Navy Fire & Emergency Services

Model and Simulation of Structure Loss Due to Fire

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SYST 798 / OR 680

5/7/2012

Executive Summary

One of the important responsibilities for the various branches of the United States Department of Defense (DOD) is to provide fire and emergency services to the general public within its installations. Due to population changes and funding constraints the placement of these services in locations that provide a timely and efficient crisis response capability is a necessity. US Navy installations around the world have diverse missions and infrastructure, but all require fire and emergency services. As the federal government continues to discuss budget cuts and spending limitations it is unreasonable to expect that federal fire and emergency services will be exempt from the planned cuts with the DOD. As these cuts are made there must be an accurate evaluation of proposed changes and the effects that these changes will have in fire and emergency service ability to respond. Any change in response time may delay initiation of crisis mitigation such that the level and likelihood of a negative outcome will increase. Treatment of injuries and smoke exposure may be delayed resulting in death that might have been prevented if earlier response was possible. Fire can spread quickly through a structure and delayed arrival of emergency response equates to time that a larger percentage of the structure will be damaged.

The scope of this project was to review and evaluate published information about the spread of fire, time for emergency services to respond, and expected damage values, and to create a loss model from which an expected change in loss percentage can be estimated. These results of this project can then be used to analyze the effects of possible budgetary cuts that would eliminate or redistribute emergency service assets for US Navy Fire & Emergency Services. The potential loss of life is expected to increase as fire damage increase, however, that change and costs are beyond the scope of this project.

The study of fire behavior and its contributing factors was significant to this project. There was no experience within the group members that directly related to this topic. Interviews with experts and an extensive open source review for potential sources of information were conducted to achieve as much detailed knowledge as possible.

Work from a previous George Mason University project team for our project sponsor resulted in a scenario simulation model coded into Excel. While we briefly considered other software choices, our loss model was implemented in Excel and should be able to be integrated with previous and follow on work. As a result of the open source research and interviews with subject matter experts, the team constructed a loss model that utilizes makeup of a Weibull probability distribution.

The total loss of a building as a function of time has a similar shape to the highly adaptable Weibull cumulative distribution function (CDF). By varying the alpha and beta parameters of a Weibull, a damage curve is produced. Since the derivative of a CDF is a probability density function (PDF), the team hypothesized that the Weibull PDF can characterize the rate of loss over time. Given arrival times for the first two response assets, a mitigation effect of the firefighters was implemented within the PDF curve that would reduce the rate of fire damage and therefore the total damage to the structure. The model uses reported percentages of national fire data related to where a fire starts, whether it is contained in a single location or spreads throughout the structure, and the performance times of different sized fire response crews.

The loss model generates repeatable results with given inputs and applied variability. The trends of the curves are consistent with expected results. Fires that burn longer and spread across multiple rooms and floors result in a higher damage percentage. The simulation results show significant levels of variation across resource conditions in expected structural damages and the histogram data which displays the frequency of damage within specific thresholds.

Further work on the project beyond the group's work here would likely involve expanding the model to include loss of lives or injuries. Additionally, the team limited the project scope to family residential building fires. While small office spaces would be expected to have similar space considerations, the likelihood of sprinklers and automatic fire alarm panels would require modifications to the current model.

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1. Introduction

1.1. Background

The United States Navy has more than 70 installations worldwide that require fire and emergency service (F&ES) resource responsiveness in order to protect personnel and building assets during accidents or other hazardous events. But the federal budget is a competitive environment where many departments face severe cuts. Agencies have been pressed by these circumstances to minimize the impact of these cuts by maximizing the value that each dollar achieves. Navy F&ES wants to be prepared when such reductions are experienced.

1.2. Need

During the fall 2011 semester a George Mason University (GMU) project team started analyzing the effects of F&ES resource changes on likelihood of loss based on type of event, priority level of event, and response times. This project group utilized a grid map system of the GMU Fairfax campus as a mock navy installation, designating three major campus structures as fire stations with varying levels of resource allocation. Using the notional distances between these grid structures a model was created in Excel known as the Fire and Emergency Services Effectiveness Baseline Evaluator (FESEBLE). This model randomly initiates events of multiple types, determines how assigned resources responded, and ultimately classifies this response as a success or failure.

Our sponsor, Fred Woodaman of Innovative Decisions Inc, indicated to us that he would like a more detailed way to model loss incurred for each emergency scenario within the installation. FESEBLE was able to simulate the timeliness of responses by F&ES resources to a scenario but it had not yet developed a way to measure loss incurred beyond a zero loss if resources arrived within a time threshold and a complete loss otherwise.

1.3. Problem Statement

Model the loss incurred due to an emergency scenario for given F&ES resource conditions.

2. Project Focus

2.1. Objectives

- Develop an understanding of how fire spreads over time within the subject structure type

- Evaluate percentage of structure loss over time as well as percent chance of spread to next unaffected space within a given time period

- Accurately model the behavior of the fire and expected loss given varying response parameters

- Use these results to enhance FESEBLE

- Accurately model the behavior of the fire and expected loss given varying response parameters

- Provide a capability for this model to simulate expected loss at a customer installation

2.2. Scope

- Sample military installation

- Single family residence fires only

- Measuring generic "loss" without regard to specifying property or dollars

The project scope focuses on the loss incurred for a specific firefighting scenario. A single scenario was used to demonstrate a proof of concept that the methodology for the model was sound. Additionally, the sponsor expressed a desire for a depth approach on the process. Anticipating future Capstone projects there was a stated desire to have the model piece developed in detail.

3. Research

In order to create a reliable loss function and model, the project team had to rely heavily on researching fire science and F&ES response methods. The two main components of this research were interviews with subject matter experts in the fields of fire response and open source literature that provided information on fire behavior and previous relevant studies on fire response policies and procedures.

