Wildfire Evacuation Home Defense Assistant

End of Project Documentation

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Executive Summary

Elevator Pitch:

In order to alleviate the pressure that delayed evacuation from residents of Wildland Urban Interface (WUI) areas puts on the evacuation routes themselves, the Wildfire Evacuation Home Defense Assistant (WEDHA) will automate one of the reasons many people choose to delay their evacuation: to try to protect their home from the flames. The device will allow WUI homeowners to spray their property with fire blocking gel to protect their homes in a wildfire evacuation scenario while also mitigating the time to full evacuation. The design of the device will allow it to patrol around the WUI house on wheels and soak the surrounding vegetation in fire suppressive material. In order to have a device which is not connected to a hose, the WEHDA will utilize an automatic refill station. The components of this device which will be tested are the device mobility, the automated refill station and the spray nozzle. The results of these tests are outlined in Section IX of this report.

Since the onset of this project, the research the team has done shed light on many different events which have transpired and led to more insights for our team regarding the importance of finding robust evacuation procedures for home-owners in WUI areas which experience intense wildfires. Between news and media outlets urging WUI-dwellers to prepare themselves for evacuation if mandated, and local authorities pleading with residents to comply with evacuation orders, there is a clear need for maximizing efficiency in an emergency wildfire scenario. As the climate of the planet continues to change, and global warming distinguishes itself as an irrefutable dilemma for present and future generations, wildfires are proving to be a troublesome and expanding issue worldwide. The purpose of this report is to summarize the data found on wildfires within the past ten years in the United States and detail the many complications that arise from the increasing severity and number of wildfires annually. The report is broken down into five subsections: (1) Wildfire Causes, (2) Annual Wildfire Data, (3) Evacuation Methods and Residential Risk, (4) Casualties, and Safety Distances, and (5) Proposed Solutions. The analysis of the reported data shows that wildfires tend to start from natural causes such as lightning strike, or natural combustion. Research supports the idea that they are increasing on an annual basis and are affecting civilian lives more each year. There is also data to support that current evacuation models may not be systematically effective since they rely too much on compliance from residents, which can be very inconsistent. Additionally, as more people choose to live in high-risk wildfire areas, more research is needed on evacuation models. The conclusions drawn from this report are that preventative measures need to be taken to combat wildfire destruction from multiple approaches, rather than relying on real-time methods.

The design will target a focused aperture on addressing the issue of evacuation protocol, as well as the complications that make these protocols less effective. When issuing an evacuation mandate, it is common for residents to delay their evacuation for a variety of reasons. One such reason is to attempt to defend one's property by way of applying a fire-blocking material around the surrounding vegetation near the house. This can be an effective method, and there are market ready gel's which have been proven to block fires and protect property with a 30-foot thickness cordon around the house. The device will assume this product will be used. Evacuation mandates give a limited time window for evacuation; these protocols are created with the assumption that the residents will immediately begin evacuation. For those residents who choose to delay evacuation, a number of complications arise. Waiting to evacuate can lead to some evacuation routes eventually closing. This leaves more traffic to congest the open routes which can result in casualties due to automobile accident, as well as a prohibition of firefighting personnel from carrying out their tasks. The device will allow residents to be able to defend their property without having to allocate the time to do so. Rather than spending time spraying one's property, the resident can immediately begin evacuation measures, then activate the device upon departure. The device will have robotic mobility and will navigate the property autonomously. Whilst navigating the property, the device will spray the fire blocking gel in a thick enough pattern to ensure that its effectiveness is sound. While the device may only have the capabilities for holding one gallon of gel, the system will factor in an automatic refill structure so the device will be able to complete the perimeter around the property. This device gives peace of mind to evacuees in knowing that their property will be defended from the flames, and will also smooth the evacuation process, resulting in less casualties and more efficient firefighting.

To develop the aforementioned features successfully the team must divide up the tasks and set deadlines based on difficulty, significance and order the tasks need to be completed because some tasks depend on others being completed. Our team has divided up the tasks into four main tasks: device mobility, spray nozzle assembly, refill tank, and assignments and reports. Then these tasks are broken down even more into hardware, software and integration. The rest of the subtasks are broken down even more into parts to be able to divide up the work for each team member for the coming weeks to finish this project in the given deadline.

This project's timeline is a valuable and important tool used to complete our project successfully. The purpose of the timeline is to provide a visual representation and time sequence of what parts of the project are already completed and what parts need to be completed to start working on the next parts of the project. This allows us to have a visual representation of what parts still need work and which parts need to be done first. The milestones represented in the PERT chart shows the progress of each part of the project and how it is to be designed in chronological order. The milestones of our project are: Identification of Societal problem, Design Idea contract, Work Breakdown Structure, Testing Device mobility, Testing Spray Nozzle, Testing

Refill mechanism, Deployable prototype, Autonomous aspect of Mobility, Combining all software to a cohesive design, final hardware design, completion of end of project report, and successful demonstration and presentation of project.These vital parts of the timeline will let the team effectively complete their project by the deadline in the time given.

The ability to manage the inevitable risks within a project is a necessary step in ensuring the completion of the project; with deadlines, limited resources, and confounding variables, not taking the time to consider all potential risks can create delays which may drastically affect the end result. The types of risk may vary. There are some obvious risks such as the need to wear safety equipment when utilizing heavy machinery or taking the proper precautions when working with electrical components. However, there are also much more subtle risks such as work conflict/overload, individual member health, and even general accidents. Since the types of risks which can come with any project are virtually infinite, it is important to take the time as a team to consider these risk factors and deliberate strategy on how it can be prevented, or mitigated. The Risk Assessment section of the report will detail the risk factors which have been identified by the team, as well as the strategy for how each one of these factors will be handled. Additionally, a risk assessment chart will show the compilation of the aforementioned risks and will offer a visual representation outlining the severity of each one. Ranking the risk factors will allow us to identify the *critical path* of the work flow structure of the project. The critical path is defined as the longest path on the PERT diagram which gives us the minimum time required to complete the project. This is essential information for the team because it allows us to cater our focus towards prioritizing the items along the critical path. Where there may be bottlenecks, and time crunches, or areas of high risk associated with the events, the team can allocate excess energy to ensuring that those things do not happen. The risk assessment section of this report will utilize these strategies for identifying and prioritizing the risks in the project which need to be addressed, and will further be able to ensure a successful completion of the device with minimal associated risk.

The first step the team took when transitioning from the Laboratory Prototype to the Deployable Prototype was to create a test plan to ensure that each of the elements described in the Design Idea Contract were working in accordance with the proposed measurable metrics. The Laboratory Prototype was a success in that it demonstrated that the teams knowledge of fundamental engineering concepts were sound; the team was able to produce a device which had mobility, refill capabilities, and a spraying function. However, all of these elements required refining moving into the Deployable Prototype. The Device Test Plan is the subjugation of these refined features; the team identified the main measurable metrics which were fundamental for the device, and created the methods for testing as well as the purpose of each test. This document will briefly summarize the test plan, and will provide an in depth overview of the results in Section IX. of this report. It should be noted that the device testing is not complete at the time of the initial writing of this report. Due to some setbacks with the hardware construction of the mobility feature, there remains two tests which need to be completed. In Section IX. the report will outline the troubleshooting process for this feature, as well as the steps taken to rectify this issue and complete the testing.

In order to actualize the potential for this project, understanding the target market is an essential component for creating a useful device for the proposed demographic. Our proposed demographic is admittedly very niche; however, its importance cannot be understated. Through our extensive research, and the work of many other experts in the field of wildfire research, we have found that the problem we are addressing is consistently growing over time. Additionally, this device has the potential to save lives in emergency situations directly by mitigating evacuation route traffic and accidents. There is a possibility for this device to be quite useful for county government and fire authorities as well.

Abstract—**Wildfires have seasonally tormented the western side of North American consistently and with the threat of global warming, the issue is seemingly increasing over time. Throughout the course of Team 13's first semester working on this project, the wildfires in California became an ever-present reminder for the importance of the project itself. The research done on this topic has yielded two conclusions: (1) Homes are being developed closer to wildfire risk locations more each year, and (2) the severity of the wildfires is not diminishing. One common theme seen this fire season is the idea of defending one's property using several different techniques in the wake of a wildfire. From local media outlets showing ways to clear flammable materials from one's property, to peer-reviewed articles which have studied the varieties of effectiveness of different home defense suppression materials, there is a clear and present demand for taking a defensive approach to wildfires in WUI areas. This has further cemented the design outlined in this report. By allowing home-owners in WUI areas to automate one of the methods for protecting one's home from wildfire, this will allow these residents to act more quickly in carrying out their evacuation plan, which would in turn create less congestion throughout evacuation routes as the wildfire closes in proximity. Evacuation in a wildfire scenario can leave homeowners frantically scrambling to prepare to leave their homes with the possibility of not returning to the same structure; the high-stakes nature of this creates and emotional decision-making process which can often times result in delayed evacuation from WUI homes. As supported by the referenced research material, delayed evacuation from urban wildland areas increases the risk of casualties by automobile accident, as well as causes traffic on the open routes, preventing firefighting personnel from being able to perform their duties properly. As a way for homeowners to mitigate the time they spend preparing to evacuate, the device detailed in this report allows evacuees to activate an automated system which works to protect their property from the encroaching flames. Using a high-powered hose, flame retardant, and a motorized tank component, the device will outline the property spraying the surrounding vegetation in fire retardant to reduce the likelihood of the fire taking the home. The device will have a route which it navigates automatically, spraying the ground and any vegetation in accordance with firefighting stipulations for preventative fire measures. The device will take multiple trips to thoroughly cover the entirety of the property. Given that most evacuation mandates come with at least a 12 hour advanced warning, this gives ample time for the device to cover the property before the flames are close.**

Since the project is constrained to a small amount of time,there is a necessity of managing time efficiently to attain the completed design. a timeline is a scheduled work breakdown structure which will organize the time frames and deadlines of the project and its features. The timeline will consist of a Gantt chart, a PERT diagram and list of milestones for the project.The Gantt chart is a visual representation of the project's requirements established in order of significance. The PERT diagram organizes and distributes tasks on a weekly basis to each member to complete the project on time. The milestones help gauge the progress of the project's completion and are as follows: Identification of Societal problem, Design Idea contract,Work Breakdown Structure, Testing Device mobility, Testing Spray Nozzle, Testing Refill mechanism, Deployable prototype,Autonomous aspect of Mobility, Combining of software, final hardware design, completion of end of project report, and successful demonstration and presentation of project

In order to have a successful project, a team must identify potential problems, or risks, that they encounter and develop a plan around the problem. A risk has a degree of impact and a degree of probability. The relationship between impact and probability with a risk is shown on a risk assessment chart.To identify risks, one must also create a critical path for the project, so that one knows which events can hinder the project from continuing. The Fire Blockers identified 8 vital events in the critical path. The following report contains the identification of three types of risks: specific technical risks, broader technical risks, and systematic risks. The specific technical risks include hardware failure, limited microcontroller pins, and water damage to parts. The broader technical risks include the terrain being too rough, obstacles in the device path, and mechanical overload.The systematic risks include the pandemic, personal safety, and accident a possibility.

This team of engineers has devoted nine months of dedicated time to produce a product which aims to reduce the number of secondhand complications which arise from wildfire evacuations by encouraging WUI residents to evacuate more prudently. This report details the research done which supports the though process for this product, as well as the procedure and an in depth analysis of what this project required. From a discrete overview of the societal problem itself, to a technical explanation of the device mechanisms, to a review of how the product will hypothetically fair on the free market, this report's goal is to inform the reader of the specific intricacies of everything that went into creating this device.

Keyword Index—**Air pollution, biosphere, carbon tax, environmental economics, fire suppression, global warming, heat sensor, infrared imaging, North America, robotics, vegetation mapping, wildfires, Wildland Urban Interface**

I. Introduction

The following report will contain information on all aspects of this project. Technical descriptions for all device components will be included as well as the Team's considerations for delineation of work, timeline progress, budgeting and spending, and a review of the project's market readiness. The introduction for this report will provide a small insight into all of these fields of consideration. The in-depth discussion for all of these factors will be provided in their respective chapters.

A. WUI Resident Behavior in an Evacuation Scenario

Recent years have seen a growing number of problematic repercussions due to global warming; higher annual temperatures reported worldwide, melting ice caps, and carbon dioxide emissions in the atmosphere, which contribute to climate change with an unfortunately cyclic and dismal periodicity, make this an undeniable condition for which all engineers can consider a solution for. Drought takes its toll on grassland environments, and with the decreased moisture comes a stronger prevalence of wildfires. Wildfires are good for the environment. They can be used as a tool to clear debris and allow for new forest life to thrive on the nutrients that come from this natural process; however, they are becoming more frequent and harder to contain [1]. It seems as if every year, fire seasons in California claim homes, property, livestock, and even civilian lives. Resources used to respond to these fires are thinning as each year has more threats to account for. While wildfire is a natural process and can be used as an essential tool for ensuring the health of forests and grasslands, it poses a threat as a growing problem each year.

Throughout this report there is data to support the increasing prevalence of wildfires within the past ten years. A summary of the mechanism in which wildfires are started is detailed, which ranges from lightning strike, to malicious arson, to a cigarette butt flicked from a vehicle on the highway. Through these methods, and several others, fires have been shown to be increasing steadily. In addition to increased quantity of annual fires, there is data which shows that more people are choosing to live and own homes in wildlife-urban interface (WUI) locations. More homes being built at the intersections of wildlife terrain and residential areas are resulting in increased home loss due to fire each year [2]. With more civilians choosing to live in WUI locations, evacuations models are proving to be an essential strategy for wildfire safety personnel each year; nevertheless, there are still some complications which make evacuation models ineffective at times. Unfortunately, there are casualties across the United States each wildfire season. Whether via smoke inhalation, convective heat, or automobile accident, casualties are an indicator of a need to address the complexity of the evacuation process. In conjunction with real-time responses to wildfire, preventative measures for homeowners in WUI locations exist. Clearing one's home of large quantities of debris and remnant vegetation, as well as establishing safety distances for homes and neighborhoods in these areas can help ensure less casualties each fire season. Aside from these two strategies, more research can be done on preventative measures for wildfire destruction.

The purpose of this report is twofold: (1) To describe the current trends in wildfire damage and provide insight on the ways it causes destruction, and (2) to outline current prevention methods as well as providing some proposed solutions to wildfire suppression and prevention. The strategy proposed in this report suggests options from a preventative standpoint, as well as tools to help facilitate evacuation for residents of WUI locations.

B. Wild Evacuation Home Defense Assistant: Design Concept

The physics of movement for wildfires spreading in dry areas is truly astounding; wildfires are capable of moving up to 6 mph in forests and up to 14 mph in grasslands without the assistance of wind, and even faster depending on the terrain as a 10 degree increase in slope can double the speed of the fire's travel [3]. With the speed at which a fire can spread, an attempt to use an automated device to address the flame's source would require an incredibly dynamic approach, one that arguably circumvents practicality. Therefore, the design of this proposed device is focused on mitigating the casualties which occur after the evacuation mandate has been ordered.

Our research suggests that delayed evacuation is the root cause of inconsistencies in the evacuation plan, such as automobile accidents, closed evacuation routes and forced traffic on open evacuation routes which delay firefighting authorities from effectively carrying out their duties. While the reason for delayed evacuation amongst residents may vary, many residents will attempt to defend their property from the oncoming fire in several ways. As suggested by fire authorities, residents can create a "defensible space" around their property and clean up as much loose vegetation (fuel) as possible. Also, making water resources available like a swimming pool or garden hoses is highly encouraged. Clearing roofs and gutters of brush and debris as well as removing highly flammable objects from the house is a necessity to ensure a home's likelihood of survival in a fire; however, many of these precautionary steps are to be done well in advance of any evacuation mandates [4]. There are products sold which attach to a hose and mix fire retardant with the water allowing the residents to soak their property as a last-ditch effort of fire security. This has been shown to be an effective way to protect the surrounding areas of one's home for up to 8 hours [4]. However, since this effective time for this product is relatively short, it must be applied after evacuations have been ordered. Furthermore, the effective distance one's home needs to be sprayed is anywhere between 30 and 100 feet, the time it would take for a resident to do this would be contradictory to the urgency of an evacuation plan. Ironically, this effective solution to home protection also attributes to the percentage of residents who choose to delay evacuation and contribute to the aforementioned complications. This device will aim to provide a solution to this problem.

When an evacuation notice is given, the resident can activate this device and continue the evacuation process in a timely manner, mitigating the risk of causing evacuation delay complications. The device will navigate its programmed route around the property spraying fire retardant and soaking the vegetation in material to render it non-flammable. The device will continue to spray until the entirety of the property is protected by a 360-degree barrier of flame suppressing material with a thickness of 30-100 feet, depending on the property. This will allow the resident, upon hearing of the evacuation notice, to simply activate the device and spend no further time ensuring the safety and protection of its home. The device will have the following features to carry out its tasks:

1) **Mobility:** The device will have large enough wheels to be able to navigate the property quickly, while also being thorough.
2) **Spray Mechanism:** The device will have a spray mechanism allowing it 360 spray travel as well as being able to pitch -90 to 90 degrees with respect to the horizon.
3) **Refill Tank and Sensor:** The device will utilize a tank on the property to refill when the on-board tank is empty. The device will automatically travel back to the refill tank when empty and return to its previous location to continue the route until completion.

Further considerations for the usage of the device are being made; however, the base of the features of the device will be generally the same. Possible uses outside of residential application are for firefighting authorities to use the device to spray fire retardant in grassland or forest areas before fire seasons. One strategy of the fire department is to spray environmentally benign fire suppressant on vegetation before fire seasons in an attempt to lessen the impact of growing wildfires. A large number of resources are allocated to carry out this task, when potentially an automated device can do the work with less people. Additionally, due to climate change, and dryer environments, trees in California specifically are losing their ability to effectively protect themselves from bark beetles, which render the trees dried out or dead thus contributing to the severity of the fire. The proposed device could also be used to spray a synthetic sap, the trees defense mechanism, on trees in the forest to help quell the exponential population growth of bark beetles.

C. Timeline and Milestone Considerations

A successful completion of any large task or project requires several different aspects of management, which includes brainstorming, planning, executing, and revising. The importance of the initial aspects of project completion cannot be understated; with a clear plan in place, the successful execution of the task will be much more likely. The "Five P's" offer the ideology which governed the early stages of this project: Proper Planning Prevents Poor Performance. However, just planning the sequence of events for the project is not enough. With fast approaching deadlines, certain tools are necessary for organizing the plan in an executable way which will allow for all deadlines and resource restrictions to be met. The timeline tools used to simplify the vision and direction of the project, and to organize the Work Breakdown Structure, are the Gannt chart, and Program Evaluation and Review Technique (PERT) diagram.

The Gannt chart was popularized during the second decade of the 20th century by mechanical engineer Henry Laurence Gannt [4]. This method for organizing the tasks that led to a completed project stood the test of time and is now used in facilitating proper planning for countless large projects. The Gannt chart depicts the time duration and deadlines for tasks to allow one to accurately gauge the percentage completion of the project. Additionally, the Gannt chart gives a visual representation of the effort required to complete certain aspects of the project; a longer event in the chart will require more time. The Gannt chart described in this report breaks down the project into its main feature set: Device Mobility, Spray Nozzle Functionality, and an Automated Refill mechanism. Integration of the features is also mentioned as it is the final step in compiling the final product of the device. From there, the components of the Gannt chart are further broken down into the work packages outlined in the Work Breakdown Structure, accounting for 100% of the tasks needed to complete the project.

The PERT diagram was used by the United States Navy in conjunction with the Polaris Project in the late 1950's [5]. PERT diagrams use nodes and networks to represent activities and milestones. It creates a web map which depicts the time duration of activities between certain milestones in the project. Using probabilistic estimates of each activity's duration, the PERT diagram will be able to give the team, or management, a qualitative representation of the total time required for a project. While the Work Breakdown Structure outlines the individual activities, which summate the entirety of the project, the PERT diagram assigns a time duration to these activities and connects them to their respective milestones. It should be noted that the milestones do not consume any time, rather, they are events which mark the completion of several steps up until that point. In the context of a PERT diagram, the activities are the network connections, and the milestones are the nodes. While the general overview of the project is an essential diagram for envisioning the completion of the project, the PERT diagram also offers insight on what milestones might cause time delays. Delays in the project are inevitable; however, if potential delays are identified, and the resources are allocated to allow the team to compensate correctly, the delays in schedule can be mitigated.

In essence the project timeline is an outline of the milestones; each one a stepping-stone closer to the completed product. The graphical depiction of the project gives insight to the team on where to allocate resources properly, as well as what components may take the most time. In addition to the host of benefits from the project timeline, it also outlines potential risks for the project as well.

D. Potential Risks

Once the design, and process for how to begin constructing the design was decided upon, the necessary step of considering the potential risks with every aspect of the device followed. Since there are multiple facets of this project which need to be completed simultaneously, it is essential that any risk be addressed. It is equally essential to have a method for mitigating said risk. We are completing this project during an unprecedented time where the typical work-life balance is challenged by the need to remain safe in the middle of a pandemic. There are additional precautions which this team will need to make in order to ensure the safety of each team member, and those who we interact with. Additionally, the methods for which we are able to continue to construct this device will need to change as there is heightened risk with things like shipping times, and stock of certain parts due to the coronavirus pandemic. Therefore, in addition to the general and technical risks we must consider in regards to specific parts of the device, we must also consider and strategize for risk that comes from the pandemic.

The critical path is defined in the Project Milestones section of this report. It outlines the longest path on the PERT diagram which also gives the minimum amount of time required to successfully complete this project. The critical path is indefinitely important because it also contains the events which, if delayed, will cause global delays to the progress of the project itself. It is then necessary that along this critical path, each risk associated with the events which make up the path is identified. Along with identifying said risk, a possible method for mitigating this risk is also useful in the event that the probability of risk is high enough that it actually happens.

After the critical path has been combed through with a risk mitigation strategy, the proposed risks will be organized and ranked by severity in the *Risk Assessment Chart*. This will graphically display and rank the discussed risk factors and will allow the team to visually represent the priority of the potential risks. Each one of the risks falls into three subcategories: *Specific Technical Risk, Broader Technical Risk, and Systematic Risk*. Specific Technical Risk may refer to the hardware parts themselves, or even faulty hardware. There is risk in choosing which parts to use for the project, and each one falls under the category of Specific Technical Risk. Broader Technical Risk may refer to factors which affect the hardware, but are not directly attributed to the hardware. For example, since this device will eventually navigate terrain, the Specific Technical Risk associated with this feature is the wheels themselves, whereas the Broader Technical Risk may refer to the terrain and obstacles for which the device will navigate. The final type of risk is much more vague, and contains several unknowns: Systematic Risk. Systematic Risk will consider the associated risks of completing this project during the pandemic, as well as any risks which affects team members individually such as illness or personal accidents. It is our priority as engineers on this project to mitigate each risk; however, in the event that any one of these events does happen, then the risk mitigation strategies outlined in the Risk Assessment section will allow us to pivot resources and continue on with the design.

E. Testing Outline

As we near the final steps of this project, it is imperative to carry out the testing procedures described in the Device Test Plan in Section IX. of this report. There have been several iterations of the design which have all been tweaked and modified as the team's knowledge about the device developed. A brief summary of the device testing is provided, and a more in-depth look at the testing protocols and results will be outlined in Section IX.

Each feature has its own set of tests. For Device Mobility, we must test (1) the route tracking, (2) the turn functionality, and (3) the startup ability. For the Refill Station, we must test (1) the pressure sensor valve, and (2) the automated device lid. And for the Spray nozzle we must test the (1) spray nozzle mobility, and (2) the on-board device tank.

The final step of our testing will be the integration of these features together. It should be understood that with the current pandemic, the team is building these three components to be completely separate of one another. For example, the Device Mobility will ideally be a working robotic cart capable of following a line. The refill station will be a standalone device which, when activated by the pressure sensor, will fill a tank to a desired level. And the spray nozzle will have a functional reservoir to pull water from while spraying through a moving nozzle tip. The final step is to simply combine these three elements together and test the integrated functionality of all of them.

II. Societal Problem

The first month of work on this project was spent solely on researching the topic as much as possible and learning everything we could as engineers about Wildfire destruction, and resident behavior. We found that the U.S. Department of Agriculture records information about origins of wildfires and the number of acres they burn [4]; however, recently we discovered that this past wildfire was exceptionally destructive with fires which were started in early September 2020 not being contained until the middle of November 2020. According to experts, over 4 million acres of land were destroyed amongst 9,639 fires which cost approximately 12 billion dollars to contain [8]. Our initial analysis used Table 1 to display some of the common ways in which wildfires start. While this information is incredibly useful, we now have a deeper understanding for how our device will aid in the efforts to combat the destruction from wildfires. Recently, after the devastation of the wildfire season from 2020, the Washington Public Lands commissioner pushed for a wildfire bill in legislation. The bill is a lengthy report which addresses the issue from many angles, however, it also includes a section which urges communities to be better prepared in the event of a wildfire near their homes. The Washington Commissioner believes its possible to "change the trajectory of these communities by helping homeowners, and neighborhoods create defensible space" in their homes and communities [7a]. With state authorities backing the option of defending the home as a legitimate method for lessening the damage from wildfires, we believe in our vision for the Wildfire Home Defense Assistant even more. This section of the report will outline everything we have learned about this topic with an in depth analysis of the research provided.

