The Application of Drones in the Costa Rican Fire Department

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Sponsor: El Benemérito Cuerpo de Bomberos de Costa Rica

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The Application of Drones in the Costa Rican Fire Department

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Abstract

The Costa Rican Fire Department (CRFD) has begun implementing drones into its emergency operations. The goal of our project was to develop a protocol for the efficient application of drones by the CRFD in their emergency response program to ensure human safety by supplementing manpower with aerial surveillance. We found that there were five main scenarios in which the CRFD could use drones as well as three adverse conditions that impacted the use of drones. We gave the CRFD recommendations of how to improve the technology it currently owns and its teaching methods to expand the drone program. Further research should be conducted to improve the drone technology of the CRFD and expand implementation into other organizations.

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Executive Summary

Background and Introduction:

Drones are an emerging technology that are revolutionizing a variety of applications, from commerce and recreation to military and safety. Ana Maria Ortega, the Chief of the Information Technology Department, believes that the aerial view drones provide can aid the Costa Rican Fire Department (CRFD) in emergency mitigation by providing data unattainable from the ground. The CRFD acquired four drones and has been using them since the start of 2015. Drones provide information that is otherwise unattainable without the use of more expensive equipment. Drones are able to capture information such as the location of the fire line, wind speed and direction, and general information about an emergency. A drone is an alternative and a more cost effective means of gathering aerial

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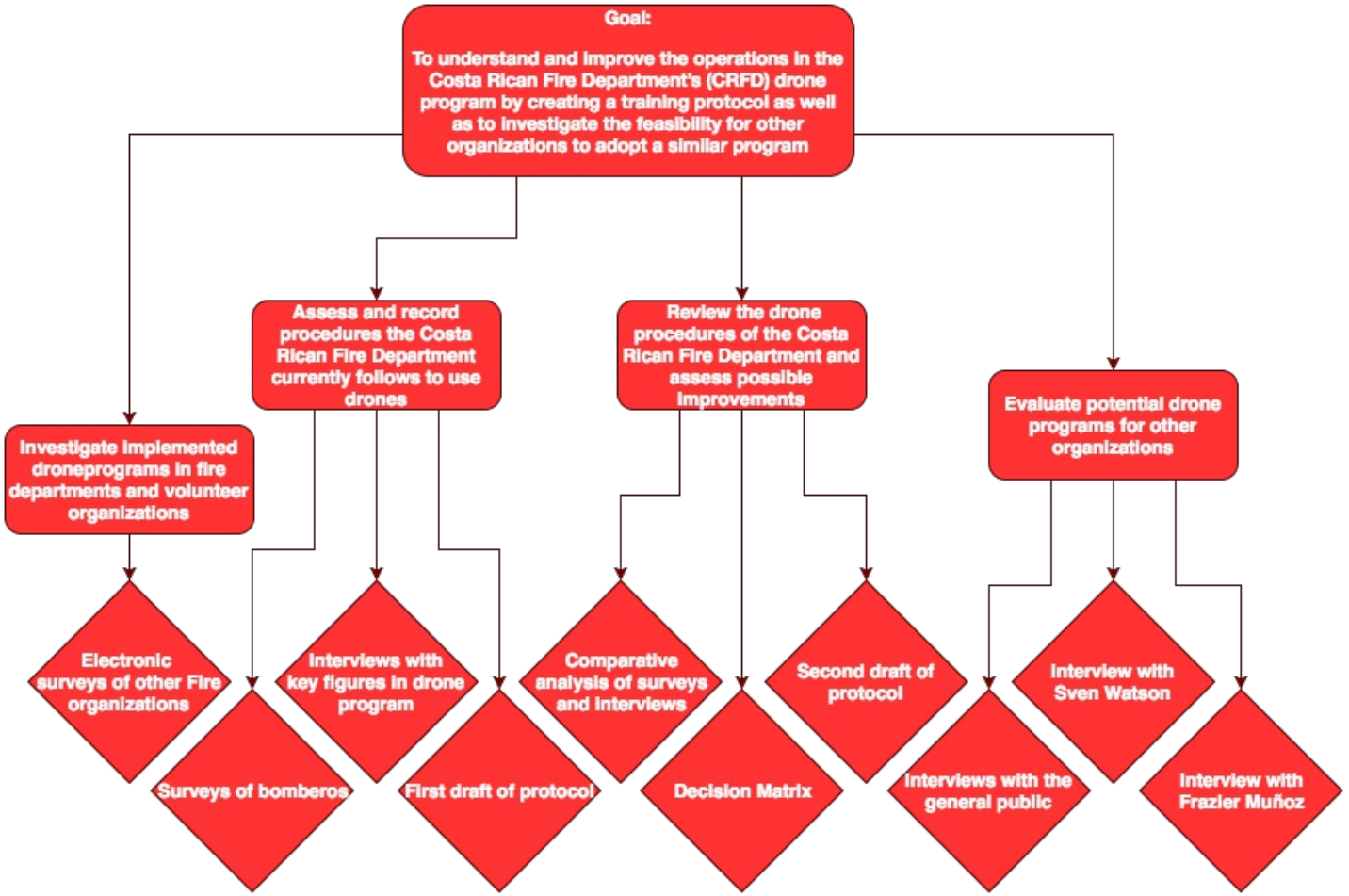
data than using a helicopter. While drones provide many benefits for the CRFD, they still have their limitations, including battery life and inability to operate in inclement weather. There are also many ethical issues to consider when using drones. Drones are notorious for harming and spying on people due to their versatility and surveillance capabilities. There are few regulations on the use of drones to provide structure and order for people who use them. Currently, Costa Rica is looking to increase regulations on drone operation to manage the growth in interest and ensure that recreational drone use does not interfere with emergency operations.

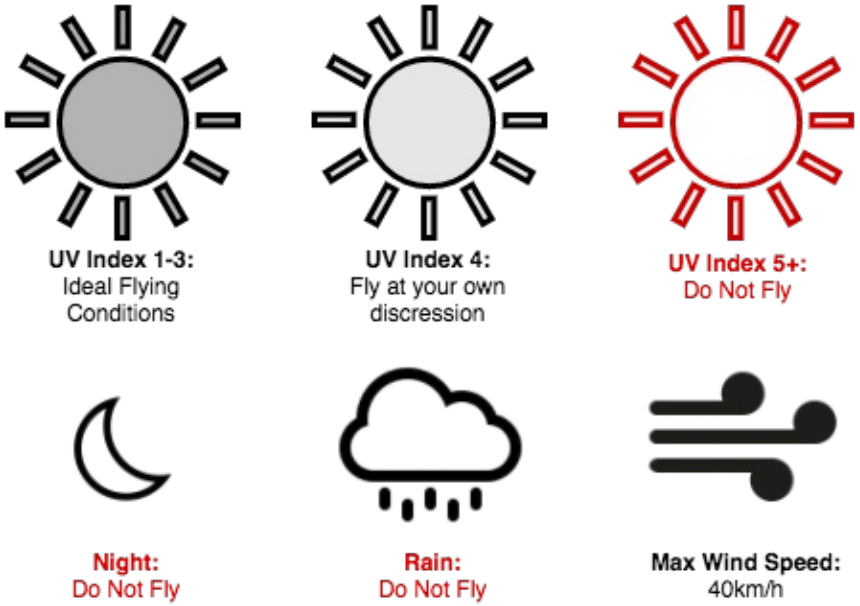
There are five main scenarios in which the CRFD deploys drones: forest and brush fires, structure fires, hazardous materials incidents, traffic incidents, and remote sensing. All of these emergencies share one common problem, the lack of visibility, and drones can be the solution. Forest and brush fires are the most common emergency that the CRFD has to address. These fires are often caused by unattended fires and improperly discarded cigarettes and can spread quickly, especially in the dry season. Structure fires pose a threat to living spaces, some of which can be congested, causing fires to spread faster and put more lives at risk. Hazardous materials incidents endanger the health of firefighters and the general public when a chemical spill occurs. Traffic incidents are a common occurrence in Costa Rica, however they are not always severe that the CRFD responds. Remote sensing can be used as a safety measure for managing risk, code enforcement, and a tool to report statistics.



Methods:

In this project, we set the following goal: to understand and improve the operations in the

CRFD's drone program to ensure human safety by supplementing manpower with efficient aerial surveillance protocols. To accomplish this goal, we established four objectives. (1) Investigate implemented drone programs in fire departments and volunteer organizations. We sent electronic surveys to 12 fire departments as well as two search and rescue groups around the world to understand how they use drones in their operations. (2) Assess and record procedures the CRFD currently follows to use drones. We conducted interviews and sent electronic surveys to personnel involved in the drone program at the CRFD to assess the methods they used when flying the drones. (3) Review the drone procedures of the CRFD and assess possible improvements. We completed a comparative analysis between the responses we received from personnel at the CRFD and outside programs to determine which aspects of programs would work best for the CRFD. (4) Evaluate potential drone programs for other government organizations. We conducted interviews with the Civil Aviation Authority (CAA) and a local drone oriented business owner to understand how the protocol we proposed to the CRFD could be adapted to other organizations. We set criteria, similar to the ones we set for determining a successful program, to determine the potential of a program for other organizations. We identified four findings with regards to the CRFD's drone program, perceptions of drones, regulations surrounding drones, and implementing drones in other organizations.



Finding #1:

There are three main adverse conditions that affect drone use in emergency situations, including rain, solar radiation, and wind. Rain poses a problem to the drone because a small amount of water can cause a short circuit and systematic failure. Solar radiation affects the video feed from the drone to the operator at a UV index of four and stops video transmission in indices higher than five. In mild and strong winds, it takes more effort from the pilot to maintain stability in the air while continuing to fly a drone, which in turn uses more battery power. Unfortunately, when these conditions present themselves, the only course of action is to ground the drone to prevent any damage from occurring, causing the CRFD to lose an important source of information.

Finding #2:

While still an issue, privacy concerns have not significantly affected the implementation of drone programs. Drones are versatile tools that are useful for recording data but unfortunately sometimes people maliciously abuse this. From the surveys and interviews we conducted, all parties agreed that privacy was a concern of the public when using drones. There was a consistent trend that all members of the public we spoke with were alarmed when seeing a drone in the air and feared for his/her privacy.

We also found that despite the privacy concerns associated with drones, programs have still been successful and are expanding. This is due to the public's understanding of how drones are beneficial to the operations of the CRFD. This understanding has resulted in a lack of political opposition for drone programs. Our team outlined four criteria that a drone program must pass to be considered successful. Although drones can cause the public to worry about privacy, a greater

understanding of drones' helpfulness allows drone programs to become more prominent throughout Costa Rica.

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Finding #3:

The lack of regulations surrounding drones has hindered the operations of the CRFD, and potentially other groups in the future. Without regulations on recreational drone use, hobbyists can interfere with emergency practices. The CAA has passed one law that creates no fly zones around airports and certain government buildings. As of April 2016, the legislation establishing more restrictions and creating mandatory drone certification program is still in deliberations within the Costa Rican government. The lack of regulations has impacted the CRFD through a lack of prioritization of the skies during an emergency.

Finding #4:

Drones can be implemented into other organizations, but it will not always be a good investment. Numerous organizations have reached out to the CRFD and inquired about the feasibility of using drones within their own operations. We used the four criteria in our methods to determine if a drone program could be implemented into other organizations. While some organizations may pass all of the criteria for success, it may not be a good investment if they do not have enough uses for drones in their operations.

The Protocol:

The CRFD's drone program demonstrated signs of success, but it was lacking an important component: a formal protocol. The creation of a protocol allows for standardized practices when using drones in emergencies. Without a protocol, procedures were based on intuition, which can lead to uninformed decisions that can cause harm to wildlife, people, and property in emergencies. A protocol also allows for the program to exist within the CRFD when its drone expert is absent or unavailable for reference. The protocol was made through the analysis of the five scenarios. In the protocol, we included the definition of each scenario, important information for drone operation, and procedures to follow.

Recommendations & Conclusion:

Although the CRFD has had success with its drone program, there is still room for improvement. We recommend that the CRFD make improvements to its drone program to allow for its growth. If possible, the primary drone pilot should allocate time to teach other pilots how to use drones since his schedule is sporadic. Because the bomberos will be learning to fly from a basic level, the CRFD should purchase inexpensive drones to practice with before upgrading to the DJI drones. The DJI drones only have

commecial capabilities and it is suggested that the CRFD purchase drones more suited to deal with adverse conditions and the emergencies the CRFD faces. The bomberos should learn to fly advanced drones last because pilots will be flying them upon graduation from the training program.

We also recommend that the CRFD initiate public outreach programs to help the public understand the drones' utility in emergencies to alleviate the privacy concerns of drones. This should be done primarily by generating positive press about the use of drones in the department, leading to more positive news stories regarding drones. The CRFD should also start a drone awareness campaign through the use of posters as well as notify the public in areas where the pilots will be training.

The last recommendation is for the CAA to certify a drone training program. The CAA can follow the protocol created for the CRFD as a baseline for safe flying practices and can create a licensing program for drones. The CAA also should create electronic restrictions to where a drone can fly, called geo-barriers, and program drones with them during routine inspection to prevent drones from entering restricted airspace.

The CRFD recently implemented drones into their fire protection program but lacked a formal protocol. A protocol provides consistent data to the bomberos and aids the program as it moves into the future and expands throughout the CRFD and other organizations. The drone program allows for aerial data and faster decision making in emergency situations. Although these implementations are still likely years away as of the completion of this project in May 2016, the impact of our project is only beginning.

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Chapter 1: Introduction

Drones are an emerging technology that are revolutionizing a variety of applications from commerce and recreation to military and public service. The most commonly known use for drones is as a weapon in war, with news stories constantly arising about government surveillance and targeted attacks. Although this is a common use, it is not their only use; drones are now being implemented in public safety applications around the world. The Costa Rican Fire Department (CRFD), known locally as *El Benemérito Cuerpo de Bomberos de Costa Rica*, has acquired this technology, but has not been able to utilize the drones to their full potential. In 2015, 12 people died from fire related causes in Costa Rica (Bomberos, 2016). Although that number was not relatively high when compared to the population of the country, the use of drones allows firefighters to know more about the situation because being prepared is crucial in an emergency. The CRFD has asked us to create a protocol to give its program structure to effectively use drones in emergency scenarios. If successful, the program can save lives and give the Costa Rican firefighters, known locally as *bomberos*, accurate and current data about fires. We believe that this protocol will standardize their productivity and help them make more impactful decisions.

Due to the surveillance capabilities of drones, they can be very beneficial to fire departments. Drones have the ability to provide more accurate data regarding emergency situations, in a more efficient manner that can save time and lives. The use of drones provides data that may not be obtained from the ground and with this information, firefighters are able to take the appropriate steps towards addressing a developing emergency situation.

In an effort to improve their service to the public, the CRFD purchased drones to use in emergency situations. As of May 2016, the CRFD did not yet have a protocol outlining their procedures because using drones in emergencies was still a relatively new concept. The lack of documentation of the department's procedures and limited number of teachers has restricted the department's ability to expand the program. A protocol serves as a framework for outlining actions and utilities as well as fortifying the structure and organization for using drones, therefore saving valuable time in an emergency situation. Unfortunately, the quality of data captured by drones may not be consistent without a formal procedure because decisions would

be based on the intuition of individual pilots. Without a formal procedure and proper training, there is an increased risk of not only damaging the drone, but also exacerbating the emergency through misplaced efforts.

The CRFD asked us to develop a protocol for the efficient application of drones in its emergency response programs. The drone program will ensure the safety of civilians and firefighters alike by supplementing manpower with aerial surveillance. To accomplish this goal the group established the following fundamental objectives: (1) investigate implemented drone protocols in other fire departments and volunteer organizations, (2) assess and record procedures the CRFD currently follows to use drones, (3) review the drone procedures of the CRFD and assess possible improvements, and (4) evaluate feasibility of potential drone programs for other government organizations based on the CRFD's program. We completed these objectives and achieved our goal through a series of surveys and interviews with fire departments, bomberos, and other organizations that have used drones in their programs.

Currently, the CRFD uses drones in five different scenarios, including forest and brush fires, structural fire, traffic incidents, hazardous materials incidents, and remote sensing. From observing the CRFD's drone usage, we found that the two main problems associated with using drones are weather conditions and privacy concerns because both have hindered the operations of the CRFD. Another issue is that the lack of legal regulations surrounding drone use has stalled the operations of organizations looking to use them. Due to the limited amount of drone programs, some organizations have reached out to the CRFD to understand how it has used drones within its operations to try and model a program to their own needs. The following chapter, addresses select background information on drone technology, existing programs, and the CRFD. Chapter three documents the methods of our research and the reasoning behind our process. Chapter four covers our findings and the analysis of our data. Chapter five details our recommendations, which consist of possible solutions for problems we identified in our project.

Chapter 2: Background

In the fifteenth century, Leonardo Da Vinci first invented the idea of the helicopter. Five centuries later, in 1903, the Wright brothers created their first powered aircraft. As time passes and technology evolves, aerial vehicles are becoming more cutting-edge and are at the point where they no longer need a pilot. Such unmanned aerial vehicles, often called drones, are used in a multitude of applications from commerce and recreation to military and safety.

Because of the potential for drones to assist in safety applications, the Costa Rican Fire Department (CRFD) is beginning to implement this new technology into their practices to provide real-time data in emergency situations. This chapter discusses (2.1) drones in emergency situations, (2.2) current drone programs, (2.3) ethics and regulations, and (2.4) the Costa Rican Fire Department.