3.1. Interviews

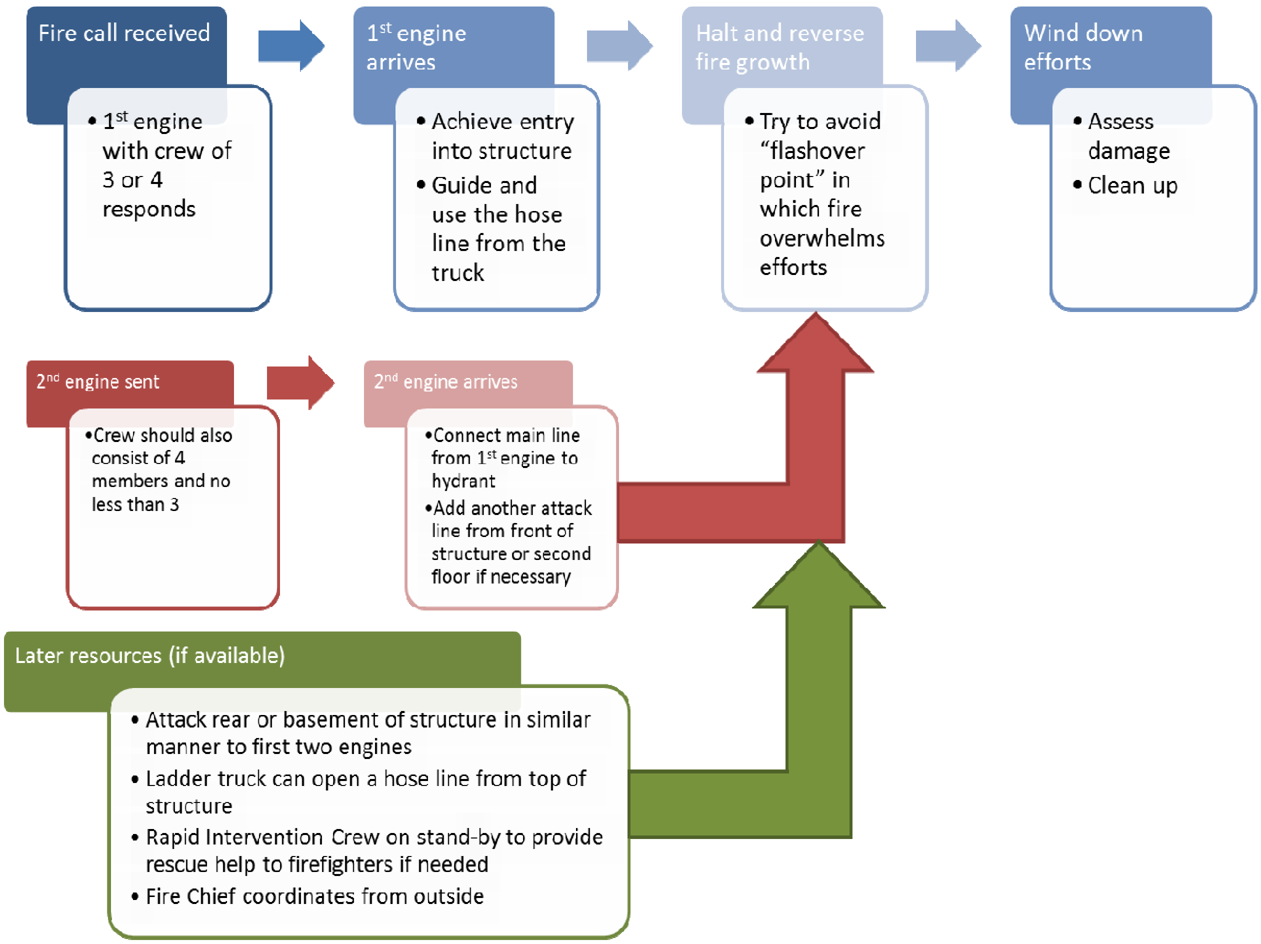
In addition to the project sponsor SME interviews came via two different sources:

- Dan Hunt – federal firefighter and volunteer in Prince George County, MD
- Patrick Cantwell – Systems Engineering doctoral candidate, George Washington University and Stafford County, VA volunteer firefighter

3.1.1. Dan Hunt

Mr. Hunt’s advice was a key to visualizing the factors in play with regard to how a fire engine crew responds to a call for a fire at a single family home. The typical practice is to send to closest available fire engine crew of four (or at least three) people to arrive within five to seven minutes of the emergency call. In practice, a second fire engine crew is almost always sent along to provide backup and to ensure the first crew does not run out of water from the truck. Later resources, if sent, will have more peripheral responsibilities such as finding secondary attack line paths and to facilitate crew rescues if needed. A visual of the procedures and guidelines Mr. Hunt described is given in Figure 1 below.

Figure 1 - Fire response procedures



3.1.2. Patrick Cantwell

Interviews with Mr. Cantwell allowed the team to ask questions of someone with experience as a fireman who could also bring a systems engineering approach to advising the team on how to model structure loss due to fire. His input on firefighting guidelines and procedures was similar to what was learned from Mr. Hunt with regard to the roles of the engine and ladder trucks that arrive at various times and the time thresholds fire companies try to work within. The goal of the local Stafford County, VA department is to have a responder on scene within eight minutes. This requirement is insurance driven rather than safety driven.

He confirmed that, even though official policy for responding personnel is to have "two in, two out" of the structure on fire, crews will drive out even if only three firefighters are available, in which case only one of the crew will be available for outside duty. Thus, a crew of three people will fight the fire but their effectiveness will be diminished compared to a full crew of four people.

Mr. Cantwell suggested that the model differentiate between the behavior and rate of loss of a downstairs fire versus an upstairs fire. An upstairs fire is more likely to spread quickly because there is typically more furniture packed within what are usually assigned as smaller bedroom spaces. Thus there is more “fuel” for the fire to burn through and spread at a faster rate than downstairs rooms where the spaces are bigger and the large furniture is farther apart. In addition, it was important for the model to account for the fact that a fire that starts downstairs is more likely to spread upstairs than vice versa because of how the fire will tend to draw oxygen from above with contributes to how the fire will grow. He informed us this was important to note because a fire that spreads across multiple floors will usually result in a total loss of the structure.

Another item pointed out by Mr. Cantwell was the type of construction used within the structure being responded to. It is common sense that different materials will suffer damage at different rates. But different structure shapes will also allow for fire spreading at different rates and probabilities as well. He advised us that most construction plates used in modern types of homes are very susceptible to heat.