A. Recent Developments in Research and Societal Problem

While the majority of our research took place in late 2020, many studies were published in the early months of 2021 about the previous year's fire season which added value to our base of knowledge about wildfires. There have been several insights gained in regards to the importance of this device as well as the certainty in its efficacy in preventing casualties from wildfires due to evacuation delays. With a deeper understanding of the issue at hand, there is confirmation in our original idea that a device which can automate one of the common reasons for delayed evacuation would be an essential tool in learning to adapt to the growing issue of seasonal wildfires. Some of the major components which have contributed to our research are (1) the increase in minimum times for full evacuations of WUI areas due to increased residents in those areas, and (2) the complexity of mapping resident behaviors in emergency evacuation situations. Additionally, (3) how attached residents are to their homes or property seems to be a large factor in determining whether or not they will leave promptly or choose to stay after evacuation orders, and this is supported by the (4) recent call for legislation urging WUI residents to adapt and learn how to live in areas with rampant annual wildfires.

1) **Increase in Minimum Evacuation Times:**
   To some, the idea of a large property in a remote area of California or Washington is a dream home. Over the past 30 years, it has become quite evident that many people are actualizing this dream with a 41% growth of residential homes in the United States with 97% of those

homes being due to the result of new WUI areas [8a]. However, more residents living in these remote WUI areas poses a significant risk to them as it creates more opportunities for traffic in evacuation scenarios.

Despite the increased number of residents building and buying property in WUI areas, many of the roads and capacity networks are not improved or updated to account for the influx of new traffic [9]. A study published in 2013 titled "Mapping wildfire evacuation vulnerability in the western US: the limits of infrastructure," showed a direct correlation between the number of homes in any low-egress area and the minimum time necessary for allowing a full evacuation of that area. As our previous research showed, the full evacuation is incredibly complex and rests in the decision-making process of these residents. Based on their decisions, that minimum time frame will increase in the case that residents choose to defend their property by spraying it down with fire suppressing materials. Equation (1) maps out certain WUI areas which have been flagged for their low-egress capability. The equation aims to calculate a rate which describes the average fire hazard of an area [9].

$$g_i = \frac{C_k(P_k - a_i)}{P_k(C_k + (o_i - c_i))}$$

where:

i = index of nodes
k = index of iteration
g_i = gain in the objective if node i is selected
P_k = total population of cluster at iteration k
C_k = total exit capacity of cluster at iteration k
a_i = population at node i
o_i = new exit capacity node i would open, if selected

Table I shows a compilation of the highest at-risk communities in the Western United States. Using the metrics from the aforementioned equation, the table ranks the risk of these communities by their fire hazard rate, as well as the number of homes per exit available for egress.

As shown in Table 1, the increase of homes in WUI areas leads to a direct increase in the Fire Hazard rate and the minimum time required for the community to be fully evacuated. With what we know about reasons that add time to the minimum time required, having a system in place which can ease the process of evacuation will cut down on these times that lead to casualties in emergency situations.

Table I
TOP COMMUNITIES WITH MEDIAN FIRE HAZARD ABOVE 0.7 (0-1)

The top communities in the West with median fire hazard above 0.7 (0–1) and 1 exit

Rank	Nodes	Fire haz	Homes	Exits	Homes-to-exits	Lat	Long	State
1	57	0.75	806.4	1	806.4	33.167	−117.134	SoCal
2	59	0.70	803.6	1	803.6	33.192	−117.319	SoCal
3	64	0.90	776.7	1	776.7	34.152	−118.211	SoCal
4	79	0.95	755.9	1	755.9	39.627	−106.417	CO
5	51	0.84	748.3	1	748.3	39.619	−106.100	CO
6	75	0.88	630.7	1	630.7	39.593	−106.010	CO
7	47	0.81	597.1	1	597.1	39.474	−106.058	CO
8	66	0.86	571.7	1	571.7	32.941	−117.158	SoCal
9	13	0.74	560.2	1	560.2	34.169	−118.530	SoCal
10	44	0.83	552.7	1	552.7	33.150	−117.291	SoCal
11	9	0.77	535.4	1	535.4	39.501	−106.158	CO
12	23	0.88	527.6	1	527.6	47.201	−122.514	WA

[1]The increase of homes to exits in each community directly correlates to the minimum time required to fully evacuation said community in an emergency evacuation situation [9].

2) **Unpredictable Nature of Resident Behavior:** Our initial analysis of this problem showed that there is irrefutable evidence that wildfires are growing more and more severe with each subsequent fire season. Due to the increased severity, many recent publications have aimed to study how residents in these evacuation scenarios behave in order to predict patterns and make a better evacuation model for WUI communities. A 2018 study which looked at influences on wildfire evacuation decisions references the Protective Action Decision Model (PADM) to understand why individuals do, or do not, take protective actions in emergency situations. According to the PADM, one of the main contributors to the response of residents to evacuate is the perceived threat. In a wildfire, this would mean things like smokey environments, seeing the fire itself, or the presence of other residents quickly and responsively evacuating [10]. The overall conclusion of this study narrowed down evacuation behavior into two categories: those who are willing to go, and those who want to stay. For the portion of those who want to stay, their reasoning is largely based on their belief in how well they know how to defend their property from wildfire. With the Wildfire Home Protection Assistant, the homeowner will have full knowledge of how to protect his/her property while also being able to automate this process without having to stay home to carry out the task.
3) **Home Attachment and the Importance of Preserving One's Property:** After the most recent fire season, more media outlets and influencer personalities began to promote the importance of creating a defensible property from wildfires. Wildfire mitigation becomes more and more critical with the increase in fire intensity which is why programs like Firewise USA aim to arm residents with the knowledge required to defend themselves and their property against wildfires [11]. According to a 2019 study, homeowners' attachment to their homes is a large factor in determining their behavior after an evacuation mandate. Figure 1 shows a direct correlation between home attachment and the probability of waiting after the mandate is issued. With a device that has the purpose of protecting the home which the resident is attached to, there can be peace of mind in executing the evacuation mandate, thus reducing the number of cars on the road during the critical moments of the evacuation[11].
4) **A Call To Adapting to Wildfires:** In 2019, the Federal

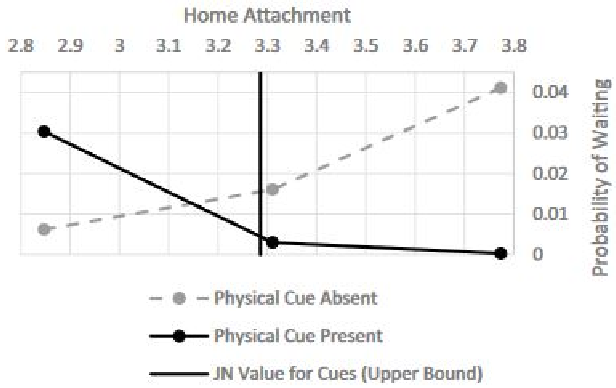

Figure 1. Home attachment interaction in the model of waiting intentions. This figure assumes mean values for all covariates in the model [11].

Table II
REPORTED CAUSES OF WILDFIRES IN U.S. 2000-2008 [4]

Cause	Average annual ignitions reported	Average annual area burned reported, acres	Percentage share of reported ignitions	Percentage share of reported area burned
Natural/Lightning	10,874	5,496,235	45.34	79.90
Campfire	1,964	179,338	8.19	2.61
Smoking	418	22,387	1.74	0.33
Fire Use/Debris Burning	1,538	100,971	6.41	1.47
Incendiary/Arson	2,969	268,962	12.38	3.91
Equipment (Use)	1,338	246,804	5.58	3.59
Railroad	117	14,193	0.49	0.21
Juveniles/Children [a]	1,063	20,464	4.43	0.30
Miscellaneous and unknown [b]	3,704	529,313	15.44	7.69

[2] Fire causes, reported average annual ignitions, reported average annual area burned in acres, and percentage shares of fires by causes and area burned from the U.S. Department of the Interior and the Forest Service, U.S. Department of Agriculture combined for January 2000–December 2008.

Forest Service of the United States published a study which cemented the logic that each subsequent fire season will be more intense. The large scale study cross examined the effectiveness of having social-ecological systems in place to encourage a new way of living with the wildfire threat. There is an increasing consensus that communities and land managers alike need to adapt and learn to live with the wildfires, despite the obvious problems which may arise. However, one possible solution is outlined in the study which proposes a ”novel risk-science approach that aligns wildfire response decisions, mitigation opportunities, and land management objectives by consciously integrating social, ecological, and fire management system needs” [12]. By informing the public of the necessity of leaving in a timely manner after the mandate has been issued, and increasing the social awareness aspect of reducing evacuation route traffic, there is potential to successfully evacuate these communities with minimal losses.

B. Human Causes Of Wildfires

Human caused fires can be divided into the categories of accidental fire, which are caused without any ill intention, and arson, which is generating a fire with malicious intent [8]. Human caused wildfires are ignited by campfires, smoking, incendiary, equipment, railroad, juveniles, arson, children, debris burning and miscellaneous (and unknown). The causes of wildfire ignitions can be broken down to biophysical drivers, social drivers and prevention. How everything is linked can be viewed in Figure 2. The main causes for wildfires differ depending on the region that is studied. To compare, the Western lands of the U.S. have lightning as the main cause for reported fires accounting for 65 percent of wildfires, the Eastern lands wildfires caused by lighting only accommodate for 11 percent [8]. The data for annual fires and the acres burned, causes is listed in Table 2.

C. Natural Causes Of Wildfires

The U.S. Department of Interior and Forest Service, the U.S. Department of Agriculture all keep lists of wildfire causes. On lands managed by the U.S. Forest Service the most common cause of a wildfire is lightning, which represents 55.8 percent of wildfires and 74.3 percent of area burned between January 2000 and December 2008. The Department of Interior reports 37 percent of wildfires and 81.6 percent of all areas burned are caused by natural wildfires [4]. Some wildfires are used for preventative measures called prescribed wildfires. These wildfires are burned to reduce the likelihood of bigger fires, to kill off any pests and snakes in an agricultural setting and to prepare land for crops. The main causes of natural fires are lighting and prescribed fires. From Table 2 the highest percent cause for wildfires that are reported in the U.S. is natural/lighting accounting for 45.34 percent of wildfires and burning 79.90 percent of land burned by fires equaling 5,496,235 acres of land.

D. Variables Leading To Wildfires

There are four main variables that lead to wildfires consisting of biophysical variables, societal variables, fuels, and management/prevention variables. Biophysical variables are the most basic level and the physical process of the fire burning itself. The presence of fuels with sufficiently low moisture levels to enable the combustion process to begin is required for an effective ignition to occur, assuming fuels are present, temperature, solar radiation, humidity, and precipitation are primarily a function of humidity content [4]. Ignition frequency increases in warmer and drier conditions leading to most wildfires to be caused towards the end of summer. The type of plants and trees in the surrounding area also play a role in how effectively the fire spreads, some vegetation serves as better fuel to the fire than others based on moisture levels. These climate conditions that favor ignitions and fire spread have become more common in recent decades, these more favorable conditions have led to larger fires and increased area burned. The second variable is societal. These are the impacts society has that cause fires ignite. Society generates a subset of individuals that intentionally set fires or accidentally through their work or normal operation of machinery [4]. Society's use of big machinery and equipment can cause fires that occur from a malfunction or during regular operation. The population and road density has increased the number of wildfires. Agriculture can lead to fires if agricultural land is abandoned and forest regrowth is allowed [6a]. Fuels are another variable to cause fires. For a successful fire dry fuel beds are needed for ignition and spread. Fires are most likely to be self-contained or small enough to be extinguished by nearby people when the moisture levels are high, or the fuel levels are low. Management and prevention also contribute to the likelihood of a successful fire ignition and spread. The way land managers take action to affect wildfire occurrence, spread and severity with the cost they have can influence the likelihood of a fire occurring on their property.

E. Wildfire Prevention

Wildfire prevention can be categorized as a long-term effort to reduce unwanted fires by planning, developing early warning systems, and training wildfire prevention personnel. Fig. 1 shows the current strategy for Wildfire Ignition Prevention. Prevention could be done by incorporating education and using fire resistant building materials. These variables contribute to the likelihood of a fire happening in an area based on how educated the inhabitants are, how well the property is managed to prevent fires and if they have any early warning detection systems.

F. Increase Of Wildfires Over Time

Wildfires have become quite routine to the point where CalFire leaders themselves suggest there is no wildfire "season" anymore (The Connection Between Climate Change and Wildfires, 2011) [14]. Though there may be an occasion where it serves a purpose, there is undoubtedly a great cost resulting from its immoderate growth. Many preventative measures are taken to combat this concern. Developing a Fire lines is one manner of containment in where the supply of fuel (flammable materials such as dry sticks, trees etc..) is cut off to prevent the spread and increase of damage. However, despite having numerous methods of fire suppression, efforts are often minimized as a result of the effects generated from climate change which will be elaborated on. We will also provide insight on the steady increase of wildfire occurrences.

G. Climate Change And Increased Fire Susceptibility

The excessive usage of fossil fuels such as coal, natural gas, and petroleum which accumulate to over 75% of energy production as of 2017 accounts for about three-quarters of our carbon emissions. Carbon dioxide acts as a blanket around the earth, causing the planet to warm up. [14] This results in numerous potential hazards such as rising sea levels, drought and given a drier climate it can lead to higher susceptibility of fire outbreaks. A data collection study was done in where a few counties in California were analyzed to record the amount of escaped fires (fires that went past containment limits) as well as the damage caused within contained fires. The purpose of this analysis was to determine the impact of fire severity and occurrence given an increase in of carbon dioxide in the atmosphere. The results are shown in the Table 2 provided by an article titled, 'The Impact of Climate Change On Wildfire Severity' [15].

Table III
IMPACT OF CLIMATE CHANGE ON WILDFIRE SEVERITY [15]

Ranger unit/ fuel	Number of fires	Number of escapes			Hectares in contained fires		
		Present climate	$2 \times CO_2$ climate	Percent change	Present climate	$2 \times CO_2$ climate	Percent change
Santa Clara							
Grass	168.1	4.5	6.9	53	938.0	1326.7	41
Brush	22.7	0.3	0.4	21	4.0	5.3	34
Tall brush	11.6	0.0	0.0	0	0.8	1.7	100
Redwood	23.0	0.0	0.0	0	0.8	0.9	7
Overall	225.4	4.8	7.3	51	943.6	1334.6	41
Amador							
Grass	58.5	1.2	2.8	143	691.6	885.8	28
Brush	62.9	5.0	11.1	121	89.6	187.1	109
Oak savanna	152.8	0.0	0.0	0	118.2	194.5	65
Mixed conifer	29.0	0.0	0.0	0	10.5	15.1	43
Overall	303.2	6.2	13.9	125	909.9	1282.5	41
Humboldt							
Grass	15.1	0.0	0.0	0	15.5	11.4	–27
Redwood	158.9	0.6	0.6	0	83.7	80.1	–4
Overall	174.0	0.6	0.6	0	99.3	91.5	–8

[3] Note that not all areas experienced the same impact as a result of increased CO. *A 'Hectare' equates to 2.471 acres or 10,000 square meters

The data shown above breaks down the impact of multiple fuel sources (grass, shrubs, trees etc..) that were used and consumed by the fires. In observing the column that shows percent change, it becomes apparent that Santa Clara and Amador have suffered dramatic losses in reference to grasslands and brush being burned. Santa Clara had a 53% increase in grass being burned and a 21% increase in brush damage as a result of fire escapes and Amador suffered even greater loss. Humboldt county however had nearly no change despite an increase in carbon dioxide emissions. This may have been most likely a result of improved fire suppression in the area, smaller fire susceptibility areas and a wetter climate. This exceptional data does not nullify the gravity of the issue but rather shows that some areas are less susceptible yet are not entirely exempt from experiencing this potential catastrophe.

H. The Rise Of Fire Occurrences

Although wildfires are prone to cause destruction to the environment and to those affected by it, there is a fundamental need for them in an ecological perspective. One article describes how fires shape the biodiversity of dry forests and there are even cases when plants contain unique adaptations for coping with fires of mixed severity [8]. However, there remain the concerns of fire severity and containment. Fires may be a beneficiary factor with regards to new growth granted it does not result in greater harm than good. Warmer climates and windier areas are only a few of the many complications resulting in unrestrained fires that spread rapidly. Often even the efforts aimed at suppressing fires can backfire in the case where past forest management may led to the build-up of flammable fuel wood [14]. As shown by [8] there has been significantly more fire escapes which account for considerable portions of ruined land in comparison to fires

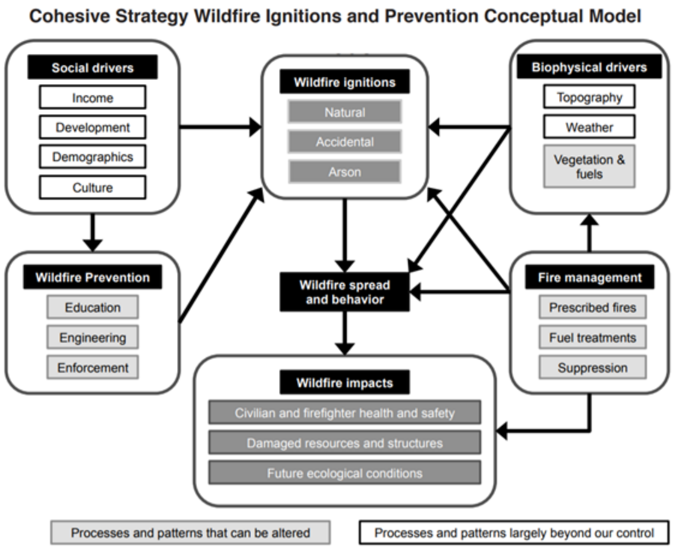

Figure 2. Conceptual model of fire ignitions and preventions [16].

that were contained. Cal Fire helps supply more awareness in providing a graphical data of the amount of land affected by the fire each year ranging from 1985 to 2018 (Figure 2) [17]. In analyzing the most recent years of the graph the number of acres burned has been substantial, even though the number of fires has decreased with few exceptions in both observed quantities. The correspondence of increased fire destruction despite a smaller record of fire activity implies the increase of severity of the existing fires. Addressing the impact from climate change, improving fire suppression methods, and reducing human activity that increases wildfire risks are a few of the many preventative methods that may diminish the severity of destruction that goes beyond the mere loss of land.

I. Key Notes

In summary, fire occurrences have increased as a result of numerous considerations including climate change and poor fire suppression. Climate change is the result of increased usage of fossil fuels which establish an environment more susceptible to wildfires. Failure to contain these fires due to lack of resources or poor management also increases the risk of experiencing more wildfires. As shown in the figures displayed above, the overarching issue resides in the need to reduce human involvement of increasing fire risk as well as the need for greater efforts in the case of containing the fires that have started.

J. Evacuation Model and Residential Risk

The Congressional Research Service tracks wildfire statistics annually based on acres burned and has shown that each year an average of 6.8 million acres burn due to wildfires [20]. However, the threat posed by wildfire is not limited to vegetation, wildlife and property; it also poses a serious threat to civilian lives in Wildlife-Urban Interface (WUI) locations. The term WUI is used to describe locations at which urban environments intersect with areas of predominant wildlife. Over the past 10 years, while there have been significant advances in technologies used to fight wildfires, there is still a concerning number of civilian casualties annually from them. This is partly due to an increased number of homeowners who are choosing to live in areas where risk of wildfire is naturally higher. The WUI location for homebuilding is steadily increasing [16]. In the United States, the general policy for homeowners in high risk areas is mandatory evacuation; however, there are several challenges that come with a mandatory evacuation, and the process has a litany of complications.

K. Current Evacuation Model Complications

The U.S. Fire Administration describes the process of a successful evacuation in five steps: Anticipation, Warning, Displacement, Notification, and Return and Recovery. As described in [16], interviewed residents following California wildfires in 2003 reported 5 major findings regarding the current evacuation model.

1) Information received from authorities via broadcast were too infrequent and did not contain timely information of relevance.
2) Residents took to searching for information in an emotionally-driven state, which changed their preference for the source of the information, prioritizing timeliness and location relevance over validity.
3) When the fire affected power lines, loss of electricity affected residents' ability to receive broadcasts.
4) Accurate, local level information was difficult to find after residents had initiated evacuation.
5) The brochure given out by authorities which detailed a step-by-step approach to evacuation proved to be very helpful.

Confusion on how to interpret the incoming information was a commonly shared problem. While there have been improvements made to methods of communication between authorities and residents since 2003, there is still an overwhelming presence of disjointed behavior from residents in the event of an evacuation.

L. Inconsistencies Of Resident Reaction To Mandatory Evacuation And The Following Effects

A study published in 2019 in Fire Technology suggested that, while more research on evacuation process needs to be done in the United States, people generally have mixed reactions to a mandatory evacuation, with over 60% of residents choosing to delay their evacuation after receiving the notice by authorities to evacuate [16]. Figure 3 describes the actions taken by United States residents when threatened by wildfire. While the majority do end up evacuation, the time in which they decide to do so has great affects on the evacuation plan as a whole.

The number one threat to civilians in wildfire scenarios is the combustion of large quantities of fuel (remnant vegetation) which gives off exorbitant amounts of convective heat. In

California Wildfires and Acres for all Jurisdictions

	CAL FIRE		Federal Firefighting Agencies		Local Government*		TOTAL	
	FIRES	ACRES	FIRES	ACRES	FIRES**	ACRES	FIRES	ACRES
1987	8,062	87,000	4,374	744,000	1,040	42,000	**13,476**	**873,000**
1988	8,121	191,000	4,160	96,000	1,009	58,000	**13,290**	**345,000**
1989	6,635	73,600	2,547	87,800	842	12,000	**10,024**	**173,400**
1990	7,283	212,100	2,670	128,100	595	25,000	**10,548**	**365,200**
1991	6,271	23,100	2,681	18,800	657	2,300	**9,609**	**44,200**
1992	7,939	191,490	3,682	86,340	426	4,915	**12,047**	**282,745**
1993	6,688	122,606	1,774	67,646	227	119,527	**8,689**	**309,779**
1994	7,207	140,792	2,698	359,227	364	26,200	**10,269**	**526,219**
1995	6,601	121,198	1,563	78,414	328	10,203	**8,492**	**209,815**
1996	7,237	232,624	2,637	488,010	736	31,738	**10,610**	**752,372**
1997	6,835	57,788	2,180	198,431	487	27,666	**9,502**	**283,885**
1998	5,227	92,456	1,860	90,246	485	32,710	**7,572**	**215,412**
1999	7,562	285,272	3,139	865,621	424	21,957	**11,125**	**1,172,850**
2000	5,177	72,718	1,884	218,578	561	3,730	**7,622**	**295,026**
2001	6,223	90,985	2,567	275,152	527	11,203	**9,317**	**377,340**
2002	5,759	112,810	1,837	366,842	575	58,564	**8,171**	**538,216**
2003	5,961	404,328	1,783	399,635	543	161,807	**8,287**	**965,770**
2004	5,574	168,134	1,852	110,082	472	32,808	**7,898**	**311,024**
2005	4,908	74,004	1,604	139,399	725	65,811	**7,237**	**279,214**
2006	4,805	222,896	2,400	603,378	650	37,071	**7,855**	**863,345**
2007	3,610	434,667	1,932	990,730	501	95,565	**6,043**	**1,520,362**
2008	3,593	380,310	2,203	1,153,973	459	59,407	**6,255**	**1,593,690**
2009	2,858	75,960	1,820	339,908	2,332	36,101	**7,010**	**451,969**
2010	2,434	25,438	1,616	98,871	2,344	10,153	**6,394**	**134,462**
2011	3,056	51,889	2,021	73,124	2,655	103,586	**7,732**	**228,599**
2012	2,922	128,956	1,562	687,013	2,557	13,255	**7,041**	**829,224**
2013	3,672	114,473	2,213	450,126	3,004	37,036	**8,889**	**601,635**
2014	2,920	163,067	1,960	451,810	2,353	10,663	**7,233**	**625,540**
2015	3,231	291,282	2,184	577,115	2,868	6,137	**8,283**	**880,899**
2016	2,816	244,556	1,220	412,990	2,923	12,078	**6,959**	**669,534**
2017	3,470	467,497	2,189	746,701	3,611	385,442	**9,270**	**1,548,429**
2018	3,504	1,063,414	1,307	793,548	3,137	118,124	**7,948**	**1,975,086**

*County Fire Departments that protect State Responsibility Area (SRA) under contract in Kern, Los Angeles, Marin, Orange, Santa Barbara & Ventura Counties. **Starting in 2009 "Local Government" also includes local fire departments that contract with CAL FIRE for emergency response and fire protection.

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Figure 3. California Wildfires And Acres For All Jurisdictions [8]

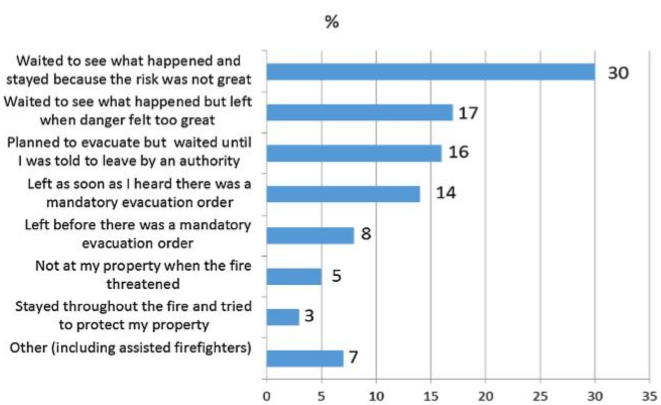

Figure 4. Actions Taken By U.S. Residents When Threatened By Wildfire [16]

addition to the heat that contributes to a vast majority of wildfire casualties, there are other factors pertaining to resident reactions to evacuation that contribute to casualties during mandatory evacuations. Generally, after the initial mandate for evacuation is announced, there are four reactions from residents.

