life and property (Delorme and Waterhouse 2018, p. 14). The economic break down of these savings considers the contributions to society by both the individual life saved and the economic benefit of the businesses salvaged, including production output, employment, and tax revenue (Delorme and Waterhouse 2018, p. 27-32). A report from the Vermont State Fire Marshal's Office notes this significance and illustrates the dollar value in

loss reported by the fire service for a number of years and shows the corresponding insurance claims in dollars. The insurance payouts take into consideration lost wages and other extra expenses not captured in the fire department's reported property loss, which shows the significance of property preservation goes far beyond that of the structure (Vermont Division of Public Safety 2019).

Physiological Impacts of Firefighting as a Profession & Staffing Implications:

As indicated, the work firefighters are tasked with can at times be strenuously taxing. The shift hours are long and in the event of numerous incidents over those hours on duty fatigue can be detrimental. In order to maintain minimum staffing, many departments employ or require overtime to be worked by their firefighters. If staffing levels are at four-person per truck levels, minimum staffing is frequently at three-person crews. However, when utilizing three-person crews, this necessitates the hiring back of staff to fill those voids, which can lead to longer shifts (Choi et al. 2014, p. 2). Choi et al. note that firefighters in general are also at a higher risk for on-the-job injuries, especially associated with obesity and aerobic fitness level. Erwin reports that firefighters are five times more likely to be injured on the job than employees in the private sector (Erwin 1995). The extension of longer shifts exacerbates this risk by inducing fatigue, obesity, and increased health risk for firefighters (Choi et al. 2016, p. 486 & 495). Griffith and Roberts state, regarding the health and well-being of firefighters, that "when the requirements of the job do not match the capabilities, resources, or needs of the worker, harmful physical and emotional consequences can occur" (Griffith and Roberts 2020, p. 411). In addition to the longer working hours, the personal protective equipment that firefighters are required to wear during long work shifts also leads to further muscle fatigue (Sobeih et al. 2006, p. 69). The risk of these health associated complications can be mitigated by adequate staffing where firefighters do not

have to fill as many overtime slots in order to maintain a minimum level of staffing, as well as enabling teams of firefighters to have more personnel on emergency scenes to spread the workload. While firefighters in general often have more positive rates of absenteeism than other public sector employees, when outages do occur, they are impactful to staffing (Litchfield and Hinckley 2016, p. 734).

Weaver et al. examined the shift work characteristics of emergency medical services personnel as those hours related to on-the-job injuries. The majority of the work firefighters now do is associated with emergency medical services with it being upwards of 65% or more of the call volume (Coughlin 2016, p. 16). This makes the Weaver study reasonable as it relates to firefighter fatigue as well. Weaver et al. did find that there was a decreased incidence in injuries to EMS workers when more part-time EMS employees were involved in working the shift (Weaver et al. 2015, p. 1275). This implies that possibly the part-time employees took much of the physical stress off of the full-time employees, or the part-time employees worked a limited number of hours as to not be as exposed to the potential for injury. Regardless, the staffing of part-time employees could possibly be explored by some agencies to fill staffing gaps, although this presents its own complications in reference to a workforce that requires a significant amount of specialized training and acquired skill.

In addition to the relationship of firefighter fatigue linked to lower staffing levels, this not only can impact firefighters, but the citizens they serve as well. A fire fatality in Prince George's County, Maryland in 1996 was controversial among fire department personnel due to what they deemed inadequate staffing of the apparatus. Specifically, the first arriving fire unit had to wait for other units to arrive before making entry into an apartment building that was on fire, where an occupant later died (Neal 1996). If fire apparatuses are staffed with at least four personnel,

then there is an established "two-in" and "two-out" on scene, where crews can immediately began search or fire extinguishment operations.

Prince George's County is not the only fire department in the DC area that has received criticism for staffing levels in the past. In the 1990's, the District of Columbia Fire Department reduced their staffing from five to four personnel on fire engines, as well as reduced the number of engines available to respond (Wilgoren 1991). This move, necessitated by budget cuts proved widely unpopular by the local firefighter union as well as congressional delegates who had a hand in the funding mechanisms for the District. Congressional members referred to the fire chief at the time as being "derelict in his duty" by making these cuts and reductions (Wilgoren 1991).

Research has been conducted as well to determine if paramedic staffing levels were an indicator of increased survivability of out-of-hospital cardiac arrest events. In a study in Milwaukee over the course of twelve years, over 10,000 cases of cardiac arrest events were examined, as was the number of attending paramedics to these events. The number of paramedics ranged from two to four, with the hypothesis that the increased number of paramedics would have a statistically more positive outcome for patients. The results of the study, however, determined there was not a statistically better chance of survival with a staffing level of four paramedics verses two (Eshmann et al. 2010).

Park notes the fragility that public safety agencies may find themselves in when associated with budget cuts during difficult fiscal times for local governments. As Park states, public safety agencies such as fire departments or law enforcement agencies have often been targeted due to their high personnel numbers and costs (Park 2019). In Park's study, he states that by creating a leaner staff environment it forces the agency to become more efficient with its performance and

resources, thus cutting out individuals that may not carry as much weight as others (Park 2019). Park's work concludes that performance associated with staffing levels can be positive to a certain point until a threshold is reached, and once this occurs performance begins to quickly degrade among public safety agencies (Park 2019).

Brett conducted a study of intensive care unit staffing evaluating the performance of the teams. While the hospital staff are not firefighters, many of the team dynamics are similar. The performance, safety, and efficiency of ICU staff were examined through interviews. Brett's study concluded that human cognitive factors had major impacts on feelings of team safety and performance. Just as firefighters work in crews, generally with a company officer making the decisions, the ICU teams that were evaluated work in similar fashion with a team leader guiding the team and frequently having to make decisions in stressful, life-threatening situations. Brett's study concluded that teams that felt psychologically safe, such as teams that had good communication, and where team members had full confidence in their team leaders were able to perform to higher standards in a psychological net of safety (Brett 2018, p. 67-68). While teams of firefighters in teams of three or four can still accomplish the same tasks, it must be considered that similar factors may need to be taken into consideration when evaluating the performance of firefighters as well.

Donahue examines the role and nature of performance measurement in the fire service and the fiscal impacts it has upon the productivity of the fire service delivery. As she describes demands for fire department services are increasing without the reciprocal increases in funding or budgets (Donahue 2004, p. 718). Donahue recognizes that fire service leaders are faced with the arduous task of providing quality fire protection that meets the needs and demands of their populations,

while doing so within limited budgets (Donahue 2004, p. 718). This sets the stage for staffing with minimum levels in order to meet needs of the community with available funding.

As fire department performance has garnered attention among fire chiefs and public administrators, methods to improve it are being examined as mentioned. Horwitz and McGahan suggest formal collaboration will decrease property loss as well as fire casualties (Horwitz and McGahan 2019, p. 425). If staffing levels are difficult to achieve, formal collaboration between entities may improve performance without requiring more robust budgets.

Fire Prevention as an Alternate to Staffing:

According to Taylor et al. there are other opportunities for fire departments to reduce the loss of property to fire and that is through preventing them. Taylor et al. acknowledge that most public services need to measure outcomes in order to achieve proficiency and ensure taxpayer funds are spent responsibly (Taylor et al. 2019, p. 418). In order to reduce property loss and human casualties due to fire, Taylor et al. suggest it is important to measure the successes of certain fire prevention efforts (Taylor et al. 2019, p. 418).

While the theme of this research is focused upon staffing of fire apparatus to enable the responding units to do their jobs more effectively, thus reducing loss and casualties, Taylor et al. introduce another theory with the idea of reducing property loss and casualties. This theory revolves around fire prevention activities, that range from efforts to reduce the impacts of alcohol, to fire departments ensuring that the populations they serve have functioning smoke alarms in their homes and are educated on how to prevent fires (Taylor et al. 2019, p. 418). Thus, through the research of Taylor et al. the intent is to better understand the impact of fire prevention activities decreasing the number of fires and fire casualties that are the result of these incidents. Taylor et al. acknowledge that there needs to be more in-depth study on the reduction

of fire prevention activities in order to reduce the number of fires, injuries, and deaths due to fire events. Funding for the fire service is key in this, but the question becomes is the funding better suited for prevention efforts or in staffing resources in order to combat these dilemmas.

In order to undertake this approach, the Merseyside Fire and Rescue Services in the United Kingdom and a university in the northwest of Britain teamed up to determine the effectiveness of fire prevention activities in the region. The research methods involved examining the overall number of fire incidences, injuries, and fatalities annually within the Merseyside Fire and Rescue jurisdiction for a ten-year period, utilizing a proportion of incidents per 100,000 people (Taylor et al. 2019, p. 421-422). The funding allocations allotted to the Merseyside jurisdiction were examined against the number of fire incidences, injuries, and fatalities that occurred over a series of years. In examining ten years-worth of data, there was a notable decrease in the instances of fire in Merseyside, as was a decrease in fire casualties when the spend per head on fire prevention increased (Taylor et al. 2019, p. 424). Thus, over the ten-year study period in Merseyside there was a clear overall decline in the incidence of fire and fire casualties as the spend per head on fire prevention efforts increased (Taylor et al. 2019, p. 426).

Interlocal Agreements as a Remedy to Inadequate Staffing:

As staffing is a major component of this dissertation, it is worth examining literature that addresses staffing within the field of public safety. Wukich does this in the frame of utilizing interlocal cooperation to achieve necessary staffing configurations that would achieve adequate deployment of resources and personnel on emergency scenes. Wukich acknowledges some challenges associated with interlocal cooperation such as personnel may not be familiar with other jurisdictional policies, procedures, or equitable competence and skills needed to perform specific job functions (Wukich 2014, p. 574). This equates to what Wukich describes as a one

agency's perception of another agency's competency when it comes to working together, such as two different fire departments responding together to assist one another (Wukich 2014, p. 574). Given the challenges that can be associated with relying on other agencies to share the same level of competency, utilizing interagency responses may not always be ideal, but are an option nonetheless. These interagency responses may or may not involve costs, such as contracts or reciprocal agreements.

Wukich addresses some of the reasons that entities may engage in interlocal cooperation and why some entities shy away from such ventures. Wukich notes that in order for interlocal agreements to work, especially in the public safety sector, there must be trust and commitment between agencies (Wukich 2014, p. 578). If agencies cannot depend upon one another and have trust that other agencies can meet their needs, then intergovernmental agreements will not be successful. In this regard, supplementing firefighter staffing through mutual aid agreements or other interlocal contracts would not be feasible. However, in the event two agencies adjacent to one another share a common vision of service to their communities and have trust built between them, this can be a practical mechanism to provide adequate staffing on fire scenes.

Wukich explores various public safety agencies in the Pittsburgh metropolitan area that consist of law enforcement agencies, fire departments, emergency medical services, and as well as emergency management agencies (Wukich 2014, p. 580). Wukich cites several factors that are at play with interlocal agreements that facilitate agencies to provide aid to each other. First, adequate staffing levels played a major role in the decision to enter into joint agreements for aid. In the Wukich study conducted in the Pittsburgh metropolitan area, the ability to staff a response crew was recognized as a crucial component of the standard of performance of over half of the fire departments that entered into aid agreements (Wukich 2014, p. 587).

While utilizing aid agreements worked with some departments to receive the staffing numbers needed to fulfill NFPA 1710-10 requirements, there were some departments in the Wukich study that deliberately avoided such agreements as adjacent fire districts were deemed to be unreliable in providing the staffing needed to supply an effective response force that would comply with NFPA-1710 (Wukich 2014, p. 587). In addition to the reliability of staffing, Wukich noted that the competency of neighboring fire crews responding to fill staffing numbers was not always on par with the jurisdiction receiving aid. While numbers to meet NFPA 1710 could be achieved by utilizing aid from neighboring departments, it did not mean that the staffing would be effective and competent in hazardous tasks (Wukich 2014, p. 588).

While aid agreements are certainly one mechanism to achieve adequate staffing on a fire scene, as Wukich highlights, there are associated challenges with that as well. This can also still create a staggered response where varying levels of firefighting crews arrive on a fire scene, whereas if fire apparatus is staffed with four firefighters, there is always a consistent number of arriving personnel.

Firefighter staffing must be considered from a management standpoint as well. While local government budgets only allow for so many employees in any agency or department, there are thresholds, as described previously that render agencies ineffective or wasteful if excess funds are allocated. As noted in the Park (2019) study personnel costs are high with public safety agencies, and from a managerial perspective if savings can be made in one area, it provides relief to another. This is where additional savings could be placed into staffing. There are options in various types of staffing, such as utilizing volunteers, part-time staff, or other configurations, but all alternative staffing programs have their obstacles and issues as well as other industries and sectors acknowledge (Houseman 2001, p. 149). Problems in firefighter staffing and funding are

not limited to the United States fire service either. In Norway, Blåka has investigated whether cooperative agreements with other local units of government provide savings while not impacting service delivery of the fire service. The findings of the study found that through interagency or intermunicipal agreements costs could be reduced to provide an acceptable level of service (Blåka 2017, p. 1103). However, what is also discovered is that the more players, as in different municipalities, that become involved in cooperative agreements costs tend to begin to rise, thus defeating the purpose of entering into such actions (Blåka 2017, p. 1103). While this study was focused on Norwegian municipalities, the concept of interlocal agreements is not foreign to American local government policy as well and can be noted for how many American municipalities enter into contracts for service to provide fire department coverage.

Options such as interagency agreements may be an option to supplement staffing and fire units on emergency scenes, other options have been looked at as well, such as filling gaps with volunteers. Volunteer labor is softer on budgets than paid employees, but as Brudney and Duncombe explain there are still significant costs associated with utilizing such labor models. Volunteer labor still utilizes a substantial portion of resources from any agency, such as facility usage, equipment needed to carry out duties, insurance costs, and other support service cost (Brudney and Duncombe 1992). The other issue identified by Brudney and Duncombe is that volunteers who are able and willing to participate in public safety activities are in short supply, particularly during normal daytime hours, which in their words, "threatens service continuity" (Brudney and Duncombe 1992). There are also questions if the quality of output from supplemental volunteers would be equal to that of paid staff. Thus, the effectiveness of services must be considered when considering costs associated with the delivery of fire protection to communities (Brudney and Duncombe 1992).