2.1: Drones in Emergency Operations

Drones are becoming more applicable in areas such as commerce, recreation, and emergency operations. Due to their versatility, drones can play a very important role in emergency situations through their remote sensing capabilities (Apvrille, 2014). Around the world, fire departments and civilians alike are using small unmanned aerial vehicles to help people. The number of groups that use drones for safety and emergency response purposes illustrate the favorable potential that drones hold for use in maintaining public safety. The numerous benefits and limitations of drones that can be applied to emergency response are detailed below.

Figure 1. Aerial view of a structure fire in Costa Rica. Photo by CRFD.

2.1.1: Benefits

Drones have the capability to collect large amounts of data from locations that would otherwise be difficult to reach by traditional means, such as in the airspace above the burning building shown in the photo of *Figure 1*, used with the permission of Ana Maria Ortega of the CRFD. Operators can deploy drones faster due to their small size, and as a result they are able to relay information quicker than a manned aircraft. The video feed that drones provide is essential to firefighters because with this information they are able to take the proper steps towards responding to an emergency. Many fires can be extinguished without aerial support, but there are some cases where it is necessary (US Forest Service). In those situations, aerial support relaying information, such as the direction of where a forest fire is spreading and what structures are in the immediate area, is very helpful. Many departments do not have access to helicopters or airplanes to gather this data (Hamilton, 2003).

Drones are a low cost alternative to helicopters that can monitor situations from the sky at a safe distance and can communicate information to firefighters on the ground. Drones are becoming a more accessible technology due in part to decreased cost. The average consumer drone, similar to the ones purchased by the CRFD, on the market varies from $500 to $1,500 (DJI, 2016). Other drones that have more capabilities, such as the ones purchased by Brewster Ambulance in Massachusetts, cost up to $5,000 (Harbert, 2015). Some fire departments in the United States opted to contract drones from a private company during large forest fires instead of purchasing them. Private organization use larger drones than most fire departments can purchase, giving them greater capabilities, including thermal imaging and longer flight times (Gates, 2015). The aerial support in place for emergency situations can be very expensive. The estimated cost of a commonly used firefighting helicopter ranges from $23 million to $30 million (Whyte, Arlington 2013). All of these benefits allow drones to be applicable in many other scenarios.

2.1.2: Emergency Scenarios

There are many possibilities in which drones can be employed. Costa Rica, the research site of this project, experiences a multitude of situations where employing drones could be very beneficial to the community. There are six common scenarios in which drones can be utilized: remote sensing, structural fires, hazardous materials, traffic incidents, search and rescue, and

brush and forest fires (A.M. Ortega, personal communication, February 2, 2016; Doheny Drones). These scenarios have one common problem, a lack of visibility, resulting in a potential deficiency of data.

Remote sensing allows fire departments to monitor areas before incidents as a precaution and after incidents to report statistics such as areas of risk and area of land destroyed by fire. In a structural fire, drones can help determine if a building is about to collapse on top of firefighters inside and if there is a risk to surrounding buildings of catching fire, by relaying information about wind (A.M. Ortega, personal communication, February 2, 2016). The number of structural fires from 2011 until 2015 has increased by more than 16% and is becoming a more common emergency (Bomberos, 2011-2015). During hazardous materials incidents, the pilots can scan an area to see if there are any unsafe materials in an area or in proximity of another situation, such as a flammable liquid near a fire, which could escalate it. Hazardous materials can also be involved in traffic incidents when larger vehicles are transporting flammable liquids and collide with another vehicle, overturn, or ignite. In traffic incidents, drones can identify gasoline leaking from a vehicle or a person ejected from a car (A.M. Ortega, personal communication, February 2, 2016). The ability of drones to fly at low altitudes, as shown in the photo of *Figure 2*, used with the permission of José Sosa of the CRFD, can also help decrease the risk to first responders by recording valuable data, such as license plates of vehicles involved in traffic incidents (Doheny Drones). In search and rescue, drones are a reliable way to search for missing persons or locate individuals in dangerous areas (Apvrille, 2014). One study tested the potential of a drone's ability to locate a missing person, and on a dual stage trip they were able to locate the person as well as deliver limited medical supplies (Doherty, 2007).

Figure 2. Aerial view of a traffic incident in Costa Rica. Photo by the CRFD.

The most common fire emergencies Costa Rica experiences are brush and forest fires as illustrated in the photo of *Figure 3*, used with the permission of José Sosa of the CRFD. The main difference between the two scenarios is that a forest fire is much larger and poses a greater threat to lives and property than a brush fire. Brush fires occur when an ignition source causes shrubs, grass, or twigs to ignite and are generally small and easily contained. Forest fires, on the other hand, occur when an ignition source causes a condensed amount of trees to ignite and they are much more difficult to contain (Ahrens, 2013). It is often difficult to fight such fires in Costa Rica due to the low visibility along with the irregular landscape. The landscape of Costa Rica varies from mountains of lush trees to plains of dry vegetation. Costa Rica's forests are also notably tall therefore it is challenging to observe a fire at ground level (Alfaro, Fernandez, Connell 1999). The challenges posed by the terrain become not only a tedious task for Costa Rican firefighters, known locally as *bomberos*, but also can mean a life-threatening situation. Drones can offer a new aerial perspective over any of these incidents, which is not easily accessible by other means.

Figure 3. Aerial view of a brush fire in Costa Rica. Photo by the CRFD.

2.1.3: Constraints

Although drones have the unique ability to gather and transmit information quickly, they do have their constraints, which include limited flying radius from the pilot, battery life, and inability to operate in inclement weather. The limited flying radius stems from the short battery life of most commercial drones, which can last approximately 15-25 minutes. The short flight times of drones only allow for a short period of data acquisition per individual drone, resulting in some of the time being lost in departure and return (A.M. Ortega, personal communication, February 2, 2016). Drones also cannot become airborne if they exceed a certain weight and can only deliver a small payload. For example, they have been used to deliver life vests to stranded

watersport enthusiasts, however they were not be able to lift a survivor to safety (Associated Press, 2015). Likewise, they cannot be used to directly fight fires because they lack the ability to carry large quantities of water (Shupe, 2013). While they are relatively straightforward to set up, drones require great attention to detail during use as there are many factors that can affect flight. The consequences of negligence can result in personal injury or damage to the equipment and property on the ground (S. Watson, personal communication, April 14, 2016). Despite these limitations, the CRFD has decided to incorporate drones into their fire mitigation program.

2.2: Programs

Several fire departments and organizations around the world, such as those in Connecticut (Raus, 2014), Massachusetts (Steimle, 2015), Washington (Gates, 2015), and Ohio (Hodapp, 2015), recently began adopting drones for use in emergency situations. A common theme is that members of the listed fire departments who own recreational drones have volunteered their devices to assist in fighting forest fires and surveying damages from storms (WCVB, 2015). Some of these programs, however, do not have a formal protocol defining under which conditions drones should be used. Despite the absence of current procedures, the opportunities for drone use are rapidly increasing due to the relatively low cost of drones.

2.2.1: Implemented Programs

There have been many cases in which drones have aided firefighters and volunteers when aerial data was needed. When a fire broke out in Branford, CT near a large storage container filled with explosives, firefighters did not know if it was safe to approach the blaze. Fortunately, one of the firefighters had his recreational drone on site and volunteered its use to help scan the area. The live video feed from the drone was imperative in determining if the area affected by the fire was safe for the firefighters to enter due to the fire's proximity to the container. Because of the aerial data, firefighters decided that the fire was safe to approach and were able to successfully extinguish it (Atherton, 2014).

Officials in Somerville, MA have been using drones to prevent roof collapses in residential, government, and commercial buildings brought about by large amounts of snow accumulation. It is difficult to predict when a building will collapse due to the weight of the snow and the roof will often times fail before preventative measures can be taken. Somerville

City Officials contracted a drone multimedia company to survey buildings around the city. After observing the drones' video about the amount of snow on the roofs, the Somerville mayor ordered schools closed for a week for workers to clear the snow. This information, combined with the susceptibility of the city's roofs to collapse, led him to this decision to keep the buildings and students safe (Steimle, 2015).

Personnel fighting a fire in the Olympic National Park in Washington used drones to view hot spots. The trees in the forest were so dense that it was difficult to determine where the hot spots and the fire line were located. Operators "were able to see through the smoke very clearly. They were able to determine the intensity of the fire" by using infrared cameras mounted on the drones to steer helicopters to drop water. Unlike other fire departments, the Bingen fire department contracted a drone from a private company. This option is more expensive, typically priced around $30,000 a day, but it allows for the use of a drone with more capabilities than commercially purchased drones (Gates, 2015).

A volunteer group based in Ohio, called Search with Aerial RC Multirotor (SWARM), has a presence in 42 different countries throughout the world with over 3,000 registered drone pilots. SWARM has been successful in finding missing persons through the use of a number of drones acting in unison to search wide areas of land. This group uses portable and thermal imaging cameras recording at a high resolution in flights that usually last up to 25 minutes (Hodapp, 2015). Another organization, called Texas EquuSearch, has been involved in over 1,350 searches for missing persons and it has successfully found and rescued over 300 people (Texas EquuSearch). Many organizations and fire departments around the world utilize drones for their ability to quickly capture large amounts of data. However, because drones are a new technology, there are limited examples of formal protocols currently in effect, and fewer that are readily available to the public.

2.2.2 Protocols and Procedures

Due to the lack of formal protocols, the quality of data captured by the drones may not be consistent. A protocol is a set of written guidelines that can give someone a general overview of a project and can be used as a training tool. A procedure, which is included in the protocol, enumerates the step by step actions and allows for a more standardized practice throughout all

future endeavors (Merriam-Webster). A protocol is essential because it allows for more effective means of gathering information during emergencies. Without a protocol, organizations are at risk of damaging equipment and entering an emergency underprepared.

The Center for Disease Control has published an eight point checklist for creating a formal emergency protocol which can be used as a model. The first section is the project overview, which contains a summary of the protocol. The second section is the introduction, which includes justifications for the need of the protocol, current knowledge about the topic, objectives, and a general approach to the problem. The third and fourth sections contain the procedures, which discuss how and where information will be received as well as how the protocol will address the issue at hand. The fifth section introduces the method variables and includes the specific procedures of how to handle an emergency and data collection instruments. The method variables categorize different scenarios and varying conditions within each. The sixth section contains the analysis process, which refers to the interpretation of data gathered through the use of the protocol. The seventh section lists procedures for unexpected or adverse events and how to respond to less than ideal conditions. The last section explains the notification process, which is the distribution of data by reporting the essential information to the correct parties (CDC).

2.3: Ethics and Regulations

As technology has advanced, people have begun to question the role it plays in the world. This discussion has become so prevalent in society that an entirely new study has been dedicated to this subject, known as the ethics of technology. On one side of the discussion, people believe that technology is inherently malicious as it is too powerful and can be easily abused. On the other side to the discussion, people believe that technology can be beneficial to society (Jonas, H. 1979). There is a concern that drones can be abused to spy on citizens, but it is important to note that drones are merely tools. Ethics of drones can be equated to the ethics of those who are flying them, as the actions they take are a direct progression of human decision (Wilson, 2014). These sentiments are echoed around the world as people are growing more concerned with their privacy. It is important to consider the public's privacy when implementing new technology.

Unfortunately, it is difficult to regulate drones and enforce laws because there is a lack of accountability for people who violate the laws. Many governments have basic regulations regarding who can own drones, where they can fly, or guidelines for user certification. Costa Rica bases many of its recommendations and laws on the United States' legislature. The Civil Aviation Authority of Costa Rica established no fly zones for drones around certain government buildings and in an eight kilometer radius around airports. Some of the basic guidelines for operating include not flying above 120 meters, not weighing more than 25 kilograms, and not flown in a way that it can violate someone's privacy. While there is potential for a way to track drones to be developed, such as a radar system, at this time authorities are relying on the public to report unauthorized drones (Dyer, 2015). As drones become more prominent, so will the laws to regulate them and the means of enforcement will improve. Regulations are necessary because, like protocols, regulations provide structure and order for people who want to use drones. This is particularly important when using drones because people are afraid that they will be used to spy on others or can be used to hurt someone. It is not a discussion of the ethics of drones, but it should be about what regulations are needed to prevent drones from being used in an ill or unsafe manner.

2.4: The Costa Rican Fire Department

Costa Rica is a small country whose fire departments do not have immediate access to many types of aerial support (A.M. Ortega, personal communication, February 2, 2016)**.** Drone use directly aligns with the CRFD's values as exploring new options for fire prevention is a part of their "constant pursuit of excellence." They define their roles and values in Costa Rica in their goal statement, which includes protecting the lives and property of citizens as well as the environment from fires and other emergencies (Bomberos, 2015). Since 2015, the CRFD has been using drones in its operations because the aerial data they acquire is vital in determining how to approach a fire. This information helps bomberos make educated decisions of where to allocate resources to best handle an emergency. The primary purpose of the CRFD is fire protection at the regulatory and operational levels. At the regulatory level, the department works to implement codes and inspect buildings as a way to prevent fires from occurring. The CRFD

adopts some regulations set by the National Fire Protection Association, an organization in the United States that sets the precedence for many international codes. The CRFD uses these codes in conjunction with the regulatory fire inspection program proposed by a Worcester Polytechnic Institute student project to ensure building safety throughout Costa Rica (Acevedo, Bartlett, Delareyna, Washburn, 2015). The department plans to use drones to help enforce codes on high rise buildings that are otherwise difficult to monitor (A.M. Ortega, personal communication, February 2, 2016). At the operational level, bomberos respond to emergencies they encounter on a daily basis which are a threat to civilian and bombero lives and have the ability to destroy large amounts of property.

Figure 4. DJI Inspire 2 drone and controller of the Costa Rican Fire Department. Photo by Tara Sharp.

Since the beginning of 2015, the CRFD has been using quadrotors with mounted cameras to monitor fires and other emergency situations to ensure the environment is safe. This new aerial view provides new information that was previously unattainable from the ground. As of January 2016, select bomberos have already had one year of experience field testing the drones, indicating that they understand the basic flying components of piloting drones and have an idea as to how the department wants to use them.

The CRFD currently possesses four drones, shown in the photos of *Figures 4* and *5*, and wishes to purchase six more by the end of 2016 (A.M. Ortega, personal communication, February 2, 2016). The CRFD has asked us to create a comprehensive and coherent protocol that they can use to teach bomberos in the pilot program about the application of drones in emergency scenarios and code enforcement. The CRFD wants to develop the drone program so that drone usage in emergencies is more effective and efficient. As the CRFD acquires more drones with varying capabilities over the course of 2016, they would like a protocol that can be standardized throughout the department to maximize the efficiency given the limitations of the

drones (A.M. Ortega, personal communication, February 2, 2016). The CRFD does not currently have the resources available to create a protocol and therefore reached out to us. It was evident through early conversations with the CRFD that the bomberos have not yet realized the full potential of the drones in their possession. The goal of the project was to create a procedure for use and implementation of drones and to determine the technical, operational, and economic feasibility for its use in other departments. The hope is that the fire department continues to expand upon the project by looking for new opportunities for drones.

Figure 5. DJI Phantom 3 drone of the Costa Rican Fire Department. Photo by Tara Sharp.

Chapter 3: Methods

The goal of this project was to understand and improve the operations in the CRFD's drone program to ensure human safety by supplementing manpower with efficient aerial surveillance protocols. To accomplish this goal the group established the following fundamental objectives:

1. Investigate implemented drone programs in fire departments and volunteer organizations
2. Assess and record procedures the CRFD currently follows to use drones
3. Review the drone procedures of the CRFD and assess possible improvements
4. Evaluate potential drone programs for other government organizations

In this chapter, we will explain what methods we used to accomplish each of our objectives and our overall goal.

Objective 1: Investigate implemented drone programs in fire departments and volunteer organizations

To understand the necessary components that needed to be included in the proposed protocol, we examined existing programs and guidelines for the use of drones in emergency situations. A number of organizations, such as fire departments and volunteer groups, have been noted for their use and implementation of drones into emergency situations. We requested the guidelines from 14 fire departments and volunteer groups for our analysis through the use of electronic surveys. In these surveys, we asked explicit questions and requested documentation of procedures to understand their attitudes toward drones and how they were used in their operations. These questions can be found in *Appendix A*. The organizations provided information about their practices, preferences, and concerns with the technology they currently possess.

We thoroughly examined the data to determine trends and common practices that were being employed throughout various fire departments. We used the following criteria to analyze the data gathered from the surveys of the external departments and determine the degree of successful implementation: (1) longevity of the program and if the program is still in place, (2) relevance to the needs of the individual organization, (3) frequency of drone usage, (4) impact of implemented protocol on significant statistics. Longevity indicated the success of a program because a strong program is more likely to be kept in place. Relevance was important because

progress can be determined by judging if a program, through its versatility, has addressed some common issues that the bomberos had presented. Frequency dictated how much a protocol can be trusted because a smaller sample size for success could indicate less reliable data. The impact was used as a direct indicator for success through statistics in emergency situations. A change in certain statistics, such as a decrease in casualties, also correlates to a successful drone program. We determined these components based on the process in a study by Make Energy Change Happen Toolkit, where they used a similar process of determining a possible success criteria, potential indicators of these criteria, viable baselines to establish observations, and how their success would be measured (MECHanisms).

The data provided an idea of feasibility while developing procedures at the CRFD. The project was given a baseline on which we could create a protocol by assessing the aspects of past programs that were successful and those that were not. We chose to do this because there was not much readily available literature regarding effective use of drones so we sought out sources that were educated on the matter to structure our protocol.