3.1.3. Fred Woodaman

Mr. Woodaman, as the project sponsor, provided background information, guidance, and insight on how to structure our project so that it helped meet Navy F&ES needs. He envisioned the project this semester as the second part of a multi-stage effort to produce a comprehensive budgetary decision-making tool for Navy F&ES. As a next step from the previous FESEBLE model, Mr. Woodaman tasked us with creating a model to quantify scenario loss results to a more detailed level than the current “all or none” version.

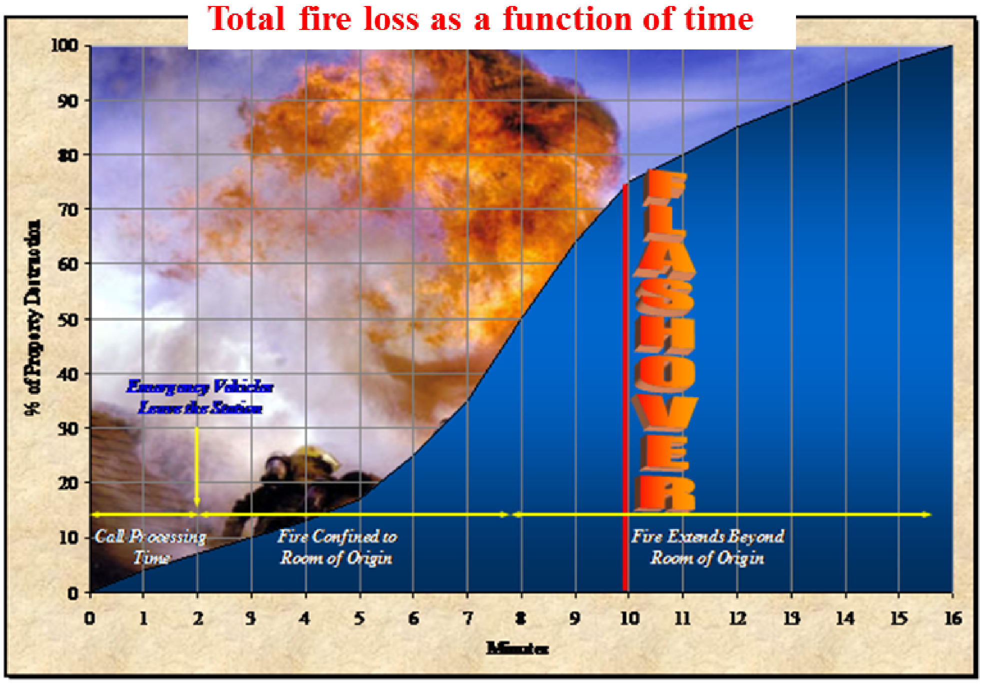
He urged the team to investigate the details of fire response procedures and the effects of under resourced response teams on the ability to mitigate fire damage. He suggested that we focus on where fires started, how they spread, and how much of an asset can be saved given arrivals at different response times that vary appropriately from an accepted standard.

3.2. Literature

In order to capture the nature of fire growth and its resulting damage in a reliable model, the team had to make use of open sources in the form of fire science and previous fire behavior studies. The bulk of these sources are listed in our reference section.

One of the most important concepts the team learned was the flashover point (FP). As seen in Figure 2 below copied from the International Association of Fire Fighters website, the FP is the point at which a fire breaks relative containment and engulfs the structure to the point that mitigating complete damage of an asset becomes near impossible. The graph indicates the FP occurs around 10 minutes into a fire where the blaze has not begun to be brought under control. Other sources featured similar FP times.

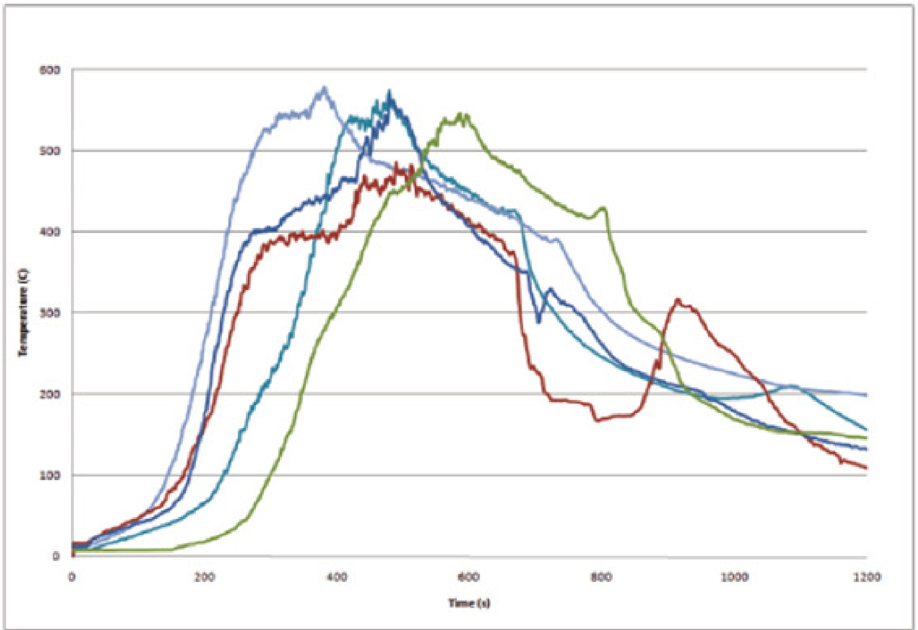
Figure 2 – Fire Propagation Curve with Flashover Point (http://iaff266.org/flashover)



The FP information also matched up with additional findings regarding energy release rate within a room that was ablaze. A fire within a residence grows when more materials ignite such as furniture or clothing. When these materials burn they release energy in the form of heat which consequently causes the temperature to rise. A study by the National Fire Protection Association (NFPA) explains that an upholstered arm chair on fire has a release rate of 1megawatt (MW) while a full sofa ablaze can have an energy release rate close to 4 MW. FP probability spikes as this 4MW level is reached.