While Brudney and Ducombe documented the short supply of fire department volunteers in the early 1990's, Colibaba et al. note that the problem persists to present times as well. Colibaba et al. describe that volunteer pools in communities worldwide are shrinking as populations age, leaving fewer individuals capable of providing extensive community service, including volunteer firefighters (Colibaba et al. 2021, p. 290). Colibaba et al. also indicate that rural communities that see significant outmigration of younger individuals are at more risk of losing available people who could serve in the volunteer fire service (Colibaba et al. 2021, p. 290).

The National Institute of Safety and Technology Residential Fireground Field Experiments:

The NIST Report on Residential Fireground Field Experiments described in Chapter 1 of this dissertation provides a foundational framework for this study and the literature associated with it is worthy of mention to underpin the importance of accomplishing fireground task. It is through this understanding that the importance of crew staffing can be illustrated. The report highlights the importance of firefighter crew staffing configurations through the simulation of conducting critical fireground tasks commonly associated with residential structure fires.

As the NIST Residential Fireground study states, there has been a longstanding consistent relationship between fire department resources deployed and firefighter and civilian safety (Robinson 2010, p. 14). As described in the NIST study, the Columbus, Ohio, Division of Fire documented in 1980 that a predetermined number of personnel deployed to a fire scene greatly impacted firefighter effectiveness. For instance, property loss that exceeded $5,000 and horizontal fire spread by more than 25 sq. ft was much greater for firefighting crews who had less than 15 personnel on the scene of a residential fire (Robinson 2010, p. 14). Prior to 1980, the Dallas, Texas, Fire Department conducted a series of test that also involved crew deployment

scenarios utilizing crew sizes ranging from three to five firefighters. This study measured the time it took these teams of firefighters to advance a hoseline and put water on a fire on the third floor of an older school building (Robinson 2010, p. 14). The Dallas experiment demonstrated the importance of crew size, as with the addition of each subsequent firefighter crew member, the time to complete the prescribe task improved (Robinson 2010, p. 14). The Dallas Fire Department conducted further experiments utilizing various crew sizes in various fire incident settings and all concluded that increased staffing levels increased the effectiveness of firefighting crews (Robinson 2010, p. 14). Through the studies by Columbus and Dallas, evidence indicated that firefighting staffing is a matter of firefighter safety on the fire scene (Robinson 2010, p. 14). This also introduced the question that the risk of firefighter injury due to lesser staffing could result in additional cost incurred to fire departments due to fireground injuries (Robinson 2010, p. 14). Additional studies in Texas and in Ontario found similar results when conducting experiments with crew sizes of three firefighters (Robinson 2010, p. 14-15).

A series of other experiments in Taiwan and the United Kingdom also illustrated the importance of firefighter staffing by demonstrating that the water supply required on the scene of fires where response times of adequate numbers of firefighter was higher than ten minutes (Robinson 2010, p. 15). While these experiments and studies were tied to response times more so than staffing, the two interrelate, as the ability to deploy an adequate number of firefighters on a fire scene can be impacted by response time when crews of three firefighters are responding from various geographic points (Robinson 2010, p. 15).

The NIST residential fireground experiment involved the utilization of a large burn prop which was setup similar to a single-family residential dwelling. Non-combustible furnishings were placed inside the burn building in order to simulate obstacles typically encountered by

firefighters entering a residential structure (Robinson 2010, p. 22). The non-combustible furnishings were utilized in experiments where firefighters entered the burn prop to simulate time to task functions. However, there were other experiments conducted in the burn prop that simulated room and contents fires where combustible materials, such as furniture were utilized to simulate room fires. In these fire experiments firefighters were not allowed to enter an atmosphere that had sufficient heating to risk a flashover (Robinson 2010, p. 29).

One of the primary objectives of the room and contents fires were to determine the tenability of subjects that were trapped inside such a fire. While fire crews were not to make entry, experiments did involve the time it took smoke alarms to sound, the typical time for firefighters to receive a dispatch, don their gear, and travel to a fire scene (Robinson 2010, p. 30-31). There were numerous tasks that fell into this category of experiments where crews were not allowed to enter the structure, such as breaching a door, applying water on a fire, accessing various windows on the structure, which involved simulations of crew size conducting experiments against specific time constraints (Robinson 2010, p. 31-32). While these experiments, and all others associated with the residential fireground study were intended to be as realistic as possible, in the end they were all somewhat controlled in an experimental environment. This included fireground tasks that involved entering the burn structure which was outfitted with non-combustible materials and those where combustible furnishing were in the burn structure, but where firefighters were not allowed to enter. Due to safety standards meant to protect firefighters with the intention to keep firefighters safe while experimenting with fireground tasks, there were still several elements that were simply experimental and not realistic. For instance, firefighters will regularly make entry into burning buildings with combustible materials in order to conduct fireground operations such as search and rescue (Norman 2019, p. 267).

The overall results of the fireground experiments demonstrated the benefits of having crews with four firefighters verses three, with all tasks being completed (Robinson 2010, p. 34-42). In addition to accomplishing fireground tasks, there were also physiological impacts to firefighters depending upon the crew size that were engaged in various fireground tasks. The Residential Fireground Experiments identified that certain physiological impacts impacted crews of different sizes. For instance, smaller crews had on average higher heart rates, especially for two-person crews (Robinson 2010, p. 50). Sudden cardiac events are the leading cause of line-of-duty deaths for firefighters, and overexertion is a leading cause of these medical emergencies (Robinson 2010, p. 50). Due to the increased workload placed upon smaller crews, and the documented increased heart rates compared to larger firefighter crews, this places smaller crews at a greater risk of experiencing a sudden cardiac event that could result in death (Robinson 2010, p. 50).

As noted, the NIST study is based off of experiments and simulations only, not factoring in a number of real-life scenarios, such as various meteorological elements, interior firefighting in actual residential structures with combustible furnishings, as well as fire crews operating in darkness during nighttime incidents (Robinson 2010, p. 51). In addition to these limitations of the study, it is identified within the study that the crews that conducted the experiments are typically part of three or four-person crews and do not operate regularly as two-person or five-person crews (Robinson 2010, p. 51). Another important aspect identified by the study was the fact that there are sometimes multiple ways to perform fireground tasks, including many that were measured in this study. While there is merit to the residential fireground experiment as it was conducted, these limitations identified reinforce the reality that there may be other means in which to accurately measure the effectiveness of crew size on fire incidents.

The National Institute of Standards and Technology High-Rise Fireground Field Experiments:

In addition to field experiments with single-family residential fires, the National Institute of Standards and Technology also conducted fireground experiments related to high-rise fires. This study also focused on various staffing configurations of fire crews, similar to that of the residential fireground experiment. High-rise fires pose a higher level of risk than single-family residential fires as well due to numerous factors. One such hazard that has been identified through high-rise fires is that greater numbers of people may be trapped at higher levels above the ground, which necessitates evacuations via either elevators, which may become inoperable during fire events, or stairwells which can also become smoke filled. However, many modern high-rise structures are also constructed with specific fire protection systems which are proven to reduce the risk to both occupants and firefighters (Averill et al. 2013, p. 7). Sprinkler systems and fire alarm systems are found in many of these structures, however 41% of U.S. high-rise office buildings, 45% of high-rise hotels, and 54% of high-rise apartment buildings in the United States are not equipped with sprinkler systems. Additional hazards of high-rise structure fires include the fact that it frequently takes fire crews much longer to reach fires in order to begin extinguishing efforts or even rescue attempts (Averill et al. 2013, p. 13).

The NIST high-rise fireground experiments were conducted simulating various fire incidents in a 30,000 square foot, thirteen-story structure. As with the residential fireground experiment, the high-rise experiments demonstrated that crew size had a direct impact on accomplishing specific tasks in the simulated fire incident environment. For instance, when crews were operating in a three-person configuration, ascending to the 10^{th} floor a medium growth rate fire released more than 60% more heat energy, than what crews of six-person teams encountered

when conducting the same task (Averill et al. 2013, p. 13). While single-family residential dwellings make up the majority of property losses and human casualties due to fire annually, they are typically classified as low hazard type incidents (Averill et al. 2013, p. 13). High-rise structures however pose a higher hazard classification. This is due to the complexity of these incidents. Although less frequent that single-family residential dwelling fires, high-rise fires have numerous challenges associated with them such as the size and scope of rescue operations that may be required, or the distance to the fire floor from a water source (Averill et al. 2013, p. 13). Therefore, given the high hazard characteristics of high-rise fires, the purpose of the NIST experiment was to determine how different staffing configurations impacted outcomes of these fires. Given the mission of this experiment, it also may provide support that crew sizes of four firefighters verses three, can have a positive impact on outcomes of property loss as well as the number and types of casualties as the result of fire incidents.

In addition to the high-rise experiment being conducted on a 13-story building, there were staffing configurations from three-person firefighting crews to six-person firefighting crews. There were four different types of response scenarios that were included in the simulations; the first was considered a high-alarm assignment where service elevators were accessible for use (four engines, four ladder trucks, two battalion chiefs with an aide for each, and three ambulances), the second, was a low alarm assignment with access to service elevators (three engines, three ladder trucks, two battalion chiefs with an aide for each, and two ambulances). The third and fourth scenarios were high and low alarm assignments as well, but with no access to service elevators with only utilizing the stairs to ascend and descend the building (Averill et al. 2013, p. 14).

Along with various staffing configurations and firefighters encountering four different assignments, there were 38 fireground tasks that were undertaken to ascertain performance utilizing crew sizes and accessibility differences. These tasks included, but were not limited to, advancing an attack line, advancing a second attack line, extinguishing a fire found on the 10th floor, a search and rescue operation on the 10th floor, rescuing victims located in specific locations, as well as operating above the fire floor, conducting search and rescue and hoseline advancement activities (Averill et al. 2013, p. 15-16).

According to the results of the experiments crew size had a significant impact on the completion of tasks, much as it did in the residential fireground experiments. For instance, in advancing a hoseline, going from three-person crews to four-person crews saw a reduction in times of between one and two minutes to accomplish the prescribed task (Averill et al. 2013, p. 16). In all tasks, the largest improvements were found going from three-person crews to four-person crews. As crew sizes increased from four-person to five-person configurations, less improvement of time difference was noted. Improvements in time to task completion ranged from between one and two minutes for the advancement of a hoseline to between 10 and 15 minutes when crews were conducting searches on the 10th floor and rescuing a single victim (Averill et al. 2013, p. 16). The average improvement when going from three-person to four-person crews was between nine and twelve minutes, which are considered very substantial when operating on the fireground (Averill et al. 2013, p. 16).

Other specific examples of where crew size had a significant impact on the high-rise experiment was that of fire development. Time advantages that larger crews had over smaller crews stretching hoselines and reaching certain points in the structure on the fire floor. For instance, in a simulation of a medium growth fire in an area of office cubicles, in simulations

using three-person crews the fire crew into five cubicles being involved in fire verses only two when the fire was attacked with a crew of six firefighters (Averill et al. 2013, p. 87). This is largely due to the impacts of larger crews being able to complete tasks much faster, such as the hose stretch and arriving on the fire floor faster than smaller crews. Larger crews are also able to transport more equipment distributed across the crew whereas smaller crews carry more of the burden, thus slowing down their ascent and progress. Ascent times coupled with a simulated victim rescue for fire crews varied by as much as almost thirty minutes. Firefighter crews of three-persons who used stairs to ascend the structure took over 51 minutes to rescue a victim, while crews of four firefighters were able to accomplish the same goal in just under 38 minutes. Larger crews, of five and six firefighters were able to accomplish the same goals in under 30 minutes (Averill et al. 2013, p. 89).

As with the residential fireground experiment there are also certain limitations to the high-rise experiment. First and foremost, the experiments were conducted in controlled environments with simulated smoke conditions. A vacant high-rise structure was located in the Washington, D.C. metro area that could be utilized for the experiments, then outfitted with certain props to deliver as much realism as possible. An artificial smoke generator was utilized to fill the spaces of the building an obscuring haze that mimicked smoke, as was a visual simulation of fire through a fire display on a screen (Averill et al. 2013, p. 32). In addition to these props, water could not be flowed in the structure either, which made it challenging for crews to conduct simulations with hoses filled with water. Therefore, sections of hoses were filled with sand and capped, to simulate the weight of a charged hoseline (Averill et al. 2013, p. 32). While these are commendable attempts to create realistic scenarios, there are still limitations as a dynamic fire scene is incredibly difficult to be duplicated.

While the simulations in the high-rise experiment validated the impact of crew size, as also was the case with the residential fireground experiment, the aforementioned limitations also illustrate the importance of evaluating actual incident data to determine the effectiveness of crew size and if the number of personnel on a crew has an impact on incident outcomes. The research in this dissertation is not meant to undermine the NIST experiments, but to validate it when taking into considerations the limitations of the studies.

As outlined by various literature, firefighter crew size appears to play an integral part of preserving property by limiting fire growth as well as reducing casualties by reaching them faster with larger crews when trapped in fire or smoke conditions. While much of the literature has focused on simulations, it would be expected that these simulations will be validated when examining actual incident data based upon crew size. Given the limitations by simulations and neither experiment noted actually involving true fire conditions that firefighters encounter, research in this dissertation is crucial for sound policy making decisions for public managers. The results of this research will either validate what the two NIST simulations have demonstrated, and NFPA 1710, or the decision making of public managers who have made policy decisions to fund and staff their fire departments with crews that are less than that recommended by NFPA 1710.

Measuring Performance of Fire Departments & Quantifying Data:

In order to provide a definitive quantitative conclusion as to whether there is a substantial difference in property loss and casualties with different firefighter staffing configurations, performance data from fire departments must be measured. O'Loughlin and Wilson note that many assessments of municipal efficiency often take one of two approaches, the first being examining overall efficiency and the other focusing on the efficiency of a certain service

(O'Loughlin and Wilson 2021, p. 2675). O'Loughlin and Wilson also see that administrative data, such as budgetary data, is very helpful when evaluating municipal services and their efficiency (O'Loughlin and Wilson 2021, p. 2675). Community welfare has long been attributed to the efficiency of local government services according to O'Loughlin and Wilson (O'Loughlin and Wilson 2021, p. 2666). While some fire department performance data for this dissertation may come from fire departments that are not part of a municipality, the likelihood is that the majority will be municipal based. Therefore, adequate data is important to measure the impact of staffing on fire outcomes regarding financial loss as well as human casualty figures.