1) **Immediate evacuation:** While this is the reaction that authorities based the evacuation model off, only 14% of residents actually begin the evacuation process immediately after learning of the mandate. Many of the residents who reported immediate evacuation also understood that they had a general lack of knowledge on the likely path of the fire, as well as the rate of its approach.
2) **Delayed Evacuation:** This response to the evacuation mandate seems to be the most troublesome and have the most second-hand effects. When residents choose to delay evacuating, whether it be to see if evacuation is actually necessary, or waiting for a different source to confirm the necessity, it has the potential to clog other evacuation routes as some may close due to the approaching wildfire. When evacuation routes close, residents are forced to inundate the same routes. This leads to traffic, automobile accidents, and prohibition of

firefighting personnel from using the routes for mobility and fire suppressive efforts. Many residents who choose to delay evacuation account that seeing smoke or hearing alarms was the precursor to their actual evacuation. Again, falling in line with the theme that in the initial stages of evacuation, there is confusion on how to interpret the information.

3) **Staying and Defending Property:** In certain areas where evacuation is not strongly advised, but is mandatory, this option is technically illegal. However, Police reported that it was difficult to know to what degree to enforce this policy. The same threat exists for police, and the same potential to clog evacuation routes for firefighting personnel exists. Additionally, this response was much more common when residents had animals on their property that needed tending to.
4) **Shelter in Place:** Remaining on one's property and not evacuating is the least common option; however, some residents still choose not to evacuate. Often these residents have cleared their property of as much fuel as possible and have made reservations in advance for a secure shelter which can withstand the fire.

With a wide spread of data which describes how residents choose to respond to mandatory evacuations during wildfire incidents, there is much more research that needs to be done.

M. Administrative Challenges In Evacuation Notice Timing

From an administrative point of view, authorities reported that the timing as to when to officially give the mandate to evacuate was challenging. It is necessary to give enough time to the residents to allow for a safe evacuation; however, accounting for delays, and the complexities of the fire's path of travel was needed to be considered.

N. Summary Of Research

Ultimately, the most determinant factor in residents' willingness to evacuate came down to the level of concern of the likelihood of the threat posing imminent danger on their property. While the study referenced in [16] considered data from North America, Australia, and Canada, the amount of research post-evacuation in the United States is lacking. The generalizations which can be made about resident reaction to evacuation are common in all 3 studied locations.

1) It should be assumed that not all residents will evacuate promptly.
2) Mandatory evacuation as opposed to recommended evacuation will increase the number of persons who evacuate.
3) Agribusiness-based residents (livestock) or those with animals will more frequently choose to stay and defend their property and tend to the animals
4) Residents will be more likely to comply if their preconceived ideas of the risk are that it is a potential threat.
5) Prior planning for evacuation, perceived danger, and enough time to prepare evacuation reservations all positively influence willingness to evacuate.
6) Modality, timing, and content of evacuation warnings is imperative.

O. Casualties, Home Loss, Establishing Safety Distances

Wildfires cause major impact on human health and the economy, thus understanding the severity of wildfires causes one to look for a solution. The following looks at the health impact of wildfire smoke and some of the solutions such as suppression and safety distancing.

P. Wildfire Impact on Human Health

Wildfire smoke has been associated with the increase of respiratory problems in humans. A review paper published in 2016 titled "Critical Review of Health Impacts of Wildfire Smoke Exposure" looked over multiple research studies to find a conclusive outcome on the wildfire smoke effects on human beings.

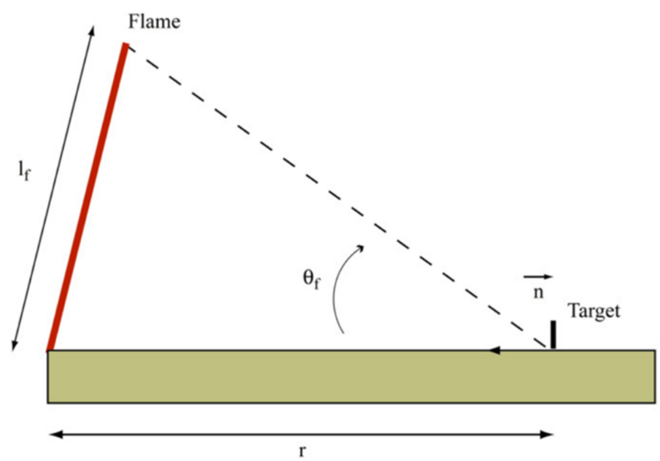

Figure 5. Acceptable Safety Distance [8].

The paper found that the studies of "health outcomes associated with wildfire smoke exposure tend to be retrospective and researchers have to rely on administrative health outcome data such as mortality or hospitalization records" [15]. For example, a study of 13.5 years of data including 48 days affected by wildfire smoke in Sydney, Australia, showed a large increase in mortality associated with smoke-affected days [15]. This data reveals that comparing days before, during, and after a wildfire gives evidence to the impact on human health. The paper concludes that evidence supports potential respiratory and cardiovascular health effects of wildfire smoke exposure and found consistent evidence of associations between wildfire smoke exposure and respiratory morbidity in general, and specifically for exacerbation of asthma and chronic obstructive pulmonary disease (COPD). Growing evidence suggests associations with respiratory infections and all-cause mortality [15]. Another paper released in 2020 studies the health impacts of two wildfire's smoke in Canada that can be applied to Californian wildfires. The paper found that "for 2013–15 and 2017–18, annual premature mortality attributable to wildfire-PM2.5 was estimated at 54–240 deaths from short-term exposure and 570–2500 deaths from long-term exposure, as well as many cardio-respiratory morbidity outcomes" [19]. The data reveals morality rates increase over time, long after the wildfire is contained and effect more dense populations such as in California. The wildfires also harm the economy due to health issues. The 2020 paper places "the economic valuation of the population health impacts was estimated per year at $410M-$1.8B for acute health impacts and $4.3B-$19B for chronic health impacts for the study period" [19].

Q. Home Loss

Another issue that wildfires pose is residential loss. A paper published in 2015 titled "Reducing the risk of house loss due to wildfires" studied past wildfires such ones in Australia and California to determine economic effects. For example, the Black Saturday fires in Victoria, Australia, resulted in the damage or destruction of over 2000 houses while the 2007 wildfires in California resulted in the evacuation of 300 000 people and the loss of 2223 houses [8]. The paper concludes that in the following years, wildfires have considerable economic impacts on communities, local business and production [8].

Burn injury vs. exposure time. The fixed threshold value is 5 kW/m^2.

Effect	*Injury time (s)*
Threshold of blistering	35–60
Second degree burn	140
Third degree burn threshold	125
Third degree burn, 50% mortality	270

Figure 6. Direct correlation between burn injury and heat exposure time [15].

The paper reviews methods of reducing the risk of home loss through suppression. If residents had readily available access to fire resistant devices, then home losses would decrease. Figure 4 shows that probability of home loss in interface and intermix communities if suppression is or is not used. As one can see, home loss is significantly decreased when suppression is available.

R. Establishing Fire Safety Distances

In order to create a device that can suppress fire damage and ensure the safety of humans, the knowledge and calculation of an acceptable safety distance (ASD) is essential. A research paper titled "An analytical model based on radiative heating for the determination of safety distances for wildland fires" published in 2011 reveals that what the ASD is in wildfire areas. First, humans only have about 4.5 minutes of fire exposure time before ultimate injury occurs, as shown in Figure 5. Anything to reduce the exposure time will greatly reduce the degree of a burn.

Table IV
IMPACT OF CLIMATE CHANGE ON WILDFIRE SEVERITY [8]

Table 7
ASD determination for 13 fuel models under a wind condition of 8 m/s (ε=0.9). The fixed threshold value is 7 kW/m^2.

Type of fuel used by Rothermel's model	l_f (m)	γ (°)	*ASD* (m) with T_f=873 K	***ASD/l$_f$* with T_f=873 K**	*ASD* (m) with T_f=1353 K	***ASD/l$_f$* with T_f=1353 K**
Short grass (1 ft)	4.6	18	10.7	**2.33**	44.9	**9.75**
Timber (grass and understory)	5.6	23	13.2	**2.35**	53.3	**9.52**
Tall grass (2.5 ft)	6.2	26.5	14.6	**2.27**	57.8	**9.33**
Chaparral	8.7	40	19.8	**2.35**	71.8	**8.25**
Brush	5.9	25.4	13.9	**2.35**	55.5	**9.4**
Dormant brush, hardwood slash	5.6	23.2	13.2	**2.35**	53.3	**9.52**
Soutern rough	5.6	24	13.2	**2.16**	53.1	**9.4**
Closed timber litter	0.5	2.3	1.1	**2.34**	5	**9.96**
Hardwood (long-needle pine) litter	5.4	22.2	12.7	**2.35**	51.7	**9.57**
Timber (litter and understory)	7.0	31	16.4	**2.34**	63.2	**9.03**
Light slash	6.1	27	14.3	**2.35**	56.8	**9.30**
Medium slash	8.4	38.6	19.2	**2.28**	70.5	**8.4**
Heavy slash	9.6	43.8	21.4	**2.29**	75.5	**7.9**

4 ASD Determination for 13 fuel models under a wind condition of 8 m/s.

Another study focused on the acceptable safety distance of wildfires was also taken into account. Figure 6 and Table 3 below can be used to determine the ASD given that we know the flame length, angle, the distance between the flame and target, and the fuel for the fire. Each area, therefore, requires a different ASD. However, average distance of 15 meters should be safe for the human. Overall, the study concludes that the analytical formulation (given by the study) can provide immediate results to the end-users and can be used to support firefighting and fire management strategies devoted to keep firefighters and structures safe at the wildland urban interface [8]. This study is useful in the creation of the proposed solution device.

III. DESIGN IDEA

A. The Wildfire Evacuation Home Defense Assistant

The Wildfire Evacuation Home Defense Assistant (WE-HDA) will have the below describe features. The deployable prototype of this device will be similar to the one initially described at the onset of this project; however, to account for the new information learned, there will be slight changes to the feature set and measurable metrics.

1) **Device Intelligent Mobility** In order to have the most comprehensive mobility for this device, it will be using infrared proximity sensors to follow a customized "track" for the route of spray. The customized track will factor in for the trips to the refill station which is centrally located in reference to the property. Much like a cloverleaf pattern, the device will navigate out, spraying fire suppressive material, and will continually return to the refill tank to top off. This simplifies the on board computation as it eliminates the necessity of GPS technology with wifi capability. The WUI homes are known for having troublesome wifi which means not having to rely on those systems makes for a more reliable device.
2) **Device Spray Nozzle** The device spray nozzle will be similar to the concept described last semester. Rather than a straight spray function, the nozzle will fan in a 45 degree pattern to ensure proper coverage of the vegetation.
3) **Automated Refill Function** The automated refill will be constructed as a standalone device. Using a weight sensor, the refill tank will measure the weight of the

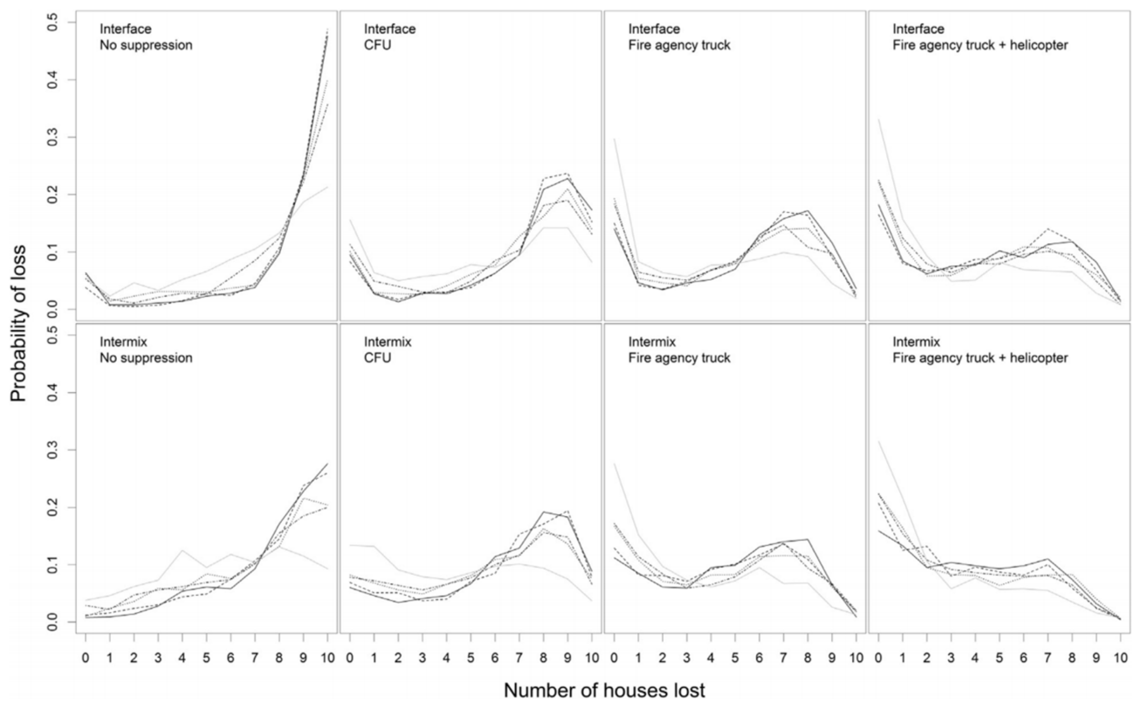

Figure 7. Comparison of Home Loss With and Without Fire Suppression Tools [8].

device and will continue to fill until it has reached its maximum weight. Afterwards, the device will continue on its path.

B. Laboratory Prototype Project Concept

Through the extensive research on wildfires and the lesser known obstacles that come with addressing them, the scope for this device has been narrowed down to a focused aperture directed at solving the issue of delayed evacuation of residents in high-risk WUI areas. As detailed in the previous section of this report, residents who choose to delay evacuation after an evacuation mandate is announced by authorities make up over 60% of evacuees. This is troublesome in that evacuation models are created under the guise that resident will execute a timely evacuation post-mandate. The delays increase the risk to potential harm, and attribute to incidents such as automobile accidents, and creating traffic on already congested routes. With how quickly a fire can spread, often evacuation routes can be closed which force residents to have to seek alternative routes. The few remaining open routes succumb to traffic which will further delay all evacuations, as well as prevent firefighting authorities from continuing to address the fire [18]. From this point of view, it can be concluded that anything that will allow residents to evacuate sooner would be useful in diminishing this problem. Of the variety of reasons residents choose to delay their evacuations, this device will be aimed at assisting those residents who delay in order to attempt to protect their property from fire damage. As shown in [7a] residents are encouraged to take preventative measures in "fireproofing" their property; additionally, there are products which allow residents to spray fire suppressant around their home to create a perimeter of non-flammable materials. However, according to the usage instruction of this product, "may last from eight to 24 hours [. . .] though in high winds such as those experienced during recent wildfires, it may last as little as 24 hours" [16].The time after the evacuation order is made is essential in allowing the residents enough time to pack necessary items and leave their homes. This does not factor in allocated time for making appropriate measures to protect one's property. Additionally, since the effect of the home-use fire suppressant decays after its been used, the time in which it is sprayed on the surrounding vegetation is significant. The proposed solution detailed in this report will allow residents to set the device to carry out these protective measures on their homes, to allow the resident to facilitate an expedient evacuation. Figure 8 shows the first design for the Laboratory prototype utilizing the wooden chassis.

In the event of an evacuation, simply activate this device and leave the property. The device will then navigate the property, spraying a 360-degree perimeter of a recommended thickness of 30 feet [16]. As the device maneuvers the terrain, the spray mechanism projecting the fire suppressive material will be directed orthogonal to the forward movement direction of the device, while also having -90 to 90-degree pitch variance with respect to the horizon. Typical market fire blocking gels are able to coat anywhere from 500 to 700 square feet with 1 gallon of gel [19]. Therefore, it is essential for the device to be able to refill its on-board tank to meet the needs of average WUI housing square footage. When the on-board

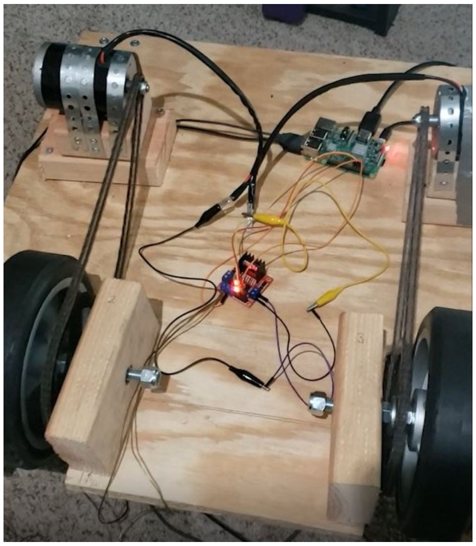

Figure 8. Wooden Platform Chassis for Laboratory Prototype

tank is depleted of its fire-blocking gel, the device will cease spraying, and will move directly back to the refill tank located somewhere on the property. The refill tank will be able to automatically top off the device, where it will then navigate back to its last location of spray and continue to cordon off the property. For the purposes of the initial prototype of this device, its path will be simplified to demonstrate the functionality of each feature. The demonstration will be as follows:

1) The device will move in a linear path straight forward while spraying water orthogonal to the forward movement a distance of 5 feet.
2) Once the on-board tank is empty, the device will move back to its starting location where the refill tank is located.
3) The refill tank will automatically fill the on-board tank.
4) The device will move forward without spraying to the point at which the water ran out, and will continue moving forward and spraying orthogonal to the forward direction.
5) Upon completion the device will return to its starting location.

In demonstrating its utility, the prototype will be using water in place of the gel fire-blocking and water mixture described in [20a] has similar physical properties to water. We will be assuming that the spray distance of the two liquids is the same. Additionally, the assumption that the gel fire-blocker's effectiveness is sound will not be tested with this prototype; the nature of how the fire blocker works will be trusted based on the reviews of the specific material.

The proposed solution addresses the problem by allowing residents to not have to spend the time setting up protective measures for their property but can rather allocate that time to carrying out the evacuation mandate. Without having to spend time setting up defensive measures, residents will not delay evacuation as long which will in turn minimize the number of automobile accidents and lessen the traffic on evacuation routes as the fire approaches. Additionally, this device can be used in a preventative approach rather than reactive. In correspondence with Stanford engineer and materials scientist, Eric Appel, the new fire-retardant substance he and his team have been working on is capable of withstanding weathering for multiple weeks. This substance can be utilized in accordance with the proposed device to target high-risk fire areas near WUI locations to spray retardant multiple weeks before fires occur.

The technologies needed for the design are well within the scope of this engineering project. The mobility feature will be governed using a Robotics Operating System (ROS) in addition to mechanical technologies used in the motor and wheel setup for the device. A simple water pump will allow use to spray water while controlling the hose mechanism with a rotary nozzle and Raspberry Pi microcontroller system to dictate the pitch angle. The technology for the automatic refill may prove to be the most challenging. The refill will use gravity to allow the water to be poured into the on-board device tank; therefore, the refill tank must be elevated higher than the device, and then a fill valve will be used to stop the automatic fill when necessary.

In designing this device, a novel approach was taken to automating a process which is typically done by a user. However, since the user needs to relocate, making the task done by some kind of machine is unique because it allows facilitation of a smooth evacuation, while also giving peace of mind to the resident or homeowner. Other designs similar to this do not have automatic features. For example, some firefighting teams use robotics to aid them in using hoses. There are also some design considerations which suggest using drones for retardant application; however, the weight which the drone can effectively carry is a limiting component.

To the extent of the research done on this topic, the other designs to address this same problem are minimal. As stated above, there are products which are used to allow residents to help protect their homes by creating a fire-proof barrier around the home using a spray nozzle (usually hooked up and mixed with water via garden hose). This approach may be worthwhile; however, the timing is a significant factor in ensuring the effectiveness of the fire suppression material, and when it comes to post-evacuation mandate, predicting when to allocate the time to spray one's property would be extremely difficult. This device allows a reactive approach to home defense while giving the attention of the evacuee to the evacuation process.

C. Punch List

1) **Feature 1: Device Mobility**
   The device will be able to navigate moderate terrain on its own. After completing its programmed route, it will return to the point where it started.
2) **Feature 2: Spray Nozzle Mechanism**
   The device will utilize a spray nozzle to distribute the fire retardant, or in this case, just water. The nozzle will operate orthogonal to the forward movement direction of the device, as well as have -90 to 90-degree pitch with reference to the horizon. The device will spray water a distance of 5 feet, and will demonstrate the nozzle angle change up and down.
3) **Automated Refill**
   The tank on the device will hold up to 1 gallon of fire suppressive material. When this container is emptied, the device will return to the starting location where a refill tank is located. The refill tank will top off the device. The device will return to its last sprayed location, continue spraying and navigating the programmed route.

D. Device Mobility

For our design we will need to establish mobility in two main areas, moving the robotic vehicle as well as the robotic spray nozzle system which will be activated by a water pump.

1) **Hardware to Implement**
   For the locomotion of the robot we will apply the Ackerman drive method in which the two front wheels are used for steering and two rear wheels are fixed in place. We will utilize two motors where one motor will be used for steering and the other motor will supply speed to the vehicle. We will also have a battery connected to these motors which will supply power. The robot supplies power to the rear-wheeled motor to travel in a linear path in accordance to its designated command which will be established through the micro-controller Parallax Propeller.
2) **Software to Implement**
   The software will be using for the parallax is simple IDE. The robot will have memory of its location so that when the fire retardant runs out, the robot can save its location, refill, and then return to continue spraying. We hope to use the SLAM, or Simultaneously Localization and Mapping, concept for the location tracking.
3) **Delegation of Work**
   We estimate that the robotic component will take most of out time, each spending approximately 5 hours per week. Mark and Jacob will be working on the hardware aspect and Roman and Mariya will be working on the software aspect. The whole team will work on the calculations to make sure the path of the robot is accurate in accordance with the programmed route.
4) **Measurable Metrics**
   The robot will have a programmed path with which it will navigate along moderate terrain (a generally flat road). The device will travel forward, return to the refill station, then continue to travel forward until the path is complete. It will then return to the start location.

E. Spray Nozzle Mechanism

1) **Hardware to Implement**
   The main component which will dictate the force of the spraying mechanism is the water pump. To start, a basin is required for holding the usable water on the device, and for the purpose of the prototype we are considering a 1 gallon tank (1 gallon of fire-blocking material is suggested for 500-700 square feet of usage[19]). Andax Industries electric water pump will provide sufficient power for the spraying mechanism. A hose will be connected to the pump at the base of the device and tank, and will run a line up to the spray nozzle at the top of the device. The spray nozzle will direct water in a fan shape, projecting up to 5 feet in distance, and 2 feet in width. As shown in Figure 7, HydroPulse Electrically Actuated Automatic Precision Spray Nozzle specifies the correct spray shape and is usable in accordance with the power output from the Andax Indrustries water pump. To control the angle of the spray nozzle, the nozzle will be mounted to a pan and tilt kit using servos. All of these components will be connected to a microcontroller to allow them to operate together.

Liquid inlet connection	1/8", NPT or BSPP
Maximum liquid flow rate	3.8 LPM / 1.0 GPM
Maximum rated pressure	20 bar / 300 PSI
Thermal insulation class	F (155°C / 311°F)
Power	10.4W @ 24VDC
Electrical connector	DIN 11mm
Maximum cycle frequency	50 cycles/sec
Nozzle construction	Stainless steel wetted components, Viton® (FKM) seals
Interchangeable BJ, BJH, and CW nozzle tip options.*	

Figure 9. HydroPulse® Electrically Actuated Automatic Precision Spray Nozzle. Information taken from https://www.bete.com

2) **Software to Implement**
   Since the tilt and pan kit which the spray nozzle is connected to is Parallax equipment, the main software used for this component is the Parallax Propellor IDE. With the Propeller, a connection can be made which governs the tilt and pan of the nozzle, as well as a connection governing the water pump itself.
3) **Delegation of Work**
   Mariya and Roman will be in charge of programming the water pump software. The program will ensure that the spray is powerful enough, and that the device only sprays when in a sensible part of the track. Jake and Mark will construct the design as well as mount the

parts to the device. The estimated time taken for these components to be created is 60 hours.

4) **Measurable Metrics**
The spray mechanism will project water orthogonal to the forward direction of the device up to a distance of 5 feet. The fan shape of the sprayed water will be a width of 2 feet. The angle of the nozzle will be able to vary between -90 and 90 degrees with respect to the horizon.

F. Automated Refill

To implement the refill sensor a magnetic floating device will be used that will be located inside the tank.

1) **Hardware to Implement**
A set of 4 reed switches (magnet diodes) will be used on the outside of the tank to measure when the tank is empty and when it is full in ¼ increments. When the pod is being refilled it will report an empty tank signal and will start to refill, once it is full it will send a full signal and stop refilling the pod. Roman will design the refill sensor and the refill station.
2) **Software to Implement**
The software to implement a refill sensor and refill station communication will be python assuming the micro-controller used will be the raspberry pi.
3) **Delegation of Work**
Roman will be in charge of designing the refill sensor. Jake, Mariya and Mark will focus on constructing the mechanism which will hold the excess water, as well as deliver the refill.To develop a refill sensor and a refill station will take an estimate of 40 hours.
4) **Measurable Metric**
The measurable metric will be the amount of fire suppressant in the tank of the pod, it will measure the capacity in the tank ranging from full to empty using ¼ increments to the refill station. When the tank is emptied, a signal will be sent to the microcontroller to initiate the refill sequence. The device will navigate back to the refill station, where the refill tank will automatically fill the device back to full. It will then resume operations with a full tank.