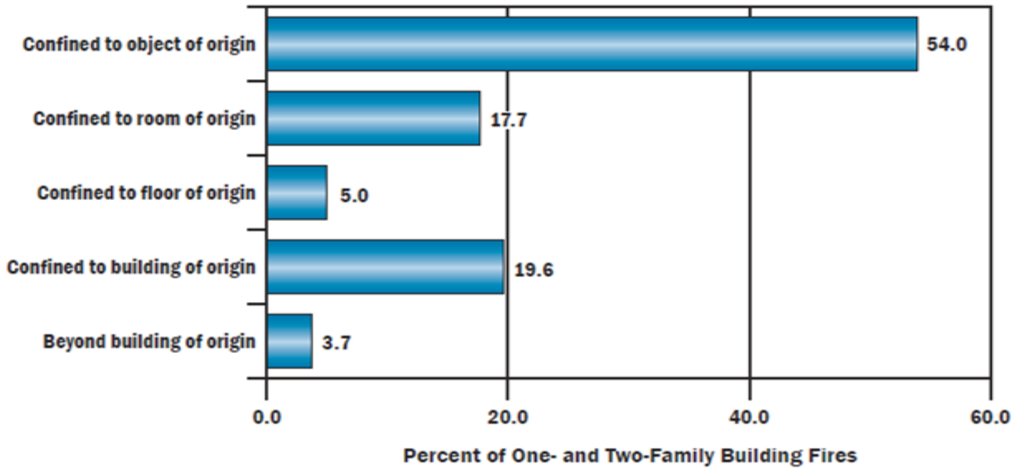
Since, as described above, the FP is determined by the energy release rate and this rate increases the temperature, the team gathered information on how temperature behaved over time. For this, the team consulted a comprehensive study performed by the National Institute of Standards and Technology (NIST). One of the visuals in the NIST study was a graph six curves that recorded the temperature timeline of a controlled room set ablaze. As Figure 3 below shows, the curves have a similar shape, but vary widely in their exact values at any given time. Furthermore, the team noted that the temperature increased sharply between 5-10 minutes for most curves. This plays into the idea introduced in Figure 2 regarding the FP: a fire will ignite, seek to grow outside of its confinement, and ultimately engulf the entire structure. This process will often take around 10 minutes which suggests responders need to arrive before this time to have any hope to save significant portions of the structure.

Figure 3 - Temperature vs. time (NIST study); each vertical axis tick is 100 deg. C, each horizontal axis number is 200 seconds



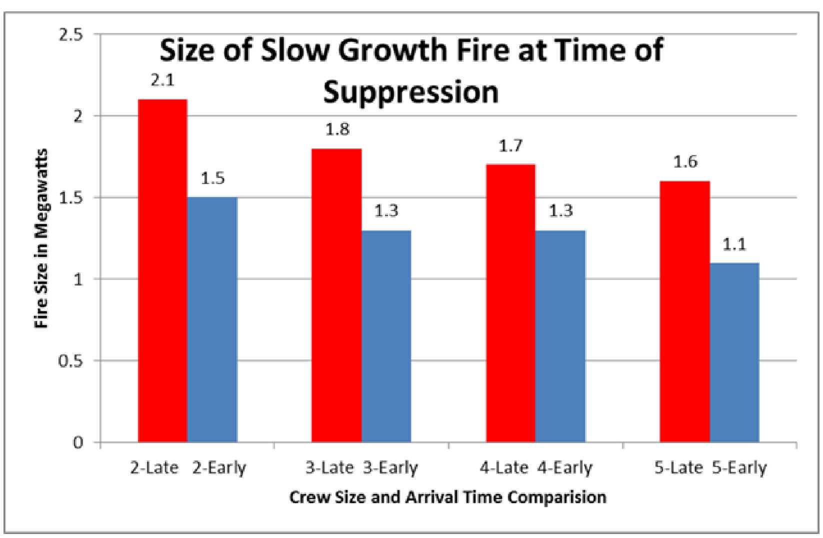
Per the guidance provided from the subject matter experts, the team also gathered information on how likely a fire would spread from room-to-room or floor-to-floor. The best source of information came from a report by the National Fire Incident Reporting System (NFIRS). The report contained a graphic of the percentages of fires that spread across rooms and floors over a period of several years for one and two family residential building fires. The graph is shown below as Figure 4. The data indicates that 71.7% of fires were confined to the object or room of origin, 5% of fires got outside the room but did not spread to other floors, and the remaining 23.3% of fires engulfed the building or spread to adjacent buildings. For the purposes of the model, fires that spread across multiple buildings are beyond the scope of this project.

Figure 4 - Extent of Fire Spread in One and Two Family Residence Fires (NFIRS)



In one of the interviews with Mr. Cantwell, he indicated that the arrivals of the first two fire engine crews were crucial in mitigating fire damage on a family residence. The later crews had their purposes, but their timeliness was not as critical to saving the structure. Another point he stressed was that the size of the initial crews was significant to reversing fire growth as well. The team found evidence within the literature study to back Mr. Cantwell up on these points. Figure 5 shows how big (in MW) residence fires grew in size before their growth was reversed depending on whether the initial crew arrived within 8 minutes of a fire or if they were late as well as how many people were in the initial crew.

Figure 5 - Energy Release rate at time of suppression vs Crew size



Data Compiled NIST Technical Note 1661, April 2010

With these concepts introduced and this data in place, the team then set about translating these main points of information into a technical approach to create a loss function and model for the single-family residence fire problem.