Komsionchi Eslamzadeh et al. reinforce this idea that effective service provision by the fire service is a paramount municipal, or otherwise, service to the public. Fire services across the globe all have similar missions as well, which are to prevent fires and reducing fire loss (Komsionchi Eslamzadeh et al. 2022, p. 360). Komsionchi Eslamzadeh et al. state that in order to measure the performance of fire departments in order to accomplish these two primary goals, the primary method has been to compare outputs and outcomes along with inputs and target values (Komsionchi Eslamzadeh et al. 2022, p. 360). This is precisely how research will be undertaken to better understand the outcomes of firefighter staffing and meeting the mission of reducing fire loss and resultant human casualties.

Komsionchi Eslamzadeh et al. define outputs as being "direct quantitative results" of a department's activities (Komsionchi Eslamzadeh et al. 2022, p. 361). In the Komsionchi Eslamzadeh et al. study, they too utilized variables such as the number of staff, budgets for departments, which were input variables, and described outcome variables such as loss reduction, the reduction of casualties and property loss, as a measure to determine what was achieved by outputs (Komsinochi Eslamzadeh et al. 2022, p. 361). The purpose of the

Komsinochi Eslamzadeh et al. article was not to evaluate the outcomes and determine differences with staffing levels and budgets as they relate to outcomes, but instead to provide a basis for how to evaluate fire department performance utilizing specific variables and methods. This dissertation will relate to the Komsinochi Eslamzadeh et al. article, as it will utilize some of these outputs to determine specific outcomes based upon the staffing levels associated with a number of fire departments.

Summary of Literature Review:

In summary, there has been little study or literature to how fire apparatus staffing levels impact human casualties and property loss from actual fire incidents. However, as indicated throughout the literature review, there have been a number of research experiments that relate to this topic, including the two NIST studies that are prominent research documents in the field of fire protection. As noted in the sections of this literature review that discussed the NIST studies, they were both scientifically calculated simulations that did demonstrate the importance of adequate staffing on fire scenes to accomplish goals more efficiently, but these were not examples of actual fireground data from real incidents. Fire incidents occur in very dynamic environments and are not controlled in ways that scientific studies and simulations are orchestrated. Therefore, the NIST studies could be argued to provide the most compelling data to staff fire apparatus at a particular level, but in the end, these studies did not factor the performance of fire crews in true emergencies in uncontrolled environments.

There are a number of public policy questions that arise when discussing any type of government staffing, where salaries, equipment, and other items are funded through public tax dollars. As is described in this literature review, there is the desire for government to be most efficient for the good of the public. The question that could be asked of public funding for the

fire service, is to what level of risk or outcome are the public and elected officials willing to accept?

Chapter Three: Methods:

Description of Rationale of Methods and Data Collection:

As identified earlier in this work, there have been numerous studies, simulations, and industry standards that have made recommendations for specific staffing configurations of fire apparatus, most notably NFPA standard 1710 (NFPA 1710). Field experiments conducted by the National Institute of Standards and Technology have also attempted to demonstrate the need for adequate staffing of firefighters on the fireground. However, none of these initiatives have compared actual incident data to determine if there is a difference in outcomes from various apparatus staffing configurations. Therefore, this highlights the importance of acquiring actual incident data, examining various apparatus staffing configurations to determine if a statistical correlation exists between lower staffing levels and higher property loss figures, as well as greater numbers of human casualties.

Given the absence of incident data used in any of the aforementioned experiments or studies the purpose herein is to examine incident data and determine if there is a relationship between fire apparatus staffing levels and certain variables. These variables include property loss sustained due to fire in a community, the number of civilian injuries due to fire, as well as civilian deaths. In addition, other variables include the number of on-duty firefighter injuries and deaths a department may have suffered throughout 2020. It is expected there will be a significant statistical difference in the amount of fire loss as well as casualties between fire apparatus staffed with three firefighters verses four. The method employed to gather data for this work was to compile a simple survey that was distributed to fire departments across the United States and Canada. The survey was comprised of the following questions (Shoffner 2022):

1. What is minimum staffing on an engine?

2. What is minimum staffing on a ladder truck?
3. How many civilian casualties (injuries only) occurred in your jurisdiction due to fire in CY 2020?
4. How many civilian casualties (deaths only) occurred in your jurisdiction due to fire in CY 2020?
5. How many fire personnel injuries occurred in your jurisdiction in CY 2020?
6. How many fire personnel deaths occurred in your jurisdiction in CY 2020?
7. What was the total amount of fire loss (in dollars) in your jurisdiction in CY 2020?
8. What was the total value of property saved from fire in your jurisdiction in CY 2020?
9. What is the population of your jurisdiction?
10. What is your department's annual budget?
11. What is your department size in personnel?

Many of these questions are asked annually in the NFPA's annual survey where data from fire departments across the United States are asked to submit data to the NFPA (National Fire Protection Association) (Evarts 2021). Specific questions that were part of the survey that are included in the NFPA annual Fire Experience survey included the estimated property loss from fire as well as human fire casualty figures for both civilians and fire personnel, including injuries and deaths. The NFPA was contacted to obtain this data on a larger scale, however the NFPA would not release aggregate data needed for this research, therefore an independent survey was created to collect needed data (Fahy 2022). This survey was accessible through a link that takes respondents to a Google form, where the survey resides.

In order to widely distribute the survey, fire department accreditation consortium contacts were sent the survey request in order to distribute it to fire departments that are members of their consortiums. There are 301 fire departments across the world that are recognized as accredited

by the Commission on Fire Accreditation International, with the majority departments being geographically located in the United States and Canada (Accredited Agencies). Thereby the distribution of this survey to these departments offers a wide sampling of departments that have significant amounts of data on their incident responses. According to Coyle et al. accredited agencies have a seal of professional approval upon them due to being required to meet certain national standards and marks, and as such the sample collected from accredited fire departments provides a certain level of confidence of quality data (Coyle et al. 2018, p. 296).

In addition to contacting accreditation consortiums, other departments identified in *Firehouse* magazine's 2020 annual run survey that reported partial data that is being requested by the survey request for this dissertation, were contacted as well to invite them to participate (Matthews 2021). For instance, the annual national run surveys published by *Firehouse* magazine provide information on fire apparatus staffing, as well as department budget and population served. The departments identified in the Annual Run Survey were contacted via email with the same request letter that was distributed to the accreditation consortium departments. Identical requests were made with the same survey questions to different fire departments whether they were reached through the accreditation consortium list or the individual departments contacted directly from the list of *Firehouse* annual run survey participants. Contact information for departments that participated in the *Firehouse* survey were found by searching the respective department's website and department contact information. Efforts were made to identify staff data analyst or chief officers that have responsibilities associated with records management or data collection. In order to identify staff that possessed relevant information, fire departments that were included in the *Firehouse* Annual Run Survey were contacted after obtaining contact information from department websites or other means

such as emails and direct conversations. It was assumed some of these departments were also accredited departments which may also have received a request through the accreditation consortium contacts.

In 2020, a total of 115 fire departments participated in the *Firehouse* annual run survey, that represented 36 different states, two Canadian provinces, and one Mexican state (Matthews 2021). For purposes of this study, the fire department in Mexico was not contacted for information. These departments also protect almost 60 million residents, have budgets totaling in excess of $12 billion, and have a complement of 2,213 engine companies and 856 ladder companies staffing in a variety of configurations (Matthews 2021). These departments vary in size as well, geographically and in population, ranging from just over 5,000 people to over four million people protected by the individual departments (Matthews 2021). Therefore, there is a wide range of fire departments represented that employ a variety of staffing configurations, including the utilization of three and four-person crews, which is the focus of this dissertation. The departments that participate in this survey are not identified by department name, geographic region, or any other method unless voluntarily conveyed. Email addresses were identifiable in the survey, but not traceable to departments in all instances. In addition, email address data was not exported from the survey therefore data analyzation did not include email addresses and potential ties to origins of data. This was purposeful as to obtain an unbiased sampling, which should represent a wide geographic range and not generate any bias from potentially known departments, whether large, small, or in the same geographic region as the author.

Data Normalization and Interpretation:

Once data collection began, given the scope of differences between fire departments and their communities, data needed to be normalized in a manner that it could be analyzed equitably. As

noted, the fire departments where data was collected have a wide range of populations served, budgets, as well as staffing, and geographic districts. It would be expected that higher populated areas, with larger districts would have more fire incidents annually, resulting in more property loss and human casualties. However, these departments may employ a variety of staffing configurations which is not necessarily dependent upon population, budget, or geographic area served.

Given the potential for the wide range of data results, such as population figures and injuries due to fire, data was broken down into injuries per capita based upon population of jurisdictions and the number of injuries and deaths in civilians. Population data was collected for fire districts as part of the survey to have the ability to break down this data. Civilian fire casualty data as well as property loss values were determined by the number of casualties per 100,000 people, while the loss values were divided by the populations to determine an amount of loss by the population. The data on firefighter-only injury and death was broken down per capita based upon the total staffing of the individual fire department. These numbers were based upon a per capita of 100 persons per department, in terms of total department staffing.

The intent of analyzing the property loss is to gain an understanding of how much property was salvaged that was impacted by fire. For instance, annually, fire departments must report to the NFPA the total fire loss, but also property value saved that was involved with fire. There are expected to be a wide range of figures reported due to the variability of fire district characteristics, with demographics, population, geographic size, and property values. Thus, the actual property loss values were broken down by the populations of the jurisdiction to obtain a variable that can be measured across the spectrum of respondents. Fire loss totals will be divided

by the population of the jurisdiction in order to have a variable that could provide an accurate measurement.

The collected data was then entered into a spreadsheet, and then imported into SPSS for data analysis. The dataset will be split into staffing categories of 3-person crews and 4-person crews. Some respondents reported other staffing configurations, and this data was collected and entered into the spreadsheet as well, but was not utilized in the study. Therefore, for further data analysis, only 3-person and 4-person crews were evaluated.

Simple statistics were sought for statistical relationships between staffing levels and the frequency of injuries or the amount of fire loss sustained under various staffing configurations. The median of frequency of injuries based upon staffing levels was to be sought in order to determine the average number of injuries per the population sample provided, in the associated staffing mode (Meier 2015, p. 91). The median of property loss was also to be sought based upon staffing configurations. Data was tested for a normal distribution to determine if the mean was the best method of measurement, or if the median would need to be sought if data had a non-normal distribution. It was determined that due to the non-normal distribution of data that the median would be a more appropriate unit of measurement for accuracy (Meier 2015, p. 95).

Data was examined for outliers, because of the potential of having the potential for it to skew the remaining dataset. Outliers can be defined as results that appear very uncharacteristic for the data set, such as an extremely high property loss or high percentage of casualties, especially in the case of firefighters when casualty figures are compared total staffing levels. This could be the result of a wild fire that may have caused extensive damage, or some other natural disaster. It could also include data from a catastrophic event where a high number of casualties were injured or perished. These extremes would not fit the purpose of the dissertation to determine if a

statistical relationship exists between staffing configurations and property loss and casualties. It could also be from incorrect data reporting or typographical errors in the survey responses. If extreme outliers are found they will be removed from the analysis (Meier 2015, p. 93). Mihaylova et al. describe the characteristics of normal distribution being sensitive to extreme values, therefore this reinforces the need to remove extreme outliers from analysis (Mihaylova et al. 2010, p. 899).

Outliers for firefighter injuries or fatalities will be considered if the number of injured firefighters or firefighter fatalities exceeds 30% of the total staffing of a department. According to Campbell, between 2010 and 2014 the average number of fireground injuries annually for firefighters was 69.2 injuries per 1,000 career firefighters (Campbell 2018, p. 466). This equates to just under seven percent of career firefighters suffering a fireground injury annually. Determining outliers for civilian injuries and fatalities could be much more challenging to determine. It is unlikely that extreme outliers would be reliably identified for civilians unless there is a comparable percentage of the total population, such as a 30% threshold used for firefighters, injured or succumbs to fireground injuries.

Fabian describes the mean as the best characteristic of central tendency of continuous distributions, but as noted since this data had a non-normal distribution, the median was the chosen method to investigate simple relationships between variables (Fabian 2021, p. 2363). Schindler also notes that if data is non-normally distributed, where there is a wide range of results, the median is the preferred measurement (Schindler 2015, p. 32).

In determining if there is a statistical difference in the median in property loss and human casualties from staffing with three-person crews or four-person crews, statistical tests will be conducted to ensure the validity of the data. These tests will be possible particularly when

analyzing fire casualty data. For instance, fire casualties will be dependent variables while firefighting crews of either 3 or 4 firefighters will be independent variables. The Kruskal-Wallis Test was run since the data had a non-normal distribution. In addition, where there was a low confidence level in the data that it had a similar distribution, the Independent Samples Median Test in SPSS was executed to examine data.

The Economic Impact:

As part of policy discussion for fire apparatus staffing, the ripple effect of fire loss can also have an impact on the local economy and thus the tax base for which the fire departments protect. If increased staffing leads to a greater preservation of property, especially in commercial properties, this may have a positive impact on the local economy. If data demonstrates that staffing engines and ladders with three firefighters, instead of four, has a correlation to increased property loss, then it may generate policy conversations among local government managers as to the financial benefit of increased staffing verses experiencing negative economic impacts as the result of community fire loss, and even human casualties.

Several communities around the United States and Canada have conducted economic impact studies of their fire departments' interventions at commercial structure fires. These interventions have preserved jobs, income, as well as taxable property. For instance, Orange County, Florida, was one such community that conducted an economic impact analysis for commercial structure fire interventions for the year 2013. This particular economic impact study demonstrated that due to the interventions of the Orange County Fire & Rescue Department from 28 total commercial structure fires, a total of 8,741 jobs were preserved (Hawkins, Thalmueller, and Nieves-Ruiz 2014, p.13).

Likewise, the Phoenix, Arizona fire department conducted what has become the model of economic impact studies of the fire service, for the time period of June 1, 2012 to May 31, 2013. The Phoenix study was published in 2014 and illustrated that the Phoenix Fire Department intervened successfully in 42 commercial structure fires during the period (Evans 2014, p. 5-6). These successful interventions resulted in the preservation of 7,446 jobs in the Phoenix area (Evans 2014, p. 6).