G. Teammate Skill Contributions

Each teammate brings a valuable skill to the group in order to finish the project goals. Jacob utilizes his electronics and hardware knowledge, along with his creativity. Mark informs the teammate on robotic and electrical matters, along with practical advice. Roman engages his programming and software expertise, along with his analytical mind. Mariya employs her computer hardware and software understanding, along with adaptability.

IV. Funding

Our estimated budget is $1000. We expect to receive no outside funding for our project.

A. Proposed Budget

The proposed budget for the prototype for this device is anywhere between $600 and $1,100 dollars (or $150 - $275 per team member). There are components of our design which are required for any type of working prototype; however, alternatives for needed parts are considered.

Table V
Estimated Budget

Item	**Cost**	**Additional Comments**
Parallax/Raspberry Pi	$0.00	Already Own
Robot Wheels	$100 - $500	Depends on the terrain tolerance.
Electric Water Pump	$100 - $200	
Magnetic Floating Device	$50	
Robot body/platform	$50	
Image Recognition/Sensor	$100	
Additional Expenses	$200	Wires, tape, sensors

The parts listed in Table IV are required, and the alternatives for each are limited. Robot wheels are expected to be robust enough to navigate moderate terrain, and in the event that we are unable to find wheels, a track may be substituted instead. The reed switch is a fundamental component for the tank fill sensor. In the event that we are not able to get a reed switch to track the water level, we can calculate the time duration for the water spray based on how long it takes to spray one gallon, and program a refill trigger every X amount of minutes.

B. Final Budget Analysis

In total, the team spent **$843.44** as shown in the spending tracker excel sheet. The spending tracker sheet itself has been provided in the Appendix. For this project the team did come in under budget; however, the team will still continue to test one more aspect of the project which will require buying more parts.

V. Project Milestones

With any project that requires months of planning and preparation, in addition to several hundred hours of work by multiple team members, it is important to highlight the steps of progress along the way. We approached our project keeping the Five P's in mind: Proper Planning Prevents Poor Performance. With due diligence put into the planning phases of our project, documentation to outline said planning is an essential component in ensuring that the team follows and executes the plan. The tools used to outline the activities which will lead to the final product of our design are the Gannt Chart, and the PERT diagram. The Gannt Chart is a linear timeline which depicts the estimated duration for certain features of the project. Our Gannt chart has 4 main components: Device Mobility, Spray Nozzle, Automatic Refill, and Assignments and Reports. Each component further breaks down to display the time required to complete each work packages, as well as where the start and end dates for these work packages lie. The PERT diagram is a node and network display to represent activities and milestones. The activities themselves are depicted as branches which connect the nodes. The nodes represent the milestones achieved when all the activities are complete. It should be noted that each node, or milestone, does not consume time, but rather represents an event signifying the completion of a feature.

A. *Gantt Chart*

In this project, we use Gantt chart as a project management tool to plan and schedule our work break down activities. The chart is a graph which shows activates performed against time. By using the chart, our team is able to understand and keep deadlines as well as track project schedules. The chart shows which activities are assigned to the members of the group. Similar to the work breakdown schedule, our activities are broken down to the features of the device. The WBS number 1 activities are pertain to the device mobility. The second activities pertain to the spray nozzle and the third pertain to the refill mechanism. Finally, the class assignments are listed. The chart also includes our class assignments. To see the chart see appendix F-5.

B. *Program Evaluation and Review Technique Diagram*

The Program Evaluation and Review Technique (PERT) Diagram is a useful tool in allowing the team to gauge the time duration of some of the milestones during the project. Please refer to Appendix F for a full view of the PERT diagram for the device. Another benefit of organizing the tasks in a PERT diagram is that the graphic makes it evidently clear what the proper sequence for activities is. Using this diagram, the team is able to gain insight on what are some of the most critical elements of the project, what elements pose a significant risk of causing a time delay, and what elements can be deemed as lower priority. Figure 8 shows a rough outline for the PERT Diagram. The following components outline the most compelling pieces of information taken from the PERT Diagram:

1) *Critical Path* - The critical path is the longest path from start to finish along the network of the PERT diagram. This path also signifies the minimum time required for a successful completion of the project; however, it should be noted that there will inevitably be some time delays with various aspects of the project. The minimum number of hours required by this project are 67 hours, with the critical path being the leftmost path on the PERT diagram found in Appendix F.
2) *Bottleneck Activities* - The bottleneck activities are the work packages which, if not sucessfully completed, will cause a large delay in the project. In the PERT diagram, the bottlenecks can be shown when any number of nodes point to the same node. For example, the following Milestone nodes all point to the same node, Deployable Prototype: Testing Device Mobility, Testing Spray Nozzle, and Testing Automated Refill. The deployable prototype is impossible to complete before these three milestones are achieved.
3) *Time Estimation* - Next to every path in the PERT diagram, a number is circled. This number refers to the number of hours the activities will take to go from one milestone to the next. It should be noted that this number is the ”most likely” time estimation; however, each time is considered with +/- 2 hours added to the most likely time. +2 hours to that time would be the ”pessimistic” estimation, and -2 hours signifies the ”optimistic” estimation.

C. *Milestones*

The milestones outlined reflect the completion of fundamental aspects of the design. They are written and considered in chronological order so that each subsequent milestone is not achievable before the ones which precede it are completed.

1) **Identification of Societal Problem**
The first milestone, the societal problem, guides the rest of the project since we build a device that provides a solution. By defining our societal problem, our team’s project can address a real, useful need in the world. Without a societal problem, a team of early engineers can struggle to think of an invention, or the invention can be impractical. We bounced around air pollution, drought, education, and finally wildfires. Our teammates pitched a problem to each other and choose wildfires since the problem is recurring and affects us directly. Finally, we presented the wildfire problem to our classmates in our zoom lecture.
2) **Design Idea Contract**
The Design Idea Contract is an important milestone because it outlines the goal for the team; the finalized product will be one which reflects the ideas proposed in this contract. After deciding on the societal problem, there are several possible methods to approach the solution to the societal problem. The Design Idea Contract narrows down this approach and gives the team the proper field of vision for which to continue working towards. This is a fundamental step in that it sets the azimuth for the direction the team will be working for the duration of the project. In the Design Idea Contract, the most important component is the list of features and measurable metrics. This concrete description for what we will be displaying is essential in identifying the work we are actually doing. The features and measurable metrics are as follows:
    a) *Feature 1: Device Mobility* – The device will have linear movement on wheels in forwards and reverse directions while carrying a weight which simulates a large volume of water
    b) *Feature 2: Spray Nozzle* – The device will have a spray nozzle capable of consistently spraying water a distance of five feet while the device is in motion. The nozzle will fluctuate between -70 and 70 degrees with respect to the horizon.
    c) *Feature 3: Automatic Refill* – When the on-board tank of water is emptied, the device will navigate

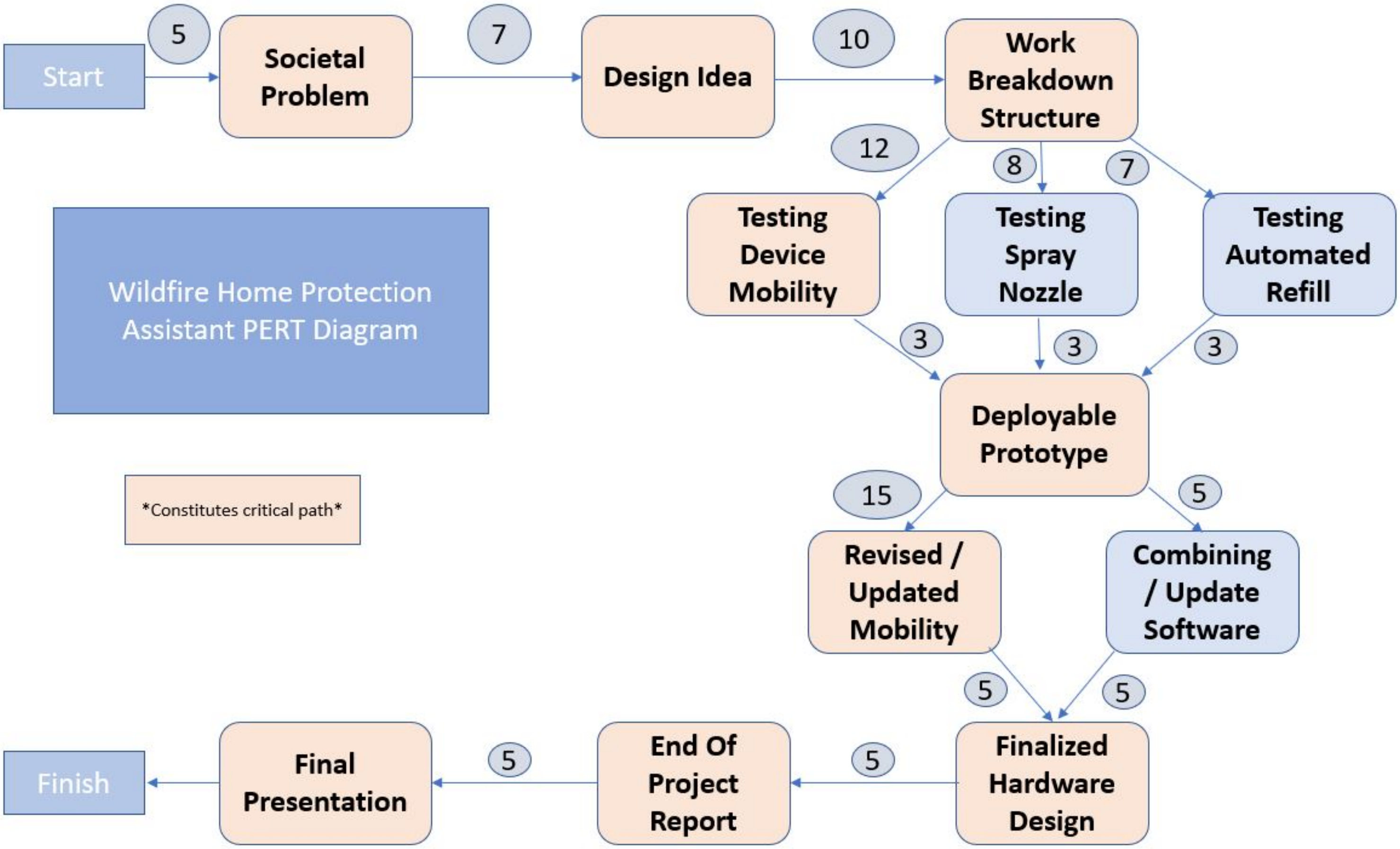

Figure 10. Simplified PERT Diagram

back to the refill tank which will trigger a sensor to fill the on-board tank to the top. It will automatically open and close the valve which controls the water.

We completed this milestone by meeting online and discussing the features which will address our societal problem while simultaneously encapsulating the knowledge we have gained throughout our time as students at California State University, Sacramento. The lessons learned from this milestone are solely related to communication, and the importance of establishing strong lines of communication early on, especially since the team is functioning remotely for the majority of the semester.

3) **Work Breakdown Structure and Project Timeline**
The work breakdown structure is a significant milestone given that it contains a detailed description of the project's features and task reports as well as the individuals responsible for completing each task. Although the project features were determined briefly in the Design Idea Contract, the breakdown structure helps expand all the main features into smaller sections that would be distributed to each member to complete over the course of the project timeline. This visual graphic also helps maintain productivity by ensuring specific facets are being completed within the intended timeframe. Without a solid work breakdown structure there is less accountability in every member contributing adequately and there is more difficulty in keeping track of the progress established. At the start of the project development the design idea was far from being established which made making any progress challenging but now that the breakdown structure is completed all that is left is to delegate responsibilities among the team members to complete the project.

4) **Testing of Device Mobility**
Mobility is a key aspect of this project design, it will allow the robot to cover a larger perimeter than if it was just stationary. It is a significant milestone that will allow the robot to patrol around the WUI home and be on the lookout for any fires to extinguish. For the first semester mobility will be demonstrated as having the robot successfully move a similar load as planned forward and backwards. The coding aspect for mobility is mostly finished, using a motor driver to communicate with the raspberry pi to get instruction on where to move.

5) **Testing of Spray Nozzle**
The spray nozzle demonstration is water pumping out of a nozzle that moves up and down in 90 degrees. Being one of the three main features, the spray nozzle is an obvious milestone. We started by buying the parts: hose, nozzle, water pump, and servo. Then, we tested that the water pump and servo are working correctly. After testing the parts, we program the servo to rotate before attaching the nozzle and hose. For this project, we use a micro controller, such as a raspberry Pi for the rotation. The spray nozzle should also know when to start and stop rotating. This can be done through the micro controller.

6) **Testing of Refill Mechanism**
The refill mechanism and refill station is an important part of this project as fires can take quite a bit of retardant to be put out. This functionality will allow the robot to know when it is out of retardant so it can drive to a refill station and refill retardant. We plan to use RF transmitters to communicate to the refill station that the robot is ready to refill and when it is full. The refill station will have another raspberry pi or microcontroller to communicate using radio frequencies to communicate to the robot when to start and stop refilling by controlling a valve using a servo. To test this the robot will drive up to the refill station and communicate that it is empty and ready for refill and the station will open the refill valve and wait till the robot tells it that it is full, then the valve will be turned off and the robot will continue patrolling the area.

7) **Deployable Prototype**
The deployable prototype is the presentation at the end of the first semester that will demonstrate our ability to follow deadlines set and the functions planned to be demonstrated. The robot will use mobility to be able to move forward and backwards, will be able to refill from the refill station, know its retardant level, and have a working spray nozzle mechanism.

8) **Updated Mobility for Autonomous Movement**
For the second semester, we plan to implement SLAM, or some type of mapping for the robot so that the robot can avoid obstacles and move to the refill station. In the first semester, we studied SLAM implementation and bought the proximity sensor. More information to be added as project progresses.

9) **Combining of Software Elements**
The device has several inter-working components which require their own programs to govern the functionality of the hardware components. Software is an essential part of the project; however, more importantly, the software components must be able to harmoniously work in conjunction with one another. With the Raspberry Pi being the basis for the majority of our software, it is necessary to consider the required power budget which will determine other factors about the design (such as battery power). Each Raspberry Pi unit used must display an efficient combination of software to reduce power used, and maximize functionality for each feature. We plan on combining the software by first getting a working program for each feature individually, then porting each program to 1 or 2 Raspberry Pis using the SD memory card on the Pi itself. The end product of this milestone will be a full functional device which controls 5 different electrical components with original code governing each one. As of now, this milestone is incomplete and therefore lessons learned from this milestone will be updated in the future.

10) **Finalized Hardware Design**
The final hardware design is established by each hardware component being fully integrated into the device. In the case of our design that will be established by the robot being fully mobile, capable of supporting the expected weight capacity, and functioning with the other features, namely the spray nozzle and refill tank. All components required for moving the device will be attached which consists of the motors, wheels, and ultimately the battery which will power all features. The water tank will also be secured to the device which will supply the water and flame retardant for spraying. The spray nozzle will also be attached to the device, being operatable by use of a pump supplying water through the hose. Rather than having one fixed point of concentration, the nozzle will be able to change its trajectory with the help of a servo motor installed. The final feature will be the construction and functionality of the Refill tank which will supply water and fire retardant to the water tank on our device. When positioned properly, the refill tank will be designed to fill the device through an opening constructed on the device's water tank that can be toggled to open and close. The final component necessary for the final hardware design is connecting the microcontrollers to the designated areas. Currently we are constructing each feature individually and will proceed to combine all features once all parts are developed fully.

11) **Completion of End of Project Report**
The end of project report is the final document which overviews the work put into the device up until the final demonstration of its functionality. This document is essential in any large project in that it gives the reader guidance on the different aspects of the project and how each one was created, from inception to presentation. In industry as professional engineers, documentation of one's work is essential in outlining to others the steps taken to perform a given task. This ensures accountability for tasks as well as proper credit being disseminated between team members for the completion of each component. The end of project report has two functions: (1) To outline and summarize the project, while also offering in depth descriptions of the inter-workings of the device. (2) to summarize the work needed to complete a task. This information can be used as a template

for predicting work duration for future projects as well. There will be a comprehensive document to go with this milestone. It will be roughly 130 pages of text, diagrams, tables, charts and figures, all which contain vital information about the device functionality, and the processes to make them. To complete this document, the team has been slowly updating different parts of the end result, allowing it to be steadily completed throughout the semester as components of the device are completed. As of now, this milestone is incomplete and therefore lessons learned from this milestone will be updated in the future.

12) **Successful Demonstration and Presentation**
This milestone shows the completion of the design idea as well as the device performing its expected tasks and functions. It also means that the design report has been completed which documents each step of the project. This is significant since we will be able to present the societal issue, explain our approach of limiting the problem's impact, and then demonstrate the completed product. We will have two demonstrations for our project, each meeting their intended purpose. The first demonstration will occur in December 2020 in which we will show that our device features all work together individually. The final demonstration and presentation will occur in May 2021 where our design has all features combined and integrated to work together though hardware/software communication. Throughout the course of these two deadlines there will be numerous reports established, project design updates and documentation of technical issues that will require troubleshooting. These will be discussed briefly to show how our team handled drawbacks and obtained our finished design.

VI. Work Breakdown Structure

A project of this magnitude requires several different interwoven components which, when executed in the right order, lead to the overall completion of the whole project. The Work Breakdown Structure (WBS) of this project was created with a "modular workflow" concept in mind; each work package described is an individual assignment which can be completed by one member of the team. Given the current pandemic which hinders in-person group work, the work packages are designed to allow the team members to take the project so far and "throw it over the wall" to the next member, building off the momentum of completed work packages, until a whole project has been created. The scope of the WBS at this stage in the project is as complete as it can be and will receive updates and edits as we learn more and develop the ideas described in the report. Each feature of the project makes up one level of the WBS. The subsequent aspects of that feature are broken into Subtasks which then further break down into activities or work packages. Each work package contains a task requiring one week to complete from one member of the team. The sum of every work package compiles into a functional project, thus, every aspect of the project is considered in the WBS to some effect. The graphical representation of the WBS is shown below in Figure 8. The main goal for the work breakdown structure is "facilitating resource allocation, assignment of responsibilities, and measurement and control of the project" [7]. The Level 1 components of this project are the features of the project as well as the assignments and reports which outline each step of progress made. A description of each level of the WBS as well as each work package will explain how they meet the aforementioned standard.

The Work Breakdown Structure utilizes each feature of the project as a Level 1 Task which needs to be completed. From there, the Level 2 Subtasks are broken down into Hardware, Software, and Integration of components to create its respective functional feature. Each Subtask futher breaks down into Activities or Work Packages which account for 100% of the considerations for completing the feature.

The end of each description of the Features, or Level 1 tasks, will outline the hours worked as a team and individually thus far.

A. *Feature 1: Device Mobility*

The main component of this device is its ability to move autonomously around the user's property. Several steps are required to govern the movement patterns of this device. For the initial prototype, a linear path will be demonstrated; however, the end result of the project is a device which can secure a perimeter around a property which requires turning and basic navigation of obstacles. The Device Mobility feature is further broken down into three Subtasks – Hardware, Software and Integration. As the names would suggest, the Hardware subtasks are all related to the mechanical aspects of the project. The Software subtasks are all related to the programming and coding aspects of the project. The Integration subtasks are all related to the combining of the hardware and software into a useable device. A description of each subdivision of these subtasks will give insight as to how the work packages contribute to the successful demonstration of this feature.

1) **Subtask 1.1: Hardware** – *All activities pertain to the mechanical aspects of this feature.*
   a) **Activity 1.1.1:** Connect Wheels to a Single Axle. Since each wheel will be individually driven with its own motor, the axle must connect directly to the wheel and spin the wheel without any bearing. All axles will be the same diameter to have congruence with the pillow bearings used to hold the axles in place. As this is a simple component, it will be completed by November 8th, 2020, one month before the prototype demonstration. Jake will be constructing this component since he has access to a welder.
   b) **Activity 1.1.2:** Connect 5" diameter gear to axles. Since the motors used are only 120W, a chain drive to a larger gear will be connected to the motor to increase the torque on the axle, resulting in high propensity for the motor to turn the wheels with less power. Since Jake has the majority of

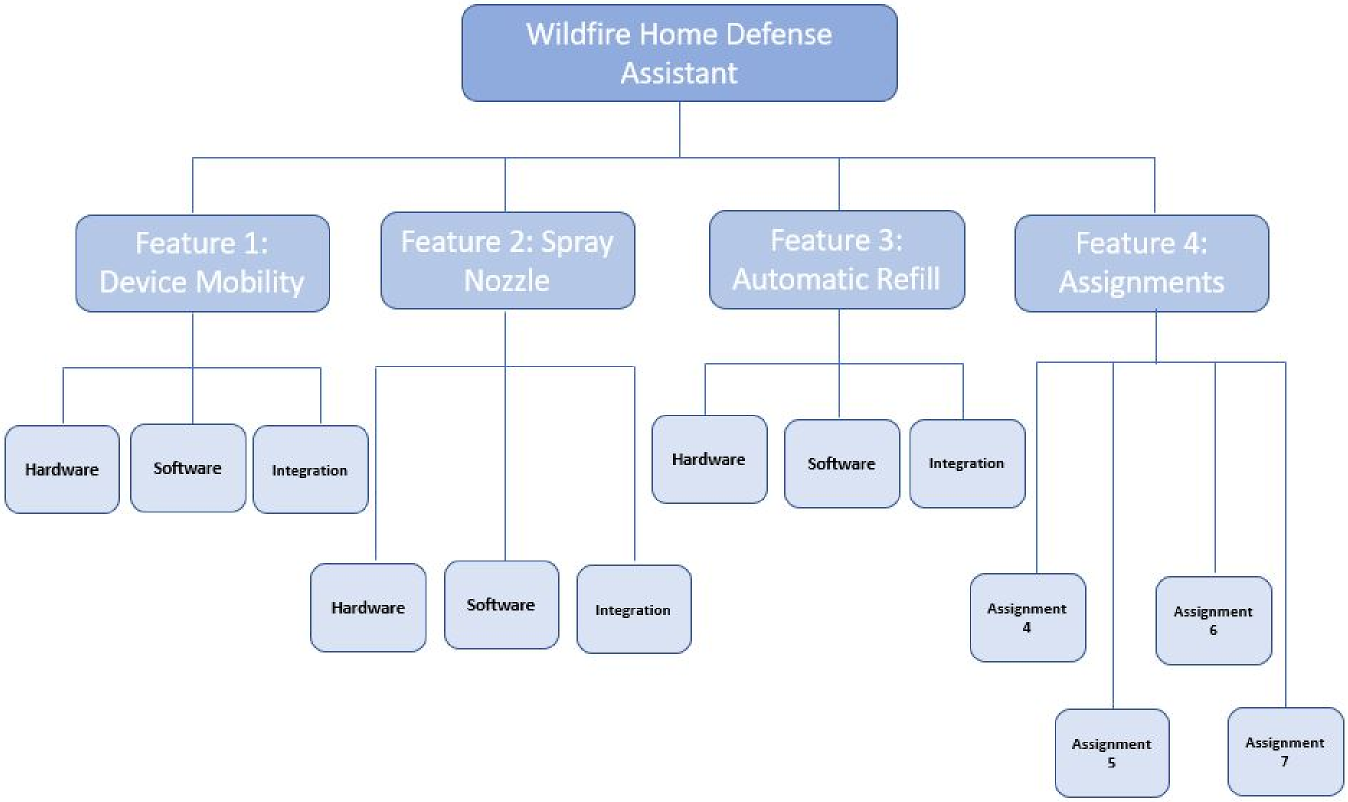

Figure 11. Overall Work Breakdown Structure.

the mechanical components for this feature, he will complete this activity. The motors need to be tested before the rest of the components can be attached to the device; therefore, this task will be completed by November 1st, 2020.

c) **Activity 1.1.3:** Attach 2" diameter gear to motor axle. Since the gear that comes with the motor is too small for the chain to attach to it; another gear must be threaded into the axle on the motor itself to connect the motor gear to the wheel axle gear. Jake will do this task the same week as Activity 2, and it will be completed November 1st, 2020.

d) **Activity 1.1.4:** Connect 2" and 5" gear using chain. The two gears will be connected using a chain drive. 90-degree separation of the chain will provide the most torque. These components will be mounted to the wooden prototype board. Jake will complete these tasks because he will have the components with him. They will all be combined the same weekend of November 1st, 2020.

e) **Activity 1.1.5:** Attach front wheels to one axle. The device will utilize variable speed motors on the real wheels to turn the device; therefore, the front wheels can be mounted on a single axle and do not require any further components. Mark will construct the front wheels of the device in order to spread the load of the work packages. This is an essential component for the prototype demonstration but will not be too complex. Because of the simplicity of this work package the proposed deadline is November 15th, 2020.

f) **Activity 1.1.6:** Create steel frame. The frame for the final design for the device will be made of steel to ensure a sturdy chassis. Mark will design the basic frame layout using AutoCAD to determine the dimensions and parts necessary which will then be ordered and welded together by Roman to form the chassis. This will be one of the final steps in creating the finished device. It will be completed February 14th, 2021.

g) **Activity 1.1.7:** Attach wheels, motors and turning mechanism to the frame. Once the frame has been developed the wheels will be attached. The front wheels will be connected to one axle shaft, along with the turning apparatus being attached to the same shaft. The rear wheels will also be connected to a single axle shaft but will also have the two motors connected to them from the gears and chain like the initial prototype. Roman will handle this responsibility since he developed the chassis and has done ample research on the mechanical design for steering. This finalizes the hardware procedure

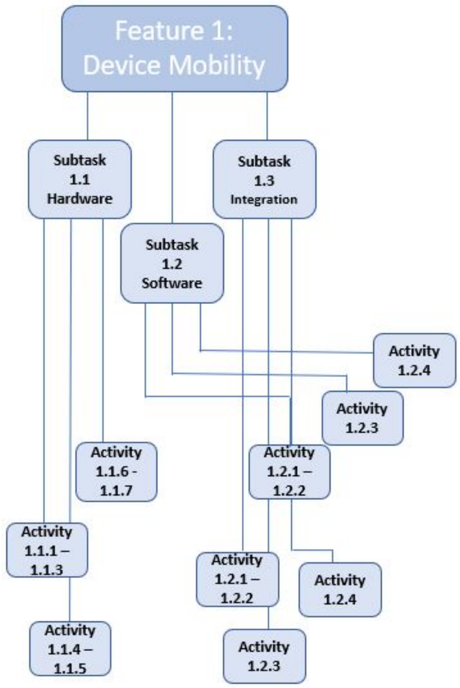

Figure 12. Feature 1 Work Breakdown Structure

for the mobile unit and will now be ready for testing and integration of all other necessary parts. It will be completed on February 28th, 2021.