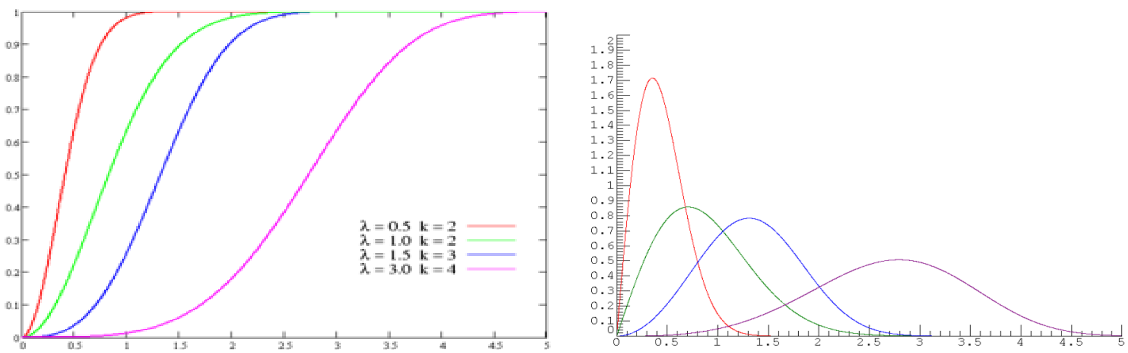
4. Technical Approach

The team developed a novel approach to modeling fire loss, fire propagation variability, and fire loss mitigation through emergency response. The approach was then implemented in a Monte Carlo simulation to link resource driven management metrics (i.e. response times of emergency services and level of emergency crew manning) to expected loss per fire incident.

4.1. Fire Loss

The shape of graphs depicting fire loss over time found in literature (figure 2) is very similar to typical Cumulative Distribution Functions (CDF) observed when studying probability. And one of the most adaptable CDFs available is the Weibull CDF. The team chose to use the general form of the Weibull CDF to characterize the total loss of fire over time. The Weibull Probability Density Function (PDF) is the derivative of the CDF, and thus was chosen to represent the fire loss rate over time.

Figure 6 – Weibull CDF (left) and PDF (right) Characteristics



General form of the Weibull PDF: $f(x; a, b) = \frac{a}{b^a} x^{a-1} * \exp\left(-\left(\frac{x}{b}\right)^a\right)$

Based on subject matter expert interviews and literature reviews, a fire originating downstairs of two story dwelling and eventually engulfs the entire house can be expected to have a fire loss rate, r(t), characterized by:

$$r(t) = f(x = \frac{t-1}{1.5}; a = 4, b = 15)$$

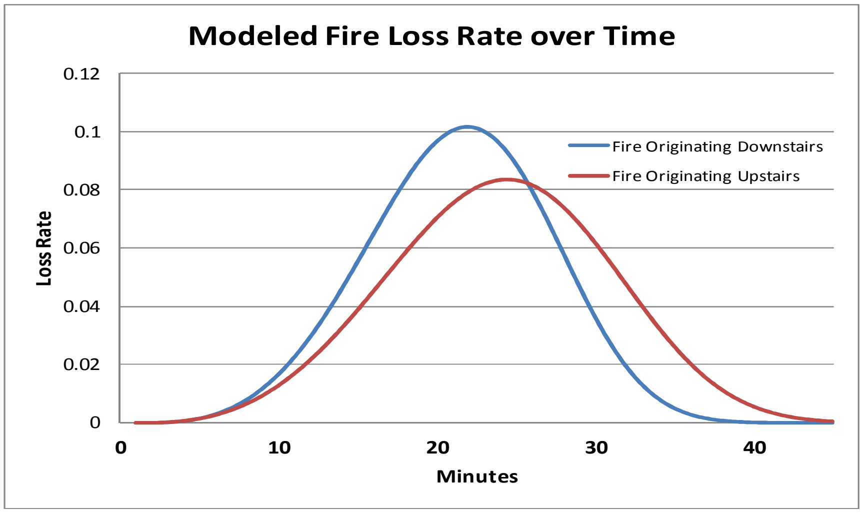
The loss rate for a fire starting upstairs and eventually engulfing the entire house is characterized by:

$$r(t) = f(x = \frac{t-1}{1.5}; a = 3.7, b = 17)$$

Both rates represent cumulative fire losses where significant loss begins at the 10 minute mark. Fires originating downstairs are expected to take 35 minutes to cause over 95%

damage, whereas fires originating upstairs are expected to take about 40 minutes to do the same.

Figure 7 - Example of unmitigated fire loss rate over time

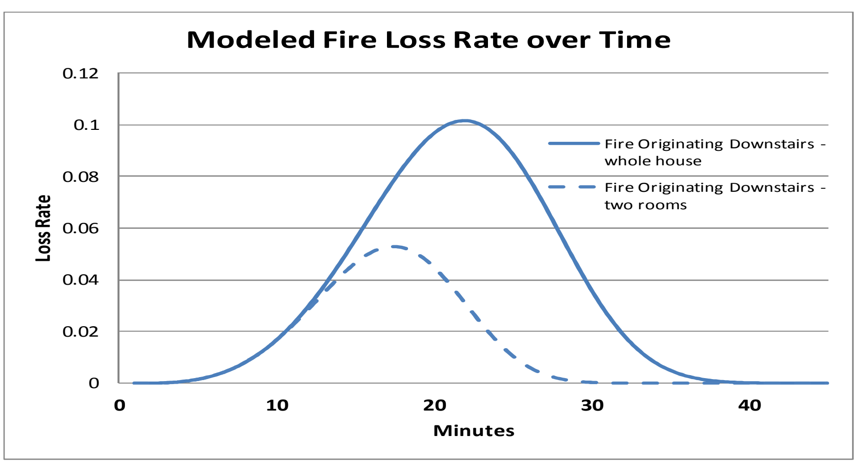


4.2. Fire Propagation Variability

As discussed in previous sections, even unattended fires do not necessarily engulf the entire home. For example, if a fire originating downstairs was self-contained to two rooms (maximum damage 40%); the loss rate would be characterized as:

$$r(t) = 0.4 * f(x = \frac{t-1}{1.5}; a = 4.07, b = 11.74)$$

Figure 7 - Example of unmitigated fire loss rate over time



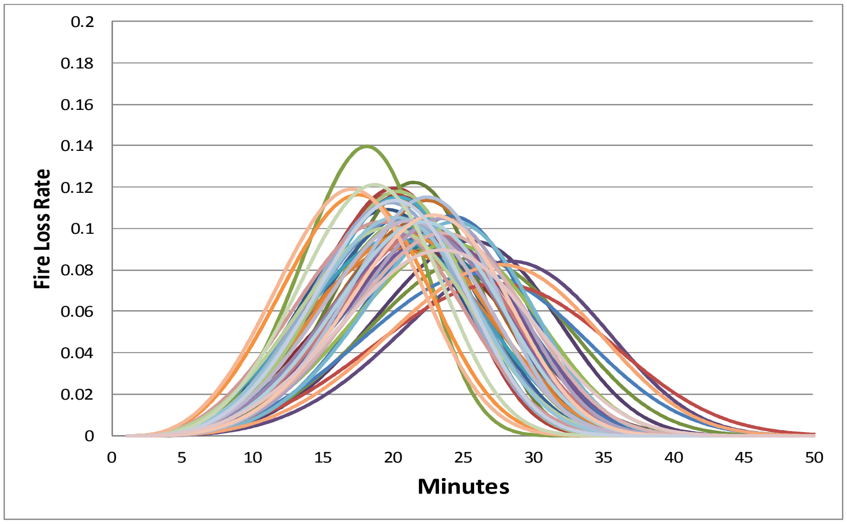
There are probabilities involved with fire origination location and spread (from room to room and floor to floor). For modeling purposes, the group assumed 70% probability of the fire originating downstairs, 85% probability of spreading from room to room, 80% probability of progressing upstairs (if originating downstairs), 60% probability of spreading to the downstairs (if originating upstairs). These assumptions are reasonable, but can be changed in the model. For example, given a house fire, there is a 10.1% probability that it will originate on the ground level and limit its spread to exactly three rooms without progressing to the upper level, causing a maximum of 60% damage if not mitigated.

Figure 8 – Probabilities and Model Parameters for Possible Fire Origination and Spread

Fire Origination	Final Spread Limited to:	Probability	Prob Bins	Damage/Scale	a'	b'
Ground Level	Original Room	0.105	0.000	0.2	4.18	9.69
Ground Level	2 rooms on same floor	0.089	0.105	0.4	4.07	11.74
Ground Level	3 rooms on same floor	0.101	0.194	0.6	4.03	13.10
Ground Level	1 Room in Other Floor	0.061	0.295	0.8	4.01	14.14
Ground Level	Whole House	0.344	0.356	1	4.00	15.00
Upper Level	Original Room	0.045	0.700	0.2	3.75	10.49
Upper Level	2 rooms on same floor	0.038	0.745	0.4	3.65	12.97
Upper Level	3 rooms on same floor	0.087	0.783	0.6	3.62	14.63
Upper Level	1 Room in Other Floor	0.020	0.870	0.8	3.61	15.93
Upper Level	Whole House	0.111	0.889	1	3.60	17.00

The previously referenced NIST study also showed that even in a controlled setting there is variability in fire progression (Figure 3). To model this variability, the team assumed that the *a* and *b* parameters from the loss rate function should be random variables characterized by the gamma distribution centered around a' and b' values, respectively. The gamma distribution always returns positive values and can form a Gaussian shape. Based on visual inspections of the NIST data, the team determined the gamma distribution parameters for *a* and *b*: $k_a = a'/0.02$, $\theta_a = 0.02$; $k_b = b'/0.15$, $\theta_b=0.15$.

Figure 9 – Possible Variations of a Fire Originating Downstairs and Engulfing the Whole House (a'=4, b'=15)



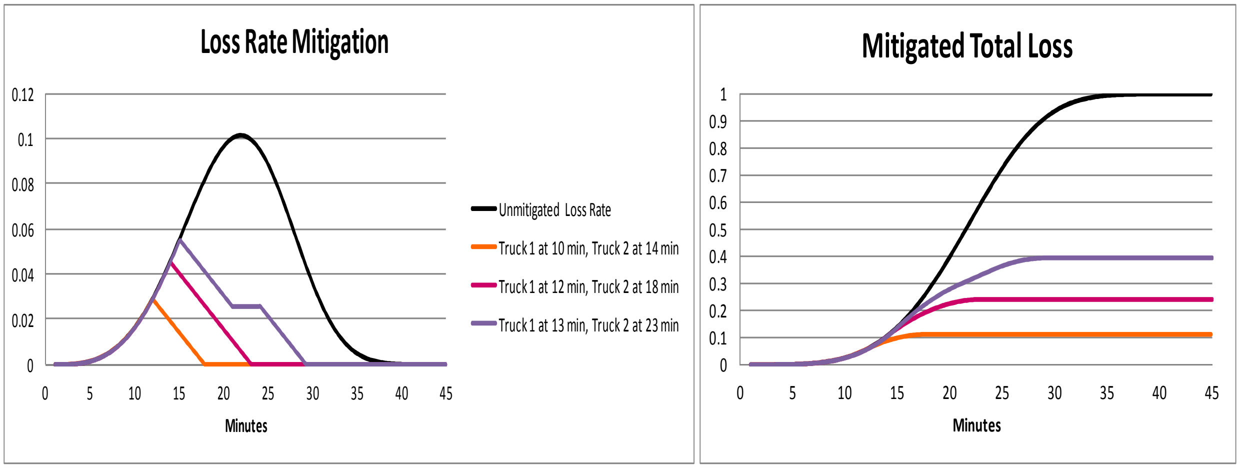
4.3. Fire Mitigation through Emergency Response

The goal of fire mitigation is to bring the fire loss rate down to zero as quickly as possible. As soon as water is applied to the fire, the loss rate begins to decrease. Upon arrival of the first fire engine, a fully manned crew (4 people) requires two minutes to get water on to the fire. A partially manned crew (3 people) requires four minutes.

The team assumed that the rate of decrease (of the fire loss rate) is constant. It was calculated from subject matter experts stating that on average one fire engine carry enough water to fight a fire that has not spread beyond the original room, and it takes roughly six minutes to empty the tank. Hence, the response time of the first engine has a significant effect on total loss containment.

The role of the crew of the second fire engine is to hook the first engine's tank to the fire hydrant such that the water supply is not exhausted within six minutes. The crew requires two minutes after arrival to secure the hydrant. The response time of the second fire engine is significant if the fire has progressed beyond the capability of the first engine.

