Societal Issue: Disaster Worker Safety

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Team 9

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Executive Summary Page:

Elevator Pitch:

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Executive Summary:

The purpose of this report is to help identify the problem of disaster worker safety and to provide possible solutions. Natural and unnatural disasters are a reality of this world and there are specialized teams and groups whose sole purpose is to respond to these disasters and assist in any way they can. Different types of disasters require different types of search and rescue operations and some natural disasters occur more frequently than others which leads to them needing more attention. Wildfires, for example, require a ground search where as a flood or tsunami will benefit more from an air search. In order for disaster workers to carry out their missions they will need equipment to assist them so that they do not come to harm themselves. Firefighters, for example, need fire retardant clothing and respiratory equipment and air ops require much more sophisticated machinery.

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***Abstract*— Search and Rescue Workers, Disaster Relief Workers, and Firefighters are all typically put into highly dangerous situations which prevents them from helping victims as thoroughly as they would otherwise like to. This document is a study into the growing rates of both natural and unnatural disasters with the emphasis on understanding the dangers rescuers are placed into and what measures can be taken to prevent bodily harm to both rescuers and victims.**

***Keywords*— Search and Rescue (SAR) , Crisis Management, Disaster Management, Aerial Drones, Quadruped, Navigation, Lidar, Robot Sensing System, Path Planning, Teleoperation Control**

***Elevator Pitch*— We are designing the control and power systems for a robotic quadruped that will be able to operate semi-autonomously to aid in search and rescue operations.**

I. Introduction

This document studies the current situations in Disaster Relief and S.A.R. efforts around the globe and attempts to find areas where improvements can be made based on existing models and what is achievable and economical. Several branches of SAR Robotics were studied, these were sorted into Aerial, Ground, and Marine. Furthermore, these categories were divided into disaster relief, search and rescue, firefighting, and crisis management.

II. Natural/Non-Natural Disaster Statistics

This section presents all of the necessary statistics regarding the amount of disasters that occur throughout the world, indicating that there is a problem.

A. Wildfires

This subsection provides numerous statistical data sets regarding wildfires.

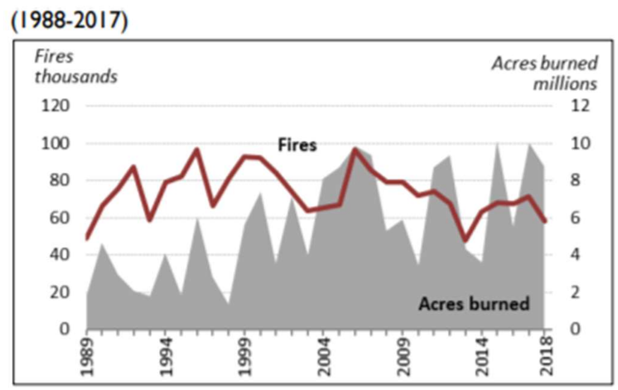


Figure 1: Number of wildfires and acres burned in the U.S. from 1988 to 2017. Reprinted from “Wildfire Statistics.”
Source: Hoover, Katie, and Laura A Hanson. “Wildfire Statistics.” *Fas.org*, Congressional Research Service, 3 Sept. 2019, fas.org/sgp/crs/misc/IF10244.pdf.

	2014	2015	2016	2017	2018
Number of Fires (thousands)					
Federal	13.0	13.8	12.6	15.2	12.5
FS	*6.8*	*7.1*	*5.7*	*6.6*	*5.6*
DOI	*6.1*	*6.6*	*6.8*	*7.3*	*7.0*
Nonfederal	50.6	54.4	55.2	56.4	45.6
Total	**63.6**	**68.2**	**67.7**	**71.5**	**58.1**
Acres Burned (millions)					
Federal	2.15	7.41	3.00	6.3	4.6
FS	*0.87*	*1.92*	*1.25*	*2.9*	*2.3*
DOI	*1.24*	*5.47*	*1.70*	*3.3*	*2.3*
Nonfederal	1.4	2.72	2.51	3.7	4.1
Total	**3.60**	**10.13**	**5.51**	**10.0**	**8.8**

Figure 2: Table format of Fig. 1. Forest Service (FS) and Department of Interior (DOI).
Source: Hoover, Katie, and Laura A Hanson. “Wildfire Statistics.” *Fas.org*, Congressional

Research Service, 3 Sept. 2019, fas.org/sgp/crs/misc/IF10244.pdf.