2) **Subtask 1.2: Software** – *All activities pertain to the programming and coding aspects of this feature.*
   a) **Activity 1.2.1:** Program Raspberry Pi for forward and reverse (linear) movement. As a team, the programming aspects of the device mobility were prioritized due to the unfamiliarity the team has with robotics. The prototype will have a simple path that will turn the motors forward for a duration of time, will stop, and will finally move in reverse for the same duration. Mark will be in charge of this work package as he is currently in Robotics Lab and has limited experience with wheeled device movement. Since this is an essential aspect of the device mobility feature, the proposed deadline is October 25th, 2020.
   b) **Activity 1.2.2:** Rewrite original device mobility code to account for turning (variable speed of each motor). The prototype design for this feature involved a linear path, but the deployable prototype will involve a turning mechanism controlled by servo motors. The turning apparatus will be connected to the front wheel shaft and will be programmed by the raspberry pi. Initially, there were two potential different methods for turning the device. Our team decided to do first option by turning the device as described above by using servo motors rather than the secondary option of having the device turn solely depending on the difference in the speed of the motor. The proposed deadline for this work package is February 21st, 2021 since it will be a fundamental component of the second semester design of the device.
   c) **Activity 1.2.3:** Write code to dictate path for device. One potential method for coding the path for the device was to use Simultaneous Localization and Mapping (SLAM). However, given the unreliability of Wifi connectivity, we resorted to utilizing sensors to navigate the device. These sensors, known as QTI (Charge Transfer Infrared) sensors detect different amounts of infrared reflectivity on different surfaces and will aid in having the device follow a specified path. These sensors will be installed on the mobile unit and will then be programmed through the raspberry pi. Mark will be working on the code since he has had experience in using these sensors in an earlier project. This activity is in conjunction with Activity 1.2.2 and will therefore be completed after that activity. The proposed deadline for this work package is February 28th, 2021.

3) **Subtask 1.3: Integration** – *All activities pertain to the combining of the hardware and software elements of this feature.*
   a) **Activity 1.3.1:** Mount motors, wheels, Raspberry Pi, and batteries to wooden prototype board. In order to demonstrate the functioning device mobility, all components will be initially designed on a wooden board for ease of organization and layout. Since Jake has many of the device mobility components, he will complete this step November 15th, 2020.
   b) **Activity 1.3.2:** Use pillow bearings to attach 3 axles (2 back, 1 front) to wooden prototype board. To limit the movement of the axles and create a sturdier design, the axles will be held in place on the wooden prototype board using pillow bearings. This step will need to be completed to finalize the prototype; thus, the proposed deadline is November 22nd, 2020.
   c) **Activity 1.3.3:** Attach Motor 2” Gear to Axle 5” gear using chain. To increase the torque on the axles, a chain drive will be used. The highest potential torque will come at a 90-degree angle and will be completed November 8th, 2020.
   d) **Activity 1.3.4:** Mount all components to the steel frame. When the steel frame is complete, the design of the mechanical components can be mounted to this finalized chassis for the device. This will be essential for testing the final product and will therefore need to be completed by March 14th, 2021.

4) **Hours Worked:** Due to the COVID-19 pandemic, the work that the team has done on this feature is comprised of online meetings for discussion and planning. Since meeting in person is highly discouraged, the team has taken the time to plan and assign work packages to individual team members to facilitate the modular workflow method for completing this feature. **The total number of hours worked as a team on Feature 1: Device Mobility thus far is 10 hours**. The total number of hours worked individually on this feature are as follows:
   - **Jake:** 9 hours
   - **Mariya:** 2 hours
   - **Mark:** 9 hours
   - **Roman:** 7 hours

B. *Feature 2: Spray Nozzle*

The spray nozzle feature will be a simple design, yet fundamental to the practicality of the device. The nozzle must be able to disseminate the fire blocking gel in a dense enough pattern to render it effective. Additionally, the spray nozzle will have some rudimentary movement to ensure a complete application of the gel to the surrounding vegetation. The direction of spray will be orthogonal to the forward movement direction of the device, but the finalized design will still include some mobility of the nozzle itself. The Spray Nozzle feature is further broken down into three Subtasks – Hardware, Software and Integration. As the names would suggest, the Hardware subtasks are all related to the mechanical aspects of the nozzle. The Software subtasks are all related to the programming and coding aspects of the nozzle. The Integration subtasks are all related to the combining of the hardware and software into a useable device. A description of each subdivision of these subtasks will give insight as to how the work packages contribute to the successful demonstration of this feature.

1) **Subtask 2.1: Hardware** – *All activities pertain to the mechanical aspects of this feature.*
   a) **Activity 2.1.1:** Attach spray nozzle hose to water pump. This activity is generally simple; however, matching a proper nozzle for to the hose on the water pump may prove to be harder than expected due to COVID-19 shipping times. Mariya will be programming the servo which will control this nozzle and therefore will also design this aspect of the project as well. This will need to be functioning before the components are combined and is proposed to be completed by November 8th, 2020.
   b) **Activity 2.1.2:** Mount water pump and tank to wooden prototype board. After the water pump and tank are selected, the need to be mounted to the board after the drivetrain components are mounted. Therefore, the deadline for this activity is November 15th, 2020.
   c) **Activity 2.1.3:** Connect water pump to Raspberry Pi. The raspberry pi will only control turning on and off the water pump; therefore, the power components will need to be assigned to pins on the raspberry pi. Since Mariya is programming this aspect of the feature, she will also be making this connection. The proposed deadline is November 1st, 2020.
   d) **Activity 2.1.4:** Connect nozzle to servo, and servo to raspberry pi. After attaching the nozzle to the servo, this servo needs to be wired to pins on the same raspberry pi which is controlling the water pump. Mariya will design this the following weekend, November 8th, 2020.
   e) **Activity 2.1.5:** Attach tank lid to servo motor. The first prototype will utilize an open lid for the on-board water tank. For the second prototype design, a sliding lid will be attached to the tank to contain the fire blocking substance more securely. This will be done after the initial prototype demonstration, February 21st, 2021.
2) **Subtask 2.2: Software** – *All activities pertain to the programming and coding aspects of this feature.*
   a) **Activity 2.2.1:** Program Nozzle servo pattern. This block of code will dictate the path of the servo nozzle, and therefore the pattern for which the fire blocking gel will spray. Mariya is coding this program and it is essential to the forward momentum of the project. The proposed deadline is October 25th, 2020.
   b) **Activity 2.2.2:** Program water Pump on/off. The code which turns on and turns off the water pump will be written by Jake. This will be ported to the same raspberry pi which is on the device. The proposed deadline for this activity is November 1st, 2020.
   c) **Activity 2.2.3:** Program Servo for opening tank lid. The second prototype of the device with a closed lid will utilize a servo motor to open the lid for the on-board tank. Roman will write the code to open this tank. It will need to be working before attaching the lid to the tank, so the proposed deadline is February 14th, 2021.
3) **Subtask 2.3: Integration** – *All activities pertain to the combining of the hardware and software elements of this feature.*
   a) **Activity 2.3.1:** Mount water pump, tank, and nozzle to wooden prototype board. Since the drivetrain elements of the device take priority, these components will be mounted to the prototype board after the drivetrain elements. However, it is important to ensure that there is sufficient time to test the device with all the components on the prototype. The proposed deadline for this activity is November 22nd, 2020.
   b) **Activity 2.3.2:** Mount all components to the aluminum frame. When the aluminum frame is com-

plete, the design of the mechanical components can be mounted to this finalized chassis for the device. This will be essential for testing the final product and will therefore need to be completed by April 25th, 2021.

4) **Hours Worked:** Due to the COVID-19 pandemic, the work that the team has done on this feature is comprised of online meetings for discussion and planning. Since meeting in person is highly discouraged, the team has taken the time to plan and assign work packages to individual team members to facilitate the modular workflow method for completing this feature. **The total number of hours worked as a team on Feature 2: Spray Nozzle thus far is 2 hours**. The total number of hours worked individually on this feature are as follows:
   - **Jake:** 2 hours
   - **Mariya:** 7 hours
   - **Mark:** 1 hour
   - **Roman:** 3 hours

C. *Feature 3: Automatic Refill*

The automatic refill feature will require some mechanical construction for the tank, as well as integrating the programming to ensure that the device navigates back to the refill tank after it is emptied. The tank will be elevated to a height which the device can comfortably fit under. The refill mechanism will then be a valve which opens when the device is underneath. The Refill Tank feature is further broken down into three Subtasks – Hardware, Software and Integration. As the names would suggest, the Hardware subtasks are all related to the mechanical aspects of the tank itself. The Software subtasks are all related to the programming and coding aspects of the device navigating back to the refill tank, and then continuing from its last sprayed location. The Integration subtasks are all related to the combining of the hardware and software into a useable device which, when emptied, automatically goes to refill, then continues its route. A description of each subdivision of these subtasks will give insight as to how the work packages contribute to the successful demonstration of this feature.

1) **Subtask 3.1: Hardware** – *All activities pertain to the mechanical aspects of this feature.*
   a) **Activity 3.1.1:** Construct elevated refill tank with valve. For sake of ease in design, the prototype for the refill tank will be a large plastic bin. Wooden components will be made to elevate the bin two to three feet off the ground to allow for the device to be wheeled underneath it. The valve will be attached to the base of the bin (melting a hole through the plastic for ease of construction). Since Jake is configuring the valve servo to open and close the refill tank, he will also design this aspect of Feature 3. The proposed deadline is November 1st, 2020.
   b) **Activity 3.1.2:** Connect Valve to Servo Arm. A common 90-degree arm valve will govern the flow of water from the refill tank. Since Jake is writing the code to the servo, he will attach this servo to the valve arm. The deadline will be the same weekend as the elevated refill tank, and will be completed November 1st, 2020.
   c) **Activity 3.1.3:** Water sensor on Device Tank (reed switch). In order to trigger the automatic refill function on the device, a reed switch will be connected to the device tank, as well as a water level sensor. Roman will construct this aspect of the project by November 15th, 2020.
2) **Subtask 3.2: Software** – *All activities pertain to the programming and coding aspects of this feature.*
   a) **Activity 3.2.1:** Program code to open servo valve. Jake will write the code to open the servo. The raspberry pi by the refill station will have its own power source, and for the purposes of the initial demonstration, this will be activated by a push button. The proposed deadline for this is October 25th, 2020
   b) **Activity 3.2.2:** Program code to initiate refill sequence. This code will affect the device mobility. Utilizing the water sensor on the device, when the water is low, it will trigger a program to run which will guide the device back to the refill sensor. A pressure sensor will be below the tank; when the device returns, it will trigger the opening of the valve. This is an advanced function which will be a part of the final design and therefore the proposed deadline is January 11th, 2020.
   c) **Activity 3.2.3:** Program code for device to return to refill station and return to last known location. This code will affect the device mobility. Utilizing the water sensor on the device, when the water is low, it will trigger a program to run which will guide the device back to the refill sensor. After the device has been refilled (using a time delay) it will return to its last sprayed location. This is an advanced function which will be a part of the final design and therefore the proposed deadline is April 28th, 2020.
3) **Subtask 3.3: Integration** – *All activities pertain to the combining of the hardware and software elements of this feature.*
   a) **Activity 3.3.1:** Substitute refill tank for steel tank. Since most of the components function separately, the code for the refill sequence will be booted to the raspberry pi on the device. The plastic refill tank will be substituted for a steel refill tank for the final design of the device. The new tank construction will be essential The proposed deadline is April 28th, 2021.
4) **Hours Worked:** Due to the COVID-19 pandemic, the work that the team has done on this feature is comprised of online meetings for discussion and planning. Since

meeting in person is highly discouraged, the team has taken the time to plan and assign work packages to individual team members to facilitate the modular workflow method for completing this feature. **The total number of hours worked as a team on Feature 3: Automatic Refill thus far is 4 hours**. The total number of hours worked individually on this feature are as follows:

- **Jake:** 6 hours
- **Mariya:** 1 hour
- **Mark:** 3 hours
- **Roman:** 2 hours

D. *Feature 4: Assignments and Reports*

The assignments and reports are an essential component of ensuring that, as a team, we are able to manage our time and, more importantly, manage the project. Each assignment contains information which aids in planning and processing certain aspects of the project. Ironically, each of these assignments must also be accounted for as they will require time and effort in working on the project. Since each assignment is large, the subtasks for this feature are the assignments themselves, whereas the work packages make up the components which are required for each assignment. Information on second semester assignments and reports is limited; however, they are still accounted for in this report.

1) **Subtask 4.1: Assignment 4 Project Timeline** – *Assignment 4 introduces the gannt chart and PERT diagram: tools used to keep the progress of the project on track. The proposed due date for every activity in this subtask is November 1st, 2020.*
   a) **Activity 4.1.1:** Gannt Chart. The gannt chart is a horizontal bar graph which creates a timeline for the project. It outlines start dates, end dates as well as the different components of the project. Every activity mentioned in this part of the report will be accounted for in the gannt chart. Mariya has already taken steps in completing this.
   b) **Activity 4.1.2:** PERT Diagram. The military utilizes the Program Evaluation Review Technique (PERT) to graphically represent a project's timeline. Jake will complete the PERT diagram.
   c) **Activity 4.1.3:** Milestones. Even though the project is only now starting the building phase, certain construction of aspects of the project are worth noting. These milestones will be dictated by Roman.
   d) **Activity 4.1.4:** Update all components and compile. To keep in accordance with the End of Project Report format, the introduction, abstract, conclusion, and bibliography must be updated. The report must also be compiled in the proper IEEE format.
2) **Subtask 4.2: Assignment 5 Risk Assessment** – *Assignment 5 will discuss the pandemic situation and the potential for risks in constructing the project. It will also mention our methods for mitigating risk as a team. All activities in this Subtask are to be completed by November 8th, 2020.*
   a) **Activity 4.2.1:** Identify critical paths and hindrances. Being able to identify where we may find problems or extra work will be essential in accurately predicting how long certain aspects of the project will take.
   b) **Activity 4.2.2:** List mitigation strategies. Simply knowing where we may find difficulty is not enough; listing the strategies for how we will allocate the resources and effort to solve these difficulties is an essential part of project management.
   c) **Activity 4.2.3:** Risk assessment chart and social distancing. A chart detailing our risk assessment as well as how we are planning on continuing to work during the COVID-19 crisis will bring insight to the added challenges to this particular senior design.
   d) **Activity 4.2.4:** Update all components and compile. To keep in accordance with the End of Project Report format, the introduction, abstract, conclusion, and bibliography must be updated. The report must also be compiled in the proper IEEE format.
3) **Subtask 4.3: Assignment 6 Project Technical Evaluation** – *Assignment 6 is concurrent with the prototype demonstration. This will detail how our projects hardware and software work in conjunction with one another to make a fully functional device prototype. All activities within this subtask are to be completed by December 7th, 2020.*
   a) **Activity 4.3.1:** Review and update punch list. Based on the completion of the prototype, the punch list of feature may need edits.
   b) **Activity 4.3.2:** Compile statistics. Statistics such as hours worked on each and every task, persons assigned to each and every task, and the status of those tasks into the associated project feature.
   c) **Activity 4.3.3:** Update all components and compile. To keep in accordance with the End of Project Report format, the introduction, abstract, conclusion, and bibliography must be updated. The report must also be compiled in the proper IEEE format.
4) **Subtask 4.4: Assignment 7 and Second Semester Assignments** – *Assignment 7 is the presentation for the Laboratory Prototype.*
   a) **Activity 4.4.1:** Create a posted to display the inner workings of the presentation and the device.
   b) **Activity 4.4.2:** Detail the impacts that the pandemic has had on the project.
   c) **Activity 4.4.3:** Update all components and compile. To keep in accordance with the End of Project Report format, the introduction, abstract, conclusion, and bibliography must be updated. The report must also be compiled in the proper IEEE format.
   d) **Activity 4.4.4:** Assignment 1 A Problem Statement Revision
   e) **Activity 4.4.5:** Assignment 1B Design Idea Re-

view

f) **Activity 4.4.6:** Assignment 1C Spring Timeline Update
g) **Activity 4.4.7:** Assignment 2 Device Test Plan
h) **Activity 4.4.8:** Assignment 3 Market Review
i) **Activity 4.4.9:** Assignment 4 Feature Report and Presentation
j) **Activity 4.4.10:** Assignment 8 End of Project Documentation

5) **Hours Worked:** Due to the COVID-19 pandemic, the work that the team has done on this feature is comprised of online meetings for discussion and planning. Since meeting in person is highly discouraged, the team has taken the time to plan and assign work packages to individual team members to facilitate the modular workflow method for completing this feature. **The total number of hours worked as a team on Feature 4: Assignments and Reports thus far is 13 hours**. The total number of hours worked individually on this feature are as follows:
   - **Jake:** 31 hours
   - **Mariya:** 25 hours
   - **Mark:** 26 hours
   - **Roman:** 20 hours

E. *Milestones Of Work Breakdown Structure*

There will be certain objectives which, when completed, will lead to great strides of momentum in furthering our progress towards the final product of this project. While some milestones may not be realized yet, there has been at least one milestone for each feature which has been identified.

1) **Feature 1: Device Mobility** – The initial program to govern the forward and reverse motion of the motors will mark a large stride of progress in understanding the device mobility. From that point, we are able to tweak aspects to ensure that the device will be able to move with the rated weight.
2) **Feature 2: Spray Nozzle** – Connecting the water pump code and the spray nozzle code to the same raspberry pi will allow us to understand the power needed to operate all the components on the device.
3) **Feature 3: Automatic Refill** – Once the push button to open the refill valve is completed, we will be able to quickly test the automatic refill function.
4) **Feature 4: Assignments and Reports** – Once Assignment 5 is completed, a report will not be turned in until the first week of December. With the time and effort required to write the reports, Assignment 5, we will have more time to focus on the completion of all the work packages.

VII. Risk Assessment

In every project there lies some level of unpredictability; this can range from hardware or software issues, to more human issues such as illness or fatigue. Regardless of the type of risk, it is important to remember that "successful projects are not selected, but shaped with risk resolution in mind" [22]. Risk will always present itself as an inevitable factor of any project, and it is up to the team's management of said risk which will determine the successful navigation to a completed project with limited issues. The root cause of risk comes from uncertainty; whether that level of uncertainty is slight or severe, the existence of unknowns prove to be important consideration during the planning phases of the project. This section of the report will aim to mitigate these risks by identifying the unknowns, as well as offering strategies for overcoming them. The critical paths of the project will be detailed, with any associated risks mentioned, and the risk assessment method will detail the potential events which may hinder the critical path. Different types of risk which exist in the design will be discussed which include: *Specific Technical Risk, Broader Technical Risk, and Systematic Risk*. Additionally, a Risk Assessment chart will assess the probability of each component of risk mentioned in the report.

A. *Critical Path*

As outlined in the Program Evaluation and Review Technique (PERT) diagram in the Project Milestones section of this report, the *critical path* is the path to completion which has the highest number of hours to complete. The critical path provides information for the most important processes for this project, as well as the minimum number of hours needed to complete the design. The critical path for this project's most likely time duration is 67 hours. As shown in Figure 8, the Simplified PERT Diagram, the critical path is the left most path of the diagram. With each milestone along the path, there is a level of associated risk which must be considered. The risk factors, and associated events, along the critical path, as well as mitigation strategies for each one, are described below:

- **Event 1: Societal Problem** – The Societal Problem Event is the first milestone of the project. This is an essential component of the project because the foundation of the project is built upon the idea that the team will be addressing this problem. Everything comes back to the societal problem. The risk associated with this event is:
  1) *Failure to Identify Societal Problem* – This can be summed up as a failure to launch. Without having the basis for the problem for which the team is trying to solve, there is no hope for a design idea with purpose. The method for mitigating this risk was to individually decide on a societal problem, then as a team, deliberate and choose which societal problem was the most pressing, as well as offered a balance between creativity and practicality for the design idea.
- **Event 2: Design Idea** – The Design Idea Event is another milestone which, if not identified early on in the project, the team loses valuable time to construct and carry out the process for completing the project. Much like identification of the Societal Problem, the Design Idea creates the foundation for which the remainder of the project will be built upon. The Design Idea takes the

features and measurable metrics, and gives them purpose and context for a practical device. The risks associated with this event are:

1) *Failure to Identify Design Idea* – Much like with the Societal Problem, failing to identify the design idea will put a halt to the momentum of the project. Features and measurable metrics of the project are an essential aspect of engineering; however, the design idea is the application of these features. The method for mitigating this risk was to deliberate as a group how to accurately address the societal problem and create a design idea from there. Assignment 2 required hours of research by the team to realistically design a device which would meet the stipulations of the project while also addressing the Societal Problem.
2) *Overreaching the Design* – Another risk associated with the Design Idea on the critical path is choosing a design which is too aggressive. The team's current design has been described as "aggressive" but is within the scope of our ability as engineers. Choosing a design which requires much higher levels of training, skill, and resources would be setting ourselves up for failure, realizing this mistake after multiple weeks have already elapsed. The method for mitigating this risk was meeting with both Project Managers (EEE193A Instructors) to discuss the outlook and idea for our design, and ask for a truthful assessment of the idea's practicality and executability.

- **Event 3: Work Breakdown Structure** – The Work Breakdown Structure (WBS) is the final event in the "planning" process for the device. This is an essential milestone because it organizes the work which needs to be done, and forces the team to take accountability for every aspect of the project. This is essential during the pandemic especially because the modular work-flow will emphasize team member's ability to work on a task individually, then pass that work along to the next member to continue the effort. Without a work breakdown structure, the number of risks is exponentially higher; the unknowns are greater, and the amount of work required for each element is not as detailed as it could be. The risk associated with this event is:

  1) *Failure to Consider All Aspects of WBS* – Since the WBS is organized in a way that "the summation of the parts creates the whole," if there is an element missing in the WBS it leaves potential to create harsh delays in the project. One example for this would be not identifying all parts which need to be ordered in advance for the project. If there comes a deadline but there are parts missing, there is an option to crash the risk and pay an exorbitant amount for next day shipping. However, by ensuring the completeness of the WBS, this risk is lessened. The method for mitigating this risk is by laying out the WBS in a matrix, and deliberating as a team to ensure that all components of the project are accounted for.

- **Event 4: Testing Device Mobility** – The path to this event contains many possible bottlenecks. The testing of the device mobility is an event because the mobility is the foundational aspect of this project. Without mobility, the device is unable to complete the other features. In other words, all features of the project rely on the device mobility. If there is a delay in this event, there is a global delay in the project itself which is why it is included in the critical path. The risks associated with this event are:

  1) *Motors Are Not Powerful Enough For Load* – Since this device will be carrying heavy volumes of water, the two motors must be able to function with 100-150lbs or more of liquid. Since the power budget of the software components used will dictate the wattage of the motors, this is a possibility for the limiting factor of the device weight capacity to be the strength of each motor. The method for mitigating this risk is using two separate motors. Additionally, the team made mechanical calculations and chose to use a chain drive with a larger gear to get more torque out of the motors themselves.
  2) *Wheel Load Capacity is Insufficient* – Since the load of the device is of high importance, the wheels not being able to withstand the load is a legitimate concern. The method for mitigating this risk is opting to pay for more expensive, yet more robust, wheels when ordering parts initially for the device.

- **Event 5: Deployable Prototype** – The Deployable Prototype is the culminating event of the first semester for this project. This marks the halfway point for the design, and the process afterwards involves tweaking and improving off this initial prototype. The risk associated with this event is:

  1) *Failing to Demonstrate All Features* – Since this event is a pinnacle point in the design, failing to meet the standard on this prototype further delays all other modifications made to the device from this point on. The method for mitigating this risk is by ensuring that as a team we stick to the work breakdown structure and complete each work package by the time of its proposed deadline.

- **Event 6: Revised/Updated Mobility** – One of the most complex aspects of this project is its autonomous mobility. The initial prototype for this device is a simple, linear path. For the second semester modifications, the mobility will use much higher levels of technology to "steer" the device. The importance of this event, and its inclusion in the critical path is similar to the "Design Idea" event: It is important to revise the idea in a way that is challenging but achievable. The risk associated with this event is:

1) *Overreaching The Design* – Similar to the design idea, this point in the project will be fundamental in creating a design which is challenging, accomplishes the objective, but is also doable within our skill set. The method for mitigating this is by utilizing SLAM imaging to help with the navigation of the device.