Figure 10 – Possible Mitigations of a Fire Originating Downstairs and Engulfing the Whole House



In Figure 10, three scenarios show the effect of response times on fire loss mitigation. In the first scenario, the first engine arrived at the 10th minute, placed the hose on the fire by the 12th minute, and contained the fire by the 18th minute. The fire damage was limited to 11% of the structure. The arrival of the second engine was not required to contain this fire. In the second scenario, the first engine arrived at the 12th minute, and had the hose on the fire by the 14th minute. The second engine arrived on the 18th minute and secured the hydrant by the 20th minute. The water supply to the hose was uninterrupted, and the fire was contained by the 24th minute, limiting fire damage to 24% of the structure. In the third scenario, the first engine arrived at the 13th minute, and had the hose on the fire by the 15th minute. The second engine didn't arrive and secure the hydrant until the 25th minute. Hence the water supply was interrupted between the 21st and 25th minutes, when the loss rate did not decrease. The overall fire loss from the third scenario is 40% of the structure.

For simple two story single family dwelling, the ladder company and other rescue units do not provide much of a fire fighting capability, but do assist in clean up. Therefore, these units were not modeled for this iteration.

4.4. Monte Carlo Simulation

The team created a Monte Carlo simulation tool that ties the expected loss from any dwelling fire to average response times of the two fire engines and the percentage of crews that are fully manned, by simulating 2,000 fires.

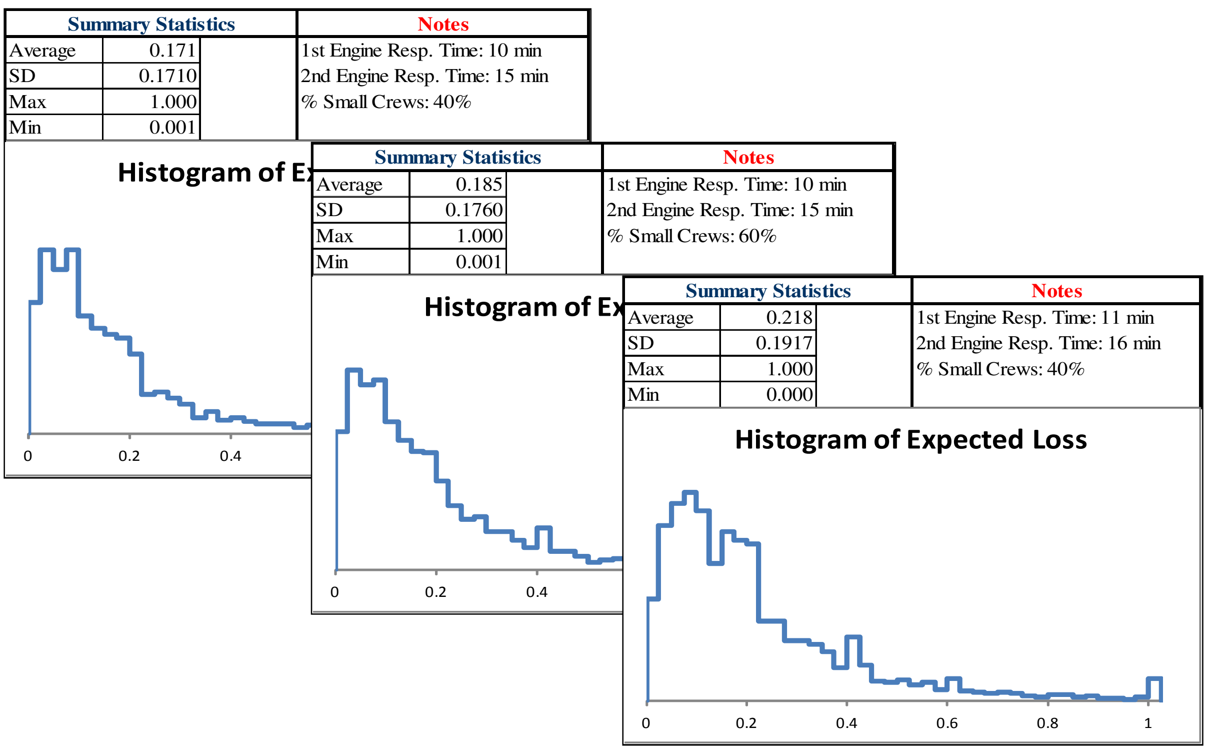
The fire characteristics (a', b', damage) are chosen from a random draw with likelihoods seen in Figure 8. The fire loss rate parameters, *a* and *b,* are chosen from the previously described gamma distributions centered around a' and b', respectively. The unmitigated loss rate takes the form (where f(x,a,b) is the Weibull PDF):

$$r(t) = damage * f(x = \frac{t-1}{1.5}, a, b)$$

The response times of the first and second engines are normally distributed with a standard deviation of two and four minutes, respectively. The percentage of fully manned crews serves as the probability that the arriving crew is fully manned.

With this tool, decision makers can run resource driven excursions. For example, in a hypothetical scenario, 40% of crews are undermanned, and average response times for the first and second engines are 10 and 15 minutes, respectively. The decision maker has to make a budget driven choice to either eliminate people or eliminate engines. Eliminating people increases the percentage undermanned crews to 60%, whereas eliminating engines increase the average response times of the two engines by one minute each. Figure 11 captures this hypothetical scenario.

Figure 11 – Monte Carlo Simulation Examples



Simulating these scenarios show that based on the assumptions, under manning the crews has a much smaller effect on increasing the expected loss than increasing response times. Baseline expected loss is 17.1%; under manning increases expected loss to 18.5%; eliminating engines increases expected loss to 21.8%. In this scenario, eliminating personnel is the better decision.

5. Evaluation

5.1. Assumptions and Limitations

While the team went to a great extent to derive quantitative parameters from published reports for the model and to consult with the SMEs for help with gaps for estimation, the project resulted in a model that cannot be verified as reliable at this time. A collection of assumptions and limitations for our loss model are present.