Objective 2: Assess and record procedures the Costa Rican Fire Department currently follows to use drones

To understand the process of how bomberos were flying drones, we investigated the current methods the bomberos were using such as where, when, and how to fly drones. To gather this information, we first conducted an interview with the lead pilot of the drone program, José Sosa. He explained the situations in which drones were used, José Sosa's interpretation of the guidelines given in the manufacturer manual to properly prepare drones for deployment, and the steps that he took once they were in the air to gather appropriate information depending on the situation. These steps are vital for the bomberos to follow in order to gather data to make decisions during an emergency in a quick and efficient manner as well as to safeguard the equipment from being damaged. It is also important to capture these steps so other pilots will be able to follow them in the future because José Sosa is currently the only pilot in the program.

We gained more insight about the CRFD through a series of unstructured interviews to determine the operational needs of the bomberos. Unstructured interviews allowed for the conversation to be open-ended so that we could ask follow-up questions important to fully understand the concept (Berg, 2012). To define the needs of the bomberos, we needed to

understand the procedures they were following to determine shortcomings in the current program. At the start of the project, the bomberos had been working with drones for a year and it was essential to gauge their knowledge of the technology to make the designed protocol clear and concise.

To assess the operational, technical, and economic feasibility of the drones for other organizations we had to take into account numerous perspectives. We conducted unstructured interviews with José Sosa, the bombero in charge of piloting the drones, as well as Ana Maria Ortega, the chief of the Information Technology Department of the CRFD. We interviewed José Sosa because he had the knowledge of how the department used drones. We interviewed Ana Maria Ortega because she is the head of the drone program and wanted us to create the protocol to expand the program. We conducted both interviews to understand how the CRFD currently uses drones in emergency scenarios and what it was looking for in a protocol. After gathering information from the electronic surveys as well as the personal interviews, we submitted an unstructured first draft protocol that the CRFD could review for accuracy. This draft included a basic outline of the procedures, but was not yet populated with the information we learned from group interviews.

Through interviews, we examined the current procedures the bomberos had in place for drones and inspected the procedures' feasibility and success. We decided to utilize electronic surveys because of the bomberos' sporadic schedules and the difficulty in coordinating a large group of them (Berg, 2012). The electronic surveys were very specific, where we had questions about small details concerning drone piloting. We sent a total of fifteen surveys and received seven responses. These questions can be found in *Appendix B*. We wanted our survey to cover as much information as possible because we were unable to ask follow up questions due to the nature of the bomberos' schedule. The purpose of the surveys was to gather as much information as possible from the bomberos because they are in the field handling the emergency situations. They are able to understand the issues that prevent them from doing their job best. Their insider knowledge was key to understanding the scope of the issues they faced and gave us valuable insight into what the bomberos needed in the protocol. The results were kept on an online database to be analyzed by comparing and contrasting the responses.

Objective 3: Review the drone procedures of the CRFD and assess possible improvements

To ensure its expansion and survival, we evaluated and improved the drone protocol for the CRFD by building upon their current program. We used a comparative analysis between the responses from the electronic surveys and the data from the group and personal interviews. The comparative analysis consisted of us taking the data we received and looking for common trends to determine what should go in the protocol. We used established programs to demonstrate what methods work best and to allow us to identify the gaps where improvements can be made. We looked to use aspects of data we received from the analysis regarding the technical use of the drones. We felt this was important because protocols are not solely training manuals so they require more technical information on how to effectively use drones. We conducted a comparative analysis and included a variety of perspectives from groups with drone programs to make logical decisions for the improvement of the protocol.

We used comparative analysis to evaluate the data acquired to help the group better understand a successful protocol. We then created a decision matrix, shown below in *Table 1*, to compare the information that we received from surveys and interviews to find what source of information is more relevant to our needs in creating this protocol. We created this decision matrix by determining which factors were the most important for determining success and weighed them accordingly in percentages totaling 100%. Each organization was rated from one to four based on its success in each criterion and the weight and ratings were multiplied and the summation was taken to produce the weighted total for each organization. We used the weighted totals to determine how much impact the research on each organization would have on our deliverable. For example, the highest weighted total had the most influence in the creation of our protocol. After that analysis, we continued speaking with José Sosa and Ana Maria Ortega to ensure that our findings were in line with what the department was expecting. We followed a similar process with the difference in responses we received from fire department and bombero surveys and further researched why these differences appeared. We reviewed the responses from other fire departments that have implemented drones into their department, to review not only

the procedures they created, but also the process they followed to create it.

	Weight:	Plymouth	St. Louis	CRFD	SWARM	Texas Equusearch	Sven Watson
Longevity of the program	20%	1	2	2	4	3	3
Relevance of the technology	50%	2	3	3	4	3	4
Frequency of drone use	30%	3	3	3	2	2	4
Total:	100%	6	8	8	10	8	11
Weighted Total:	100%	2.1	2.8	2.8	3.4	2.7	3.8

Table 1. Decision matrix weighing influences on the proposed protocol. Table by Oliver Simon.

We created the proposed protocol for the CRFD based on its own previous protocols on other operations and the Center for Disease Control (CDC). We used protocols from other operations of the CRFD to create a template that would be familiar and easy for bomberos to teach and follow. The CDC is a reputable source that has handled numerous emergency situations and its protocol was beneficial to create the protocol for the CRFD. The first step was to define a general set of practices for drone use that is applicable to all five scenarios. This would include what would be required to fly drones, the general restrictions, and adverse conditions. We then defined the scenarios in which drones would be used. Each scenario was populated with information about the definition, the causes, the importance, and the steps to follow to react to the situation. Finally, we drafted a general policy and purpose statement to use in an official protocol.

With the data from the interviews and our new guidelines from protocols, we created a second draft protocol to be reviewed by the CRFD. In this draft, we added structure and made changes that reflected the concerns of potential pilots of the drone program. To ensure that the protocol was feasible, we spoke with a number of people that would be using it. First, we spoke with Ana Maria Ortega, who created the program and has a vision of how she wants the program to develop. We wanted to ensure that the protocol accurately reflects how the drones should be

used. We then spoke with José Sosa, who will be the one teaching new pilots how to operate drones, to ensure that the program can be easily taught. Finally, we spoke with potential pilots in small group interviews. We wanted to ensure that they would be comfortable piloting the drones given the proper education. There were no formal questions prepared for these meetings because we did not want to ask the bomberos any leading questions. We set these meetings up so that the bomberos could give us feedback on what they liked and what they felt was missing from our draft protocol.

Objective 4: Evaluate potential drone programs for other government organizations

Drones are a relatively new technology and few regulations have been established in organizations. Several organizations in Costa Rica have already reached out to the CRFD regarding their drone program. We wanted to gather different perspectives, such as those of civilians, business owners, and federal employees, on drones to determine where and how they can be applied elsewhere. We contacted Sven Watson, the owner Terraprecision, and Frazier Muñoz of the Civil Aviation Authority (CAA) to conduct interviews. These interviews were set up in a semi-structured manner in which we had a number of set questions to ask and left room for additional questions (Berg, 2012, 81). Due to time constraints, one of these interviews was conducted over the phone.

Sven Watson is a drone enthusiast and has professional experience using drones in agricultural applications. His perspective offered a civilian and professional view as to how regulations affect non-government individuals and organizations. We wanted to understand if he had faced any regulatory problems regarding his commercial use of drones and if he is having similar problems to other drone users. The questions we asked can be found in *Appendix C.* The CAA is the branch of government in charge of governing the Costa Rican airspace. The perspective of Frazier Muñoz provided us with a better understanding of where how the proposed regulations will affect everyone wanting to use a drone. The questions can be found in *Appendix* D. The Costa Rican Red Cross is an organization that works to alleviate the impact of a crisis on vulnerable people. José Sosa and Ana Maria Ortega stated that the Red Cross had contacted the CRFD for assistance, so this perspective offered us insight about the other kinds of emergencies in which drones can be applied. Although efforts were made to contact them, we

were unable to communicate with them so instead we used the information relayed to us by the CRFD to study feasibility of the impact of the CRFD's programs in the operations of the Red Cross.

To learn more about privacy issues and public opinion we surveyed the general public. We went to the San Pedro downtown area to survey people and ask them questions about what they know about drones and what connotations they have, the questions can be found in referenced in *Appendix D*. We kept the surveys short so that people would be more inclined to participate.

Once the perspectives were collected and organized, we evaluated the potential use of drones in other organizations based on four criteria. The first criteria was the need for an alternative program, which was used to determine the various ways drones can be applied to improve existing practices. The second criteria was the similarity to the procedures of the CRFD, which demonstrated how well the protocol can be applied to other programs. The third criteria was the anticipated frequency of drone usage to determine if seeking to implement drones into a program is a feasible option. If the drones are rarely being used, then it is not a cost or time effective solution. The fourth criteria was their expected outcome of using drones, which was used to determine what each outside organization wanted to achieve by using drones. Each of these criteria is closely related to the others and each is a logical progression of the last. These were adapted from and are similar to the criteria we used to determine success when we were creating the proposed protocol and were also applicable here as well. The similarities between the criteria show how relatable the information we receive is, therefore it is important to make a distinction between the data (MECHanisms). The specifics of each criterion make that distinction so analysis of the data was easier to process.

Our primary deliverable for this project was to create a protocol for the CRFD. The objectives we outlined have helped us not only create a protocol but also generate a template for using drones in general. All of these objectives were carried out to fully meet the goal the group had set. Our findings show the full extent of how effective our methods achieved data which we then analyzed for use in our project.

Chapter 4: Discussion and Findings

The goal of our project was to understand and improve the operations in the Costa Rican Fire Department's (CRFD) drone program by creating a training protocol as well as to investigate the feasibility for other organizations to adopt a similar program. The protocol was our most important deliverable and the process of developing it was the first step in accomplishing our other objectives. Speaking with other organizations who use drones, interviewing bomberos about their experiences with drones during emergencies, and learning about the perceptions of drones in the country all were significant factors to consider during the creation of the protocol.

4.0.1: Justification for the Protocol

The absence of a written protocol led to inconsistent data collection and difficulties with workforce development in the department, therefore one was needed. All the organizations we interviewed who have implemented drones into their operations agreed that there was a need for a written protocol with background information to build a foundation for a program. A protocol allows for organizations to react to conditions in a similar manner every time instead of making decisions based on intuition, which can be wrong. Ana Maria Ortega expressed that time is valuable during an emergency because every second counts. A protocol saves time because everything is outlined for the user for easy reference. The data from the drone is essential to their decision making process because without a protocol, it is possible that the pilots do not reach the same conclusion every time they fly. Structure is important during an emergency because disorganization in the decision making process leads to distractions, which can lead to loss of life and property.

Many organizations have struggled to train their employees to use drones because they are a relatively new tool. The St. Louis County Fire Department stated in our survey that one of the biggest problems they encounter with drones is the idea of "new technology [and] maintaining a group of competent, trained operators." The background knowledge the public has about drones is limited by the lack of readily available literature. Currently, the CRFD relies on José Sosa to train new pilots about piloting drones. José Sosa is a full-time bombero working as

the chief of the Monteverde Fire Department, so the pilots in training are limited by his availability. Pilots cannot further their training until José Sosa has time to teach them. Written guidelines are necessary to establish a standardized training program for greater ease and efficiency in instructing new pilots. Documentation of how to use drones is especially important in this situation because it will give flexibility and assurance to pilots in training if the instructor is overwhelmed by his workload. By archiving the data, the CRFD is guaranteeing that the knowledge will be maintained.

The protocol is particularly important for the CRFD's expansion efforts because the department wants to place drones in more stations throughout the country and need more trained operators. The protocol is also vital for teaching the new operators how to use drones in a consistent and uniform manner. It is important to ensure that the inaugural class fully understands the program because if the CRFD were to expand the program without a protocol, it allows bad habits and inconsistencies to spread throughout the program. Verbal instructions suffer from severe degradation of clarity and meaning (A.M. Ortega, personal communication, February 2, 2016). Protocols are essential to any successful organizations' operations, especially in emergency scenarios. We used five scenarios as a baseline for the protocol, which include forest and brush fires, structural fires, hazardous materials, traffic incidents, and remote sensing. All these scenarios have a common problem, a lack of visibility of the entirety of an emergency which can result in a deficiency of data. We have outlined this by explaining how drones can be used in each scenario.

4.0.2: Forest and Brush Fires

Forest and brush fires are the most common emergencies that the CRFD responds to. A recurring cause of the brush and forest fires is the people leaving fires unattended or improperly discarding cigarettes (J.P. Sosa, personal communication, March 22, 2016). Costa Rica takes pride in its biodiversity, but unfortunately poachers hunt the wildlife and intentionally set fires as a distraction for the local authorities. While the poachers illegally hunt wildlife, the authorities are focused on preventing the fire from spreading to other parts of the region and destroying the landscape. Other times after poachers are arrested and released, they will return to the area and start a "revenge fire" (Sosa, J.P., Personal communication, April 19, 2016). The intentional and

revenge fires create emergencies that bomberos would otherwise not need to handle and divert services away from other potentially dangerous situations. Drones aid in the efforts of bomberos by reducing the amount of wasted time, effort, and money by providing the data which allows bomberos to streamline their approach. Bomberos use drones to determine the direction of the fire so they can move tactically and efficiently to extinguish it. To combat these fires, a group of bomberos will move around the head of the fire with machetes to cut grass and bushes away to remove the fuel source from the fire so it will burn out (J.P. Sosa, personal communication, March 22, 2016). The sooner a fire is put out, the less habitat it destroys and the more effort the bomberos can apply elsewhere.

4.0.3: Structural Fires

Structure fires can be dangerous because they put both people and property at risk. The most common causes of these fires include electrical shortages, fires in kitchens, burning trash, and improperly discarded cigarettes (J.P. Sosa, personal communication, March 22, 2016). A small fire can rapidly spread and consume many homes, taking lives and large amounts of property in the process because there are many congested living spaces in communities in Costa Rica. Before using drones, bomberos would enter buildings unaware of the condition of the declining structural integrity of the building. Drones are helpful in structural fires because bomberos need to know how the fire is spreading and that information can be much more difficult to gather from a grounded vantage point, especially in some of the congested living spaces. In taller buildings, drones are used to see if habitants are still in rooms, and is a more efficient and safer means than searching room by room (J.P. Sosa, personal communication, April 14, 2016). With the new vantage point provided by drones, bomberos are looking for threats of collapse which will help them determine if they should evacuate the building. Drones can be used to survey the roofs of buildings to determine signs of collapse that would otherwise be difficult to obtain.

4.0.4: Hazardous Materials

Emergencies that the CRFD handles are not limited to fires, but also include hazardous materials among others. Hazardous materials include any material that is flammable, explosive, or toxic that if mixed with any other substance becomes an irritant. Chemical spill incidents are

often caused by accidents involving tankers, pipelines, and storage facilities, usually while these hazards are in transport to users. Other causes include mistakes, equipment degradation, natural disasters, vandals, or illegal dumpers (J.P. Sosa, personal communication, March 22, 2016). Often these emergencies occur when there is a leak or spill of chemicals that have the potential to be dangerous to the immediate area by putting the public in jeopardy. Due to the precarious nature of these incidents, only two or three bomberos will enter the secure perimeter. It is dangerous to approach chemicals on foot because exposure can result in sickness or bodily harm. Drones in these scenarios are used to give the bomberos a better understanding of where a hazardous material is and the severity of the situation, so they can be better prepared to approach and contain the hazard. Drones act as an extra pair of eyes for the bomberos outside of a secure perimeter to monitor the situation and ensure the procedures are followed (A.M. Ortega, personal communication, February 2, 2016).

4.0.5: Traffic Incidents

Traffic incidents are usually caused by human or mechanical error, such as distracted driving or brake failure. These kinds of incidents occur daily, however they do not always require a response from the bomberos. The CRFD responds at a certain level of severity and such incidents are not very common. When the bomberos do respond, it is often difficult to access the vehicles involved because of the traffic congestion on tight roads. The clogged environments will often not allow for a fire truck to pass through and as a result, drones are used to provide more information to the bomberos about the severity of the incident. For example, there was a traffic incident involving a bus full of passengers that struck a larger truck in 2015. The bomberos focused their efforts on evacuating people on one side of the bus while using a drone to survey the entire scene to ensure that there were no more casualties and to view the extent of the damage to both vehicles. While the drone was in the air, the bomberos noticed that there was a substantial amount of gasoline leaking from the other side of the bus and were able to clean it up before it escalated the emergency (J.P. Sosa, personal communication, March 22, 2016).

4.0.6: Remote Sensing

The CRFD uses drones in remote sensing to scan and take pictures of an area. Images are then combined to create a larger overall image that is used to determine high and low risk areas. This defines how quickly an emergency can escalate, how containable the situation is, and how congested a living space is. From there, the CRFD takes the proper precautions to ensure higher risk areas are kept safe by monitoring the area and having a pre-determined plan of action. Drones can also aid in code enforcement where they can reach heights higher than the span of a ladder and will not take apparatus out of service for a building inspection. Following any fire related incidents, the CRFD uses drones to determine area lost due to fires for use in statistics and reporting exact numbers to the government. For example, a woman whose property was partially destroyed by fire filed a lawsuit accusing the CRFD of taking too long to respond to the fire. The bomberos prioritized the living space over the rest of the property. The larger image of the area, illustrated in the photo of *Figure 6* used with permission from José Sosa, showed the fire line where the bomberos extinguished the flames near a living space (J.P. Sosa, personal communication, March 22, 2016). Had the bomberos let the fire burn closer to the living space, they would have put more lives and property at risk. The image demonstrated the actions of the bomberos and they were able to justify their prioritization.