- **Event 7: Finalized Hardware Design** – The prototype of this device will be on a wooden frame. This will allow for ease of organization of the several components which will go into constructing this device. However, for the final product, the frame will be steel. The components will dictate the shape, but this event will cement the shape of our device, thus restricting the changes we can make after the construction of the frame. The risks associated with this event are:
  1) *Final Design Is too Heavy* – Weight of the device is a reoccurring consideration in the design. The motors we specifically chosen to be able to operate with python; therefore, they are an essential hardware element for the project. If the weight of the frame renders the motors useless, then more time will need to go into creating a frame light enough to allow for mobility. The method for mitigating this risk is constructing the prototype in a way that simulates the final weight of the device.
  2) *Access to Welding Implements* – Since the steel frame will need to be made from scratch, a welder will be necessary to finish the design. Access to a welder will be dependent on local supplies, and there is a litany of subrisks associated with using the welder. The method for mitigating this risk is keeping the frame design simple and renting the welder early enough to allow for guaranteed access to it.
- **Event 8: End Of Project Report** – The End of Project Report is the culminating report which details the entirety of the process in planning, building, and executing the design. The risk associated with this event is:
  1) *Failure to Allocate Time to Complete EoP Report* – This document will be close to 130-150 pages when completed. The time it will take to complete the entire document will range from 20-30 hours. The method for mitigating this risk is by completing the mandated Assignments of the end of project report as we go, allowing us to compile the report in small chunks rather than all at once.

B. Risk Assessment Chart and Ranking of Risk Factors

The risk assessment charts plots risk in an impact versus degree probability type graph. Those with a high impact and high probability are most dangerous to the project and in which the team spends resources to overcome. With some risks the probability may be high, but the impact low and thus the risk is worth taking and not allocating many resources to fix. On the other hand, the impact may be high but the probability so low that the risk is taken, and the team hopes the problem does not arise.

Risk Assessment Chart

Probability	5		Pandemic	Mechanical Overload		
	4			Obstacles		
	3	GPIO pins		Hardware Failure		
	2		Personal Safety	Terrain Too rough	Water Damage	
	1				Accident / Health issue	
	Level	1	2	3	4	5
	Impact					

Table VI
RISK ASSESSMENT RANKING

Risk Factor	Impact	Probability	Risk
Hardware Failure	3	3	Medium
Not Enough GPIO pins	1	3	Low
Water Damage to Parts	4	2	Medium
Terrain Too Rough	3	2	Medium
Obstacles	3	4	Medium
Mechanical Overload	3	5	High
Pandemic	2	5	Medium
Personal Safety	2	2	Low
Accident / Health Issue	4	1	Medium

C. Specific Technical Risks

A specific technical risk is the possibility that some specific aspect of the project can fail and the impact project and system used for the project. This should be addressed before it happens so the team can plan ahead of time for the possibility of this risk happening and how it should be avoided, mitigated or handled. A technical risk is the possibility of hardware failure and data loss. Another potential risk is running out if I/O pins on our raspberry pi.

1) **Hardware Failure** - Testing out separate parts of our projects can lead to hardware failure. In the case the raspberry pi device fails the team members have multiple raspberry pis as backup that can be used from previous projects. This risk is not as likely to happen as raspberry

pi devices have safety measures to prevent device failure and if it does happen our team has a backup plan. Another possible risk is data loss from the sd card. For this case our team will incorporate using github to backup all of our files as we work on them to avoid this loss.

2) **Not Enough GPIO Pins** - There is a possible risk that the amount of sensors our team will use can use up all the GPIO pins on the raspberry pi and not have enough pins. This risk is quite low, in the case it does happen our team will use a separate chip that will allow the expansion of pins on the raspberry pi device to accommodate the extra connections that will need to be made.
3) **Water Damage to Parts** - This project involves using liquids and electronics are easily damaged by liquids. In the case our devices get damaged from water the team has spare parts for most of the items. This risk is medium level and our team will encapsulate any exposed electronics in water tight containers to avoid this from happening.

D. Broader Technical Risks

Broader technical risks refer to the case in which our basic features and measurable metrics need further evaluation and improvement. In the initial planning stages, we established the design idea and elaborated the main features of the design which contained measurable metrics. Now that the project design is being further developed, certain risks need to be addressed to ensure that our design is meeting the expected results. Some of these broad technical risks will include focusing on the mechanical mobility and structure of the design which is fundamental to the design.

1) **Terrain Too Rough** - Since one of our device's main features is mobility, its imperative to consider the potential risks that may hinder movement. The variability of terrain may influence the overall mobile efficiency in a negative manner. Homes that are susceptible to wildfires may have various terrain surrounding the vicinity that could prevent the device from following its specified path which will limit its fire suppression purpose. Rougher terrain may cause the device to overwork and consequently underperform since it may consumer more power to maneuver and the nozzle in turn may use excessive amounts of water in disproportionate measures towards a given area. To avoid this risk or reduce the likelihood of occurrence we may install tires more suitable to rough terrain so that there may be more stability and uniform motion. Another consideration would be to increase the power utilized in the motors so that small debris or difficult terrain may be negligible in its impact.
2) **Obstacles** - Ideally the device is meant to follow a designated path and perform its designated functions but since every environment may have unique surroundings, there are some things to consider. Weather conditions may affect the area causing there to be debris around the path area. There may also be cases where the natural landscape of an area has potential obstacles such as shrubbery or rocks. This may cause harm to the device apart from impeding it to perform its task. One manner of limiting these risks is to develop obstacle detection and avoidance through use of sensors. These sensors would be able to detect an object that is blocking the path, send the data to the microcontroller which then would program the device to go around it, returning to the designated path.
3) **Mechanical Overload** - Although the device components are developed with consideration of longevity, there are external and internal risk factors that may cause mechanical overload to the project. Since there will be a considerable amount of weight, there may be a lot of pressure exerted on the two motors navigating the device. Rough terrain may also contribute to this regard if the tires are not sufficient or the motors become damaged by any debris. Motors may be susceptible to misalignment from this which would draw more current and may overload the battery system which is also connected to numerous components. To help reduce the risk over motor overload we will distribute the weight of the device evenly which will not only relieve pressure but will also aid in the use of brakes when it will be implemented in our design. Another manner of improving the design would be to develop a covering for the motors to prevent any direct contact with any debris.

E. Systematic Risks

Systematic risk is the broadest variation of risk; there are several unknowns, and even more unpredictable events which can affect the outcome of the project. The team is working during and unprecedented time: The COVID-19 Pandemic. Considering the several guidelines from authorities, the team is having to work together to create something while not having the luxury of working together. In addition to the pandemic, Systematic risk can extend to family crises, environmental crises, and even individual crises which would impede the progress of a team member's work on the project. Each of the following are the Systematic Risks which were identified for this project; additionally, a mitigation strategy is given for each.

1) **Pandemic** – With the implementation of a nationwide quarantine, followed by restricted access to working in groups, the team has fully implemented a remote work-style conducive to the restrictions. Despite the team's ability to communicate with one another via any number of online communication systems, there are still numerous risks associated with the pandemic which affect the process of completing the project. As per university guidelines, "the primary objectives are to continue with virtual instruction and to work remotely whenever possible through the end of the fall semester" [23]. With campus resources not available to the team,

we are having to utilize public spaces to complete aspects of the project. As per guidelines from a state and local level, masks are required in public at all times, and the importance of hand washing cannot be stressed enough. As a team, we are adjusting to these stipulations by sticking to the Work Breakdown Structure which was created with the intent of having individual packages completed with interaction only necessary in compiling the packages. In a sense, the team will only meet in person a handful of times to integrate the work everyone has done individually, while also making sure to follow regulations regarding social distancing. The mitigation strategies for the additional risks of the pandemic include increased hand washing, wearing a mask in public at all times, ensuring to keep a 6 foot distance from others at all times, and limiting social interactions as much as possible.

2) **Personal Safety** – In addition to the pandemic, there are still the usual annual sicknesses to be aware of. This semester coincides with the usual flu season, as well as allergies and smoke particulate from fires in California. Personal safety keeps team members from falling behind due to reasons such as illness, or hospital visits. In order to mitigate the risks associated with personal safety, the team is taking extra precautions when traveling, similarly to the precautions taken to mitigate risk due to the pandemic. Personal Protective Equipment (PPE) will also be used when operating machinery or tools which have associated risks. For example, when using a circular saw and power drill, team members will be sure to use protective eyewear, as well as gloves when using a soldering iron.
3) **Accident / Health Issue** - Since there are several mechanical aspects of this project, there are multiple opportunities to use tools and devices which are risky in nature. Accidents when using this kind of equipment is a systematic risk in that user error is the culprit in any event which would cause harm to a team member. Additionally, accidents when traveling such as car accidents are to be considered when contemplating systematic risk. Physical risk to one's health is mitigated by committing to staying aware of one's presence and environment; however, mental health also requires risk mitigation. In a time when external stressors can be extremely high, it is important to consider the possible risk from mental overload and exhaustion. The way to mitigate the risks associated with mental health are to ensure balance in the team member's day to day activities. Additionally, the Team Leader is always conscientious of each team member's individual work load from other class commitments so that when team members have tests or big events for other classes, they can deload the work required of them for the project that week.

With great risk comes great reward, and while the proposed design in this project may have certain levels of risk, the strategies in which the team is addressing each risk individually creates an avenue to safely navigate each risk factor to ensure a completed product with little to no prospect for peril. By taking the time to outline the potential risk factors, and addressing each one with a mitigation strategy, the team can ensure a potential plan of action in the event that any hindrance to an event were to occur.

VIII. Design Philosophy

A. Final Design of Mobility Hardware

The chassis of the device from the Laboratory Prototype to the Deployable Prototype is the most significant change for the device. The first semester iteration used a wooden chassis to provide ease of organization for the electronic components; however, the second semester design chassis was swapped out for a more robust and sturdy steel frame. Figure 13 shows the new hardware design of the chassis.

Figure 13. Deployable Prototype Welded Steel Frame.

In addition to using a new chassis for the device, the smaller hardware components which pertain to the device mobility were also changed for sturdier elements. Figure 14 shows an up close picture of the new mobility hardware including new pillow bearing assemblies, drive chains for the motors, and rear wheels.

One of the main complications from the Laboratory Prototype was that the device was unable to go from a stopped position to starting. We concluded that the motor controller was unable to handle the transient period required for the startup of the device and therefore decided it was best to change all components pertaining to mobility to allow for the most efficient startup.

B. Final Design of Spray Nozzle Hardware

The spray nozzle in the Laboratory Prototype was kept separated from the device itself to streamline first semester testing of all features. The nozzle elements themselves were kept the same from first semester from second semester; however, the nozzle base arm was mounted directly to the

Figure 14. Deployable Prototype Welded Steel Frame.

chassis to provide support, and a consistent spraying area. Figure 15 shows the placement of the spray nozzle base arm. In an attempt to reduce the cost of the design, the team opted to utilize a plastic bucket as the on-board reservoir for the device as opposed to the heavier steel basin in the original concept design. The plastic bucket also provided the ideal dimensions for the overall design concept. Figure 16 shows the placement of the on-board water tank and the spray nozzle hose assembly.

With all the elements of the mobility and spray nozzle integrated into one device, the final design for the hardware culminated with a lightweight cover. The cover ensured that the electronic components on the inside of the device would be sheltered from any potential water from destroying the components. Figure 17 and Figure 18 both provide the overall picture of the device for the Deployable Prototype.

The protective covering for the device was coated with a plastic waterproofing material which allows for the device itself to get wet, but still maintain its integrity to protect the devices.

C. Design Philosophy Summary

The device itself is designed to be able to withstand moderate terrain - WUI properties usually have pavement or easily navigable terrain. Because of this, the team chose to allow the device to have a low profile, and robust frame to avoid potential tipping of the device. The steel frame allowed for lightweight design to maximize the amount of water able to be held on the device, while the pillow bearings and wheels allow the device to be as efficient as possible in transferring power from the motors into the wheels themselves. The spray nozzle is at a height that allows the device to have coverage up to 6 feet from the path, and the plasti-dipped covering keeps the inside electrical components safe from spraying.

Figure 15. Spray Nozzle Base Arm Placement.

IX. Deployable Prototype Status

With the litany of components required to create the Wildfire Defense Home Assistant, it is imperative to have a system in place to check and test each component in order to ensure the function of everything before combining all elements into the final deployable prototype. The overall goal of testing the device is to ensure that it meets the engineering requirements and specifications which the team set out to accomplish at the onset of this project. The main factor we considered when designing the tests for this device is for it to be able to be ”thrown over the fence.” Completing this project is a lofty goal in and of itself; having to do so while working remotely in a pandemic situation only adds to the difficulty of completing the tasks. With that in mind, we are ensuring that each component can be tested individually. With tested and functioning individual parts, we will be able to combine the parts into our working device while also being safe and respecting social distancing guidelines.

We will be utilizing both black box testing and white box testing in the completion of the deployable prototype. Black box testing will occur when the team is starting and running each feature without taking a look at the components used to govern them. Preceding the black box testing will be white

Figure 16. Spray Nozzle Hose Assembly.

Figure 17. Deployable Prototype with Protective Covering.

Figure 18. Deployable Prototype with Protective Covering 2.

box testing in which each team member is able to look at the parts used and test for accurate voltages, connections, and code.

While writing the tests for each measurable metric we have made efforts to ensure the tests are accurate, economical, limited in complexity, repeatable, traceable, and self-cleaning. For example, as described below, the method for testing the turn functionality of the device will be to do a "dry run" of the movement code with turning without having the device loaded to its max capacity. It is accurate in that it shows that the turn mechanism is functioning and is coupled correctly. It is economical in that it does not waste time or resources to test. The test itself is not complex and can be repeated simply by running the code again. The code itself will show traceable steps for the test, and at the end of it, all components will still be usable (self-cleaning).

Below outlines the methods for our device testing including which aspects we are going to test for each feature set of the project, as well as the method and measurable metrics for how we will test each one. Additionally, an update to the timeline for this project will be made to reflect the device testing to ensure a timely finish of the project.

A. *Features To Be Tested*

1) **Device Mobility**
   - Route Tracking:
     The design for the intelligent mobility of our device has changed throughout the life cycle of this project.

The Mk. I version of this project did not have any real mobility; its initial purpose was designed to stop wildfires in the grasslands of western America, however that proved to be rather illogical. The Mk. II version of the device aimed to use Simultaneous Localization and Mapping (SLAM) to guide its movement, however this method was deemed too robust for the scope of this project. The Mk. III version of the device has settled on route tracking for mobility in which the device follows an IR line along its proposed route. This simplifies the code required to govern the device as its path will be predetermined, and set up before the device itself is running. Before we are able to combine all the aspects of this project, we must first test that the mobility of the device functions on its own. This is a critical aspect of the project itself and therefore this functionality is tantamount to test, and have deployable as soon as possible.

- Turn Function:
  The Mk. II device was the laboratory prototype which was finalized last semester; this version of the Wildfire Home Defense Assistant only utilized linear mobility to demonstrate the functionality of the mechanical aspects of the device (the motors and the drivetrain). This semester, in order to make the device a useful tool, it will need to be able to turn to thoroughly navigate the IR track for which it will be following. The front axle of the device will be completely changed in order to account for the turning ability, and will factor in a 45 degree shift of the wheels.
- Startup Ability:
  One of the largest hurdles from last semester was the inability of the device to begin movement from stationary with the weight of the laboratory prototype. One of the potential problems was the nature of the motor controller not being able to handle the transient spike of current in the startup period. Using the proposed weight, it will be essentially to test and verify that the device will be able to move with maximum loads.

2) **Spray Nozzle**

- Nozzle:
  In order to protect the surrounding area, the nozzle is required to spray water in an up and down motion. The spray nozzle is controlled through a servo connected to a Raspberry Pi. Since water is largely used in the project, we must make sure that the servo and the micro-controller are waterproofed. Additionally, the spray nozzle needs to handle varying water pressure if the water pump malfunctions or the water runs out. If the water runs out, the nozzle needs to stop its movement.
- Device Tank:
  When the tank is out of water, the water pump and spray nozzle need to stop, and the device needs to activate its refill functionality. On the other hand, a full tank activated the spay nozzle function. Therefore, the project uses magnetic sensors on the tank that send the level of water to the microcontroller. Our project needs to test that the correct data is received.

3) **Refill Station**

- Device Tank Lid:
  Since the device will be taking many trips to the refill station, it is imperative that the lid for the on-board tank is able to open and close without issue. The lid itself will be connected to an ultra sonic sensor which will engage when the device is underneath the refill station.
- Pressure Sensor Valve:
  Since the entire refill station will be functioning as a standalone feature, the refill mechanism itself will need to be fully functional on its own. The pressure sensor will weigh the device, and will open the valve if the weight is under the proposed maximum load. If the weight is at an acceptable range, the valve will close and the device will be able to egress and continue its route.

B. Testing Methods

1) **Device Mobility**

- Route Tracking:
  Since the code which will govern the route tracking is the most sophisticated aspect of this project, it has been allocated the most time to complete. That being said, the code will need to function with the mechanical nature of the chassis and drivetrain of the device; while the device mechanics are being perfected, the IR tracking mobility will be tested using smaller devices. Mark has experience using IR line following tools with a small 4-wheeled robot, and will be able to create the code with and test using this device. The test will be as follows: (1) Created a rectangular pattern using the IR tape which the device will follow. (2) do 1 full lap around the rectangular pattern. (3) Stop for 30 seconds (refill station). (4) Complete one more full lap around the pattern.
- Turn Function:
  The turn function of the device will require specific parts to connect a servo motor to the axle to turn it. Additionally the servo will need to be able to turn the wheels even in the event that the load is over 150lbs. The test for the turn function will be as follows: (1) Perform 1 turn for the wheels in both directions without load. (2) Perform 1 turn for the wheels in both directions while moving under light loads. (3) Perform 1 turn for the wheels in both directions while moving under maximum load.

- Startup Ability:
  The startup ability of the device is a crucial element in the mobility feature. The testing of this feature will involve multiple trials using the Laboratory Prototype of the device at varying weights to see what capacity the motor controller will be able to run. The test will (1) involve starting the device and letting it run in the forward direction for 5 seconds at a light weight. (2) The distance traveled will be recorded (3) Weight will be added and the test will be done again to see the upper limit of the motor controllers startup ability.

2) **Spray Nozzle**
   - Nozzle:
     To ensure the spray nozzle works accurately, we need to waterproof the electronics involved. The servo will be made waterproof by dipping it in plastic dip, which we will test the waterproof servo by exposing it to water. The micro controller, however, will stored in enclosed location on the device away from the spray nozzle. This is highly important since the device is designed for outdoors where it can rain. For our testing of the spray nozzle, we will save all our code on an online source in case our preventive measures were ineffective, let the device run out of water by the spraying the surrounding area, and wait a couple of days to make sure there was no water damage.
   - Device Tank:
     We test the tank function by pouring water into the tank, which should activate the water pump and the spray nozzle. If the water pump does not start, we know there is an issue with the data being received and processed by the Raspberry Pi and magnetic sensors. Moreover, the device must respond well to no water in the tank by stopping the spray nozzle function and activating the sequence to refill the tank. How we will test this function is letting the tank run out of water or starting the device with no water in the tank.

3) **Refill Station**
   - Device Tank Lid:
     The device tank lid will utilize an ultrasonic sensor which will activate a servo motor connected to the lid when close enough to the refill station. One of the tricky aspects about this is ensuring that the lid does not open at random from branches or debris. The lid will open when something is close enough to the sensor, and will stay open for the duration that the ultrasonic sensor registers that proximity. The test for the device tank lid will be as follows: (1) Test functioning servo motor to lid connection performing 10 test opens. (2) Test that the lid stays closed when registering proximities too far and too close from the proposed refill sensor proximity. (3) Perform a test open for 30 seconds ensuring that the lid stays open for the entire duration.
   - Pressure Sensor Valve:
     The pressure sensor valve will have slightly sophisticated code to govern the opening and closing of the refill tank valve. The tank will only open if the sensor registers a weight that is below the weight of the tank when it is at 90% capacity. The testing for the refill sensor valve will be as follows: (1) Test that the valve stays closed at weights over the 90% capacity weight. (2) When activated, test that the valve opens for the entire duration that the weight is below the weight of the device at 90% capacity.

C. Test Timeline and Assigned Tasks

Timelines are deeply important in projects. Timelines keep the project organized and provide clarity to the team members as everybody is responsible for a specific task. The project is broken up into three testable parts, the device mobility, the spray nozzle, and the refill station. Our goal for this project is to complete the project by Spring Break, which is March 22nd.

Table VII
TIMELINE

Task	Assigned Member	Deadline
Route Tracking	Mark	March 22
Turn Function	Mariya	March 22
Startup Ability	Jacob	March 22
Nozzle	Mariya	March 22
Device Tank	Roman	March 22
Device Tank Lid	Roman	March 22
Pressure Valve	Jacob	March 22

D. Testing Results

The finalization steps have been taken for device testing for each of the features of the project. The overall goal of testing the device is to ensure that it meets the engineering requirements and specifications which the team set out to accomplish at the onset of this project. The main factor we considered when designing the tests for this device is for it to be able to be ”thrown over the fence.” Completing this project is a lofty goal in and of itself; having to do so while working remotely in a pandemic situation only adds to the difficulty of completing the tasks. With that in mind, we are ensuring that each component can be tested individually. With tested and functioning individual parts, we will be able to combine the parts into our working device while also being safe and respecting social distancing guide. Below is a brief description of the testing method for each feature as well as a discussion of the results, and how that impacted the project.

1) **Device Mobility**
   - Route Tracking: The device navigates along a set path that is detected via infrared sensors.The path is set to surround the property. The sensors will detect the distinction between the normal terrain and

the intended path and in this manner will track and proceed along the specified path.

Testing Purpose: The following items will be tested: (1)Creating a rectangular pattern using the IR tape which the device will follow. (2) do 1 full lap around the rectangular pattern. (3) Stop for 30 seconds (refill station). (4) Complete one more full lap around the pattern. Testing is necessary to find any issues and develop improvements. A few things to consider for this test would be to ensure that the device would be able to follow the route as accurately as possible and stopping at the refill station when necessary.

Testing Methods: As described above the test consists of four parts, with the primary part being more of adequate preparation for the route tracking. For the first part, I set up a simple rectangular path as well as another path that had a gradual turn to analyze what path would be most suitable for the device's turning capability. The second test would be to ensure the device would be able to follow the track for a full lap. This would help determine the code's functionality as well as testing the mechanical specifications of the device such as alignment of the wheels, motor placement and overall balance of the device. The third test would need to have the device stop once reaching the refill tank sensor to then have the tank be replenished. one manner of testing this would be to add a sleep function in the code which would allow the device to stop and wait for a set period of time. This is currently being developed. The final test would be to verify that the device is sustainable for prolonged use by navigating the route for at least two or more laps. This would help reaffirm if any adjustments need to be made to the device such as the case of deviating from the track.

Testing Results: Prior to accidentally breaking the first motor driver, the code functioned as intended and the motors responded to the IR sensor readings. However, after rewiring the new components the code started detecting syntax errors irregularly when executing the code. This is being examined as well as all the wiring referenced within the program. As a result, these tests have not been verifiable but will be performed once all errors have been resolved.

- Turn Functionality: This is a vital part of the mobility that allows it to change the direction it is going. This is an important aspect because it allows the device to turn and change direction so the device can patrol around the property.

  Testing Purpose: The following items will be tested: (1)turning in both directions with no load, (2) turning in both directions with a light load, and (3)turning in both directions under anticipated project load. Testing is necessary to find any issues and develop improvements. An issue encountered during testing was that the front wheel assembly would get jammed when turning in one direction and abruptly switching direction the other way. A potential solution is to mount the wheel more sturdily and instead of one wheel have two wheels, one on each corner in the front.

  Testing Methods: As mentioned above the tests will be broken down into three separate parts. All turning tests were tested from a stop. For these tests only one motor was activated to spin faster than the opposite to encourage a change of direction. The first part is to test the turning functionality by testing it with no load in both directions. The second part is to test the turning in both directions with a light load, for this part I used the weight of the batteries. The third part was to test the turning ability with the maximum load, for which I used an approximate weight for the project, a 52 pound weight.

  Testing Results: All tests were preformed from a stopped position. When testing the turning ability with no extra weight the assembly was able to turn in both directions easily and was able to speed up quickly. For the second part the turning was also working the same with a light load of about 10 pounds, turning easily in both directions and with ease. For the last part testing with a 52 pound load the turning worked the same as for the first two tests, but it took longer for the device to start from a stop with such load. For all the tests the turning seemed to not be as sharp and the device took a bigger radius. To improve the turning and make the device turn sharper the differential turning should not only include making one motor turn faster, but also have the opposite motor either have a break applied to it or have the signal to spin in the other direction. The turning test was a success and the device turns in both directions under the three loads that were tested.
- Startup Ability: A potential problem was considered when considering the mobility and that was the problem of the motors requiring high amperage to start moving the motors from a stop. The problem was that if the motors require too much amperage to move from a stop they can fry the motor driver. To avoid this we will nee to install fuses that will fry first in case too much amperage is drawn by the motors at a single time. To make sure the motors actually start moving from a stop full power will be sent by the raspberry pi to the motor driver for a small duration and when then decrease the power to reach desired speed after the wheels are in motion.