The team bases its model on the assumption that, suggested from the literature studies, fire damage rate at any given point in time can be approximated by the amount of energy being released at that moment and, consequently the temperature of the room. It is by this assumption that the team arrives at the idea that the fraction loss incurred by a structure is then equal to the area under the loss rate curve. The team feels confident in the validity of this assumption from consultations with the SMEs involved in the project even though the exact relationship cannot be conclusively defined here.

The project team also operated under the belief that Weibull PDF curve shape is sufficient to approximate temperature behaviors for an accurate extraction of quantitative losses. The limitation here is that there was no exact temperature data for the team to compare to the Weibull curve to determine a quantitative fit. Instead, the model relies on the concepts learned regarding time taken to achieve 100 degrees Celsius within a room on fire and time needed for a room to reach its FP.

Additionally, the team needed to address the stochastic nature of fire growth. The conjecture made as a result of this was that the team should vary the parameters of the Weibull PDF via a gamma distribution would provide a variety of temperature curves for the purpose of a simulation. Using the gamma distribution to provide this sample gave the team a way in which to produce a set of temperature curves similar to the type of graphs in the NIST study. This is an assumption made with a lot that is unknown because the NIST study provided only six such temperature curves and there was not much information to determine the extent to which these temperature curves truly are variable.

Two of the final key theorizations made by the group were that the reduction of the fire loss rate from firefighters is best demonstrated as linear in nature and that all personnel are fully trained and competent. This latter assumption is based on an inherent human element which would be very difficult to remove for a more accurate depiction of performance within the model. The former matter did not have much support from literature and was not discussed extensively with SMEs. However, the simulation results and consequent comparisons across different resource profiles would not change much with an alteration in loss mitigation away from a linear rate.

5.2. Analysis of Results

A simulation using this model can be used for reliable quantitative comparisons of expected structure loss across different resource availability levels. The team was able to accurately model fire behavior in accordance with observations from previous studies and reports and discussions with SMEs. Furthermore, the fire response and mitigation parameters are based on the researched policies, tactics, and performance levels consistent with those found in the referenced studies. Lastly, probabilistic fire spread values are used from literature based on nationally collected data from 2005-2007 (NFIRS).

One final note about any comparative results across simulations of different response parameters is that the magnitude of the difference in expected loss can vary significantly through adjustments to the parameters that are customizable within the model. For instance, experts stated that fire damage varies qualitatively based on origin of the fire and materials of the structure. This model allows for adjustable quantitative values for these parameters.

6. Recommendations

- Suggested additions to this model
    - Additional building types (offices, apartment buildings)
    - Effects of built in fire mitigation devices (sprinklers, extinguishers)
    - Additional scenarios and effects of simultaneous incidents
- Refinement of fire ignition point and type of spread data percentages
- Analyze available data within Department of Defense Fire Incident Reporting System (DFIRS) as to fire types and frequency differences from national data to adjust probability segments within naval installations.

7. Future Development

- Develop and examine the impact of loss of life or injury on model recommendations
- Assign future GMU project teams to develop new functionalities desired by Navy F&ES and the sponsor
- Integrate these efforts into a single tool to produce the desired comprehensive analysis.

8. References

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Appendix A – Work Breakdown Structure

WBS	Task Name	Start	Finish
1	**Navy Fire & Emergency Services Project**	**Thu 1/26/12**	**Fri 5/11/12**
1.1	**Project Management**	**Thu 1/26/12**	**Fri 5/11/12**
1.1.1	**Project Launch**	**Thu 2/2/12**	**Thu 2/23/12**
1.1.1.1	Initial Sponsor Meeting	Thu 2/2/12	Thu 2/2/12
1.1.1.2	Establish WBS	Fri 2/10/12	Thu 2/23/12
1.1.1.3	Create EVM Chart	Fri 2/17/12	Sun 2/26/12
1.1.2	**Deliverables**	**Thu 1/26/12**	**Fri 5/11/12**
1.1.2.1	Preliminary Project Description	Thu 1/26/12	Thu 2/2/12
1.1.2.2	Initial Project Proposal	Fri 2/3/12	Thu 2/9/12
1.1.2.3	Final Project Proposal	Fri 2/10/12	Thu 2/16/12
1.1.2.4	Progress Report I	Thu 3/8/12	Thu 3/8/12
1.1.2.5	Progress Report II	Thu 3/29/12	Thu 3/29/12
1.1.2.6	Final Presentation Dry Run	Thu 4/19/12	Thu 5/3/12
1.1.2.7	Project Website	Mon 4/30/12	Mon 5/7/12
1.1.2.8	Final Report	Mon 4/9/12	Mon 5/7/12
1.1.2.9	Initial Preparation for Final Presentation	Thu 4/5/12	Thu 4/12/12
1.1.2.10	Final Presentation	Thu 5/3/12	Fri 5/11/12
1.2	**Research**	**Thu 2/9/12**	**Sun 3/18/12**
1.2.1	**Fire Research**	**Thu 2/9/12**	**Sun 3/4/12**
1.2.1.1	SME Interviews	Thu 2/9/12	Thu 3/1/12
1.2.1.2	Fire Ops Research Literature	Thu 2/23/12	Sat 3/10/12
1.3	**Model Development / Implementation**	**Thu 3/1/12**	**Thu 3/15/12**
1.3.1	**Loss Function**	**Sun 3/4/12**	**Sun 3/11/12**
1.3.1.1	Derive Mathematical Algorithm	Sun 3/4/12	Thu 3/15/12
1.3.1.2	Sponsor/SME feedback on loss function	Wed 3/7/12	Wed 3/7/12
1.3.1.3	Sponsor/SME consensus approval on loss function	Thu 3/8/12	Fri 3/30/12
1.3.1.4	Sensitivity Analysis for identified assumptions	Mon 4/2/12	Thu 4/5/12
1.3.1.5	Obtain Sponsor/SME feedback on sensitivity analysis	Thu 4/5/12	Thu 4/12/12
1.3.2	**Test and Evaluation**	**Sun 3/11/12**	**Thu 3/15/12**
1.3.2.1	Configure model to run limited event types	Sun 3/11/12	Wed 3/14/12
1.3.2.2	Verify that algorithms implemented appropriately within model	Wed 3/14/12	Thu 3/15/12

Appendix B – Earned Value Management Chart