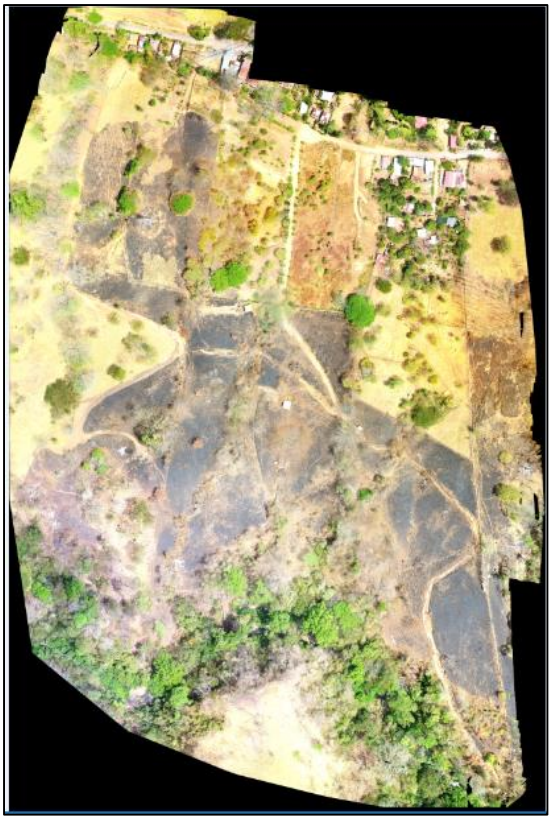

Figure 6. Remote sensing image after a brush fire occurred in Costa Rica. Photo by the CRFD.

During emergencies, bomberos risk their safety and wellbeing to mitigate disasters. Drones are useful in these situations through their ability to aid in risk analysis and relay information about dangers not visible to the bomberos. Without a protocol, however, these emergencies might remain incorrectly interpreted and the information relayed to the bomberos

can do more harm than good by diverting their attention and allowing emergencies to escalate. Throughout our research, we found many common themes about drone use, such as the challenges of using drones and the determination of success of drone programs.

Finding #1: There are three adverse conditions that can limit drones in emergency scenarios.

The bomberos currently experience some challenges when handling emergencies, including rain, solar radiation, and wind. Rain severely impacts the flights of drones when moisture enters any part of the drone because it short circuits and causes systemic failure. Information we gathered from multiple surveys from fire departments, bomberos, José Sosa, and Sven Watson, co-owner of Terraprecision, who uses drones for agricultural mapping, indicated that regardless of the type of drone, custom or commercial, they are unable to be flown in the rain. Of the seven surveys and three interviews we conducted with bomberos and fire departments, all of them indicated that at the first sight of rain, drones are returned immediately for protection. This has prevented the CRFD from using drones in necessary situations because they are unable to operate in these conditions.

In Costa Rica, the sun is intense and the effects are notable when using drones. Solar radiation begins to affect the video feed in commercial drones in UV indexes higher than 4. Due to the interference of solar radiation, the video feed can be interrupted and even halted from being broadcast to the pilot (J.P. Sosa, personal communication, March 15, 2016). The solar radiation can modify the propagation of the video feed transmitted by the drone, meaning the radio signals that the camera emits have a harder time reaching the controller. We learned from Sven Watson that solar radiation has not affected his drones because he builds his own. He mentioned that his drones were open and all the wiring is visible. As a result, the heat is more readily able to escape from the drone so heat from the sun does not affect the inside like it would in commercial drones with the enclosed wiring. This makes them more susceptible to rain damage however all drones are usually grounded at any signs of rain. Upon further analysis, we determined that the solar radiation was not affecting Sven Watson's drones because his drone does not relay information like the drones of the CRFD do. He uses drones for remote sensing and they operate by taking pictures and saving them on a memory storage device embedded in

the drone as opposed to the live feed that the CRFD operates with. From our survey sent to the bomberos, we found that once the drone is incapable of receiving any data, it can lose its calibration. The drone will be grounded, depending on the UV index, to avoid physical damage and the possibility of losing all contact with the drone. Similar to rain, solar radiation restricts the CRFD.

Wind speed has an effect on the operator's control and the battery life of the drone. The direction of the wind can determine how the CRFD will approach a situation as it can be detrimental when high winds allow the fire to grow larger. There are three things that are needed for a fire to occur: heat, fuel, and oxygen. An increased wind increases the source of oxygen to the fire, thus allowing the fire to expand. Unfortunately, most types of drones cannot withstand winds exceeding 40 kilometers per hour and are forced to land at the risk of being damaged. In lower and more manageable winds, drones can be flown, however flight times are much shorter because more battery power is used to maintain stability. According to José Sosa, the DJI Phantom drones that the CRFD uses have a battery life of approximately 17 minutes in mild wind conditions. On the other hand, Sven Watson's custom built drones carry larger batteries and have flight times of up to 50 minutes in mild wind conditions. Wind is a weather condition that can worsen a fire but, along with the landscape, can also be used in the bomberos' favor. We accompanied José Sosa to a brush fire in the Heredia province close to the Information Technology building. From the drone data, he found that there was a small river flowing through the valley where the fire was burning and the wind was blowing away from the river. José Sosa relayed this information to the bomberos fighting the fire so they knew the fire would burn out on its own and they were able to focus their efforts elsewhere. Wind is an unpredictable factor as sometimes it can force the bomberos to ground the drone but in some cases it can aid them in their operations.

Weather conditions cause the CRFD to ground the drones and lose an important tool. Without the data from the drones, the bomberos have to rely on only what they can see and are suspect of making an uninformed decision which could result in casualties or increased property damage. Using drones is one of the safest measures bomberos can take, as knowledge is critical when entering into any of the five listed scenarios. Weather conditions are unpredictable, however, and there is no way to avoid grounding a drone until the CRFD owns drones that are

more weather resistant. These adverse weather conditions apply to all five scenarios equally and therefore effect operation protocols.

Finding #2: Privacy concerns have not significantly affected the implementation of drone programs because there is generally a positive perception of drones.

One of the benefits of drones is their ability to survey and record data, however this feature can be abused. Privacy concerns have often been thought of as problems to drone programs. In the surveys we conducted with drone operators and members of the public, we found that they believe that the invasion of privacy is one of the biggest issues when using drones. The 30 members of the general public surveyed have negative perceptions of drones because of privacy concerns. Both of the fire departments that responded to our surveys and all seven of the bomberos surveyed agreed that the public's concern for privacy is an issue when using drones. The public was afraid that drones could be used to spy on them while the fire departments were afraid of the potential backlash from using drones. There was an article prevalent in Costa Rica regarding a male in the United States used a drone to film a young girl sunbathing. The girl's outraged father shot the drone out of the sky after she notified him (Wellman, 2015). This article is an example of how easily drones could be abused to spy on unaware targets. After multiple training session in the CRFD parking lot, the department received a complaint from one of the homes nearby claiming that it was using the drone to spy on their daughter. The family saw the drone in the air and immediately assumed it was being used in a malicious manner (J.P. Sosa, personal communication, March 22, 2016). Privacy concerns about drones, however, have not been enough to deter organizations from using them.

Out of those 30 people we surveyed, 24 supported the use of drones by bomberos and even referred to the technology as useful. The support of the public benefits the organizations looking to use drones because it leads to little political opposition. Frazier Muñoz, the Director of Security Operations of the CAA, has not received any public opposition to the use of drones. With the support of the public, the CRFD has proven to be quite effective based on our four criteria to determine a successful program: (1) the longevity of the program, (2) how the program addressed the CRFD's needs, (3) frequency of drone usage, and (4) impact on the statistics. The CRFD has been using drones since the start of 2015 to aid in their fire mitigation program and

drones have the potential to be used for many years to come. The drone program has effectively addressed the CRFD's needs by providing an aerial view that was previously unattainable. With the proposed protocol and the expansion of the program, the CRFD will be using the drones more frequently than they currently do as of May 2016. Although they will not see a significant impact on the statistics in the immediate years, given time and more experience, the impact will be more apparent.

Terraprecision has also been successful according to our four criteria despite privacy concerns. Sven Watson has been using drones since 2014 to analyze spatial data, calculate area, and create digital models of farms in Costa Rica more efficiently than when conducted manually. We found that the majority of these organizations have been successful because there was generally a positive perspective about drones. This is because they realized that, although the surveillance capabilities of drones could be used maliciously, drones could also be used for beneficial purposes such as emergency mitigation.

Finding #3: The lack of drone regulations and the uncertainty surrounding drones have hindered the operations of organizations looking to use them.

The CAA has passed one law and is lobbying for more laws to be passed regulating the operation of drones. Currently, they have a law stating that drones cannot be flown around certain government buildings or within an eight kilometer radius of an airport, otherwise known as a no fly zones. They submitted a proposal to the Costa Rican government for the overall certification process, more restrictions on the height and weight, flying out of the operator's sight, and flying with the intent to spy on others. Legislation may take a lot of time to process but drones will become regulated once the laws are passed as the CAA has never faced issues when trying to pass a law.

Sven Watson stated that currently the CAA has a proposed license program where drone operators can apply to get a license to fly and a license plate for their drones. The CAA has plans in place to make this program into law by charging drone pilots a onetime fee to become certified. Unfortunately, the CAA does not have a way to enforce regulations because the government has not yet processed the proposal, meaning that they are only recommendations, not actual laws (F. R. Muñoz, personal communication, April 19, 2016). To enforce the

recommendations the CAA has made, Costa Rica needs a way to track operators and violators. The licensing program cannot be made mandatory until after the government has passed the laws that the CAA has proposed. Until then, there is no way to enforce the drone regulations of the CAA. This has created many confusing and difficult scenarios for drone programs because the interpretation of those recommendations are left to the drone operator (S. Watson, Personal communication, April 2016).

The CRFD has had issues because of the loosely defined regulations. It was using a drone to gather information during a fire emergency when an unidentified civilian drone appeared and occupied the airspace around the fire as well. Unfortunately, the CRFD had to ground its drone and continue battling the fire without their aerial support because it is very hazardous to operate in proximity to an unidentified drone (A.M. Ortega, personal communication, February 2, 2016). There is potential to damage the drone or its exterior sensors in a collision. Grounding a needed drone was a problem because it restricted an important source of data the bomberos needed to make more educated decisions, and it was also a distraction to the bomberos. In an interview, Ana Maria Ortega mentioned that the regulations are very unclear and unspecific. The bomberos are lobbying the CAA to create a law that will give the bomberos control of the skies during an emergency. At the time of the incident, the pilot was not breaking any laws because there is no formal regulation regarding prioritization of the skies during an emergency. The main concern is that there is no way to enforce them without the licensing program. It is difficult to find a drone pilot in a large area or crowd, leading to a lack of accountability.

Sven Watson also elaborated on how the regulations are very loose and sometimes unclear. As Sven Watson said, “The CAA website isn’t well set up… The [drone] recommendations aren’t well written and are open to interpretation.” The ambiguity surrounding the recommendations has led to drone operators finding loopholes. For example, one regulation recommends that drones should only be flown up to 120 meters from the ground. Sven Watson admitted, “You could easily break this regulation. [You can] fly your drone to a volcano or a mountain and go up 120 meters from there. Technically you are still following the recommendation.” The regulation does not specify where the ground level is, whether it is at sea level or at canopy level. Another regulation states that drone operators are not allowed to use drones to invade the privacy of other people. However, it is difficult to prove intent to violate

someone else's privacy. The law also does not specify what constitutes "invading someone's privacy" and it is left to the judgement of the user (CAA). The law was written with good intentions, but it has instead created another problem by it being open to interpretation. Ambiguous regulations can cause many unforeseen problems as the regulations have not been clear enough to provide the structure a law requires. The regulations have not served their purpose as they have failed to provide the community with order by being either difficult to enforce or being too ambiguous.

Finding #4: Drones can be implemented into other organizations, but it will not always be a good investment.

Numerous organizations have reached out to the CRFD and inquired about the feasibility of using drones within their own operations. The two most notable organizations are the Costa Rican Red Cross and the Transit Police. The Red Cross wants to use drones for its search and rescue operations and the Transit Police wants to use it for license inspection (J.P. Sosa, personal communication, April 21, 2016). This information was provided to us by José Sosa because the CRFD would like to see drone usage expand to other organizations. We created the four criteria in our methods to evaluate the potential use of drones in other organizations based on certain criteria. These criteria include: (1) the need for an alternative program, (2) similarity to procedures of the CRFD, (3) anticipated frequency of drone usage, (4) their expected outcome of using drones.

Both organizations expressed the need for an alternative program. The Red Cross wants to use drones for search and rescue while the Transit Police want to use drones to inspect license plates. The Red Cross does not have similar procedures to the CRFD, however the Transit Police do. The search and rescue groups we researched use a large number of drones simultaneously as it is actively searching an area because the general location of the missing person is unknown. This contrasts with the procedures of the CRFD, because it only uses one drone to survey a scene. The Transit Police want to use one drone to survey a general area for license inspections. This is similar to the procedures of the CRFD. Search and rescue incidents occur less frequently than license inspections. The Red Cross and Transit Police both have high hopes for a drone program. The Red Cross hopes that drones will help them find people more efficiently than it

does now by searching more areas in a shorter period of time. The Transit Police hope to be more efficient because they will be able to monitor roads better by looking at multiple licenses from the aerial perspective of the drone (J.P. Sosa, personal communication, April 5, 2016).

We found that the Red Cross and the Transit Police could use drones in their operations because they met most of our criteria. There are several examples of organizations using drones in similar fashions in other programs around the world. However, this does not imply that it would be cost effective for either the Transit Police or the Red Cross. We determined although the Red Cross could use drones in search and rescue applications, it would not be a wise investment as the Red Cross would have to buy multiple drones only to be used less often. A drone can only search for a limited time with a short battery life. Search and rescue operations often use a large number of drones and to purchase such a quantity would be a great fiscal concern to the organization. The drone program of the CRFD would not be able to directly transfer over because of the difference in drone quantity so the Red Cross would need to build its program from a different source.

We also determined that it would not be cost effective for the Transit Police to only use drones for license inspection. There are less expensive ways to monitor roads, such as stationary cameras, so it would not be the wisest decision to invest in drones. According to Sven Watson, the short battery life of a drone would make it unsuitable for searching for license plates. He also mentioned that it would be difficult to see the license plates because of the angle at which the drone would observe them. We believe that if both organizations look to expand their programs further than these two situations, it could be a practical investment.

4.5: Content of the Protocol

Our findings led to what we decided to put in the protocol as we wanted a way to address all of the issues we found. We did this by defining each scenario in the protocol, as well as the possible adverse conditions, and how to react to those conditions with drones. A quick reference guide we created for the adverse conditions in the protocol is shown in *Figure 7*. The protocol also includes technical instructions for properly setting up drones for flight and any other information needed is organized in a way that it can be easily referenced during an emergency. The first part of the proposed protocol for the CRFD includes the general purpose and policy. The purpose states why a protocol is necessary for any procedure which was especially important for this protocol because new technology is being applied when there is limited literature on the subject. The next section of the protocol is the glossary which includes the definitions of each scenario so that a new pilot or bombero can read the manual and immediately understand the risks in each emergency. The policy portion discusses what should be included in a drone kit. The kit contains the properly labeled equipment itself along with instructions detailing how to store the kit so that it may be easily accessible during an emergency. The later parts of the protocol go in depth about the causes, assessments and actions the operator must take in each emergency in which the CRFD would use drones. The possible causes of each emergency are included to give background information that may be useful for the bomberos handling the emergency and also for statistical analysis. The assessment section of the protocol is there to relate an adverse condition to the plan of action describing how to handle the situation. This is done to ensure that time is not wasted trying to determine the correct course of action.

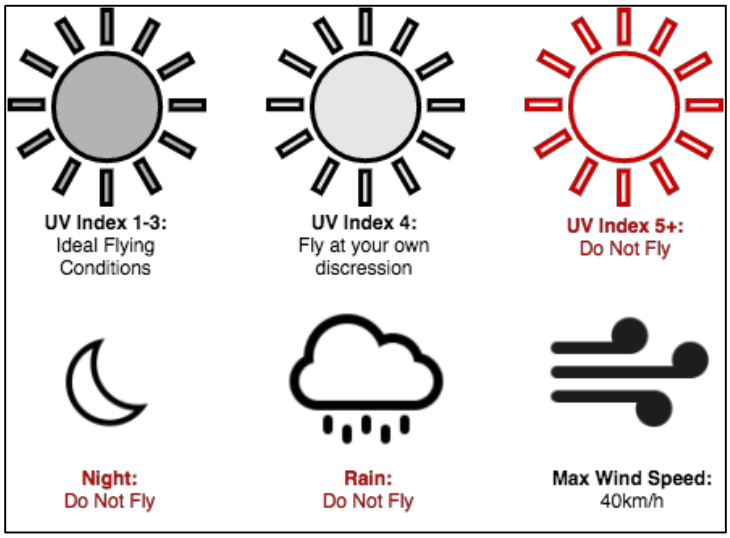

Figure 7. Reference guide for when drones can be flown in adverse conditions. Graphics by Oliver Simon.

4.6: Limitations

Throughout the course of this project, there were several factors that led to potential shortcomings in our data. These factors included a limited number of people with experience using drones, limited feedback from bomberos due the nature of their availability, and a small sample size regarding our public surveys. There are not many drone experts in the field because drones are relatively new to emergency response programs. We interpreted any information we received from experts as a common problem throughout all drone users, which may not be the case. Some experts that we interviewed experienced issues that were unique to their operations, such as the CRFD having issues with solar radiation whereas Sven Watson did not. The primary deliverable of our project was to create a protocol for the CRFD. We had made plans to formally interview the bomberos and drone pilots about what they would like to see in a protocol. Those plans changed because the bomberos we wanted to interview were called to attend to a multi-day fire emergency. We then created detailed surveys, which limited us because we were unable to ask additional questions. We sent out surveys to fire departments around the world and conducted interviews with the public, however both were small sample sizes. Of the 14 surveys that we sent out, only two responded. Due to the lack of response, the data does not accurately reflect the concerns or comments that other fire departments may have. We also interviewed members of the general public in the downtown San Pedro area that favored a certain demographic. We interviewed more people that were younger in age and presumably had a more progressive outlooks on technology. Their input may have biased the results, favoring the use of drones because of their age they may be biased in a more liberal way. We had to extrapolate data because of the small sample sizes, which in turn may have skewed our overall findings. For future research, larger sample sizes with a more representative demographic should be taken for more conclusive results.