In the province of Quebec, two municipal fire departments undertook significant economic impact analysis studies of their interventions as well. The Montreal Fire Department (Service de Sécurité Incendie de Montréal) and the Sherbrooke Fire Department (Service de Prévention Contre Les Incendies de la Ville de Sherbrooke). These studies reflected similar results as the studies in Phoenix and Orange County. Both Quebec studies were also modeled after the Phoenix study, utilizing assistance from Phoenix Fire Department personnel as well as faculty from Arizona State University in developing methods and data analysis of their respective studies (Delorme and Waterhouse 2017 & 2018).

In addition to analyzing the impacts of interventions on commercial structure fires, the Montreal study also examined the economic impact of medical interventions which placed a value on a human life (Delorme and Waterhouse 2017). The value of a human life is significant to this dissertation in that human casualties are a data point when examining the impacts of fire apparatus staffing, in addition to property loss. The Montreal study utilized several models to determine the economic contribution of a human life through several models, both from the United States and Canada (Delorme and Waterhouse 2017). According to Delorme and Waterhouse, the value of a statistical life has been calculated by using various methods since the 1970's with two primary output methods. The first is taking an approach of an individual's

economic output, recognizing an individual's income and subsequent economic output. The second approach considers the commitment an individual would have in order to decrease his or her mortality (Delorme and Waterhouse 2017).

The American and Canadian studies had various levels of value placed upon a human life, ranging from $4.7 million to $8.4 million. The three studies that are taken to account in this work are Dionne and Lanoie (Canadian study), who placed the value of a human life at $4.7 million, Knieser et al. (American study), who placed the value of a human life at approximately $8.4 million, and Viscusi (American study), who placed the value of a human life at $6 million (Delorme and Waterhouse 2017). Therefore, the value placed upon a human life for purposes of this dissertation will be an average of these three studies, at $6.36 million, for the economic contributions an individual may make over their life in a given community, including payment of various taxes that support public infrastructure and services. This figure will be relevant when examining the difference in human casualty figures from fire incidents. If there is a difference found in the mean number of casualties, especially in terms of fatalities, between apparatus staffed with crews of three or four, the value assigned to a human life can be used to illustrate the economic advantage of one staffing configuration or another.

Just as there can be an economic advantage illustrated by the difference in casualties, incorporating the value and economic output of a human life, similar value can be derived by examining the difference in property value conservation in departments where the staffing array is either three or four firefighters on engines and ladder trucks. As noted in NFPA data from the years from 2015 to 2019, approximately 23% of fires were in occupancies other than residential structures (*Fires By Occupancy Type* 2020). These fires also resulted in 10% of injuries from all fires, and 3% of fatalities (*Fires By Occupancy Type* 2020).

While non-residential structure fires make up the minority of structure fires, they do carry significant economic impact. According to the NFPA, between 2015 and 2019, 29% of the total value of fire loss from structure fires was attributed to non-residential fires. The importance of property preservation in non-residential structure fires is closely connected to the economic well-being of a community when considering the impact of employment loss, as well as production and economic output. This is clearly illustrated through the four economic impact studies previously described, as countless jobs are connected to commercial properties and even small measures that improve property preservation can pay dividends in job preservation or the resumption of business operations. There is a clear public welfare benefit if it is determined that staffing fire apparatus with four firefighters verses three can preserve more property, and thus more jobs when considering commercial structure fires. It also would demonstrate a benefit to the healthcare system if four firefighters verses three show a reduction in human casualties.

Summary of Methods:

As noted in the beginning of this chapter, data collection was a significant undertaking in order to obtain historical incident data from fire departments across the United States and Canada. However, data collected is the core of this study and will support the hypothesis that staffing levels of four firefighters on fire apparatus has a positive impact on fire loss and human casualties, which in turn has an economic impact on communities, or it will demonstrate there is no correlation. Public Policy makers must balance the cost of service provision with the benefits of outcomes following those service provisions. The fire service, while frequently not recognized as a public service function that produces revenue for local governments, does in fact protect investments of both the public and private sectors, and thus protects the local tax base that funds most local governments. Economic impact analysis studies by several fire

departments across the United States and Canada demonstrate this as noted throughout this chapter. Therefore, even minimal differences in property preservation as well as a reduction in human casualties by adding staff can have significant economic benefits to a community and the local government unit.

In summary, the collection of data will be the most significant component of this research and will be undertaken by requesting various fire departments across the United States and Canada to complete a brief survey in an attempt to gather necessary data to conduct the analysis of the impact of staffing levels on property loss and human casualties. This survey was distributed by utilizing a standardized letter requesting the same data from every department that received the request. Some fire departments were targeted as previously described in this chapter, through using Firehouse Magazine's annual run surveys, where departments have included partial data that is being requested. In addition, the standardized letter and survey were distributed to fire department accreditation consortiums located throughout the United States and Canada. These consortium groups were then able to forward the survey request out to accredited agencies within their consortiums who then chose whether or not to participate in the study.

The data collected was then normalized so data would not be skewed from departments with larger populations and higher volumes of fire loss which would otherwise offset the dataset. This allowed for data from smaller departments to be analyzed along with data from larger departments so that all data from departments of various size held equal weight. The data was then entered into an excel spreadsheet, where it was then imported into SPSS statistical analysis software. The data was then be statistically analyzed to determine whether the mean or median was higher or lower for the occurrence of greater fire loss, or higher human casualties with the different staffing configurations. The difference found between the two staffing configurations

can then be tied to an economic contribution of one staffing configuration or another if there is a difference between the two, especially in examining the difference in fire fatalities. The aforementioned methods employed in the various fire department economic analysis studies were utilized to determine what the extent of economic benefit of a certain staffing configuration is upon any given community. A limitation of this study and these methods is that while it was possible to determine the economic value, based upon previous methods employed by others, on the difference in fire fatalities in different staffing configurations, other hard values will be difficult to determine. It can be assumed that any reduction in fire loss will result in a quicker resumption of business operations from commercial structure fires. It can also be assumed that a reduction in fire loss will result in preservation of the tax base which funds local government. In general terms, the goal of the fire service is to reduce property loss and any efforts to do so would be considered a positive. However, it is difficult to place an economic value on the difference in total property loss that will be reported and through this data. Therefore, while generally accepted as a positive and it can be assumed that any improvements in property preservation can translate into an economic benefit, the actual value cannot be determined in this study.

Another limitation that must be considered in the data collection and analysis is that fire departments generally report property loss values using their best judgement and estimates. These values are not typically provided by formal appraisers who are trained in the art of property valuation. In addition, property loss numbers or casualty figures do not reflect costs associated for healthcare for treatment of injuries, lost time at work for people injured that require medical treatment, or the lost time in education if fire victims are school age (Vermont Division of Public Safety 2019, p. 20).

Therefore, there are many variables that are impacted by even slight increases in fire loss and casualty figures. If staffing can improve these figures, which then improves the quality of life in a community and the economic viability of a locality, public policy makers must ask themselves if increases in staffing will provide greater benefit to their communities. There is no simple answer for providing additional funding and staffing, but it is important that government officials have adequate information in which to base their funding and allocation decisions. This purpose of this study is to assist in providing policy makers in making those decisions by illustrating the value placed in increased staffing of fire apparatus and what that can mean to their communities.

Chapter Four: Findings:

Description of Datasets and Conceptual and Operational Definition of Variables:

Fire departments across the United States and Canada staff various apparatus in different configurations, which frequently differ from the NFPA's recommendations laid out in NFPA-1710. The purpose of this research is to determine if staffing certain apparatus at those suggested levels has a positive impact on human casualties and property loss from actual incident data. It was hypothesized through data analysis that staffing engines and ladders with four firefighters verses three firefighters will show a statistical advantage in lower numbers of casualties as well as lower property loss figures.

In order to conduct analysis and determine if there was a clear advantage with certain staffing levels data was collected from 53 different fire departments across the United States and Canada. The survey that requested information specifically did not request the name or geographic location of the fire department in order to collect raw data that was not easily identified as from any specific location. It is not known from which locations in the United States and Canada the surveys came, however, as previously mentioned, accreditation consortiums representing departments in the contiguous United States and all of Canada were contacted for survey distribution, along with fire departments that had previously participated in Firehouse Magazine's annual run survey reports. Given the potential for the wide range of data results, such as population figures and injuries due to fire, data was divided into different categories, such as injuries per capita based upon population of jurisdictions and the number of injuries and deaths in civilians. Data was also analyzed on civilian and fire casualties based upon the total population of the jurisdiction. The data on firefighter-only injury and death were based upon per capita of the total staffing of the individual fire department.

The original intent of analyzing the property loss was to gain an understanding of how much property was salvaged that was impacted by fire. For instance, annually, fire departments must report to the NFPA the total fire loss, but also property value saved that was involved with fire. There was a range of figures reported, some of which in all practical appearance appeared to represent the entire jurisdictional tax base saved from fire, which was not likely to be a correct variable. The National Fire Incident Reporting System requests the amount of property value that was involved in fire, that was salvaged, and not the entire tax base of a community (National Fire Incident Reporting System 2015, p. 23). This fire reporting data is what is submitted to various reporting agencies, such as the United States Fire Administration and the NFPA. Given this potential flaw in data, the actual property loss values were normalized by dividing the fire loss of the jurisdiction by the populations of the jurisdictions to obtain a variable that could be measured across the spectrum of respondents with a greater likelihood of data being accurate. Fire loss totals were divided by the population of the jurisdiction in order to have a variable that could provide an accurate measurement.

The collected data was entered into a spreadsheet, and then imported into SPSS for data analysis. The dataset was split into staffing categories of three-person crews, and four-person crews, among fire engines and ladder trucks. Some of the fire departments that utilized staffing levels other than three or four persons on engines and ladders was not used for analysis although they still responded to the survey request. This resulted in 46 fire departments who staffed engines with three-person or four-person crews. A total of 42 departments staffed with three-person or four-person crews for ladders. In situations where departments staffed one of the two apparatus types with any configuration other than three or four firefighters, only apparatus with three or four personnel was used for analysis. The median was sought for the data analyzed in

order to determine if one staffing configuration or another had a statistical difference from the other in terms of property loss or casualties. The median of frequency of injuries based upon staffing levels was sought in order to determine the average number of injuries per the population sample provided, in the associated staffing mode. The median of property loss was also sought based upon staffing configurations and populations of the jurisdictions. Meier notes that in certain instances, the median is preferred to the mean in determining the central tendency (Meier 2015, p. 95). In this instance due to data not being normally distributed, the median was the preferred statistic, over the mean. This is largely due to outliers often skewing the mean more so than the median (Meier 2015, p.95). While some outliers were accepted into the data analysis, some were not due to easily distinguishing them as being questionably accurate. Outliers were found in firefighter injuries from six departments that exceeded 30% of their total work force. Some of injury rates with their staffing illustrated in excess of 50% of their total personnel being injured over the course of 2020. Due to these outliers having such a large difference and the potential for it to skew the remaining dataset, this data was removed from the analysis of firefighter injuries (Meier 2015, p. 93). Mihaylova et al. describe the characteristics of normal distribution being sensitive to extreme values, therefore this reinforces the need to remove the extreme outliers from analysis (Mihaylova et al. 2010, p. 899). Table 1, in the Appendix, illustrates the raw data that was utilized for data analysis for this research. As noted, not all departments had data that was usable for all categories, but was analyzed where applicable.

Eight different statistical tests were run in order to determine if there was a statistical difference in property loss and human casualties where departments staff their engines and ladders with three or four firefighters. For six of these statistical tests, a Kruskal-Wallis test was

utilized. Tests analyzing civilian injuries associated with engine staffing and fire loss associated with engine staffing levels utilized an Independent-Samples Median Test from SPSS.

Discussion of Preliminary Findings, Interpretation, and Implications:

Data Analysis for Firefighter Injuries Per 100 Firefighters – Engine Staffing:

The first data analysis presented is that of firefighter injuries per 100 firefighters from departments that submitted data where they staff engines with three or four personnel. In order to determine if there was a statistical difference in the prevalence of injuries a Kruskal-Wallis test was run. There were a total of 38 fire departments that kept record of firefighter injuries and staffed engines with three or four personnel which were eligible for analysis. The resultant data analysis revealed that there was not a statistical difference in the number of firefighter injuries where engine crews are staffed with three personnel verses four. The p-value of the test was .900, which indicated that there was not a statistically significant relationship between higher injuries with either of the staffing levels assessed.

Chart 1:

Independent-Samples Kruskal-Wallis Test Summary

Total N	38
Test Statistic	.016[a,b]
Degree Of Freedom	1
Asymptotic Sig.(2-sided test)	.900

The test statistic is adjusted for ties.[a]

Multiple comparisons are not performed because there are less than three test fields.[b]

In order for there to be a statistically significant relationship where one staffing level showed to prove more beneficial in reducing firefighter fire scene injuries, there would need to be a p-value of less than .05. Chart 1 illustrates this finding above.