  Testing Purpose: In order to have the device successfully move forwards and backwards the device has to be able to move from a full stop and gain traction and direction. This is an important part that was considered earlier to ensure the device can

perform it's mobility task. this test will make sure the device can move from a full stop in the desired direction. With such heavy load the device needs to be tested to ensure it can successfully gain traction from a stand still.
Testing Methods: For these tests the device will need to be tested in two parts: (1)moving from a stop with no load, and (2)moving from a stop with anticipated load, which is assumed to be between 50-60 pounds. To test the first part the device will be stopped and power will be applied to see if the device can move from a stop without issues. For the second test the device is tested under a load, which will truly test the capability of starting from a stop as it will require more power to move from stationary to being in motion.
Testing Results: As mentioned within the route tracking test details, the device has not responded to the program execution and is currently unable to meet the startup ability tests. These errors are currently being addressed to help proceed with testing.

2) **Refill Station**

- Pressure Sensor Valve: Initially the pressure sensor valve was intended to be an above ground tank with an electronic valve underneath it. This valve would then be connected to a pressure plate which could detect the weight of the device, and would open based on the weight not meeting certain criteria of fullness of the on-board device tank.
Testing Purpose: During testing, the following problems were encountered: (1) The flow rate of the valve was dictated by the level of water in the refill tank. Since we were using gravity as the projecting source for the water flow, this would slowly attenuate over time, leading to inconsistent fill times. (2) The load cells used to measure the weight of the device were not rated high enough to be able to withstand the projected weight of the device. This consistently led to incorrect weight readings. (3) The scale used to measure the weight of the device was elevated. Since it sat roughly 3 inches off the ground, the device would need to utilize a ramp to be weighed; however, with the problems the team saw with device mobility speed in regards to the weight of the device, we decided that making the terrain more advanced would also lead to time delays.
The solution for these problems were to (1) use a water pump from a refill tank which would be adjacent to the device. This would lead to easier construction of the refill tank itself and would also yield a more consistent flow rate making the timing of the fill simpler. (2) The pressure plate would be connected directly to the pump and would stay on as long as something is applying pressure to the plate. This streamlines the code needed to govern the refill as it can be included as a stop time for the device mobility.
Testing Methods: As outlined above, the first testing method for the Pressure Sensor Valve is to test that the valve stays closed when the weight of the device is above 90% of the target proposed weight of the device, and to open when the weight is below. For the new iteration of this valve, the code which governs how long the device would be filling is written into the device mobility. Whenever the pressure switch is connected, it will turn the water pump on and supply water for as long as is written in the device mobility code.
Testing Results: The results from the testing for the pressure sensor valve yielded a positive result. The constructed pressure plate switch which opens the valve worked successfully and stayed open while pressure was applied, as well as immediately turned off as soon as the pressure was pulled away. One of the problems seen in testing was that the water pump worked too quickly which would yield a risk in getting essential components wet. The code was changed to give a 3 second delay at the onset of the pressure plate switch being activated to ensure that the device is in the proper spot before the water begins to flow from the pump.
- Proximity Lid Sensor:
Testing Purpose: In order to have an enclosed tank that can still have automated refilling, the device tank must have an opening and closing lid to activate while being filled. This portion of the device has yet to be tested; however, the testing methods for this remain the same.
Testing Methods:
The device tank lid will utilize an ultrasonic sensor which will activate a servo motor connected to the lid when close enough to the refill station. One of the tricky aspects about this is ensuring that the lid does not open at random from branches or debris.The lid will open when something is close enough to the sensor, and will stay open for the duration that the ultrasonic sensor registers that proximity.The test for the device tank lid will be as follows:(1) Test functioning servo motor to lid connection performing 10 test opens. (2) Test that the lid stays closed when registering proximities too far and too close from the proposed refill sensor proximity. (3)Perform a test open for 30 seconds ensuring that the lid stays open for the entire duration.
Testing Results: *Will be updated when testing for this portion is complete.*

3) **Spray Nozzle**

- Spray Nozzle Mobility: The spray nozzle is required to move in an up and down motion while spraying fire suppressing material. The spray nozzle mobility is controlled by the Raspberry Pi and moves by a servo motor.
  Testing Purpose: The spray nozzle mobility needs to work efficiently to cover adequate surface area. Otherwise, the entire device is not worth the cost and effect to a WUI homeowner. Thus, we need to ensure that the spray nozzle moves in an up and down motion and that it covers considerable ground with water.
  Testing Methods: The spray nozzle needs to move at least 45 degrees or greater to be efficient, therefore when testing the device, we need to measure the movement of the servo translates to the spray nozzle well. We also need to check that the spray nozzle sprays at least ten or more feet. Most importantly, the servo needs to handle the load of the metal tube and spray nozzle as well as the pressure of the water.
  Testing Results: Initial problems I have encountered is the servo motor and the Raspberry Pi, however, thankfully those have been solved due to the change of servo motors. Previously, the servo would just tick and not create any consistent movement. I have found that the servo can handle the pressure of the water and the weight of the metal as long as the servo motor is securely attached to a surface. This created the good tension to put the energy of the servo into moving the spray nozzle. When the device turns on, using an angle ruler, I am able to measure the angle of the spray nozzle and measured the spray nozzle to move greater than 45 degrees to achieve efficiency. Furthermore, when the spray nozzle is turned on and connected to the water tank, I am able to measure the distance of the water, or fire suppressing material, and using a measuring tape the water sprays about ten feet.
- On-Board Device Tank: For efficiency, the spray nozzle needs to stop when the water runs out and to begin not when the water refills, but when the device is back to the location where it stopped spraying. This part is connected with the mobility of the device and due to covid, and inability to meet with teammates, this part has yet to be tested.
  Testing Purpose: The way the spray nozzle was originally coded was that the spray nozzle moves whenever the device starts and sprays water when the tank has liquid. However, our robot will be running of water, refilling, and returning back where it left off spraying. Therefore, we had to reprogram the device so that the spray nozzle only moves and sprays water when it returns to the correct location.
  Testing Methods: To test the device, we allow the device to run out of water, then mark that location. Once the tank is refilled, but not at the mark location, the spray nozzle should not turn on. Only when the device is at the mark location, the spray nozzle should turn on.
  Testing Results: Testing needs to be completed for when the spray nozzle is connected to the device's overall mobility.

E. Integration and Troubleshooting

While the testing for each component individually was a success, the integration of all three components of the measurable metrics proved to be more troublesome than initially conceived. Below are the issues which the team encountered while compiling the final design for the Deployable Prototype:

1) **IR Sensor Inconsistency:** When testing the device mobility earlier in the year, the lighting outside was more consistent. As it came time to test the device in the late spring, the lack of overcast in the sky caused more reflection on the route path. This reflected light led to some stray elements picked up by the IR sensors which caused the device to veer off course.
2) **Parallel Process - Raspberry Pi:** For the device mobility and spray nozzle to be shared on one Raspberry Pi, the code was integrated into the same file. However, this led to a delay in running the code for the mobility because the spray nozzle code as being run first or vice versa. This delay caused the device to veer off the track, or caused the spray nozzle to stay motionless as the device moved.
3) **Refill Tank Aiming:** One of the challenges of creating the project in a remote setting is that having components which can function individually makes integration more tricky. The refill tank utilized a stop function for the mobility of the device - the IR sensors would register the "stop" color when the device was by the refill tank. In order to get the device to continue moving, the refill tank has a mechanical arm to place the "go" color underneath the IR sensors after refilling. This process was difficult to do repeatedly due to the inconsistencies of the hardware.
4) **Hardware Malfunction:** The team was unable to fully test all three features for the device in one run. While testing the mobility and spray nozzle, one of the key pieces of hardware was damaged by water which required replacement. At the time of this incident, the team was already in the process of compiling the report. The new parts have been ordered to complete this testing; however, they will not be in until after this report will be submitted. Updates will be made periodically (5/3/21).

X. Marketability Forecast

Despite the hours of work put into the device already, the design as it stands is still in the early development stages. However, to fully achieve the scope of this project, the target market must be identified to allow us to gauge the level of interest, and therefore possible investment, into the project. Refinement will need to be made on the deployable prototype to achieve a marketable device based on our research of the current market. The research is detailed below organized into the following sections: (1) **Consumer of Work** – possible companies and organizations who would be willing and interested in investing in this type of project. (2) **Proposed Client Research and Overview** – our take on the proposed demographic who this project will appeal most too, and our research into why this demographic is relevant. (3) **Market Understanding** – our analysis of the potential competitors in this market, as well as the supply and demand considerations for a product such as this. (4) **Strategic Plan** – our plan to deploy the device with as much momentum as possible for an efficient path to being market ready.

A. *Consumer of Work*

CAL FIRE's mission is to protect life and property through means of fire prevention tactics, education, and Enforcement. We believe our developing project could be of significant impact towards helping reduce potential destruction caused by wildfires in the WUI areas while encouraging residents to evacuate the area immediately. This helps ensure the overall safety of the community as they are following protocol and leaving the affected areas in a timely manner which then allows the fire prevention agencies to concentrate on containing the wildfire spread rather than wasting costly resources by directing the residents. Furthermore, this device adds to the existing prevention and mitigation resources for the WUI homes. One method of improving fire prevention would be to follow the building codes for WUI areas. The building standards for these homes require materials such as roof coverings, fire resistive walls, fire dampers, electrical appliances as well as many other regulations to protect the exterior part of the homes. Our device would create another line of defense by dousing the exterior of the house with flame retardant as well as the surrounding area. The more devices placed in these areas, the greater the coverage and containment. As a result, there is more time elapsed for other services to put out the fires. Given more research and development we believe the product would be a good investment in fire prevention agencies such as CAL FIRE.

B. *Proposed Client Research and Overview*

The client which we are trying to reach is albeit a small demographic; however, the size of that demographic does not reduce the importance of the societal problem the team is aiming to address. We have shown a multitude of research which describes the increasing severity of annual wildfires across the western United States, and how the evacuation protocols are sometimes ineffective based on the timeliness of resident evacuation. There is a clear need for something to increase the punctuality of evacuation while also adding some comfort to the residents in defending their homes that they are leaving behind. In California alone, there are over 11.2 million people living in WUI areas who are at risk for annual wildfires [24]. In these areas, average property value is around $200,000 [25], which gives us insight into what kind of budget our device would require to be relevant and affordable for people in these areas. Our proposed clients are the people in these areas who are willing to defend their property in the event of an evacuation, which according to our previous research outlined in Section II, is approximately 30% of people who live in WUI areas [16]. A rough estimate using these figures means that the size of our proposed client demographic is approximately 3.36 million people who the device could potentially help.

C. *Market Understanding*

From what we were able to find, there are no products like ours currently in use. Our product combines autonomous robotics with sound fire safety principles which has the potential for some refined technologies to make it even more applicable. While the deployable prototype will only utilize a low level of autonomy, an increased budget and timeline could yield a device with a much more robust level of control. The use of several systems and feedback loops in conjunction with different sensors gives this device the potential to be smart enough to make the decisions for flame suppressant coverage that would be unknown to a manual sprayer. The largest benefit to the product we are designing is the idea that it can be activated and can complete the task all without any input from the resident. This directly addresses the issue of delayed evacuation traffic and accidents which some of the competitor products does not do.

While there are no devices exactly like ours on the market as of now, there are some products which offer a similar task that we would like to highlight and compare to our project. As an aid to firefighters there is some use of robotics for mechanized hose capabilities. A device which closely replicates the theme of ours is used to combat fires in real time. While they may look similar, these devices are incredibly different in use. Our device is focused on preventative action versus real time fire disposal. Additionally there is the Tactical Hazardous Operations Robot (THOR) which is used aboard U.S. Navy ships for automated fire handling [26]. This model is like the one used by firefighting authorities in that its main objective is to extinguish fires rather than mitigate their destruction. In the realm of home defense, a novel idea is being employed. Ember Defense System creates a grid of sprinklers around the residents home which are activated from towers [27]. This allows for a great deal of coverage across the home which is proven to be of assistance in wildfire scenarios. This is the most similar device to ours; however, there is little guarantee on the level of coverage from a blanket sprinkler system. Despite the similarities of our product and others, there are no devices on the market specifically like ours yet, and we see a clear demand for one.

D. *Strategic Plan*

Our plan for the deployment of this device is going to lean heavily on our market analysis. A review of the small business model for market analysis guided our team in the plan, as we have no marketing experience between the four of us. The structure for creating the plan was broken up into 7 different steps which all helped us gain insight to make decisions about the method for which we will deploy the prototype: (1) Determining the purpose of our device. (2) Understanding the industries outlook. (3) Pinpointing target customers. (4) Comparing our competition. (5) Gathering additional data. (6) Analyzing our findings. (7) Putting the analysis into an actionable plan [28]. Steps 1 – 5 have been completed during the earlier stages of this plan, and moving forward, we will describe steps 6 and 7 in the body of this section.

Analyzing our findings – From the research we have done, it seems that the bulk of this market is aimed towards finding fire solutions for military and firefighting purposes. There are very little products in place which market directly to the residents themselves. Additionally, we found that due to the nature of the complications of evacuation mandates, there is a large market that exists in local government authorities in WUI areas. For example, when solar energy was at the cusp of becoming consumer available, many counties offered tax breaks on homes who chose to "go green" and pay for the invest of using solar energy. Similarly, we can work with state or even federal government organizations to offer benefits to residents who choose to invest in the device to minimize the damage done in WUI areas.

Putting the analysis into an actionable plan – The strategic plan for deploying this device has two prongs: marketing to the residents themselves, and marketing to the local and state authorities. To a certain extent, these two prongs can go hand in hand in that by marketing to the local and state authorities, we hope to achieve a government benefit to the resident for employing the device on their property. The direct residential marketing will be in the form of highlighting the novelty and uniqueness of this device, while demonstrating its effectiveness in protecting property.

XI. Conclusion

A. Summary of Research

There are mountains of evidence to support the ever-growing problem of seasonal wildfires due to global warming and climate change. Wildfires result from an ignition source, fuel and the conditions that promote the fire to grow. Ignition sources can be broken down into two main categories: natural causes and human causes. Regardless of the cause, there is a level of predictability when it comes to the location for where wildfires naturally start, and this information is essential in identifying any type of preventative approach. There is a litany of data which supports the idea that wildfires are steadily increasing in severity and quantity each year; areas with higher level of carbon dioxide emissions have been shown to have more destructive wildfires which insinuates a direct correlation to climate change. Although wildfires are prone to cause destruction to the environment and to those affected by it, there is a fundamental need for them in an ecological perspective. One article describes how fires shape the biodiversity of dry forests and there are even cases when plants contain unique adaptations for coping with fires of mixed severity. Wildfires can be beneficial to the environment; however, each year wildfires consume millions of acres of land, including privately owned and residential homes. In turn, the loss due to wildfires each year is steadily rising and shows a significant effect of the nation's economy. As suggested in the studies referenced above, the "economic valuation of the population health impacts was estimated per year at \$410M-\$1.8B for acute health impacts and \$4.3B-\$19B for chronic health impacts for the study period." In addition to the loss of property and homes, wildfires lead to the loss of lives as well.

Over the past 10 years, while there have been significant advances in technologies used to fight wildfires, there is still a concerning number of civilian casualties annually from them. Home owners are increasingly more interested in living in WUI locations and because of this, authorities are having to be more dedicated to establishing a sound evacuation model. Evacuation routes have been shown to have less than ideal complexities which makes the evacuations models currently in place in need of a restructuring. With the challenges that come from evacuation, there is a clear need for some type of preventative action, rather than always responding to wildfires in a reactive manner. There is hope in the line of flame-retardant substances as a new gel-type material has shown promising features in recent tests. This highly-effective flame retardant shows promise in allowing firefighters to not have to repeatedly spray areas of high fire risk during a season. Considering the weight of the problem, and using the technological advancements in materials science, a new device is proposed for helping combat wildfires which takes a preventative approach to stopping wildfires before they can grow.

B. Design Proof of Concept

The impact of wildfires across the country cannot be understated. Even this most recent summer, the smoke from the wildfires in California has been shown to be affecting the air quality on the eastern coast of the United States and Canada. The macro-level issue is apparent, and the further one investigates in the minutia of complications from the increasing severity of wildfires, the micro-level issue seems to be equally significant. In the event of evacuation of WUI locations, casualties are happening due to indirect factors such as automobile accidents and unsuccessful evacuation from high-risk areas. Rather than try to quell the flames of budding fires in the forest, this device focuses its efforts on aiding those who are mandated to evacuate their homes. Spraying one's property with fire-blocking gel is a proven method for home defense; however, the time taken to carry out this action is too high. The device will allow homeowners to activate it upon their departure and have the peace of mind that their property will be secured by the time the flames encroach. Using a pre-programmed route, the device will navigate the perimeter of the property while simultaneously spraying a fire-blocking gel (for the purposes of this prototype, water will be used). Since one gallon of fire-retardant is rated to cover 500-700 square feet, the device will have an on-site tank for which it can continually refill its capacity until the task is complete. The mobility of the device will be using a robotic operating system. The spray nozzle will be guided using a microcontroller and water pump. The refill mechanism will utilize a reed switch to alter the device of a necessary fill up. With a full working model, this device has the potential to save lives, as well as save property. Any mitigation of casualties due to the increasing severity of wildfires is worth considering.

For the purposes of this demonstration, the feature list and measurable metrics will be simplified; however, with further funding and time, a more sophisticated model with a more complex route is very attainable. The device will move in a linear path, straight forward, while projecting water five feet from the device. The direction of the water will be orthogonal to the forward movement of the device, while the pitch of the spray nozzle will vary in angle from -90 to 90-degrees with respect to the horizon. Upon emptying the on-board tank, the device will cease spraying, and will automatically navigate back to the starting point where the refill tank is located. The refill tank will automatically top off the device which will then trigger it to continue forward movement. Upon returning to its last location of spray, the device will continue spraying until the task is complete, and will then return back to its starting location.

C. Delineation of Work

Now that there has been adequate research conducted concerning the devastation caused by wildfires and the device features have been determined, a work breakdown structure would be an ideal manner of having the project come to fruition. Developing a well detailed work breakdown structure would help allocate responsibilities based off every member's skills, improve time management, and would provide specific detail regarding the design, implementation, and contribution. Given that each member of the team has unique experience and skills, the work will be allocated so that each member is efficiently performing suitable tasks while briefing the procedure.

The work breakdown structure is comprised of 4 features: the device mobility, the spray nozzle, the refill tank, and the assignment report. Each feature has numerous subtasks along with a corresponding deadline to ensure that each member is contributing to the development of the device within a timely manner. The subtasks also help organize the core detail of each component, especially since each procedure has numerous steps. The subtasks themselves are broken down into the categories of Hardware, Software, and Integration. For the mobility feature, the primary tasks consist of building the robotic frame with multiple parts including motors, wheels, axles, and brakes. The secondary task focuses on programming the device to move in accordance with the installed microcontroller. The final task, integration, is focused on ensuring that the mobility design is fully capable of operating in synch with the other features. In summary, Jake will contribute to this area with the robot construction since he is supplying the parts as well as access to essential sources such as welding. Mark will aid in installation of the wheels for the device as well as developing the program to move the robot in a linear path, utilizing a microcontroller. Roman and Mariya will construct and program the brakes for the robot. For the spray nozzle feature, the primary tasks consist of attaching the nozzle to a water pump, the mobile robot as well as a microcontroller. The secondary task is to have a separate microcontroller control the nozzle to spray in accordance with the set parameters. The integration task consists of mounting the pump to the mobile robot. For this feature, Mariya will construct the water pump component and will connect the pump to a Raspberry Pi which will program the pump to spray specific parameters. Jake will contribute by programming the water pump to turn on and off and Roman will develop a program to operate the lid on the tank to open and close when in need of refilling. For the refill tank, the primary task is to construct the tank which would contain a valve controlled by a servo sensor and would be activated by a water sensor. The second task is to program the refill tank and its functionality. To integrate the design the mobile robot will travel to the refill tank when it runs out of water to spray. Jake will construct a valve servo and will program it to open and close the refill tank using an arm valve. Roman will connect a reed switch and water sensor to the design to ensure there is an automatic refill function. The assignment report is a detailed timeline containing the whole procedure of the design project from start to completion. Each week there will be a subtask comprised of activities distributed amongst the members to work on individually which will then be expounded upon in the report. These tasks are articulated within the work breakdown structure along with the expected completion date. These specified deadlines help gauge the progress of the design and show the necessary procedures needed to proceed towards the final development. The report will be a collective effort established by everyone through distributed activities.

The project timeline is a necessary step in ensuring that the activities and tasks required for a successful functional device are completed within the constraints of deadlines and resource allocation. The importance of the initial aspects of project completion cannot be understated; with a clear plan in place, the successful execution of the task will be much more likely. The timeline works in conjunction with the Work Breakdown Structure, and is made up of two main components: The Gannt Chart, and the Program Evaluation and Review Technique (PERT) diagram. The Gannt Chart is a linear timeline which depicts the estimated duration for certain features of the project. The features of note in this project's Gannt chart are the *device mobility, spray nozzle functionality, automated refill mechanism, and the assignments and reports* due periodically during the work period. While the Gannt chart shows the time duration of each feature as they pertain to the calendar, the PERT diagram shows the work packages and how they relate to the project milestones. Each work package is accounted for, and creates a branching network of task paths. The PERT diagram offers insight as to how long certain branches will take. This guides the team in choosing how to allocate resources properly to facilitate a successful project completion by the proposed deadline. Additionally, the PERT diagram shows graphically where there may be bottlenecks in the completion of these tasks in a timely manner. The critical paths are highlighted, and extra attention is brought on them to ensure that the inevitable time delays that come with any large project are mitigated as much as possible. Each milestone described encapsulates a fundamental step of progress towards the final product. The milestones are written in chronological order and critical paths have been identified in the Project Milestones section of this report. With the planning stages of the project complete, the team can now focus on the execution and implementation of the work packages in accordance with the Work Breakdown Structure and Project Timeline.

D. Market Applications

Market analysis benefits the team in understanding how to deploy a strategy to sell the produce. Understanding the audience and the market allows the team to cater to the audience and make changes to the device if necessary.The marketability forecast plan is broken down into several parts: consumer of work, proposed client research and overview, market understanding, and strategic plan. The consumer of work section describes the possible companies that could be interested in our product and would be willing to invest. We know that our device allows people who live WUI areas to leave their property without stopping to hose down their property. The proposed client research and overview section breaks down our potential clients, which would be people living in WUI homes. By knowing the clients, we are able to estimate the product's selling value. The market understanding section goes into detail describing our market and our competitors. Our team has not found any direct competitors as our device will be an autonomous device. However, our autonomous robot will compete with a product that has the same idea in protecting the home from fires. The other product is a grid of sprinklers spread around the property. The strategic plan section helps the team determine how much work is left to know how to execute this product successfully based on the market and the market needs. Our strategic marketing plan is to market to the residents of WUI areas, and local and state authorities by explaining the benefits of our device and its efficiently in protecting homes. The marketability forecast assignment is a useful assignment to research and understand the consumers and competition of our product.

E. Final Results and Testing

As mentioned, the purpose of testing is to meet the requirements and metrics of the project to then prepare it for real-world implementation. In having successful test results we are able to verify that that specification has been met and in the same manner we are able to locate areas of improvement prior to presenting a product. The Majority of our test results have been successful which now gives more time to place emphasis onto repairing any faults or underdeveloped areas of the project.

The final elements for testing of this device are not yet complete. While the features all work individually, the mobility and spray nozzle have not yet been tested in with the refill station. Because of this, the team will continue to work on the project to get this vital aspect of testing complete. When doing a wet run of the device, one of the main components of hardware was damaged by water and will need to be replaced; however, this happened before testing was able to be performed.

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GLOSSARY

Fuel Easily combustible vegetation like grass, shrubs and trees.

IR Sensor Infrared sensor that detects infrared wavelengths of light.

Pod A standalone device that uses internal power for all functions.

Reed Switch A switch that is operated to the on position in the presence of a magnet or magnetic field.

Retardant A substance that resists fire.

Wildlands Areas that are not heavily occupied with humans and usually overgrown with plants.

WUI Wildland-Urband Interface, where wildland vegetation and homes intermingle.

Appendix A
User Manual

The device must be started using Raspberry Pi to initiate the motors.

APPENDIX B
HARDWARE

Figure 19. Deployable Prototype Welded Steel Frame.

Figure 20. Deployable Prototype Welded Steel Frame.

The protective covering for the device was coated with a plastic waterproofing material which allows for the device itself to get wet, but still maintain its integrity to protect the devices.

Figure 21. Spray Nozzle Base Arm Placement.

Figure 22. Spray Nozzle Hose Assembly.

Figure 23. Deployable Prototype with Protective Covering.

Figure 24. Deployable Prototype with Protective Covering 2.

APPENDIX C
SOFTWARE

Appendix D
Mechanical Aspects

Appendix E
Vendor Contacts

No vendors were accessed in the completion of this project.