Chapter 5: Recommendations

Based on our findings and analysis, we have developed three key recommendations along with various auxiliary recommendations that will allow the Costa Rican Fire Department (CRFD) to fully realize the potential of the drone program as well and expand upon it, both internally and externally with other organizations.

Recommendation #1: The CRFD can make various improvements to the current drone program.

Prior to the protocol, the CRFD used an intuition based decision making process in which drones were flown at the pilot's discretion. If possible, **we recommend that José Sosa dedicate time to training new pilots to fly the drones in the CRFD's program.** José Sosa is currently the chief of the Monteverde Fire Department and is often called away to fires to pilot the drones, causing a sporadic schedule. A training program exists, but José Sosa must be the one to train new recruits and should set time aside to do so because he is the only pilot with extensive experience piloting drones. As the program grows a stronger base with more pilots, José Sosa will not have to dedicate as much time to teaching the program and can focus more on piloting the drones himself.

We recommend that the CRFD purchase or build drones with greater imaging and stability capabilities. The DJI Phantom drones that the CRFD currently possesses are commonly used by drone hobbyists and have most basic capabilities commercial drones are fitted with, which are just basic cameras. Other fire departments, such as the one in St. Louis County, use better drones that are specifically created for professional applications. By obtaining a higher end drone with more capabilities such as longer battery life, improved stability in stronger winds, and well as thermal imaging cameras, and more data would also be available to bomberos.

We recommend that pilots first learn to operate inexpensive drones because the drone program starts teaching pilots from a very basic level. Sven Watson mentioned that the best way to learn to maneuver drones is to first learn the basic components of flying. By learning to operate on smaller and less expensive drones, the pilots will be able to orient themselves with

the flight axes and learn to focus on the small details. Pilots need to be aware of the weather conditions and their surroundings as well as be able to communicate with the bomberos through different channels. The different channels include communications with the base station controlling the airspace and the drone operator relaying information to the bomberos (S. Watson, personal communication, April 14, 2016). Once they understand the basic capabilities and flight axes of drones, they can graduate to the DJI Phantoms to begin learning to look at the screen that produces the live video from the drone and working with a partner who will be watching the drone in the sky. Once the pilots reach this stage, they can begin practicing in actual scenarios in which they would begin learning about the information they are seeking in each. After the pilots have mastered these skills, they can move to higher end drones with greater capabilities.

We recommend that the new protocol be used as the base of the pilot training program because the protocol contains very basic instructions for using drones in fire emergencies. A protocol is in place to create guidelines in specific scenarios, but because of the detailed response plan and basic information included in our deliverable, it can be used to train any level of pilot. Learning from the protocol will also assist in remedying the division between pilots learning to fly and learning the proper procedures. Instead, pilots learn to fly by using the proper procedures outlined in the protocol. The protocol should not only be used as a training manual, so **we recommend that it be used by the CRFD to enforce a formal set of guidelines that bomberos must follow.** By abiding by these guidelines, bomberos will be more efficient in their practices and can ensure their own safety along with the safety of equipment and civilians. The protocol can be easily checked and a copy should also be included with each drone kit for reference purposes. Refer to *Appendix G* for the full protocol.

Recommendation #2: To better the reputation of drones, the CRFD should raise awareness within the community through public outreach programs.

People associate drones with privacy concerns and as Sven Watson said, most of what Costa Rica hears about drone comes from the media and most of that news is negative. **We recommend that the CRFD start generating press about their use of drones.** During or following an incident, when the CRFD talks to reporters about what happened and how they handled the emergency, they should talk about the role that drones played. The media already has an impact on how drones are viewed, so the CRFD can use that to their advantage to convey

that drones are a useful tool that can benefit society. It will be helpful for society to understand the purpose drones serve and that drones are making a difference in the CRFD's operations. They should also understand that drones will not replace a bombero in an emergency as people are needed to pilot the drones, and the bomberos are the ones ultimately working to extinguish the fire. Instead drones can provide important data that can help them extinguish a fire more efficiently. **We recommend that the CRFD focus on informing the public about the potential benefits of using drones in emergencies through the use of posters.** These posters would include the different ways that drones help in emergencies and would be placed on billboards, bus stops, and advertisements in newspapers. These posters can be seen in *Appendix F*. It is up to the CRFD to continue encouraging the public to understand the benefits of drone use and using the media would be an ideal way to do it. Costa Rica has not yet had the opportunity to fully explore drones and the CRFD can be an organization that helps increase awareness on the subject because it has the respect and credentials to raise awareness in Costa Rica about the benefits of using drones. The purpose of the public outreach campaign is to start a positive dialogue and eventually change the social climate around drones heading into the future.

If possible, **we recommend that the CRFD notifies residents in the surrounding area when it is training new pilots.** Ideally, the public outreach will notify enough people that they would assume a drone near an emergency means it is the CRFD. Based on the 30 people who participated in our community survey, only 27% knew that the CRFD was using drones in its operations. José Sosa stated that Costa Ricans have a great respect for firefighters and sometimes they might get wary when seeing a drone in the air. But as soon as they figure out that the CRFD is using the drone, they calm down. By notifying the owners that the CRFD will be using drones, civilians will know it is not a person flying a drone with malicious intent.

Recommendation #3: The CAA should certify a drone training school and help establish geo-barriers to prevent drones from entering restricted areas.

The CAA is waiting for its recommended laws to pass through government, but when the laws are passed, there will not be a formal training program for those looking to fly drones. The CRFD will have a written protocol that they follow to help teach its firefighters how to fly a drone. **We recommend that the CAA certify a school that can use this protocol as a basis on how to teach people to fly.** There are already some schools that train potential pilots but there is

no standardized training and none of the schools are formally recognized by the CAA. The CAA should follow the example of how the Directory of Motor Vehicles (DMV) certifies driving schools in the United States. As Sven Watson said, “It is difficult to learn how to fly a drone because you need to teach yourself how to do it and it requires a lot of attention to detail.” It is the responsibility of the government to make sure potential pilots are properly trained to keep the public safe because drones require focus and practice. It is more difficult for potential pilots to practice flying drones without a formal place or organization to train them, especially because the criteria for the proposed exam are not regularly available. The practical action would be to establish a training program to add structure and order for those aspiring to fly drones.

One of the most important laws the CAA has passed is the no fly zones around airports and certain government buildings. Geo-barriers are programs that are embedded in a drone’s computer that will prevent it from entering areas where it is not allowed. **We recommend that the CAA create geo-barriers to restrict drone flight regions in Costa Rica.** During the licensing process drones will be programmed with local geo-barriers to comply with the standards set by the CAA. By creating these barriers, the CAA can dictate where the drones are able to fly. The United States already has this implemented for the drones purchased in the country. Most of the drones that are purchased in Costa Rica are from the United States, so the existing geo-barriers only work in the U.S. and not in Costa Rica. The geo-barriers will effectively prevent any stray drone from entering restricted airspace or potentially crashing into a plane and make flight much safer. While this may not be directly related to the CRFD, geo-barriers will allow for the safer operations of drones throughout other organizations.

Chapter 6: Conclusion

The Costa Rican Fire Department (CRFD) has recently implemented drones into their fire protection program but has lacked a formal protocol on how effectively use them. Our contact, Ana Maria Ortega, was spearheading this project. Her ultimate goal for the program is to expand it from the four drones it currently has to a drone in every fire truck in Costa Rica. Everyone we interviewed agreed that drones are necessary in the CRFD's operations, creating a need for a protocol that they did not have. Without a protocol, the data that pilots were receiving while handling emergencies may not have been efficient or consistent. To ensure the survival of the program and to improve current procedures, our main deliverable for this project was a protocol. Over the course of our stay in Costa Rica, we interviewed and surveyed fire departments that use drones, bomberos, drone experts, and the general public about their perspectives on drones and their intended use.

Although the effects of implementing a protocol into the CRFD may not be immediately visible, the impact in the future can be very large due to the increased ease of expansion the protocol offers. Although the aim of this project was to improve the operations of the CRFD, more research is needed. Although we previously recommended that the CRFD further its current state of technology by purchasing sturdier and more effective drones, more research must be done on how to improve drones so that they better handle adverse conditions. This further research would include drones with more sensory options as well as increased rain resistance and durability in high-wind scenarios. Because of the limited use planned in the Red Cross and Transit Police, further research would aid in ascertaining more areas in which the employment of drones could be of use. Any company looking to use drones in its operations must analyze its operations to determine feasibility and opportunity. Although the official ratification of regulations and potential implementation of this project are likely not occurring immediately, Frazier Muñoz, the Director of Security Operations of the Civil Aviation Authority, stated, "Drones are coming to revolutionize many processes." Drones have only recently entered into the public eye, but their benefits are being quickly recognized.

Bibliography

Acevedo, M., Bartlett, H., Delareyna, S., Washburn, T. (2015). Regulatory fire inspection program for El Benemerito Cuerpo de Bomberos de Costa Rica, Unidad de Ingenieria, San Jose, Costa Rica. WPI.

Ahrens, M. (November 2013). Brush, Grass, and Forest Fires (NFPA No. USS89).

Alfaro, R., Fernandez, W., & Connell, B. (1999). Detection of the forest fires of april 1997 in guanacaste, costa rica, using GOES-8 images. International Journal of Remote Sensing, 20(6), 1189-1195. doi:10.1080/014311699212948

Allen, L. (2015). Louisville Fire & Rescue using drones to help in firefighting, search missions. Retrieved from http://www.wdrb.com/story/29496576/louisville-fire- and-rescue- using-drones- to-help- in-fire-fighting-search- missions

Apvrille, L., Tanzi, T., & Dugelay, J. (2014). Autonomous drones for assisting rescue services within the context of natural disasters. Paper presented at the General Assembly and Scientific Symposium, Beijing, China. doi:10.1109/URSIGASS.2014.6929384

Atherton, K.D. (2014). Connecticut fire department gets help from a drone. Popular Science. Retrieved from http://www.popsci.com/article/technology/connecticut-fire- department-gets- help-drone

Aviation. (n.d.). Retrieved from http://www.fs.fed.us/fire/aviation/

BBC. (2015) Manchester fire service uses drones to fight blazes. Retrieved from http://www.bbc.com/news/34637892

Berg, B., Lune, H. (2012) Qualitative research methods for social science. Pearson. Print.

Blankenbuehler (2015) Firefighting Drones Could Save Costa Rican Rain Forests. Newsweek. Retrieved from http://www.newsweek.com/2015/04/24/firefighting-drones- could-save- costa-rican- rain-forests-321718.html

Carpenter, S. (2015). Fighting forest fires before they get big- with drones. Wired.

CDC. (n.d.) Developing a protocol. 2-8. Retrieved from http://www.cdc.gov/niosh/nas/mining/pdfs/Protocol%20Checklist.pdf

DJI - The World Leader in Camera Drones/Quadcopters for Aerial Photography. (n.d.). Retrieved from http://www.dji.com/

Doherty, P., & Rudol, P. (2007). A UAV search and rescue scenario with human body detection and geolocalization. Paper. 4830 1-13.

Drone hits small plane over Costa Rica park (November 2015). Retrieved from http://www.ticotimes.net/2015/11/05/drone-hits- plane-costa- rica-park

Dyer, Z. (2015). Local business owners swat at new regulations, fees for drones, The Tico Times.

Retrieved from http://www.ticotimes.net/2015/09/18/buisness-swats- new-regulations- fees-drones

Emergency Response Drone Applications - Doheny Drones. (n.d.). Retrieved from http://www.dohenydrones.com/drones-for- emergency-response

Ethics in Engineering. (n.d.). Retrieved from https://www.asme.org/about-asme/advocacy-government-relations/ethics-in-engineering

FLIR Systems. (n.d.). Retrieved April 28, 2016, from http://www.flir.com/

Gates, D. (2015, August 28). Drone tracks fire hot spots in successful Olympic forest test. Retrieved from http://www.seattletimes.com/business/boeing-aerospace/drone-tracks-fire-hotspots-in-successful-national-park-test/

Hamilton, L. (March 2003). AERIAL FIREFIGHTING SAFETY. Retrieved from https://www.gpo.gov/fdsys/pkg/CHRG-108shrg87175/html/CHRG- 108shrg87175.htm

Hodapp, P. (2015). Search and Rescue Teams Aim to Save Lives with Off-the- Shelf Drones. Make. Retrieved from http://makezine.com/2015/12/15/search-and- rescue-teams- aim-to- save-lives-off-the-shelf-drones

Kashmir, H. (2014). Drone Team That Finds Missing People and Dead Bodies Would Like To Keep Doing That. Forbes. Retrieved from http://www.forbes.com/sites/kashmirhill/2014/04/07/drones-that-find- missing-people- and-dead- bodies-want- freedom-from- faa/#6cc774253448

Make Energy Change Happen Toolkit. Examples of successful criteria, indicators and baselines for different types of projects. Retrieved from: http://webcache.googleusercontent.com/search?q=cache:yu9weklW5ugJ:mechanisms.energychange.info/sites/default/files/examples/examples-success-criteria-indicators-and-baselines-different-types-projects.doc+&cd=1&hl=en&ct=clnk&gl=u

Maine crews use drone to rescue 2 boys from raging river (2015). Associated Press. Retrieved from http://bigstory.ap.org/article/d0117575faeb40e8acdaa7aaca09ca44/maine-crews- use-drone- rescue-2-boys-raging-river

Manchester fire service uses drone to fight blazes - BBC News. (2015). Retrieved from http://www.bbc.com/news/34637892

Plymouth uses drones to survey storm damage (2015). WVCB. Retrieved from http://www.wcvb.com/news/plymouth-uses- drones-to- survey-storm- damage/31040442

Procedure. (n.d.). Retrieved from http://www.merriam-webster.com/dictionary/procedure

Raus, A. (2014). Drone Used to Help Firefighters Fight Dangerous Fire. NBC Connecticut. Retrieved from http://www.nbcconnecticut.com/news/local/Drone-Used- to-Help- Firefighters-Fight-Dangerous-Fire--243022711.html

SAR Drones | UAV Search And Rescue Drones. (n.d.). Retrieved from http://sardrones.org/

Shupe, J. (2013). Its gallons per minute that put the fire out! Retrieved from http:/ www.fireengineering.com/articles/print/volume-166/issue- 10/features/its-gallons- per-minute-that-put-the- fire-out.html

Steimle, S. (2015, February 20). Somerville Officials Using Drones In Effort To Prevent Roof Collapses. Retrieved from http://boston.cbslocal.com/2015/02/20/somerville-officials- using-drones- in-effort- to-prevent-roof- collapses/

Texas Equusearch. (n.d.). Retrieved from http://www.texasequusearch.org/

Wakeham, R., & Griffith, J. Unmanned Aerial Systems in the Fire Service: Concepts and Issues.

Wellman, A. (August 2015). Dad shoots down drone 'spying on his sunbathing daughter' - and is arrested by cops. Retrieved from http://www.mirror.co.uk/news/world-news/dad- shoots-down-drone-spying-6177304

Whyte, S., & Arlington, K. (November 2013). Time to buy air-crane helicopters: Blue Mountains mayor. Retrieved from http://www.smh.com.au/environment/weather/time-to- buy-aircrane- helicopters-blue-mountains-mayor- 20131103-2wuuk.html

Wilson, M. (2015). Illinois City Asks Fire Department to Create Drone Policy | Firefighter Nation. Retrieved from http://www.firerescuemagazine.com/article/news-2/illinois- city-asks- fire-department-create-drone- policy

Appendix A: Electronic Survey Questions for Fire Departments with Drone Programs

We are a group of students from Worcester Polytechnic Institute in Massachusetts. We are conducting surveys with firefighters to learn more about their experiences with drones. Our ultimate goal is to create a protocol for the Costa Rican Fire Department and your insights will be extremely useful.

Your participation in this survey is completely voluntary and you may withdraw at any time. If you would like, we would be happy to include your comments as anonymous, though it would be useful for readers to understand who has made them.

If interested, a copy of our results can be provided at the conclusion of the study. Your participation is greatly appreciated.

Questions:

1. You have been selected to receive this survey because of your notable use of drones in your operations. Does your department still employ the use of drones?
   a. Yes
   b. No
2. Please provide the name of your fire department. If you would like the name of your fire department to remain anonymous, please enter "N/A"
3. If you have used a protocol or specific guidelines when using drones, would you be willing to provide a copy to us by uploading the file? It would be used to develop a set of best practices for drones in the Costa Rican Fire Department.
4. If you have used a protocol, how has the use of the protocol helped or hindered your operations?
5. What kind of drones do you currently and/or have you used in the past?
6. For how long have you used drones?
   a. 0-6 months
   b. 6 month - 1 year
   c. 1-2 years
   d. 2+ years
7. What are the most common types of emergencies you experience in which you use or have used drones? (i.e. forest fires, hazardous materials, residential fires, etc.)
8. What are your biggest equipment needs in these emergencies in relation to the use of drones? (i.e. battery life, types of cameras/sensors, flying distance, etc.)
9. Does the use of drones affect how your organization's manpower is allocated? If so, how?
10. What do you find particularly useful about drones?