Chart 2:

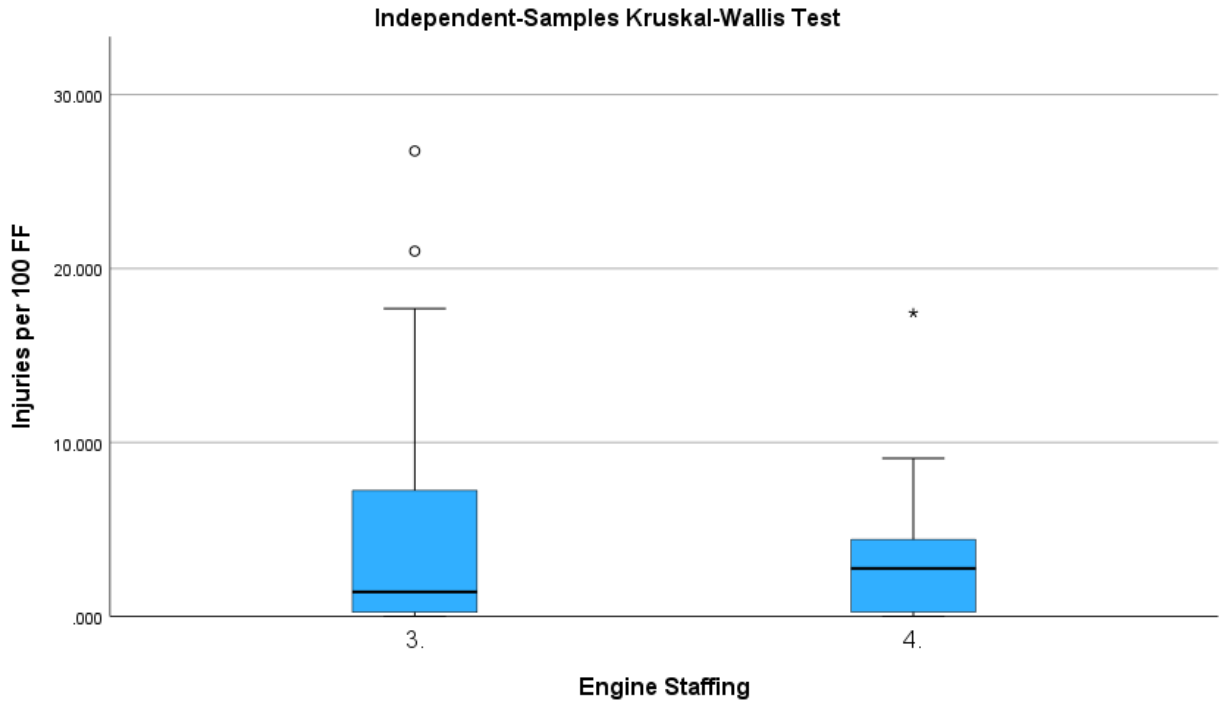


Chart 2, above, illustrates the boxplot from the data analysis. While it illustrates several instances where there are more injuries per 100 firefighters where engines are staffed with three personnel, it also illustrates some higher outliers. Thus, when statistically tested using the Kruskal-Wallis test, the significance is minor and therefore there is support to retain the null hypothesis, which rejects the notion that staffing with four firefighters on engines reduces fireground injuries for firefighters.

Data Analysis for Firefighter Injuries Per 100 Firefighters – Ladder Staffing:

The second set of data that is analyzed to determine if staffing configurations play a role in the prevalence of firefighter injuries on the fireground is the analysis of the number of firefighter injuries per 100 firefighters as it relates to ladder truck staffing configurations. In order to determine if there was a statistical relationship between ladder truck staffing configurations of three or four firefighters and the number of firefighter injuries, the Kruskal-Wallis Test was also used for data analysis. There were a total of 35 fire departments that had data that could be analyzed for this particular category. The p-value which was the result of running the Kruskal-Wallis Test for firefighter injuries per 100 firefighters where departments staff their ladder trucks with three or four personnel was .894. This value is greater than .05 and thus demonstrates that there is not a statistical relationship between ladder truck staffing levels of three or four firefighters and greater firefighter injury rates on the fireground.

Chart 3:

Independent-Samples Kruskal-Wallis Test Summary

Total N	35
Test Statistic	.018[a,b]
Degree Of Freedom	1
Asymptotic Sig.(2-sided test)	.894

a. The test statistic is adjusted for ties.
b. Multiple comparisons are not performed because there are less than three test fields.

Chart 3, above illustrates the p-value which is .894 and supports retaining the null hypothesis. The p-value would need to be less than .05 in order for there to be a statistical

relationship between staffing ladder trucks with three firefighters and having a higher incidence of firefighter injury compared to that of departments that staff ladder trucks with four personnel having a lower rate of injury.

Chart 4:

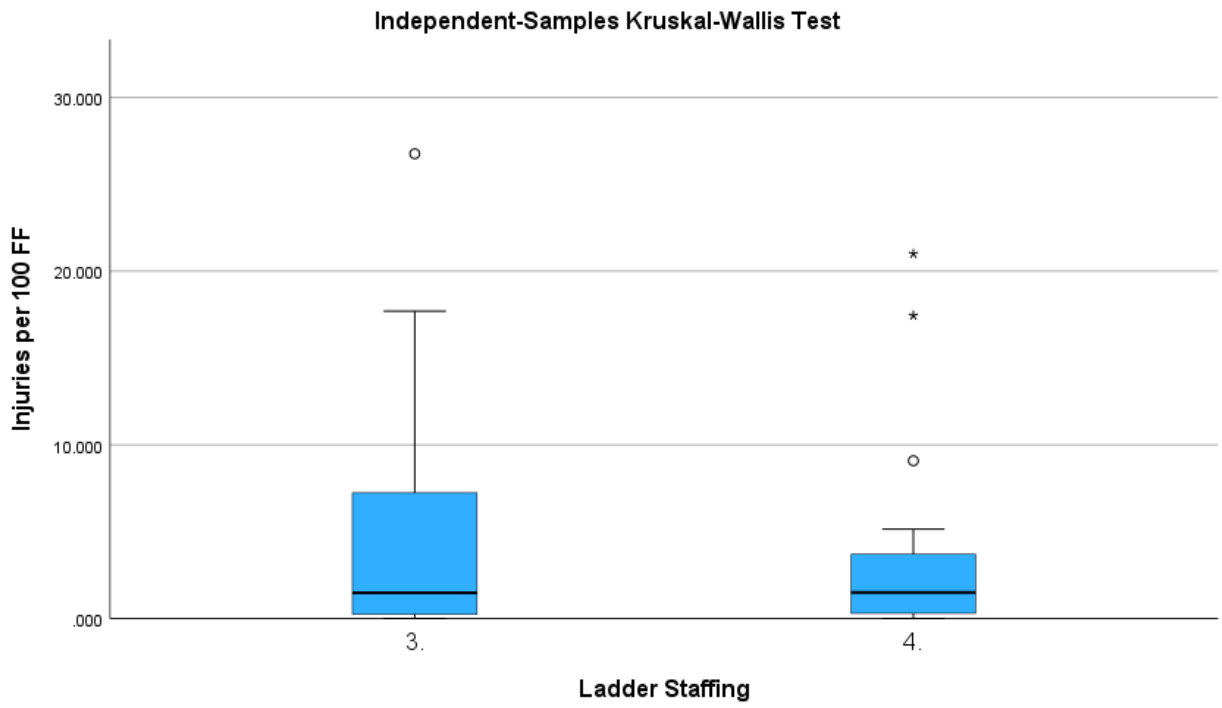


Chart 4 above illustrates a handful of values that are outside the normal distribution of the data. Chart 4 also illustrates a very slight prevalence in injuries where engines are staffed with 3 firefighters, but again, just as with engine staffing, when considering all values and running a statistical test, there is no statistical relationship noted between staffing configurations of three or four firefighters and injuries per 100 firefighters.

Data Analysis for Fire Fatalities per 100,000 People – Engine Staffing:

The next dataset for analysis examined the number of civilian fire fatalities per 100,000 people where departments staff their engines with three and four-person crews. This category saw data from 46 different fire departments that was eligible for review and analysis. Following running the Kruskal-Wallis Test on this dataset, the p-value was determined to be .220 which indicates that there is not a statistical relationship between engines staffed with three firefighters verses four as it relates to civilian fire fatalities. As previously noted, in order for there to be a statistical relationship, the p-value would need to be less than .05 and not greater than this value.

Chart 5:

Independent-Samples Kruskal-Wallis Test Summary

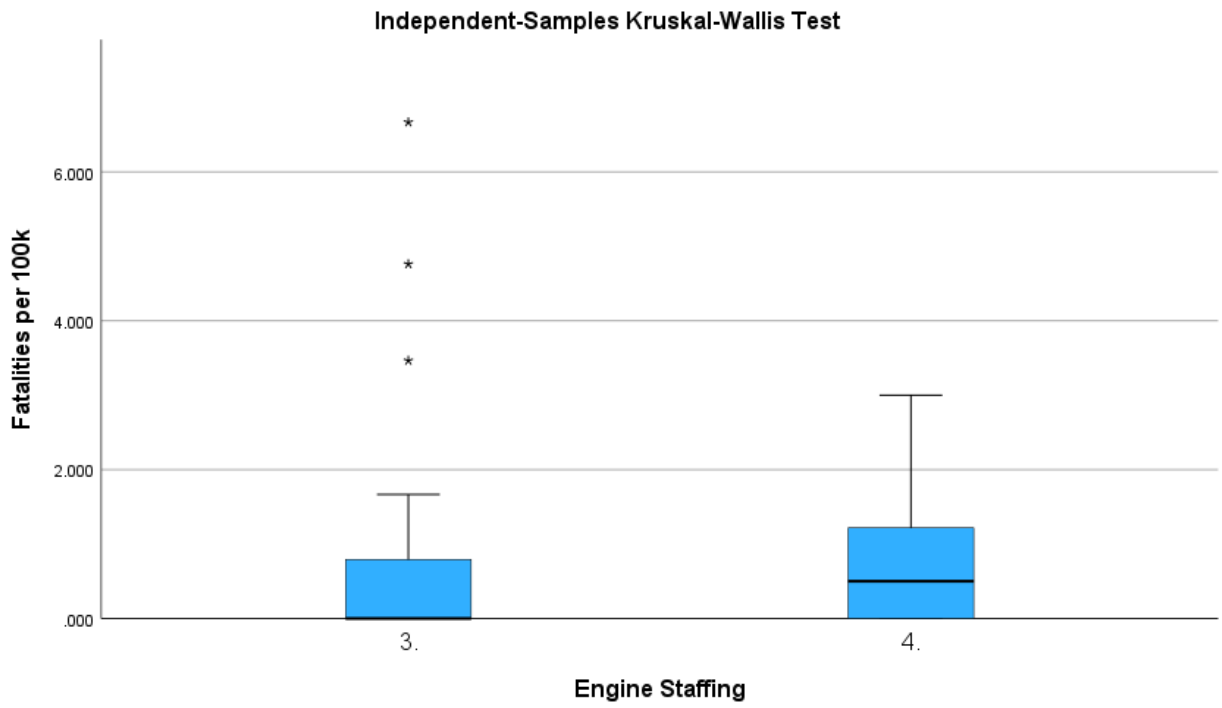
Total N	46
Test Statistic	1.506[a,b]
Degree Of Freedom	1
Asymptotic Sig.(2-sided test)	.220

a. The test statistic is adjusted for ties.
b. Multiple comparisons are not performed because there are less than three test fields.

Chart 5, above shows the p-value which at .220 suggests to retain the null hypothesis. This statistical analysis had the most departments represented in any data test performed throughout this research, as noted with data from 46 departments examined. As previously mentioned, while 53 departments submitted survey data, a maximum of 46 of them had data that was pertinent to this research.

In Chart 6, below, the boxplot illustrates several higher values within the category where engines are staffed with three personnel. However, due to the concentration of fatalities identified within the four-person staffing model after analysis there is not a statistical relationship between the staffing configurations and civilian fire fatalities. This is contrary to the hypothesis that lower staffed fire apparatus would yield a higher prevalence of fire fatalities.

Chart 6:



Data Analysis for Fire Fatalities per 100,000 People – Ladder Truck Staffing:

The next dataset for analysis involves ladder truck staffing and civilian fire fatalities per 100,000 people. There were 42 departments that submitted data that were relevant to this

dataset. This data was also tested using the Kruskal-Wallis test to determine if there was a statistical relationship between ladder truck staffing with three or four firefighters and the prevalence of civilian fire fatalities. The p-value found through testing this dataset was .369. Given the result was greater than .05, the analysis revealed that there was not a statistical significance between ladder trucks staffed with three firefighters and those staffed with four firefighters as it relates to civilian fire fatalities. Chart 7, below, illustrates the findings.

Chart 7:

Independent-Samples Kruskal-Wallis Test Summary

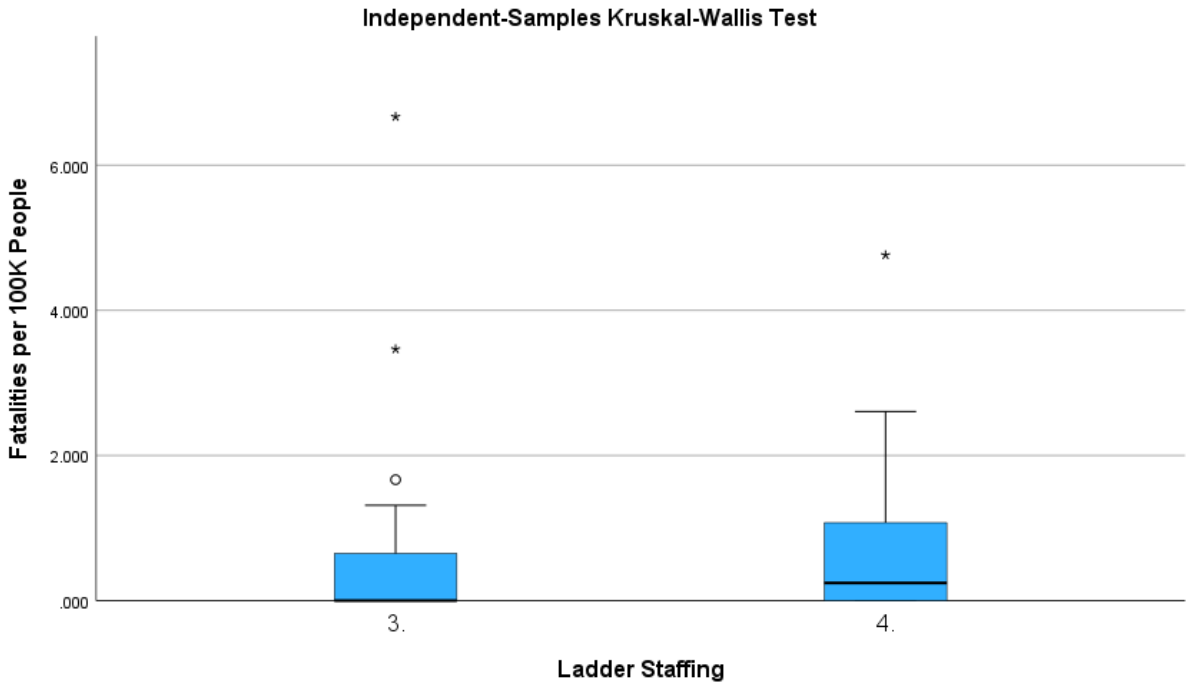
Total N	42
Test Statistic	.807[a,b]
Degree Of Freedom	1
Asymptotic Sig.(2-sided test)	.369

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because there are less than three test fields.