Feature 1: Device Mobility

Jake	Mariya	Mark	Roman

Subtask 1.1: Hardware

Activity	Proposed Deadline
Activity 1.1.1: Connect Wheels to single axle	November 8th, 2020
Activity 1.1.2: Connect 5 inch diameter gear to axles	November 1st, 2020
Activity 1.1.3: Attach 2 inch diameter gear to motor	November 1st, 2020
Activity 1.1.4: Connect 2" and 5" gears using chain, 90 degrees for greatest torque	November 1st, 2020
Activity 1.1.5: Attach front wheels to 1 axle	November 15th, 2020
Activity 1.1.6: Create Steel frame	February 14th, 2021
Activity 1.1.7: attach wheels, motors, and turning apparatus to frame	February 28th, 2021

Subtask 1.2: Software

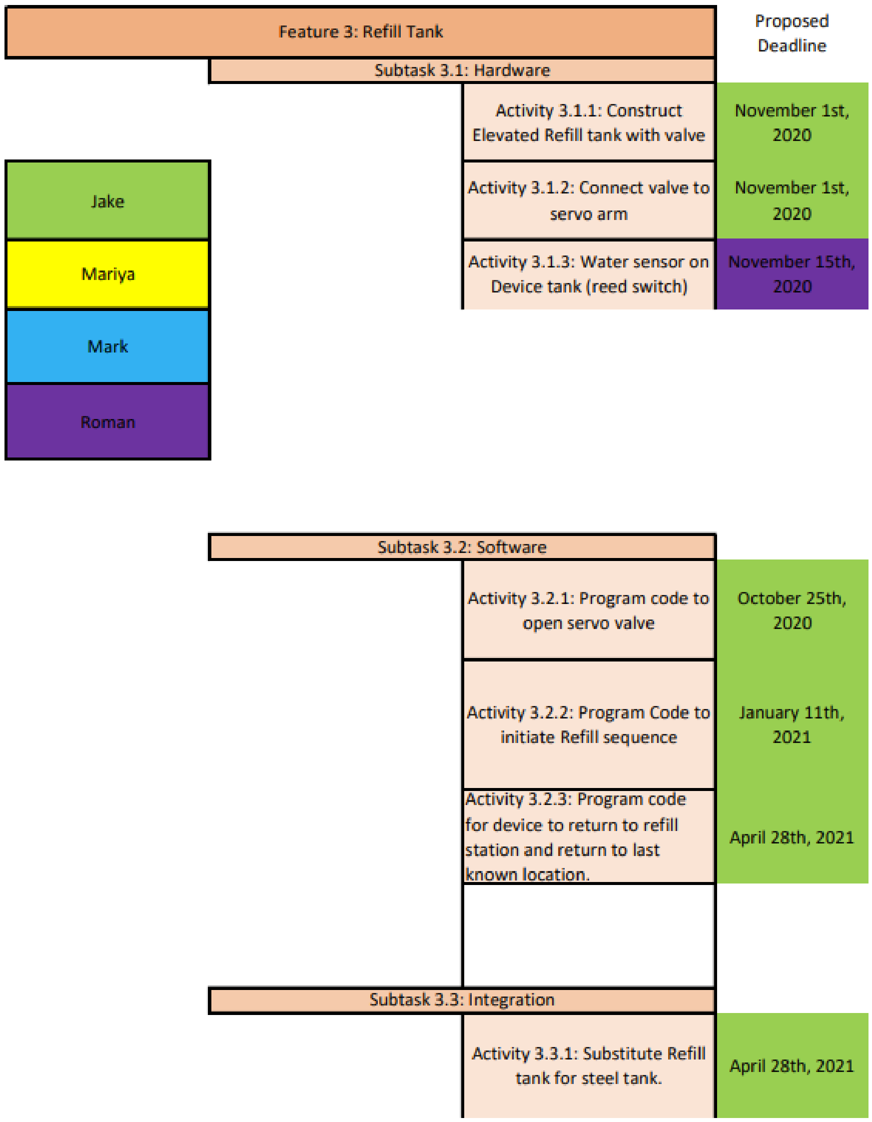
Activity	Proposed Deadline
Activity 1.2.1: Program Raspberry Pi for forward and reverse movement (linear) for device	October 25th, 2020
Activity 1.2.2: Rewrite original device mobiilty code to account for turning (variable speed of each motor).	February 21th, 2021
Activity 1.2.3 Write code to dictate path for device (around property).	february 28th, 2021

Subtask 1.3: Integration

Activity	Proposed Deadline
Activity 1.3.1: Mount Motors, wheels, raspberry Pi, and batteries to wooden prototype board.	November 15nd, 2020
Activity 1.3.2: Use pillow bearings to attach 3 axles (2 back, 1 front) to wooden prototype board.	November 22nd, 2020
Activity 1.3.3: Attach motor 2" gear to 5" axle gear using chain.	November 8th, 2020
Activity 1.3.4: Mount all components to the steel frame	March 14th, 2021

Feature 2: Spray Nozzle		Proposed Deadline
Subtask 2.1: Hardware		
	Activity 2.1.1: Attach Spray Nozzle Hose to Water Pump	November 8th, 2020
	Activity 2.1.2: Mount Water Pump and tank to wooden prototype board	November 15th, 2020
	Activity 2.1.3: Connect Water Pump to Raspberry Pi	November 1st, 2020
	Activity 2.1.4: Connect Nozzle to Servo and Servo to raspberry pi	November 8th, 2020
	Activity 2.1.5: Attach Tank lid to Servo Motor	February 21st, 2020
Subtask 2.2: Software		
	Activity 2.2.1: Program Nozzle servo pattern	October 25th, 2020
	Activity 2.2.2: Program Water pump on/off	November 1st, 2020
	Activity 2.2.3: Program servo for opening tank lid.	February 14th, 2020
Subtask 2.3: Integration		
	Activity 2.3.1: Mount Water pump, tank, and nozzle to wooden prototype board	November 15th, 2020
	Activity 2.3.2: Mount all components to the Steel frame.	April 25th, 2020

Jake
Mariya
Mark
Roman


Feature 3: Refill Tank
Proposed Deadline
Subtask 3.1: Hardware
Activity 3.1.1: Construct Elevated Refill tank with valve
November 1st, 2020
Activity 3.1.2: Connect valve to servo arm
November 1st, 2020
Activity 3.1.3: Water sensor on Device tank (reed switch)
November 15th, 2020
Jake
Mariya
Mark
Roman
Subtask 3.2: Software
Activity 3.2.1: Program code to open servo valve
October 25th, 2020
Activity 3.2.2: Program Code to initiate Refill sequence
January 11th, 2021
Activity 3.2.3: Program code for device to return to refill station and return to last known location.
April 28th, 2021
Subtask 3.3: Integration
Activity 3.3.1: Substitute Refill tank for steel tank.
April 28th, 2021

Feature 4: Assignments and Report			Proposed Deadline
	Subtask 4.1: Assignment 4 Project Timeline		
Jake		Activity 4.1.1: Gannt Chart	Novermber 1st, 2020
Mariya		Activity 4.1.2: PERT Diagram	Novermber 1st, 2020
Mark		Activity 4.1.3: MILESTONES	Novermber 1st, 2020
Roman		Activity 4.1.4: Introduction/Abstract/Conclusion/Compilation	Novermber 1st, 2020
	Subtask 4.2: Assignment 5: Risk Assessment		
		Activity 4.2.1: Identify Critical Paths/Identify Hindrences	Novermber 8th, 2020
		Activity 4.2.2: List mitigation Strategies	Novermber 8th, 2020
		Activity 4.2.3: Risk Assessment Chart ->Social Distancing	Novermber 8th, 2020
		Activity 4.2.4: Introduction/Abstract/Conclusion/Compilation	Novermber 8th, 2020
	Subtask 4.3: Assignment 6 Project Technical Evaluation		
		Activity 4.3.1: Review and Update Punch List	December 6th, 2020
		Activity 4.3.2: Compile Statistics	December 6th, 2020
		Activity 4.3.3: Update past assignment parts	December 6th, 2020
	Subtask 4.4: Assignment 7 and Second Semester Assignments		
		Activity 4.4.1: Create Poster	December 10th, 2020
		Activity 4.4.2: Pandemic Impacts	December 10th, 2020
		Activity 4.4.3: Update Past Assignment Parts	December 10th, 2020
		Activity 4.4.4: Assignment 1 A Problem Statement Revision	January, 2021
		Activity 4.4.5: Assignment 1B Design Idea Review	February, 2021
		Activity 4.4.6: Assignment 1C Spring Timeline Update	March, 2021
		Activity 4.4.7: Assignment 2 Device Test Plan	March, 2021
		Activity 4.4.8: Assignment 3 Market Review	March, 2021
		Activity 4.4.9: Assignment 4 Feature Report and Presentation	April, 2021
		Activity 4.4.10: Assignment 8 End of Project Documentation	May, 2021

Appendix G
Project Timeline

Home Fire Defense

Gantt Chart Template © 2006-2018 by Vertex42.com.

Fire Blockers

Project Start Date 10/1/2020 (Thursday) 18

Project Lead

Week 18 25 Jan 2021 | Week 19 1 Feb 2021 | Week 20 8 Feb 2021 | Week 21 15 Feb 2021 | Week 22 22 Feb 2021 | Week 23 1 Mar 2021 | Week 24 8 Mar 2021 | Week 25 15 Mar 2021

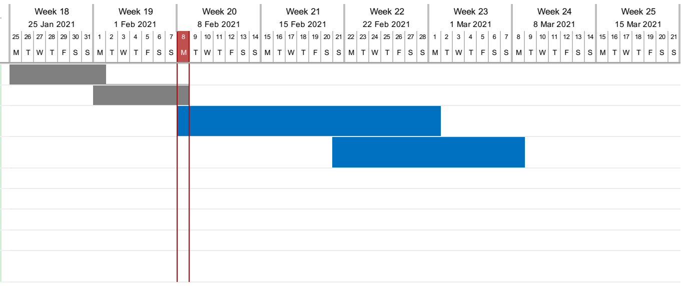
WBS	TASK	LEAD	START	END	% DONE
1	**Feature 1: Device Mobility**				
1.1.1	Connect Wheels to single axle	Jake	Sun 11/01/20	Sun 11/08/20	100%
1.1.2	Connect 5 inch diameter gear to axles	Jake	Sun 10/25/20	Sun 11/01/20	100%
1.1.3	Attach 2 inch diameter gear to motor	Jake	Sun 10/25/20	Sun 11/01/20	100%
1.1.4	Connect 2" and 5" gears using chain, 90 degrees for greatest torque	Jake	Sun 10/25/20	Sun 11/01/20	100%
1.1.5	Create Aluminum frame	Roman	Thu 4/01/21	Sun 4/18/21	10%
1.1.6	Attach front wheels to 1 axle	Jake	Sun 11/08/20	Sun 11/15/20	100%
1.2.1	Program Raspberry Pi for forward and reverse movement (linear) for device	Mark	Sun 10/18/20	Sun 10/25/20	100%
1.2.2	Program code for engaging brake servo	Mark	Sun 1/17/21	Sun 1/24/21	0%
1.2.3	Rewrite original device mobiilty code to account for turning (variable speed of each motor)	Mariya	Mon 2/01/21	Mon 2/08/21	0%
1.2.4	Write code to dictate path for device (around property)	Mariya	Mon 2/01/21	Mon 2/08/21	10%
1.3.1	Mount Motors, wheels, raspberry Pi, and batteries to wooden prototype board	Jake	Fri 11/20/20	Fri 11/27/20	100%
1.3.2	Use pillow bearings to attach 3 axles (2 back, 1 front) to wooden prototype board	Jake	Sun 11/15/20	Sun 11/22/20	100%
1.3.3	Attach motor 2" gear to 5" axle gear using chain	Jake	Sun 11/01/20	Sun 11/08/20	100%
1.3.4	Mount all components to the aluminum frame	Roman	Mon 2/01/21	Mon 2/08/21	0%
1.3.5	Route Tracking Testing	Mark	Mon 3/01/21	Mon 3/22/21	0%
1.3.6	Turn Function Testing	Mariya	Mon 3/01/21	Mon 3/22/21	0%
1.3.7	Startup Ability Testing	Jacob	Mon 3/01/21	Mon 3/22/21	0%
2	**Spray Nozzle**				
2.1.1	Attach Spray Nozzle Hose to Water Pump	Mariya	Sun 11/08/20	Sun 11/15/20	100%
2.1.2	Mount Water Pump and tank to wooden prototype board	Mariya	Tue 12/08/20	Tue 12/15/20	0%
2.1.3	Connect Water Pump to Raspberry Pi	Mariya	Sun 11/01/20	Sun 11/08/20	100%
2.1.4	Connect Nozzle to Servo and Servo to raspberry pi	Mariya	Sun 11/01/20	Sun 11/08/20	100%
2.1.5	Attach Tank lid to Servo Motor	Mariya	Sun 1/24/21	Sun 1/31/21	0%
2.2.1	Program Nozzle servo pattern	Mariya	Sun 10/18/20	Sun 10/25/20	100%
2.2.2	Program Water pump on/off	Mariya	Sun 10/25/20	Sun 11/01/20	100%
2.2.3	Program servo for opening tank lid	Roman	Sun 2/21/21	Sun 2/28/21	0%
2.3.1	Mount Water pump, tank, and nozzle to wooden prototype board	Jake	Tue 12/08/20	Tue 12/15/20	0%
2.3.2	Mount all components to the aluminum frame.	Jake	Sun 1/24/21	Sun 1/31/21	0%
2.3.3	Nozzle Testing	Mariya	Mon 3/01/21	Mon 3/22/21	0%
2.3.4	Device Tank Testing	Roman	Mon 3/01/21	Mon 3/22/21	0%
3	**Refill Tank**				
3.1.1	Construct Elevated Refill tank with valve	Jake	Sun 10/25/20	Fri 11/27/20	100%
3.1.2	Connect valve to servo arm	Jake	Sun 10/25/20	Sun 11/15/20	100%
3.1.3	Water sensor on Device tank (reed switch)	Roman	Tue 12/01/20	Tue 12/08/20	100%
3.2.1	Program code to open servo valve	Jake	Tue 12/01/20	Tue 12/08/20	100%
3.2.2	Program Code to initiate Refill sequence	Roman	Mon 1/04/21	Mon 1/11/21	0%
3.2.3	Program code for device to return to refill station and return to last known location	Mariya	Wed 4/21/21	Wed 4/28/21	0%
3.3.1	Substitute Refill tank for steel tank	Mark	Wed 4/21/21	Wed 4/28/21	0%
3.3.2	Device Tank Lid Testing	Roman	Mon 3/01/21	Mon 3/22/21	0%
3.3.3	Pressure Valve Testing	Jacob	Mon 3/01/21	Mon 3/22/21	0%
4	**Class Assignments**				
4.1.1	Assignment 4 Project Timeline		Sun 10/25/20	Sun 11/01/20	100%
4.1.2	Assignment 5: Risk Assessment		Sun 11/01/20	Sun 11/08/20	100%
4.1.3	Assignment 6 Project Technical Evaluation		Mon 11/23/20	Mon 11/30/20	100%
4.1.4	Assignment 7		Sun 12/06/20	Thu 12/10/20	100%

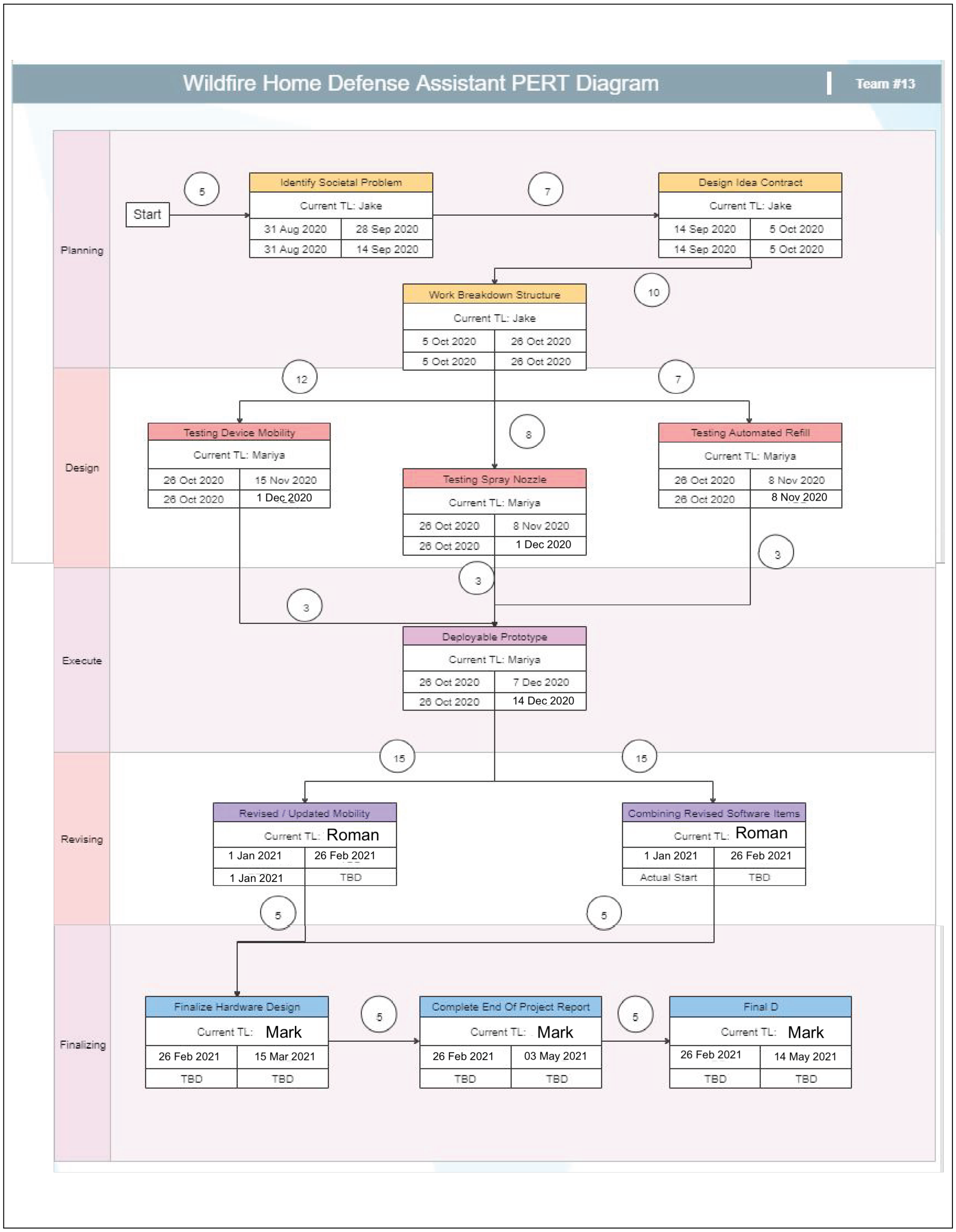
Project Start Date: 10/1/2020 (Thursday)

Project Lead:

18

WBS	TASK	LEAD	START	END	% DONE
4.2.1	Assignment 8: Revised Problem Statement		Sat 1/23/21	Mon 2/01/21	100%
4.2.2	Assignment 9: Device Test Plan		Mon 2/01/21	Mon 2/08/21	100%
4.2.3	Assignment 10: Market Review Report and Presentation		Mon 2/08/21	Mon 3/01/21	0%
4.2.4	Assignment 11: Individual Feature Report and Presentation		Sun 2/21/21	Mon 3/08/21	0%
4.2.5	Assignment 12: Testing Results Report		Mon 3/29/21	Mon 4/05/21	0%
4.2.6	Assignment 13: Ethics Quiz		Mon 4/12/21	Mon 4/19/21	0%
4.2.7	Assignment 14: Deployable Evauation		Mon 4/19/21	Mon 4/26/21	0%
4.2.8	Assignment 15: End of Project Documentation		Tue 4/27/21	Mon 5/03/21	0%
4.2.9	Assignment 16: Public Deployable Prototype Presentation		Fri 5/07/21	Fri 5/14/21	0%




Wildfire Home Defense Assistant PERT Diagram
Team #13
Planning
Design
Execute
Revising
Finalizing
Start
5
Identify Societal Problem
Current TL: Jake
31 Aug 2020 | 28 Sep 2020
31 Aug 2020 | 14 Sep 2020
7
Design Idea Contract
Current TL: Jake
14 Sep 2020 | 5 Oct 2020
14 Sep 2020 | 5 Oct 2020
10
Work Breakdown Structure
Current TL: Jake
5 Oct 2020 | 26 Oct 2020
5 Oct 2020 | 26 Oct 2020
12
8
7
Testing Device Mobility
Current TL: Mariya
26 Oct 2020 | 15 Nov 2020
26 Oct 2020 | 1 Dec 2020
Testing Spray Nozzle
Current TL: Mariya
26 Oct 2020 | 8 Nov 2020
26 Oct 2020 | 1 Dec 2020
Testing Automated Refill
Current TL: Mariya
26 Oct 2020 | 8 Nov 2020
26 Oct 2020 | 8 Nov 2020
3
3
3
Deployable Prototype
Current TL: Mariya
26 Oct 2020 | 7 Dec 2020
26 Oct 2020 | 14 Dec 2020
15
15
Revised / Updated Mobility
Current TL: Roman
1 Jan 2021 | 26 Feb 2021
1 Jan 2021 | TBD
Combining Revised Software Items
Current TL: Roman
1 Jan 2021 | 26 Feb 2021
Actual Start | TBD
5
5
Finalize Hardware Design
Current TL: Mark
26 Feb 2021 | 15 Mar 2021
TBD | TBD
5
Complete End Of Project Report
Current TL: Mark
26 Feb 2021 | 03 May 2021
TBD | TBD
5
Final D
Current TL: Mark
26 Feb 2021 | 14 May 2021
TBD | TBD

Jake Baker

jacobwilliambaker@csus.edu

Objective

To actualize the last 5 years of my education with a career in the Electrical Engineering field.

Education

- California University, Sacramento, CA
- Electrical/Electronic Engineering Major | Expected Graduation: May, 2021
  - Major Courses: Modern Communication Systems, Network Analysis, Signals and Systems, Electronics, Introduction to Microprocessors, Electromechanical Conversion, Power Systems Analysis

Skills

- Person to person communication
- Programming Languages: MySQL, Objective C, Java, Python, Verilog, x86 Assembly
- Dependable, quick learner, ambitious, detail oriented, optimistic mindset

Experience - Projects

May 2010 – July 2014

United States Army. Worked two years as a combat engineer squad leader in charge of 15 soldiers and multi-million dollar equipment. Transitioned to the United States Military Academy for two years; served as Cadet Platoon Leader for Company F-2

August 2017 – August 2020

Team USA athlete for the sport of Olympic Weightlifting. Represented the United States at an International Level. National Medalist and Current American Open -102kg Champion.

Mariya Shtevnina

mariyashtevnina@csus.edu

Objective

To utilize the computer skills I learned at CSUS to better the world.

Education

- California State University, Sacramento
- B.S. Computer Engineering Major | Expected Graduation: May 2021
  - Major Courses: Discreet Logic Structures, Advanced Computer Architecture, Computer Hardware Design, Advanced Logic Design, Data Structures & Algorithm Analysis, Computer Interfacing, Operating System Principles, CMOS VLSI Design

Skills

- Programming Languages: C, Java, Python, Verilog, VHDL, x86 Assembly.
- Good Analytical, written, and verbal English communication skills.
- Flexible and able to work in a team environment.
- Bilingual in Russian and English.

Experience

May 2019 – January 2020

Interned at California ISO for the energy management system team. Helped build over 10,000 display for the new Siemens Spectrum 7 system. Acquired experience and knowledge on the operations of the energy market and grid. Gained experience working in a fast-paced environment.

June 2016 – June 2019

Upheld methodical filing systems, data management, upkeep of clientele confidentiality, excellent customer service, and maintained office environment.

Projects

September 2020 – May 2021

Senior Design project. Building a robot that is activated during a fire evacuation call. The robot moves around land and sprays fire retardant.

Mark Zaverukha

Markzaverukha@csus.edu

Objective

Apply my knowledge and experiences established through education to areas of employment where growth and opportunity exists for engineering.

Education

- California State University, Sacramento, CA
- Electrical Engineering Major | Expected Graduation: May 2021
  - Major Courses: Applied Electromagnetics, Modern Communication Systems, Network Analysis, Signals and Systems, Electronics, Introduction to Microprocessors, Introduction to Feedback Systems, Electromechanical Conversions

Skills

- Bilingual: English and Ukrainian
- Proficient with Microsoft Office products specifically Word, Outlook, Access and Excel
- Software: AutoCAD, PSPICE, Multisim, Matlab and Cadence Release
- Detail Oriented, Self-Motivated learner, Disciplined in Time Management

Work Experience

Student Drafting Assistant

California Governor's Office of Emergency Services – Sacramento, CA

August 2017 – Present

Projects

January 2019 – May 2019

Patch antenna design project

Fabricated a Patch Antenna comprised of Makrolon and applied Impedance Matching procedures in accordance to our simulated design using Cadence Release to minimize signal loss.

Roman Yamaletdinov

romanyamaletdinov@csus.edu

Objective

Secure a responsible career opportunity to fully utilize my education and skills, while making a significant contribution to the success of the company.

Education

- California University, Sacramento, CA
- Computer Engineering Major | Expected Graduation: May, 2021
    - Major Courses: Database Management, Discreet Logic Structures, Advanced Computer Architecture, Computer Hardware Design, Advanced Logic Design, Data Structures & Algorithm Analysis, Network Analysis, Computer Interfacing, Operating System Principles, CMOS VLSI Design

Skills

- Multilingual: English and Russian
- Programming Languages: MySQL, Objective C, Java, Python, Verilog, x86 Assembly
- Dependable, quick learner, ambitious, detail oriented, optimistic mindset

Experience - Projects

June 2019 – July 2019

Designed a remote-control car using multiple microprocessors with a team of students in less than 6 weeks for Computer Interfacing course. Responsibility included designing the mechanical, electronic, and coding aspect for a moonroof using python, raspberry pi and h-bridge transistor design to control motor functions.

August 2019 – December 2019

Designed a schema and MySQL code for a mini-bookstore project given the specification with corresponding foreign keys, reference keys, primary keys and tables.