11. What were your biggest challenges when you used drones?
12. On average, how long does it take to transport the drones to the site of the emergency?
    a. <15 min
    b. 15 min - 30 min
    c. 30 min - 1 hour
    d. 1+ hour
13. On average, once on site, how long does it take for the drones to be ready for operation?
    a. <1 min
    b. 1 - 5 min
    c. 5 min - 10 min
    d. 10+ min
14. Has weather ever been an issue when attempting to deploy drones? If so, please explain in the box provided below.
    a. No
    b. Yes
15. Which personnel can use the drones in an emergency?
16. Which personnel can call for the use of drones in an emergency?
17. Who took part in forming the protocol? (i.e. department personnel, administrators, etc.)
18. Please rate the following on a scale from 1 (Very Poor) to 10 (Excellent) by selecting the appropriate circle.
    a. Usefulness of data provided by drones
    b. Speed of the drones
    c. Battery life of the drones
    d. Durability of drones
    e. Flying radius of drones
    f. Flexibility of uses for drones
    g. Overall rating of the drones

Appendix B: Electronic Survey Questions for Bomberos and Information Technology Members

We are a group of students from Worcester Polytechnic Institute in Massachusetts. We are conducting surveys with firefighters to learn more about their experiences with drones. Our ultimate goal is to create a protocol for the Costa Rican Fire Department and your insights will be extremely useful.

Your participation in this interview is completely voluntary and you may withdraw at any time. If you would like, we would be happy to include your comments as anonymous, though it would be useful for readers to understand who has made them.

If interested, a copy of our results can be provided at the conclusion of the study. Your participation is greatly appreciated.

Questions:

1. Please provide your name.
2. Are you in the pilot training program?
3. What have your experiences been with drones in the field/in general?
4. Would you choose to use a drone in an emergency? Please explain.
5. Are there certain situations you would you choose to not use them?
6. Has weather been a factor when attempting to use drones? (i.e. wind, rain, solar radiation, etc.)
7. What do you like about using drones? (i.e. the ease of use, effectiveness, etc.)
8. How are drones most useful?
9. Do you feel that they hinder your ability to handle an emergency?
10. What kind of information are you looking for from drone support?
11. How have you used this information to allocate resources?
12. Do you think more sensory options would be beneficial? (i.e. thermal imaging, wind direction/speed, etc.)
13. When you are flying the drone, are you looking predominantly at the screen with the video feed or are you also looking at the drone itself to ensure it will not fly into anything that can damage it?
14. Can you walk us through how you use the drone? Beginning with after you have set up the drone, what is the first thing you look for?
15. How high do you prefer to fly the drone and why? Does it change significantly in different emergency scenarios (between forest fires and brush fires or between structural and traffic incidents)?

16. Is there a specific time of day that you would not use drones? If so, why?
17. Say it begins to rain, what do you do? Do you continue flying or do you return immediately? What techniques would you use to ensure the drone is not damaged?
18. Say the winds become very strong, what would you do? What decision process you use to ensure the drone is not damaged?
19. Say the smoke becomes too thick to see through, what would you do? Would you look for a new spot to gather information from or would you just return?
20. Say the video feed begins to cut out, what would you do?
21. What do you do when you see you have low battery? What if you do not think you are able to return?
22. Is there any other information you feel is important to know when operating the drones? If so, why?
23. Is there anything that you feel the drones are lacking? If so, what?
24. Has the battery life been a concern?
25. Is the flying radius impacted by battery limitations?
26. Has there been a problem with the quality on the camera? If so, in what situations?
27. How has solar radiation impacted your ability to use drones?
28. What are the biggest needs you feel the department has?
29. What are the biggest challenges you feel the department is facing?
30. Is there any other information you would like to share about drones?

Appendix C: Interview Questions for Sven Watson, Terraprecision

We are a group of students from Worcester Polytechnic Institute in Massachusetts. We are conducting this interview to learn more about your experiences with drones. Our ultimate goal is to create a protocol for the Costa Rican Fire Department and your insights will be extremely useful.

Your participation in this interview is completely voluntary and you may withdraw at any time. If you would like, we would be happy to include your comments as anonymous, though it would be useful for readers to understand who has made them.

If interested, a copy of our results can be provided at the conclusion of the study. Your participation is greatly appreciated.

Questions:

1. How many years of experience have you had with drones?
2. What do you primarily use drones for?
3. Why did you start a drone company in Costa Rica?
4. Do you have a protocol for certain procedures for drones?
5. What sensory options do you have for drones?
6. What do you particularly like about drones?
7. Is there anything you dislike about drones?
8. What are your thoughts on the regulations that are trying to be passed through the government?
9. When you are flying the drone, are you looking predominantly at the screen with the video feed or are you also looking at the drone itself to ensure it will not fly into anything that can damage it?
10. Is there a specific time of day that you would not use drones? If so, why?
11. Say it begins to rain, what do you do? Do you continue flying or do you return immediately? What techniques would you use to ensure the drone is not damaged?
12. Say the winds become very strong, what would you do? What decision process you use to ensure the drone is not damaged?
13. Say the video feed begins to cut out, what would you do?
14. What do you do when you see you have low battery? What if you do not think you are able to return?
15. Is there any other information you feel is important to know when operating the drones? If so, why?
16. Is there anything that you feel the drones are lacking? If so, what?

17. Has the battery life been a concern?
18. Is the flying radius impacted by battery limitations?
19. Has there been a problem with the quality on the camera? If so, in what situations?
20. How has solar radiation impacted your ability to use drones?
21. How do you interpret the information you receive from the drone?

Appendix D: Interview Questions for Frazier Muñoz, the Civil Aviation Authority

We are a group of students from Worcester Polytechnic Institute in Massachusetts. We are conducting this interview to learn more about your experiences with drones. Our ultimate goal is to create a protocol for the Costa Rican Fire Department and your insights will be extremely useful.

Your participation in this interview is completely voluntary and you may withdraw at any time. If you would like, we would be happy to include your comments as anonymous, though it would be useful for readers to understand who has made them.

If interested, a copy of our results can be provided at the conclusion of the study. Your participation is greatly appreciated.

Questions:

1. Where is the CAA right now in terms of the regulatory process?
2. Are there any obstacles that you have faced? If so, what are they?
3. How have you overcome these obstacles?
4. What is the end goal for the regulation program? How long do you think that will take?
5. How will you enforce these regulations?

Appendix E: Interview Questions for General Public

We are a group of students from the United States studying at Worcester Polytechnic Institute in Massachusetts. We are working with the Costa Rican Fire Department to create a protocol and your insights will be extremely useful. Your participation in this interview is completely voluntary and you may withdraw at any time. If interested, a copy of our results can be provided at the conclusion of the study. Your participation is greatly appreciated.

Questions:

1. Do you know what drones are?
2. How do you feel about drones?
3. Do you think drones pose any privacy concerns?
4. Do you know that the CRFD is using drones?

Appendix F: Posters to Increase Awareness about the CRFD Using Drones

These posters are meant to be displayed in public areas, such as on billboards and at bus stops, as well as in newspapers as a means of raise awareness about the Costa Rican Fire Department using drones in its emergency operations.

Figure 8. Traffic Incident poster. Graphics by Oliver Simon.

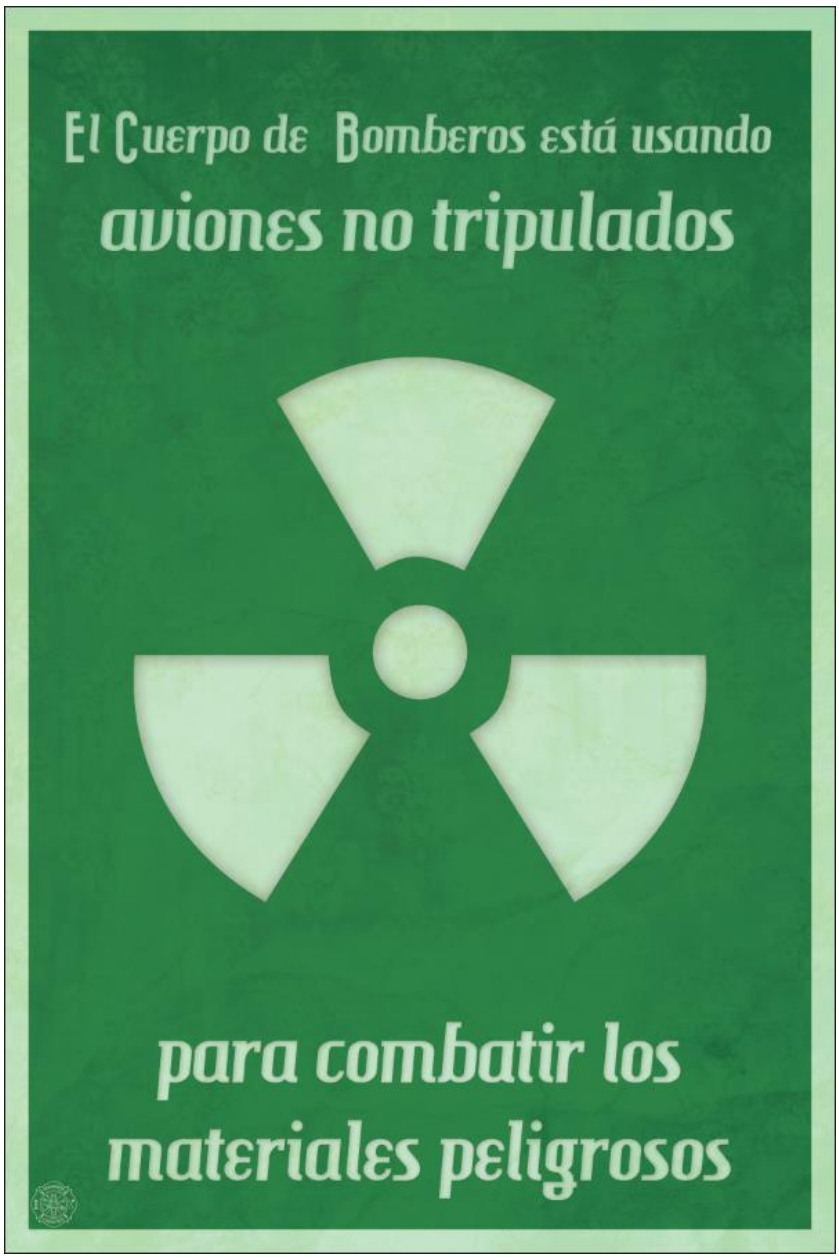

Figure 9. Hazardous Materials Incident Poster. Graphics by Oliver Simon.

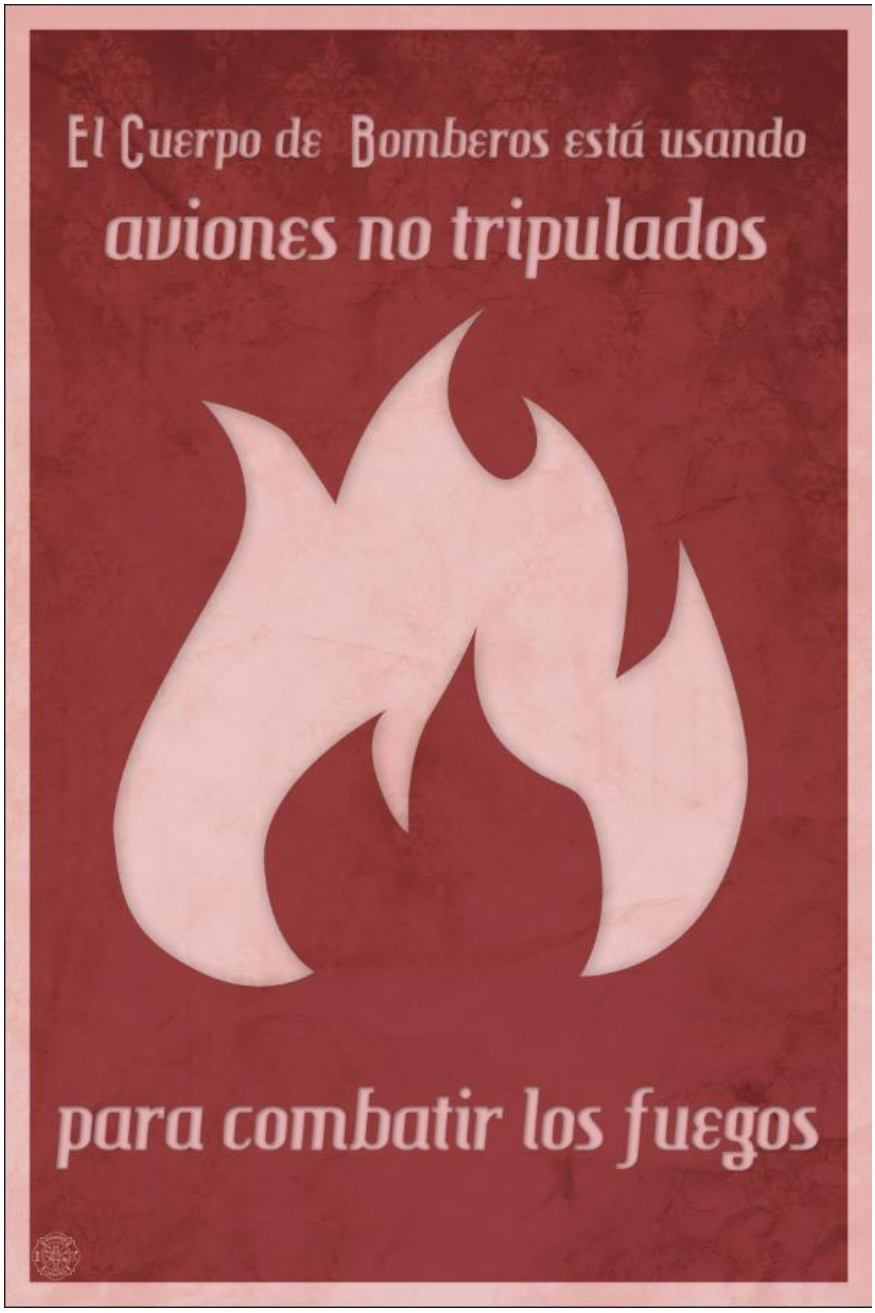

Figure 10. Fire poster. Graphics by Oliver Simon.

Appendix G: Costa Rican Fire Department Drone Program Protocol

The protocol was our main deliverable for the Costa Rican Fire Department was a written document outlining the operations of their drone protocol. Please see next page for the protocol.

El BENEMÉRITO CUERPO DE BOMBEROS DE COSTA RICA

GUIDELINES FOR EMERGENCY DRONES IN FIRE SETTINGS

Year 2016

ELABOARDO POR:	REVISADO POR:
Joseph Alvarado, Tara Sharp, Samuel Sierra, Oliver Simon	Ana-Maria Ortega

Table of Contents

I. Introduction

Drone technology is becoming more readily applicable in emergency situations. Drones can be a useful tool for el Benemérito Cuerpo de Bomberos because of their various capabilities.

The purpose of this protocol is to provide guidance on how to effectively use drones in order to acquire data during fire emergencies. Through this protocol, information gathered through the use of drones will be considered in order to carry out the best plan of action for firefighters. Local factors such as anticipated drone response time, the availability of trained personnel to operate the drone, and urgency of the emergency will be considered to determine a course of action. This protocol will detail the basics of how to use a drone, but it is important to use these directions at your own discretion as nothing can replace the real life experiences of a bombero.

II. Mission

To utilize drones effectively during emergencies by acquiring reliable data to make educated decisions. Prospective drone pilots should analyze this protocol and have hands on training to completely understand the responsibilities of using a drone.

III. Vision

The goal is to create a drone program that can be utilized throughout all fire departments in Costa Rica. The way that drones are used will differ between provinces, but it is important to understand the basics of drones first. Our drone program will expand as drones become more prominent, therefore it is important to begin with a structured program. With this protocol, we will hope that it will be easier to train others and expand the program.

IV. Principles

As stated previously, operators must demonstrate an understanding and responsibility when handling drones. Not only is the equipment very fragile and expensive, but the operator must also be aware of his surroundings as his decisions affect the lives of bomberos.

4.1 Legality

As of May 2016, the only law that is currently enforced is that a drone is not permitted to enter the airspace within an *8 km* radius of any Costa Rican airport. However, there are many recommendations the Civil Aviation Authority has regarding drones. The full list can be seen in Appendix B: Regulations, however these recommendations are currently under consideration to be passed into law. Therefore, the procedures outlined in this drone program will strictly follow the current recommendations.

4.2 Structure

This protocol was designed to provide structure to the drone program. Drones have recently become available for public use, so there is not a lot of literature or information about them yet. This protocol was created to educate our employees about the use of drones in emergency scenarios.

4.3 Effectiveness

El Benemérito Cuerpo de Bomberos is always improving its operations and drones address an important issue the bomberos face. Drones are very useful for surveillance and data acquisition from a new point of view. This will greatly help our bomberos make educated decision with this new line of sight.

4.4 Efficiency

Drones have been implemented in our fire mitigation program because the data captured by the drones will help us make informed decisions. This data will improve efficiency in our operations as we will now be able to interpret situations in ways we could not before.

4.5 Ethics:

There are several ethical issues regarding the use of drones. It is crucial that drone operators only use the drone for the purpose for which they were acquired. Bomberos are held to the highest integrity and it is imperative that we apply that same integrity when using drones. Drones are a new technology and it is important that we do not allow society to develop reservations about the positive impact this technology can have on our lives.

V. GLOSSARY

Brush fire: A brush fire is similar to a forest fire but on a much smaller scale. These kinds of fires happen in open patches of grass throughout a plain.

Buffer: A strip of land that has been cleared or plowed to prevent a fire from spreading to remove the fuel source.