As with the Kruskal-Wallis Test utilizing data for engines staffed with three verses four firefighters, there were several outliers with ladder trucks staffed with three or four firefighters. Ladder trucks staffed with three firefighters saw more outliers that were higher values than those staffed with four firefighters. However, as Chart 8 illustrates in the boxplot below, there was a higher concentration of fatalities with ladder trucks staffed with four firefighters. Therefore, when statistically tested, as previously stated, the result is to retain the null hypothesis.

Chart 8:



Data Analysis for Fire Loss per 100,000 People – Engine Staffing:

Fire loss per 100,000 people as it relates to engine staffing was the next dataset tested for a statistical relationship in terms of whether more staffing has a statistical relationship to lower fire loss where engines are staffed with four personnel. Due to having more scattered outliers in this dataset, an Independent-Samples Median Test was chosen over the Kruskal-Wallis Test to determine any statistically significant relationship. There were 40 different fire departments that submitted data which could be analyzed for this particular statistical test.

In running the Independent-Samples Median Test for fire loss per 100,000 where engines are staffed with three or four personnel, the p-value was determined to be .311. As with the Kruskal-Wallis Test, in order for there to be a statistical relationship between fire loss and staffing levels, the p-value would need to have been .050 or less. Given the value was greater than .050, the

result of the test suggests to retain the null hypothesis which states there is not a statistically significant relationship between staffing levels and fire loss. Chart 9, below, illustrates the findings of the Independent-Samples Median Test.

Chart 9:

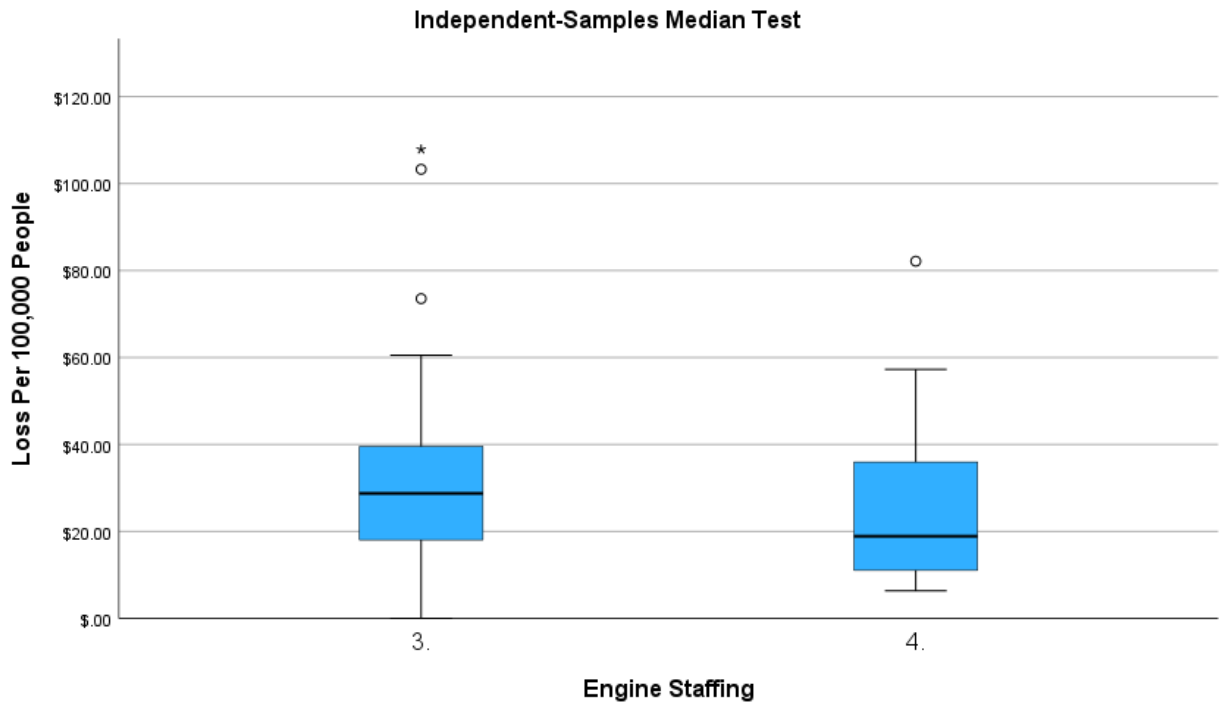
Independent-Samples Median Test Summary

Total N		40
Median		25.256
Test Statistic		1.026[a]
Degree Of Freedom		1
Asymptotic Sig.(2-sided test)		.311
Yates's Continuity Correction	Chi-Square	.456
	Degree Of Freedom	1
	Asymptotic Sig.(2-sided test)	.500

a. Multiple comparisons are not performed because there are less than three test fields.

The boxplot, in Chart 10, below illustrates the various outliers from the dataset as well as the concentrations of the data.

Chart 10:



Data Analysis for Fire Loss per 100,000 People – Ladder Truck Staffing:

The next dataset examined is the fire loss per 100,000 people for departments that staff their ladder trucks with three or four firefighters. There were 37 fire departments that reported data that was eligible for data testing in this research. Unlike fire loss and engine staffing, this dataset was tested using the Kruskal-Wallis Test. The p-value when examining ladder staffing with three or four firefighters and the associated property loss due to fire was .543. Since this value was less than .05, the result indicates retaining the null hypothesis, which means that there was not a statistical relationship between staffing ladder trucks with four firefighters verses three and having a lower figure for property loss due to fire. Chart 11, below illustrates the p-value found.

Chart 11:

Independent-Samples Kruskal-Wallis Test Summary

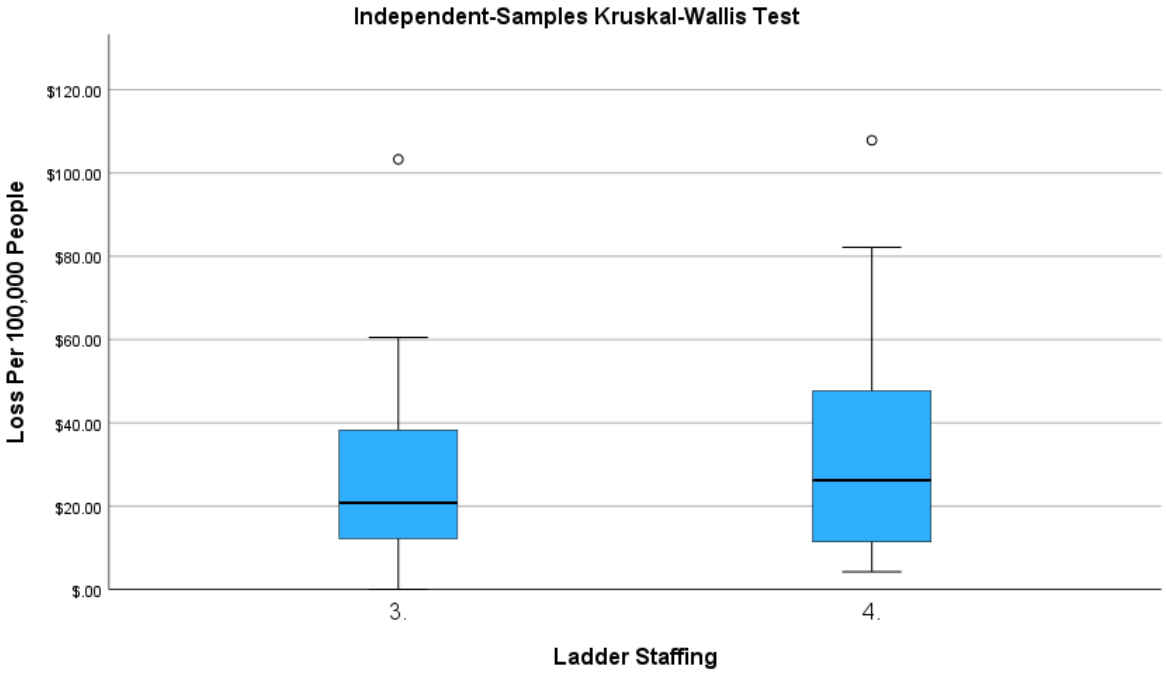
Total N	37
Test Statistic	.369[a,b]
Degree Of Freedom	1
Asymptotic Sig.(2-sided test)	.543

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because there are less than three test fields.

In Chart 12, below, the boxplot illustrates that for both staffing configurations there was a single outlier. Given the concentrations of property loss in a similar range in both staffing levels, the chart below reinforces the finding supporting retaining the null hypothesis.

Chart 12:



Data Analysis for Civilian Fire Injuries per 100,000 People – Engine Staffing:

The remaining dataset that examines engine staffing configurations is data for civilian injuries per 100,000 people related to engine staffing with three or four firefighters. An Independent-Samples Median Test was run instead of the Kruskal-Wallis Test due to extreme outliers separate from the concentrated data in both staffing categories. A total of 43 fire departments had data that could be tested in this category.

When engine staffing and the corresponding civilian fire injuries per 100,000 people was tested using the Independent-Samples Median Test, the resultant p-value was .666. Given this value is greater than .050, it indicates that the null hypothesis should be retained and that there is not a statistically significant relationship between the staffing levels and number of civilian fire injuries. Chart 13, below illustrates these findings.

Chart 13:

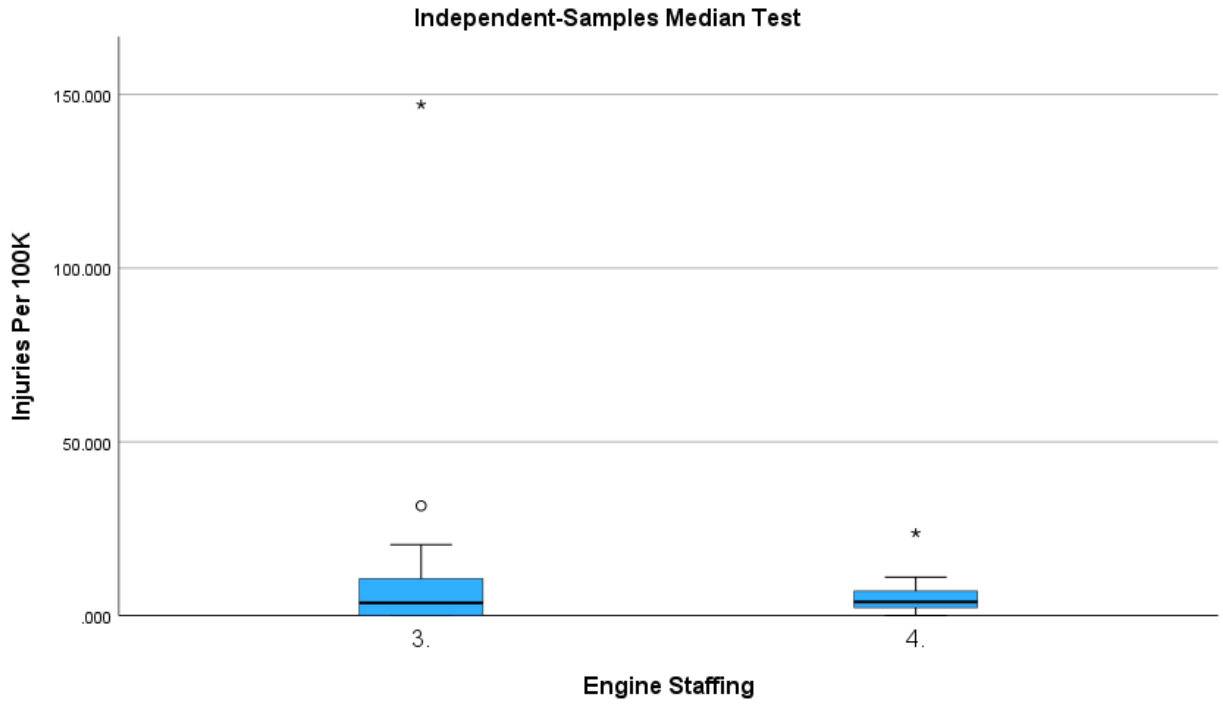
Independent-Samples Median Test Summary

Total N		43
Median		3.750
Test Statistic		.186[a]
Degree Of Freedom		1
Asymptotic Sig.(2-sided test)		.666
Yates's Continuity Correction	Chi-Square	.012
	Degree Of Freedom	1
	Asymptotic Sig.(2-sided test)	.911

a. Multiple comparisons are not performed because there are less than three test fields.

The boxplot below illustrates that there is very little difference in the concentrations of injuries per 100,000 people between departments that staff three and four firefighters. An extreme outlier does appear in the category where three personnel are staffed on engines. This is the reason for the Independent-Samples Median Test instead of using the Kruskal-Wallis Test with this dataset.

Chart 14:



Data Analysis for Civilian Fire Injuries per 100,000 People – Ladder Staffing:

The final dataset to be statistically tested was that of civilian fire injuries per 100,000 people as it relates to ladder staffing configurations of three or four firefighters. This dataset was tested using the Kruskal-Wallis Test with a resulting p-value being .102. In order to support findings that one staffing configuration or another shows a statistical advantage of having fewer civilian fire injuries, the outcome would have to have been .05 or less. In this case, as it was .102, as illustrated below in Chart 15, the null hypothesis would be retained.