Drone: An unmanned aerial vehicle controlled by a remote pilot.

Fire Line: The line of flame that separates the land that is already burnt and the land that is not.

Forest fire: A forest fire is an uncontrolled fire occurring in largely wooded areas. This kind of fire is usually larger in nature and occur in heavily wooded areas.

Hazardous Material: Any material that is an air- or water-reactive, flammable, combustible, corrosive, explosive, radioactive, toxic, unstable, biological in solid, liquid, or gas form that if mixed with any substance or mixture becomes an irritant, strong sanitizer, generates pressure through exposure to heat, decomposition, or other means.

High risk area: An area where an emergency can escalate quickly. This is based on how containable the situation is and how congested a living space may be.

Hot Spot: Areas where there may not be visible flame but might still be burning underneath.

Low risk area: An area where and emergency can easily be contained.

Remote Sensing: Remote Sensing is used as a safety measure to determine high and low risk spots of an area in danger of a fire before an incident occurs. It is also used after incident to report statistics, such as area lost to a fire, to the correct parties.

Structural fire: A structure fire is one involving the structural components of various types of residential, commercial or industrial buildings. Residential buildings range from single-family detached homes and townhouses to apartments and tower blocks, various commercial buildings ranging from offices to shopping malls, and industrial buildings range from machine shops to factories.

Traffic Incident: Traffic incidents are events such as traffic crashes, disabled vehicles, spilled cargo, highway maintenance, and reconstruction projects, and special non-emergency events.

VI. DEFINITION OF EMERGENCY DRONE KIT

All emergency drones and supplies should be kept together in a secured kit that is easily moveable and readily accessible during the hours of day when drone usage is most effective. Drone equipment should be checked bi-weekly by a drone pilot with careful attention to moving parts and condition of equipment.

Emergency drone kits are the supplies needed to set up and use the drone. They must be handled with care at all times as the equipment is very fragile. The kits must meet the following requirements to ensure a time efficient means of setting up the drone.

1. Storage of Drone Kit

Emergency drone kits should be stored onboard a vehicle ready to use at an emergency. The kits should also have foam insulation to insure a proper environment for preservation of the supplies in them.

2. Labeling – Exterior of Drone Kit

The exterior of emergency drone kit will be labeled clearly so that it will unmistakably indicate that it is an emergency drone kit and is for use in emergencies and testing only.

3. Labeling – Interior of Drone Kit

All supplies contained within emergency drone kits will be labeled in accordance with the name of the part and what assembly it should be a part of.

4. Removal of Supplies from Drone Kit

Supplies and parts will be removed from emergency drone kits only for the purposes of emergency, testing, repair, or inspection.

5. Inspections of Drone Kit

- Each emergency drone kit will be opened and have its content inspected by the personnel trained to operate the drone. Bi-weekly inspection will be documented on a check-off log sheet which includes:
    - The listing of all supplies and equipment
    - The condition of all supplies and equipment
    - The personnel's name who performed the inspection
    - The inspection date
- Upon completion of the inspection, the emergency kit shall be placed in the appropriate storage location on a fire response vehicle

6. Supplies and Equipment in Drone Kit

- Drone Case
    - Drone
    - Propellers for each of the drone's 4 motors
    - Spare Batteries
    - Mountable Camera (DJI Inspire 2)
    - Drone Controller and Stand
- Miscellaneous Equipment Case
    - Viewing Device (iPad/Tablet)
    - USB cable
    - Charging cables for viewing devices and drone batteries
    - Solar powered charging pad
    - Camera

Refer to *Appendix A* for images of cases.

VII. PROCEDURE ON PROPER SETUP OF DRONES

7.1 EFFECTIVE DRONE FLIGHT RECOMMENDATIONS

- There should be **two** drone operators, the pilot, who is focused on the screen displaying the live video feed from drone, and the spotter, who is focused on where the drone is in the sky.
- Drone pilots should know how to maneuver drones before emergencies so it is recommended they have had at least 30 hours of flight experience before using the drone in an emergency. 20 hours should be spent learning how to pilot and 10 hours should be spent learning how to spot.
- Always keep the drone level, whether in the air or on the ground, to prevent damage to the equipment and to take accurate readings.
- Always make sure you know where the bomberos are in relation to the drone. It is your responsibility to ensure bombero safety given the perspective the drone allows.
- Have at least 4 charged spare batteries for the drone in its case, in the event the scenario lasts a long period of time. Typically the battery will last around 17 to 20 minutes.
- To preserve the drone and the life of the battery, return from flight if battery falls to 20%.
- Land the drone on a blanket or tarp on the ground. Do not grab it from the air.
- Clean all equipment with a disinfectant wipe after each use (Refer to *Figure 2*).
- Check and charge all batteries after disassembling drones.
- Ensure all controllers and drones are powered down prior to storage.
- When first arriving on scene, ask the incident commander what information is a priority.
- Use an application on your phone to view the UV index and determine if you are able to fly the drone.
- The flight recommendations from the DJI Drone Manual can be seen in *Figure 1*.

(1) Before your first flight, please allow yourself some flight training (Using a flight simulator to practice flying, getting instruction from an experienced person, etc.).

(2) DO NOT fly in bad weather, such as rain or wind (more than moderate breeze) or fog.

(3) The flying field should be open and void of tall buildings or other obstacles; the steel structure within buildings may interfere with the compass.

(4) Keep the aircraft away from obstacles, crowds, power lines, trees, lakes and rivers etc.

(5) Try to avoid interference between the remote controller and other wireless equipment. (No base stations or cell towers around)

(6) The flight control system will not work properly at the South Pole or North Pole.

(7) All parts must be kept out of the reach of children to avoid CHOKING HAZARDS; if a child has accidentally swallowed any part, you should seek immediate medical assistance.

Figure 1. Flight recommendations from the DJI Drone Manual

Figure 2. Proper cleaning of equipment

7.2 CONSTRAINTS

- UV index of 1-3: can fly
- UV Index of 4: at your own discretion
- UV Index of 5+: cannot use
- Cannot be flown with wind speeds in excess of 40 km/h
- Battery Life of approximately 20 mins
- Cannot be flown in rain
- Cannot be flown after dusk

For a quick reference, refer to *Figure 6* below.

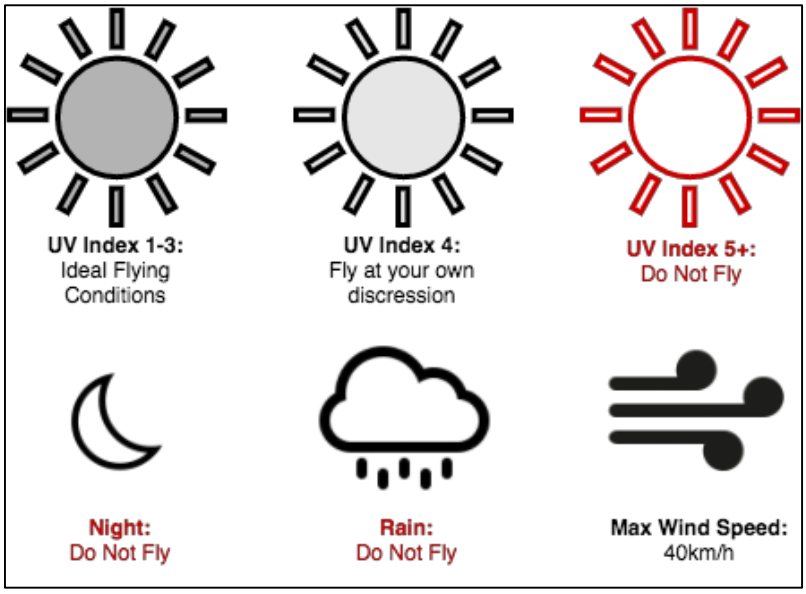

Figure 6. Adverse conditions affecting drone use

7.3 SET UP/CALIBRATION

1. Carefully remove drone from case
2. Place drone on level ground
3. Remove camera from case (DJI Inspire 2)
4. Place camera under front nose of drone and lock into place
5. Remove blades from case
6. Match the color on top of the blades (grey/black) to the color on the drone's screws (if applicable)
7. Rotate the blades counterclockwise to screw onto drone
8. Rotate the mount below the screw clockwise to lock blades in place
9. Remove light and fixture from case (DJI Inspire 2)
10. Place light on rear of drone and lock into place
11. Remove controller from case
12. Remove viewing device from case (iPad/iPhone)
13. Place viewing device on controller stand and lock in place using the clip
14. Connect the viewing device to the controller using a USB cable
15. Place drone on a blanket/tarp in an open and level area clear of debris
16. Turn on the drone, then the controller, and finally the viewing device
17. On the viewing device select calibrate
18. Pick up drone with the blades facing the sky and hold horizontally at arm's length from chest
19. Turn around until two lights under the arms holding the blades turn green
20. Turn the device so the blades face outward and hold horizontally at an arm's length from chest
21. Turn around until the two lights under the arms holding the blades turn yellow
22. Place drone on ground clear of debris

Refer to *Appendix B* for select images of drone set up.

VIII. PROCEDURE OUTLINE

It is important to note that this protocol will not be able to outline every problem you may encounter during an emergency and that you are not bound to follow the protocol as written. Nothing will replace the intuition of a bombero, although this protocol was meant to help train bomberos who are new to using drones.

The following procedures will be outlined in the manner illustrated below. Each assessment will have a corresponding action labeled with the same number. For example, searching for signs of collapse is the first assessment in *Structural Fires*. If you observe signs of collapse with the drone, you will then proceed to Action 1 and follow the instructions from there. After that action is accomplished you will want to proceed to Assessment 2 and move on to action 2. Repeat as necessary.

Cause

The cause will outline the common reasons the emergency has occurred. This may be valuable information for the bomberos handling the emergency and also for statistical analysis.

Plan

The plan is the basic ideas you should have in mind as soon as you arrive onto the emergency. This will tell you how to position the drone in the air in order to properly assess the situation and also the goals you should accomplish during the emergency.

Assessment

The assessment relates to the actions of the drones while they are in the air. This part outlines what you should be actively searching for with the drone. If you spot one of the assessments, move onto the corresponding action.

Action

The action corresponds with the assessment of the same number. Follow the actions as instructed. Remember, this protocol is not binding, if you feel that the drone or lives are at risk, take appropriate action to protect either.

Flowchart

This will be a visual representation of the step by step process to guide you through making decisions. It is important to read the literature before an emergency to have a better understanding of the situations at hand.

IX. GUIDELINES FOR BRUSH AND FOREST FIRES

CAUSE

Brush fires occur when an ignition source causes shrubs, grass or twigs to ignite and is generally small and easily contained. Forest fires occur when an ignition source causes a condensed amount of trees to ignite and are much more difficult to contain. These types of fires can be caused by both natural and human causes. During the dry season, it is much easier for dry grass to catch on fire. Many forest fires are also started by citizens who leave fires unattended or may have improperly discarded a cigarette. There are also poachers starting fires as a distraction or as revenge.

PLAN

Fly *50 meters* from the ground relative to the controller. Travel higher if necessary to obtain a larger picture, but do not exceed *400 feet (120 meters*). Next, aim the camera of the drone towards the fire and begin recording. The objective is to contain the fire and protect as much land as possible.

ASSESSMENT

1. Take note of the position and direction of the fire
2. Look for aspects of the landscape that may be useful
3. Take note of any property or roads that may be in the area
4. Take note of the position of the bomberos relative to the fire

ACTION

1. Determine the position and direction of the fire. Observe in which direction the wind is blowing and any living spaces in proximity to the fire. Relay this location to bomberos through radio and instruct them to create a buffer by clearing brush *25 meters* from the head of the fire to contain it.
2. Use the drone to identify any aspect of the landscape that could be of help, such as bodies of water. Keep the drone level and scan a *100 meter* radius from the controller. For example, if the fire is close a river, use the wind to direct the fire toward the water or use the water to fight the fire. If necessary, instruct bomberos to establish a buffer *25 meters*.
3. If there are living spaces in the vicinity, prioritize these areas as lives may be at risk. Instruct bomberos to create a buffer *25 meters* from the head of the fire.
4. If the bomberos are at risk, alert them as soon as possible with details posing the threat. This could include changing wind direction or wildlife. If conditions change, bomberos need to determine a new plan of action to extinguish the fire.

FLOWCHART FOR FOREST AND BRUSH FIRE PROCEDURES

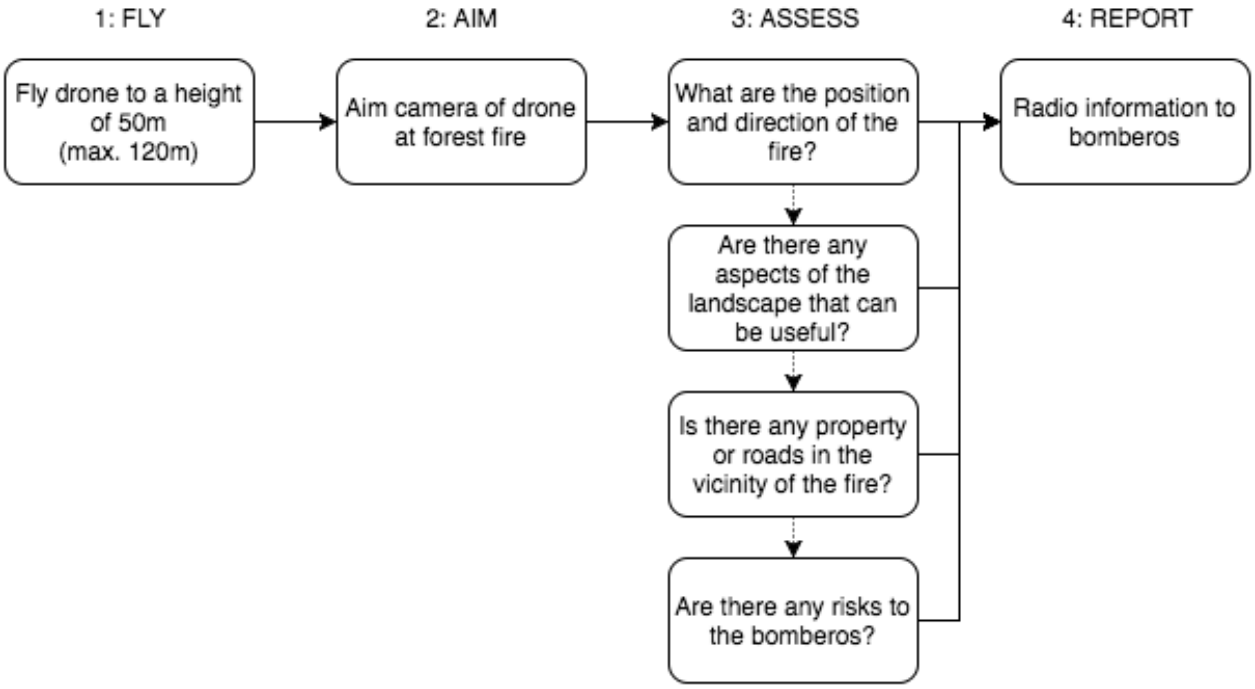

Figure 7. Flowchart to follow during a brush or forest fire

X. GUIDELINES FOR STRUCTURAL FIRES

CAUSE

Structural fires are generally caused by electrical issues or pre-lit fires. Residential homes do not have suppression systems and the loss of life and property is greater than a commercial building. The NFPA defines five types of structures made from different materials which display varying signs of failure. The building types are defined below in *Table 1*.

Type **I**: Fire Resistive	Construction with limited-combustible materials. The material comprising the structure is either inherently able to withstand significant exposure to fire, or in which a fire resistive covering is applied to structural members. Generally concrete and protected steel.
Type **II**: Non-combustible	Construction with non-combustible materials. Walls reinforced with masonry or roofs reinforced with metal structures.
Type **III**: Ordinary construction	Exterior walls and structural elements constructed with non-combustible or limited-combustible materials. Typically unenforced masonry with wood roofs.
Type **IV**: Heavy Timber	Interior structural elements constructed with approved non-combustible or limited-combustible materials. Typically made of solid or laminated wood.
Type **V**: Wood frame	Structural elements are entirely or partially constructed with wood material.

Table 1. Five Building Construction Types

PLAN

Fly *10 meters* above the building. Travel higher if necessary to obtain a larger picture, but do not exceed *400 feet (120 meters*). Next, aim the camera of the drone towards the fire and begin recording. The objective is to ensure the area is evacuated and then work to save the property.

ASSESSMENT

1. Assess building for signs of collapse
2. Take note of habitants, if any, in the building
3. Take note of other living spaces in proximity to the fire
4. Analyze the inside of the building for hot spots (Only applicable if drone has thermal lens)

ACTION

1. At a distance of *10 meters* from the side of the building, take two laps around the top of the building at a 45 degree angle to observe the roof and sides for signs of collapse. If there are signs of collapse, evacuate the building and the immediate areas around the building of personnel. The following are signs of collapse that affect all types of construction:
    1. Visually deformed roof steel
    2. Cracked or split wood members, walls, welds of steel construction
    3. Bends or ripples in metal supports
    4. Doors or windows are difficult to open or pop open
    5. Creaking, crackling, or popping sounds
2. If bomberos mention that there are or there is uncertainty about habitants still inside the building, fly the drone to a distance of *5 meters* from the side of building and slowly scan the windows to see if habitants are trapped. If you find a habitant, relay the information about the location and include the side of the building, floor number, and location from the closest corner to a bombero.
3. At a distance of *10 meters* from the side of the building, scan the surroundings buildings to see if there is risk for the fire to spread. Observe which directions of the wind and the flame. If there is an indication that the flames will spread, relay this information to the bomberos.
4. If the drone has thermal imaging capabilities, fly the drone to distance of *5 meters* from the side of building and slowly scan the windows to find hot spots. If you find a hot spot, relay the information about the location and include the side of the building, floor number, and location from the closest corner to a bombero.