Chart 15:

Independent-Samples Kruskal-Wallis Test Summary

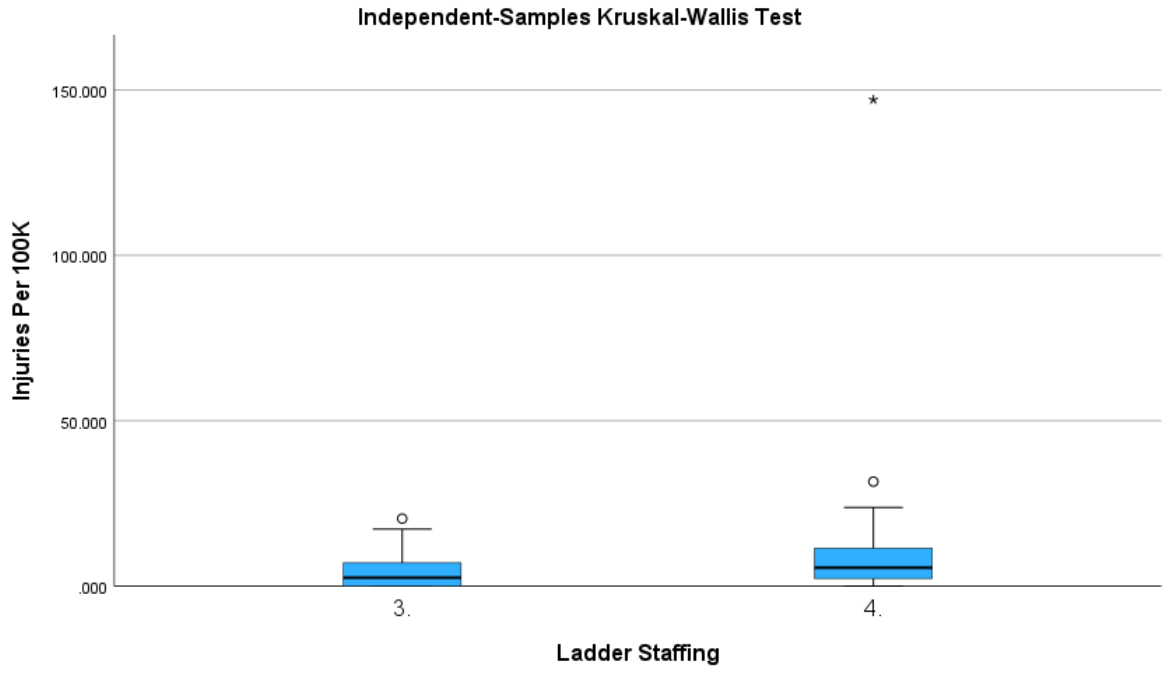
Total N	39
Test Statistic	2.679[a,b]
Degree Of Freedom	1
Asymptotic Sig.(2-sided test)	.102

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because there are less than three test fields.

In Chart 16, below the civilian fire injuries per 100,000 people as it relates to ladder truck staffing are fairly low. There were two outliers for each staffing configuration, just above the primary concentrations, with one extreme outlier where ladder trucks are staffed with four firefighters. It is unknown why this outlier was so far and above other data, but it did present itself as a singular oddity.

Chart 16:



Summary:

Following the evaluation of the previous charts and statistical tests it was determined that there does not appear to be a correlation between higher staffing levels of fire apparatus and fewer human casualties and lower property loss, in most cases. There were some minor differences found throughout the data analysis, but in all instances of the aforementioned data testing, staffing with four personnel did not demonstrate a higher level of protection of life and property.

This finding was surprising, as there are many other studies, such as the NIST fireground experiments that indicate larger fire crews, particularly those of four firefighters are more efficient than smaller crews such as three firefighters accomplishing critical fireground tasks.

This would lead one to believe that more efficient crews accomplishing fire ground tasks more expediently would have a positive result on property loss as well as human casualties. There were some categories within this research that showed minor differences where arguments could be made that one staffing configuration over another when looking very simplistically at the data. For instance, in firefighter injuries, it appeared that there were more instances of injuries to firefighters when department's staffed engines and ladders with three personnel. The same could be argued for fire loss as well, with a wider range being shown for three-person engine staffing. However, as noted, in these instances when considering all of the data, it was insufficient to give credibility to stating one staffing configuration or another proved beneficial in lessening fire loss and human casualties. This necessitated the need to conduct scholarly accepted statistical testing, including incorporating the Kruskal-Wallis Test and the Independent Samples Median Test. Thus, the null hypothesis appears to be supported, that higher staffing levels do not result in less property loss and fewer fire casualties as statistically noted both staffing configurations resulted in similar results.

Chapter Five: Conclusions:

Overview and Discussion:

As discussed in the concluding paragraphs of Chapter Four, there appeared to not be a correlation between higher staffing levels of certain fire apparatus types and lower numbers of human casualties and property loss due to fire. Two types of statistical tests were run in order to determine if there was a statistical relationship between the staffing configurations and lower property loss due to fire as well as fewer human casualties due to fire. The most prominent statistical test utilized in this research was the Kruskal-Wallis Test. The Kruskal-Wallis Test was chosen largely due to the fact that the data was determined to be not normally distributed. This is due to the range of fire departments that reported data, serving populations ranging from just under 7,000 to almost 3,000,000, with a wide range in between. Given the fire departments that reported data had this significant of a population range, with fewer departments reporting data that had populations above 750,000, data was clumped at the lower end with data becoming more sporadic as populations increased. While these communities all have professional firefighters, they also all have a wide range of resources available to them, including fire apparatus, training resources, and fire prevention services and education, which all can have an impact on fire outcomes.

In looking at casual observations, while there were no statistical correlations indicated between the staffing levels and higher property loss or casualties, there are negligible differences illustrated in several of the box plots. For example, with engine staffing levels, there were very slight observed advantages in lower firefighter injuries, civilian injuries, and lower property loss due to fire with 4-person staffing. These observations were minimal and proven not statistically significant through data testing. However, it is important to note the difference when examining

engine staffing, as engines are the primary apparatus type that all fire departments utilize to respond to the majority of emergencies within their jurisdictions. Fire engines are the primary type of apparatus that respond to and conduct fire suppression activities and emergency medical responses and are generally focused on a quick response to these types of incidents (Norman 2019, p. 39). The NFPA states that engine companies "primary functions are to pump and deliver water and perform basic firefighting at fires, including search and rescue" (NFPA 1710, 2020, p. 1710-11).

Ladder trucks, while an integral part of any structure fire response with departments that utilize them, assume a different role in fire response as defined by the NFPA. NFPA 1710 states that the primary functions of ladder companies involve forcible entry, ventilation, search and rescue, aerial operations for water delivery and rescue, utility control, illumination, overhaul, and salvage work (NFPA 1710, 2020, p. 1710-11). While ladder trucks are intended to function differently than engines at fire scenes, depending upon the arrival sequence of apparatus types, their personnel sometimes may find themselves performing other duties as necessary to ensure scene objectives are met, therefore ladder truck staffing is relevant in this study as they are also heavily relied upon in many career fire departments.

In addition, NFPA 1710 states that ladder companies shall be staffed with a minimum of four personnel (NFPA 1710, 2020, p. 1710-11). Given the NFPA recommendation of a minimum staffing of four personnel for ladder companies, it is perplexing that in this particular dataset, ladder trucks that are staffed with three personnel illustrated slightly lower numbers of civilian injuries, lower fatalities, and lower property losses than departments that staff their ladder trucks with four personnel. It is important to recognize that in this data analysis though, many of these fire departments staffed engines with configurations other than four firefighters. These results

also point towards the importance of engine staffing and the significance that engines play in early mitigation of structure fire incidents.

Again, there were not statistical correlations between one staffing configuration or another and lower property loss and lower casualties. However, the casual observations of differences between apparatus types and staffing configurations affirm that there was not a reliable correlation between larger crews and property savings or fewer casualties.

The process which was undertaken to obtain data was tedious as well as time consuming in order to reach as many departments as possible. Challenges were encountered in efforts to obtain data from fire departments. Many fire departments readily responded to the survey where data could be input for the purposes of this study. Other departments did not participate, as 109 fire departments were contacted directly for necessary data to be used to evaluate the benefits of different staffing configurations. Fire accreditation consortiums were also contacted to distribute the survey to the 531 fire departments represented by these consortiums.

Efforts to reach departments began with contacting fire accreditation consortium groups across the United States and Canada, which act as a support system for fire department accreditation. The request was that the consortium groups distribute the survey and survey link to their membership, which in some cases included fire departments in multiple states, and in the entirety of Canada. Some consortiums responded with enthusiasm, such as those in Texas, North Carolina, and the Rocky Mountain Regional Consortium, and readily distributed the data request to their members. Outside of the consortium groups contacted, departments were individually contacted by going down a list of departments that had submitted annual run data to *Firehouse Magazine*. It was not apparent how many of these departments responded, but given the number of departments contacted as previously described, the response rate was marginal at best.

Only Canadian and American fire departments were sought out and contacted directly to request their participation in the data survey. This dissertation is premised upon the assumption that the vast majority of departments that participated in this research are accredited departments, largely based on the fact that in order to be accredited, orderly data is kept readily accessible and frequently utilized to evaluate department performance. In addition, these departments strive for continuous improvement as part of their accreditation model, therefore any research to further the fire service is expected to be met with interest. The trend for the fire service to accept data as part of its performance improvement is encouraging. There are still great strides to be made in scholarly research related to the fire service. This dissertation will contribute greatly to the lack of academic research and study of fire service data.

As noted, it was discovered that there was not a statistical relationship between lower numbers of fire casualties and lower property loss when fire engines and ladders were staffed with four personnel. This finding was surprising based upon literature and documentation about the increased efficiency of four-person crews found from conducting the NIST fireground experiments, both the residential fireground experiments and the high-rise fireground experiments (Butler 2013; Robinson 2010). For instance, in experiments in both in measuring the amount of time it took to put water on the fire and the time it took to conduct a primary search in the NIST residential fireground experiment, four-person crews did both of these tasks 6% faster than three-person crews (Robinson 2010, p. 39-40). These two fireground tasks in particular would be important in terms of preserving property by stopping the fire as soon as possible by applying water to it. Likewise, if there are victims trapped in a fire, the primary search is the task that would discover them and have firefighters pull them to safety.

Limiting the fire spread, by applying water onto it alone, does a lot to minimize property loss due to fire, as well as to minimize the danger to any occupants that may need escape or have to be rescued by responding fire crews. It was hypothesized that an increase in the time to apply water on a fire and stop it would conversely show greater fire loss and increased casualties. It is also hypothesized that according to the NIST studies, these actions would take longer with three-person fire crews instead of four-person crews. When looking at a dataset from multiple fire departments with various staffing configurations on fire apparatus from this research though, and statistically testing the data, this hypothesis is disproven.

The same hypothesis could be made for statistics related to fire fatalities and fireground injuries, to both civilians and firefighters when considering differences in time to conduct a primary search. If it takes a crew of four less time to locate a victim during a search, it would be expected for departments that staff with four firefighters verses three on apparatus that this would illustrate a positive difference in outcomes related to fire casualties. However, given the results that there was not a statistical correlation between the two staffing levels and a difference in casualties, both injuries and fatalities, then possibly other factors become more relevant. For instance, the nature of rapid spread of fire may be a more important variable related to casualties than staffing levels of fire apparatus. This means that even if multiple fully staffed apparatus with four firefighters responded to a fire, other conditions may play a more prominent role in the outcome of any fire victims. This may include, but not be limited to, the extent of fire growth before the emergency response system is activated, or even as simple as responding fire apparatus are geographically distant to their destination.

The variable of the growth of a fire before responders arrive to mitigate it also is likely a factor in how efficient the fireground task of applying water to a fire impacts an overall fire

incident. As described, while crews of four firefighters have been shown to be the most efficient in the NIST Residential Fireground Experiment, if there is rapid fire growth before their arrival, or if other responding fire apparatus are some distance away, it simply may not be enough of a factor to limit loss or diminish casualty figures.

The primary goal of this research was to determine if staffing levels on engines and ladder trucks lent itself to lower casualties due to fire and to determine if there was a correlation with lower fire loss and staffing these apparatuses with four firefighters verses three. While it was determined that there were no statistical relationships between these two staffing configurations and lower property loss and casualties, its important to take a brief look into what other actions may lower these variables.

Recommendations for Future Research:

Given that there has been extensive experiments conducted that demonstrate optimum staffing levels of four-person fire crews are more efficient on the fireground that three-person crews, it is notable if the question of utilizing four-person crews verses three-person crews can make an overall impact on fire loss and casualties after determining there was not a statistical relationship found in this dissertation? However, if future research is undertaken in this area it would be beneficial to seek a larger survey pool. This was a challenge in and of itself however, as fire departments were contacted across the United States and Canada, directly and indirectly as noted previously. Response rates were low based upon the number of contacts made. If more department data could be obtained then it would provide a wider sample size to undertake research. The results may not differ, but a larger sample base would provide a more comprehensive overview of data. In addition, if a wider sample base could be obtained, multi-year data should be undertaken. In this particular study, only data for the year 2020 was utilized.

Just as more department data would provide a wider sample, multi-year data would do the same. According to the Center for Public Safety Excellence fire departments have been slow to begin utilizing data for the benefits it can bring to improve public safety, but there is a shift from "tolerating data to embracing it" for the information it can provide to deliver a more effective service (Fire Analyst 2022).

There were other factors identified throughout the research of this study that have impacts on fire loss and human casualties. As discussed in the previous section, fire prevention activities, whether they be active, passive, or discretionary have been shown to be beneficial in reducing fire loss and casualties. As briefly mentioned in Chapter Two, fire prevention and fire safety education activities may be an avenue worth exploring for fire departments in order to reduce fire risk and subsequent casualties and fire loss. Fire prevention and fire safety education is already a staple in most departments in order to reduce the risk of fire in communities. However, it may play a larger role that is frequently credited, as it is difficult to determine the amount of fire loss and casualties that didn't occur due to fires not occurring.

Delorme and Waterhouse have however done extensive work in determining the economic benefits of prevention activities, particularly in the province of Quebec. One such study for the municipality of Thetford Mines, which has a population of over 25,000 and serves an area of 87 square miles, seeks to place a value on the benefits of fire prevention activities in this municipality (Delorme and Waterhouse 2022, p. 7). An example of the benefits that were found from the investment in fire prevention activities in Thetford Mines was that an increase in 1% of fire prevention investments saw a 15% increased benefit in property value preservation (Delorme and Waterhouse 2022, p. 2).

Delorme and Waterhouse describe two types of prevention activities, active and passive, and discretionary. Active and passive prevention efforts are described as building code regulations and other structural components such as the utilization non-combustible building materials and the installation of fire sprinklers as examples (Delorme and Waterhouse 2022, p. 20). These prevention activities require an initial investment, but as Delorme and Waterhouse note have long lasting impacts (Delorme and Waterhouse 2022, p. 20). The authors indicate that active and passive fire prevention activities are the most accurate in terms of quantifying value (Delorme and Waterhouse 2022, p. 20).

Discretionary prevention activities involve targeting certain populations for fire safety education, such as school programs and other public education events. These programs are effective at targeting specific populations, but have some challenges as well. Delorme and Waterhouse note that these activities require constant evaluation to determine target audiences based upon recent fires, the socio-demographic nature of a community, and the staffing and funding required to conduct the education (Delorme and Waterhouse 2022, p. 20). Nonetheless, the investments of the combined fire prevention activities of active and passive methods in conjunction discretionary ones are proven methods to decrease fire loss and decrease casualties.

Another study of the benefits and positive impacts of fire prevention activities was conducted in Sweden by examining the number of fires in a specific region between 2000 and 2016. Beginning in 2010, a regional fire and rescue service in southern Sweden began a fire prevention initiative to utilize on-duty fire personnel to conduct in-home fire safety inspections. The model utilized fire crews already on-duty and targeted populations that were deemed more at risk for a residential fire, such as the elderly and the young who had recently moved out from their parents' home (Sund et al. 2019, p. 40). The study examined two types of fires at residences,

one referred to as a “fire” where a fire had occurred and fire services arrived on scene, and a “developed fire”, which would be considered a fire that was still active upon the arrival of firefighters (Sund et al. 2019, p. 40).

For the years 2010 through 2016, the study revealed that there was a 6% reduction in fires per year and an 8% reduction in developed fires per year. The study attributes this reduction to the in-home fire safety visits that the regional fire and rescue services undertook (Sund et al. 2019, p. 45). Given these home safety checks involved on-duty personnel in existing fire stations, there was not an added cost to implement this program. However, an initiative such as this would have to be voluntary with residents in private homes granting permission for local firefighters to conduct these checks.

Expanded studies in localities above and beyond what has been done by Delorme and Waterhouse would show the benefits of investing in fire prevention measures in other jurisdictions as well. Most municipal career fire departments carry out some form of fire prevention activities by either conducting fire safety inspections or conducting public education about fire safety. This can be using a dedicated division to conduct these duties or utilize suppression personnel who are on shift to carry them out (Lacey and Valentine 2008, p. 38-40). Research into the benefit of additional fire prevention personnel to counter fire loss and fire casualties is worth exploring as real economic benefits have been shown as tangible in studies of the economic benefits of fire prevention activities. The benefit of additional fire prevention personnel should be researched to determine if this is a more cost-effective staffing option to adding additional firefighters to apparatus if the goal is to decrease fire casualties and property loss due to fire.

Another factor for consideration in the research of decreasing fire casualties and property loss due to fire as it relates to staffing is to consider the geographic placement of fire apparatus and dependent upon staffing configurations what role this may play? Do more fire trucks with less people on them provide for more rapid responses to fires and thus promote a faster application of water to fire, thus stopping it? As described in Chapter 1, the NFPA recommends a certain compliment of firefighters to attend residential structure fires, with either 16 or 17 firefighters depending upon the types of apparatus involved (NFPA-1710 2020, p. 1710-12). As noted previously personnel costs are ongoing whereas equipment cost while recurring, are much less so than additional personnel. It is imperative that policy makers provide their communities with proper and adequate fire protection, but research would be valuable to determine if smaller crews on more apparatus would be as efficient as more personnel on fewer apparatus.

Overall, research on the effectiveness of fire crews and their staffing compliments should be explored again, either using multi-year data, or attempts should be made to obtain a wider sample. It has been demonstrated through simulations that crews of four are more effective at accomplishing fireground tasks than crews of three, therefore additional research would either reinforce the findings from this study or support the NIST studies in their findings that crews of four provide more favorable results on the fireground.

Conclusions:

The research from this dissertation begins to fill voids in academic research in the efficiency in the delivery of fire protection services for communities. The findings from this dissertation offers evidence for data driven local governments and fire departments to make sound decisions in protecting their communities through balancing adequate services without undue tax burdens being placed upon citizens that fund government service provisions. This dissertation also raises

questions and encourages future research into finding optimum levels of fire apparatus staffing for the safety of communities and firefighters alike. In addition, other segments of services provided by fire departments are identified that deserve future research as methods to further enhance fire protection, reducing property loss, and lowering the number of fire casualties.

Through extensive data gathering and statistical testing it was determined that there was not a statistical correlation in fire apparatus staffing with three or four firefighters and a reduction in property loss due to fire or an increased number of human casualties due to fire from the data gathered. These findings were not expected as there is a considerable amount of research, as indicated throughout this text, of simulations and experiments that attribute staffing levels of four firefighters being optimal to performing critical fireground tasks. Firefighting is a physically demanding profession which also requires a team of firefighters to accomplish critical and frequently hazardous tasks. Therefore, if there are fewer people to accomplish these tasks, it can be physically taxing on the individuals undertaking them. However, while this study examined apparatus staffing levels it did not address individual department response plans and how many apparatus and personnel a fire department would typically dispatch to a structure fire incident. This research is meant to compliment existing studies where firefighter crew staffing configurations were examined, such as the NIST studies referenced throughout this text. The NIST studies were simulations, while this study was conducted to investigate whether actual incident data reflected the results from the NIST studies which would then translate to less property loss and fewer casualties with apparatus staffed with 4 personnel. While the NIST studies did illustrate efficiency with optimal staffing configurations, the statistical tests and data gathered through this research deemed staffing difference between 3 and 4 firefighters on

engines and ladders inconclusive of an advantage of one configuration or the other using actual incident data.

Implications as a result of these findings may be beneficial to policy makers as long as it is taken appropriately and policy decisions that involve fire apparatus staffing are not taken literally as the result of this study only. The provision of adequate fire and rescue services to a community involves a number of factors and variables and while staffing configurations are critical, each community must decide what is proper by taking into consideration all of these factors and not just this study. These variables can include but are not limited to, the hazards present in a community, the available budget of the jurisdiction, the number and geographic placement of fire or rescue apparatus, as well as specific services that a particular community demands of its local jurisdiction.

The findings however, do have value in that they demonstrate little significant difference in staffing between three and four firefighters in terms of property loss and human casualties due to fire from true incident data. As noted previously, these facts should not be used against other long trusted research that has demonstrated the efficiency of crews of four firefighters on firegrounds verses three. This research simply illustrates the lack of a statistical relationship between the two staffing configurations and an advantage on property loss and human casualties.

Due to the findings, there is concern that some policy makers would choose to reduce fire department staffing in order to preserve funding or divert it to other governmental services. Considering each community and its needs are unique this may not be advisable or prove in the community's best interest in terms of fire protection.

There is also the potential that many fire personnel will seek to reject the findings of this study as it does not promote the staffing of four firefighters on engines and ladder trucks as a

method to reduce property loss or casualty figures and can be interpreted as being contrary to the NIST studies. Firefighting is an inherently dangerous activity and those engaged in it may find strength in numbers. While this research does not promote the reduction of an effective response force of 16-17 firefighters for a first alarm assignment to a residential structure fire, as recommended by NFPA, there is the potential for some policy makers or firefighters to suggest it does in fact do that.

The results of this research have not only identified the lack of a statistical correlation between staffing levels of apparatus and fire loss and casualties, but has also highlighted other identified methods to reduce fire loss and casualties. Fire prevention methods have been identified as a proven investment in reducing the number of fires, which then result in property loss and human casualties. Sufficient personnel to extinguish a fire and operate safely on a fireground remains critical for the safety of communities, but the importance of fire prevention methods identified herein cannot be underestimated to have a positive impact on this well.

It was also the intent of the research to determine if there was an economic advantage of one staffing configuration or another if one of them showed a marked decrease in property loss and casualties. However, as indicated, with no statistical advantage to either staffing configuration demonstrating a decrease in property loss or casualties, it was determined that neither staffing level examined provided an economic advantage such as preserving property and decreasing casualties which also impact a community economically as discussed in prior chapters.

Summary:

In summary, firefighting is an important function of many local governments in the United States and Canada and it is of interest to policy makers and citizens alike to determine methods to improve the service. Determining an optimal staffing level for fire apparatus in order to

provide the most efficient service that can meet the challenging nature of responding to emergencies is an important element to fire chiefs and local governments. Determining the optimal staffing level of each fire department in different communities should be a decision based a number of factors. These may include budget, determined need, NFPA recommendations, among other factors. Therefore, the findings of this research, while useful, should not solely be the consideration of policy makers when determining how to staff their fire apparatus.

While numerous trusted sources and research have shown efficiency in certain staffing models, this did not readily apply in this research. This study utilized actual incident data, along with fire apparatus staffing information, gathered from over 50 fire departments across the United States and Canada that included property loss, civilian deaths, civilian injuries, and firefighter injuries that were related to fire incidents in the year 2020. Through statistical testing utilizing SPSS statistical software, it was determined that there was not a statistical relationship that demonstrated and advantage of one staffing configuration or another, 3 verses 4 firefighters on an apparatus, on reducing casualties and property loss due to fire.

The data gathered from these fire departments was widespread, as it included departments that served populations from just under 7,000 people to almost 3 million. Fire department budgets from those that submitted data also ranged from a reported low figure of $750,000 to a high number of over $507 million. These departments had various staffing levels on their engines and ladder trucks which predominantly consisted of three or four firefighters. It was this data that was tested statistically for any relationship that demonstrated an advantage of either staffing level in reducing casualties and property loss. While there were minor differences among datasets in differences, none in the entire analysis was statistically significant. Even

though there were no findings that indicated staffing a fire apparatus with four personnel reduces property loss and casualty figures verses a staffing of three personnel, it is still the hope that this research can be a tool for policy makers when deciding on the optimal model for fire protection for their communities. Fire protection services must be sufficient to protect citizens from known and potential hazards that impact their local areas, as well as to provide the firefighters that protect them the confidence that they are equipped with proper resources and personnel to do so regardless of the results of research.

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Appendix:

Table 1: Survey Data

Engine Staffing	Ladder Staffing	Civilian Injuries	Civilian Fatalities	Firefighter Injuries	Firefighter Fatalities	Fire Loss	Jurisdiction Population	Department Budget	Total Department Staffing
4	3	Not Reported	13	Not Reported	0	Not Reported	2,000,000	$285,181,940.00	2733
3	3	2	1	1	0	$2,432,050.00	60,000	$10,000,000.00	115
3	3	0	1	0	0	$1,245,225.00	180,000	$65,000,000.00	270
3	4	5	0	2	0	$2,959,420.00	62,000	$16,761,772.00	139
4	3	9	0	5	0	$1,710,839.00	174754	$24,744,362.00	245
3	3	0	1	2	0	$0.00	15,000	$5,700,000.00	36
4	4	95	6	75	0	$20,000,000.00	400,000	$62,000,000.00	430
3	3	10	0	2	0	$1,750,395.00	116,000	$26,000,000.00	145
4	4	36	3	16	0	$11,938,561.00	489,683	$80,385,250.00	459
	3	3	0	46	0	$1,592,784.00	164,000	$46,000,000.00	132
3	4	17	1	0	0	$12,619,581.00	117,000	$29,159,000.00	286
3	3	1	0	0	0	$2,540,830.00	146000	$25,500,000.00	152
4	4	2	0	0	0	$1,007,000.00	85,400	$22,200,000.00	150
3	3	0	0	0	0	$78,265.00	19,000	$35,000,000.00	150
3	3	4	0	3	0	$10,719,664.00	278,000	$41,000,000.00	308
3	4	5	2	1	0	$1,574,047.00	42,000	$10,000,000.00	145
3	3	2	2	6	0	$3,619,595.00	152,244	$32,288,768.00	280
4	4	3	0	0	0	$1,655,430.00	150,000	$43,000,000.00	303
3	3	0	0	0	0	$942,000.00	41000	$16,000,000.00	71
4	4	43	22	333	0	$19,368,360.00	1700000	$507,076,141.00	3666
4		36	5	3	0	$24,167,071.00	1,280,000	$168,169,144.00	1492
4	4	3	0	3	0	$1,599,019.00	44473	$13,576,702.55	81
3	3	0	0	1	0	$2,065,600.00	20000	$750,000.00	63
3	3	11	0	11	0	$1,121,971.00	53922	$13,000,000.00	152
3	4	0	0	0	0	$127,300.00	30000	$4,400,000.00	53
3	4	10	0	10	0	$500,000.00	6800	$2,000,000.00	30
4	4	10	0	6	0	$12,338,960.00	150,227	$36,421,705.10	400
4	4	0	0	2	0	$227,900.00	36,000	$10,341,300.00	55
4	4	33	2	31	0	$7,794,443.00	298,263	$65,325,096.00	603
3	3	48	0	89	0	$11,672,500.00	367,758	$80,510,389.00	503
3	4	9	4	8	0	$4,490,252.00	240,000	$37,000,000.00	369
4	4	3	2	75	0	Not REported	76,728	$15,991,479.00	148
3	3	14	1	70	0	$8,068,744.00	555,000	$146,000,000.00	581
3		4	0	5	0	$2,566,191.00	72,000	$12,000,000.00	130
4	4	51	8	10	0	$18,000,005.00	2304580	$507,076,141.00	3398
3	3	0	0	2	0	Not Reported	321,357	$15,995,407.00	874
3	3	7	0	44	0	$2,462,028.00	40,687	$23,632,100.00	143
3		0	0	8	0	$1,293,771.00	45,000	$9,500,000.00	70
3	4	12	0	21	0	$1,000,000.00	38,000	$10,000,000.00	100
4	3		20	0	0	Not Reported	2,900,000	$376,322,560.00	3,100
4	4	8	1	420	0	Not Reported	700,000	$190,000,000.00	802
3	3	12	1	7	0	$12,695,607.00	334,000	$72,364,581.00	600
3	4	6	1	3	0	$4,124,601.00	136,000	$24,700,000.00	310
4		20	3	244	0	$14,100,000.00	246,161	$84,000,000.00	501
3	3	7	0	21	0	$1,525,702.00	75,000	$13,694,643.00	141
3	3	11	7	118	0	$12,124,255.00	201,998	$53,230,908.00	441
4	N/A	Not Reported	6	Not Reported	0	Not Reported	200,000	$45,000,000.00	427