FLOWCHART FOR STRUCTURE FIRE PROCEDURES

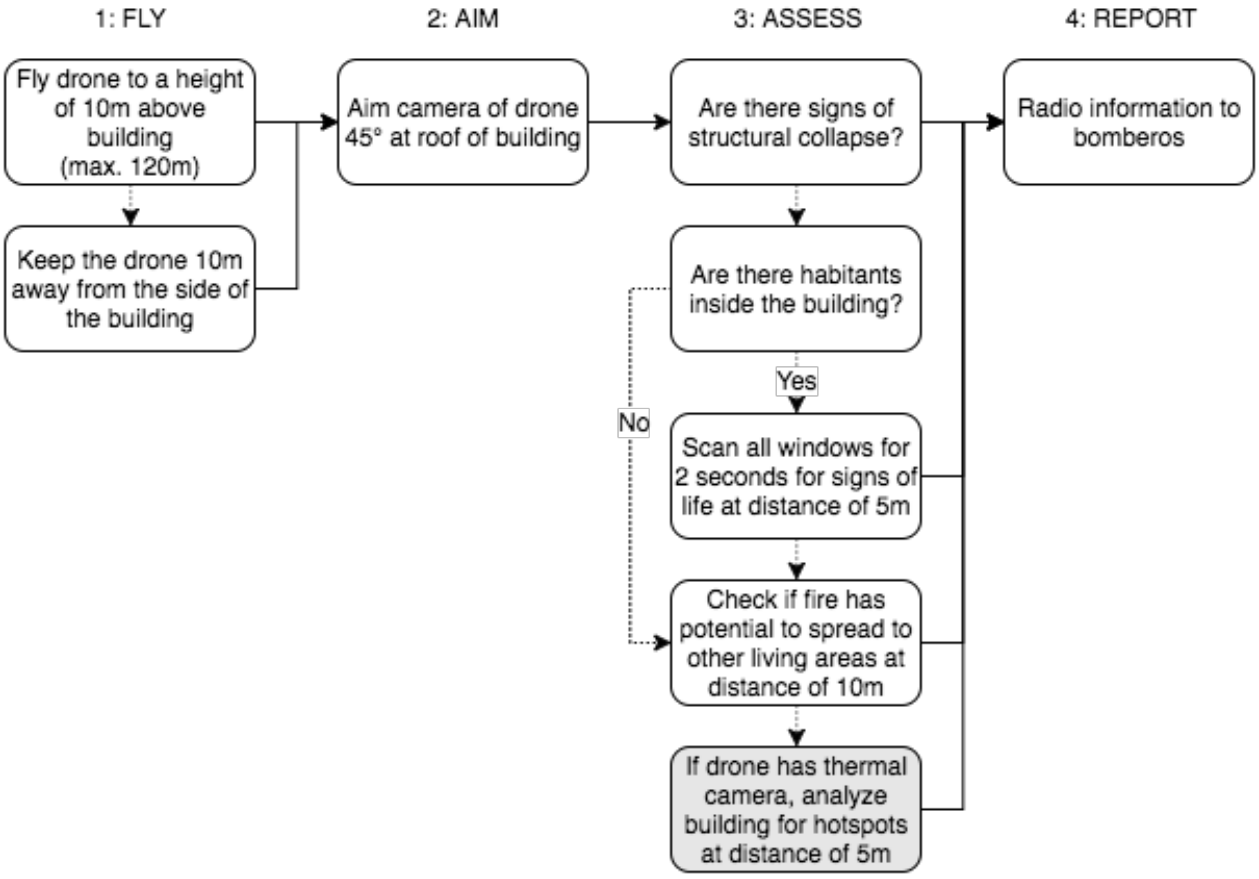

Figure 8. Flowchart to follow during a structure fire

XI. GUIDELINES FOR HAZARDOUS MATERIALS

CAUSE

Hazardous materials incidents often occur while materials are being transported to users. These incidents involve tankers, barges, pipelines, refineries, and storage facilities. Other causes include human or mechanical error, natural disasters, vandalism, or illegal dumpers.

PLAN

Fly at the recommended height from the ground relative to the controller depending on the assessment. Next, aim the camera of the drone towards the incident and begin recording. The objective is to establish a perimeter and begin localizing the hazardous material.

ASSESSMENT

1. Ensure the area is evacuated
2. Locate the hazardous material
3. Observe the bomberos handling the incident

ACTION

1. If the bomberos are uncertain that there are still people in the area, fly the drone *30 meters* from the ground relative to the controller and slowly scan a *100 meter* radius form the controller for people within the established perimeter. If you find a person, relay the information about their location to a bombero.
2. After ensuring the area has been evacuated, fly the drone *15 meters* from the ground relative to the controller and to locate the hazardous material. Scan a *50 meter* radius relative to the controller for the material.
3. Fly the drone *15 meters* from the ground relative to the controller. Observe the surroundings and the bomberos handling the situation. If there is anything that can cause the material to ignite or explode, inform the bomberos handling the incident.

FLOWCHART FOR HAZARDOUS MATERIAL INCIDENT PROCEDURES

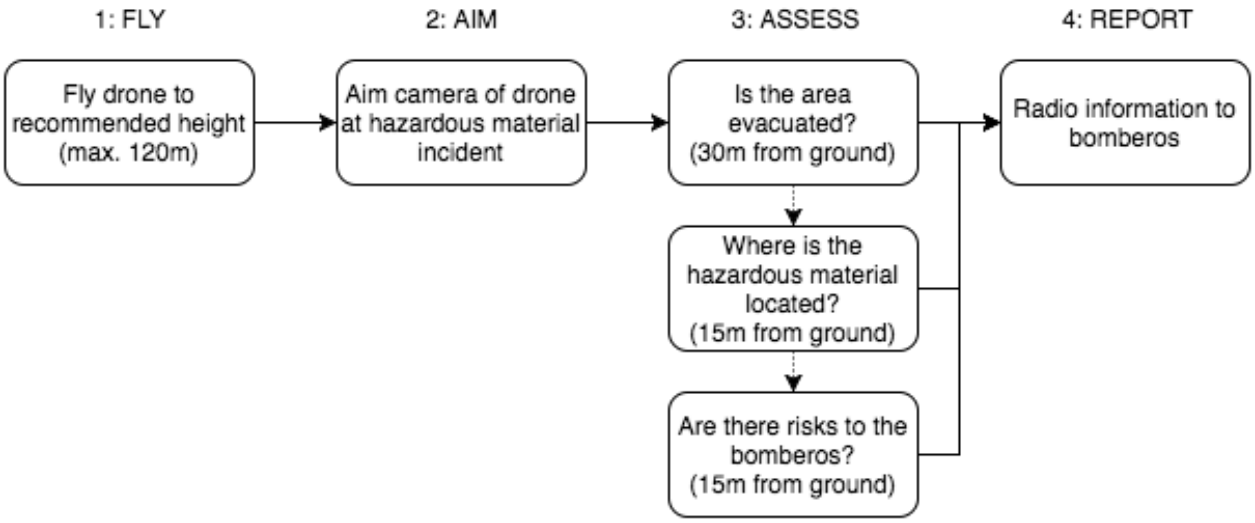

Figure 9. Flowchart to follow during a hazardous materials incident

XII. GUIDELINES FOR TRAFFIC INCIDENTS

CAUSE

Traffic incidents are usually caused by human or mechanical error (e.g. distracted driving or brake failure).

PLAN

Fly *15 meters* from the ground relative to the controller. Next, aim the camera of the drone towards the incident and begin recording. The objective is to evaluate the entirety of the incident.

ASSESSMENT

1. Scan the area for hazardous materials
2. Scan the area for fire
3. Scan the area for victims
4. Use the drone to help direct traffic

ACTION

1. If it is believed that there is a hazardous material, please refer to Section VIII of this protocol.
2. Slowly scan a *30 meter* radius from the incident for any vehicles on fire. If you find a fire, relay the location to bomberos.
3. Slowly scan a *30 meter* radius from the incident for victims trapped in or ejected from a vehicle. If there is a victim trapped, relay their location to the bomberos for removal. If a victim is ejected, contact the Red Cross or medical services for medical care.
4. Slowly scan a *30 meter* radius from the controller to see if there is congestion on the road. If possible, find an alternate route and instruct bomberos to redirect traffic while others handle the situation or clean up on scene.

FLOWCHART FOR TRAFFIC INCIDENT PROCEDURES

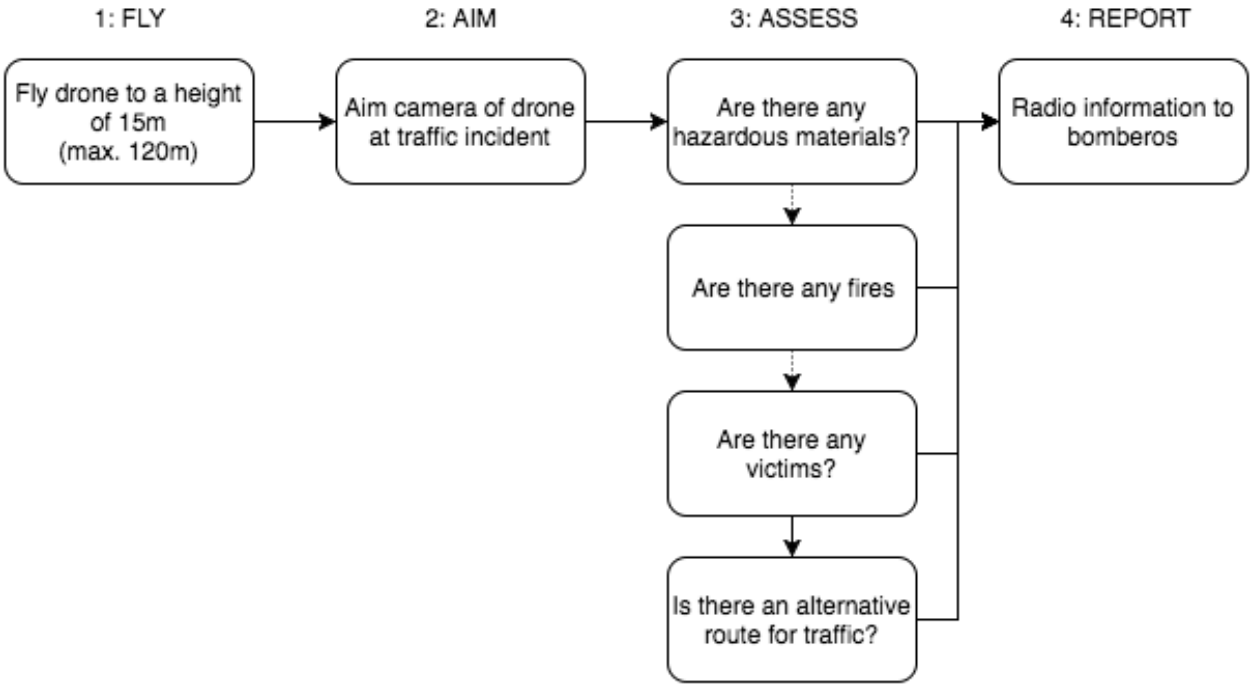

Figure 10. Flowchart to follow during a traffic incident

XIII. GUIDELINES FOR REMOTE SENSING

CAUSE

This operation can be premeditative to prevent fires, used to gather statistics after a fire, or used to enforce codes.

PLAN

Fly at the recommended height from the ground relative to the controller depending on the assessment. Next, aim the camera of the drone towards the ground or building and begin recording. The objective is to take pictures of a large area to combine into one large image to assess risk, gather statistics, or enforce codes.

ASSESSMENT

1. Determine area for assessment
2. Map a large area
3. Scan a building
4. Evaluate ways to mitigate risk

ACTION

1. Determine an area for assessment by evaluating certain neighborhoods that are deemed high risk areas due to the conditions of the living spaces or buildings that need external inspections as a part of enforcing codes.
2. Fly the drone *100 meters* from the ground relative to the controller. Slowly scan a *300 meter* radius from the controller, or the desired area, and continuously take pictures.
3. At a distance of *5 meters* from the side of the building, slowly scan each side of the building vertically.
4. Upload all photos to a computer program to create an overall image of the area. If determining high risk areas, observe the overall image and create a plan of action in case of an emergency. If an incident has already occurred, use the overall image to determine the area lost due to fires for use in statistics and reports. Refer to *Figure 12* so an image of the software. After scanning a building, play back to video to ensure that all codes are met.

FLOWCHART FOR REMOTE SENSING PROCEDURES

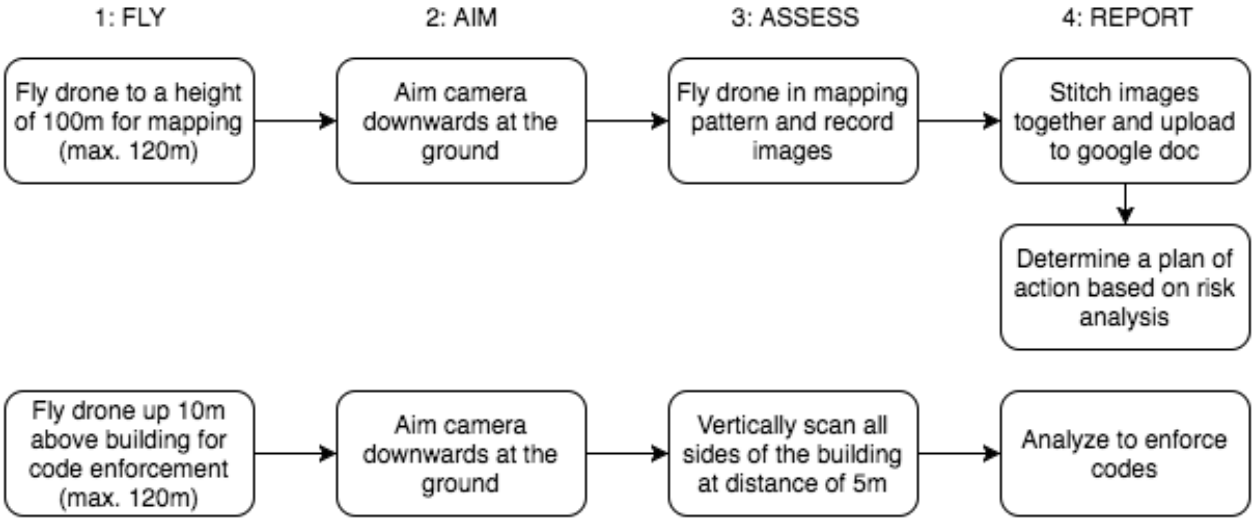

Figure 11. Flowchart to follow during a remote sensing

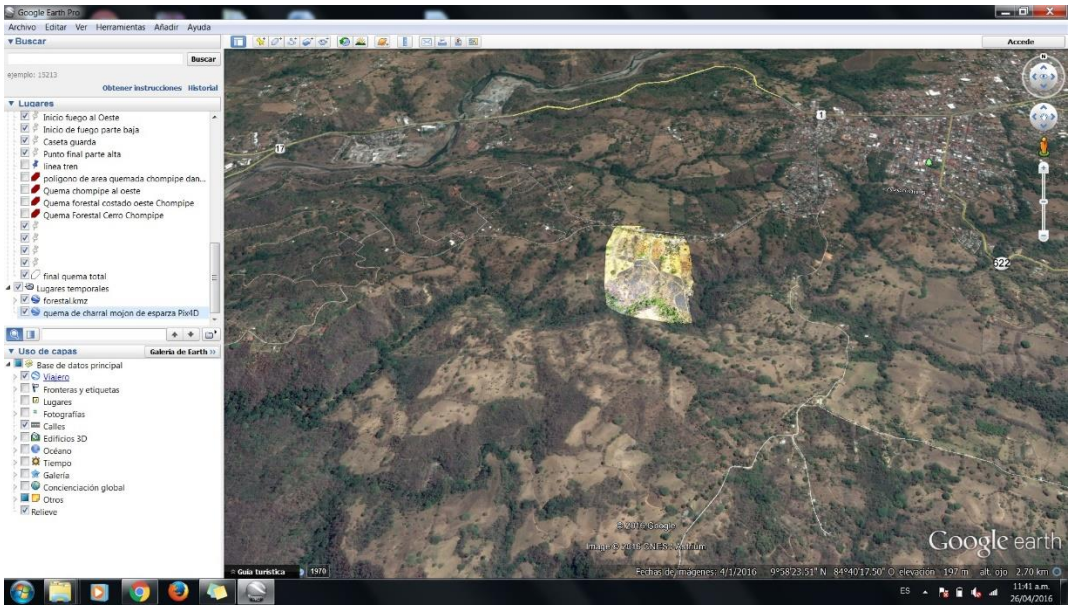

Figure 12. Image of the software used after a fire to determine statistics of area lost

XIV. APPENDIX A. IMAGES OF DRONE CASES

Image 1. Drone Case containing the DJI Inspire 2 drone

Image 2. Drone case containing the DJI Phantom 3 drone

Image 3. Miscellaneous Equipment Case

XV. APPENDIX B. IMAGES OF PROPER SET UP

This appendix demonstrates the steps to properly set up the DJI Inspire 2 drone.

Image 1. Step 2: Place drone on ground

Image 2. Step 4: Place camera under front nose of drone and lock into place

Image 3. Steps 7 and 8: Fastening blades to the drone

Image 4. Step 9: Place light on rear of drone and fasten in place

Image 5. Step 13: Place viewing device on controller stand and lock into place using clips