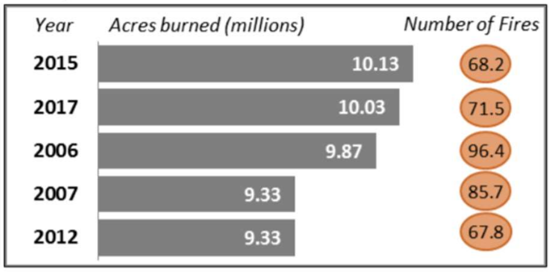


Figure 3: Top five years with the largest number of acres burned since 1960 in U.S.
Source: Hoover, Katie, and Laura A Hanson. "Wildfire Statistics." *Fas.org*, Congressional Research Service, 3 Sept. 2019, fas.org/sgp/crs/misc/IF10244.pdf.

	2015	2016	2017	2018
Personnel				
FS Firefighters	10,000	10,000	10,000	10,000
DOI Firefighters	3,997	4,129	4,514	4,492
Losses				
Firefighter Fatalities	13	12	14	19
Structures Burned	4,636	4,312	12,306	25,790

Figure 4: Number of personnel and losses for FS and DOI
Source: Hoover, Katie, and Laura A Hanson. "Wildfire Statistics." *Fas.org*, Congressional Research Service, 3 Sept. 2019, fas.org/sgp/crs/misc/IF10244.pdf.

Up to this point, all of the data represented occurs within the U.S. but wildfires are an issues experienced worldwide. Fig. 5 shows the 2017 wildfire mapping of the burned and unburned areas of Pedrógão Grande, located in Portugal.

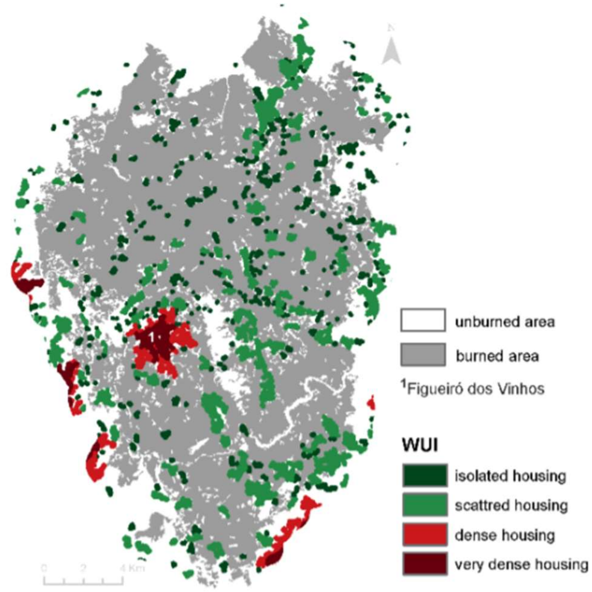


Figure 5: Burned/Unburned mapping of Pedrógão Grande in 2017
Source: Tedim, Fantina, et al. "Understanding Unburned Patches Patterns in Extreme Wildfire Events: Evidences from Portugal." *Researchgate.net*, International Conference on Forest Fire Research, July 2018, www.researchgate.net/profile/Fantina_Tedim/publication/326394395_Understanding_unburned_patches_patterns_in_extreme_wildfire_events_evidences_from_Portugal/links/5b56fde5aca27217ffb723ba/Understanding-unburned-patches-patterns-in-extreme-wildfire-events-evidences-from-Portugal.pdf.

B. Earthquakes

This subsection presents statistical data regarding earthquakes and other relevant earthquake-related information.

Worldwide Earthquakes 2000–2016

Magnitude	2000	2001	2002	2003	2004	2005	2006
8.0+	1	1	0	1	2	1	2
7–7.9	14	15	13	14	14	10	9
6–6.9	146	121	127	140	141	140	142
5–5.9	1344	1224	1201	1203	1515	1693	1712
Estimated Deaths	231	21357	1685	33819	298101	87992	6605

Magnitude	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
8.0+	4	0	1	1	1	2	2	1	1	0
7–7.9	14	12	16	23	19	12	17	11	18	16
6–6.9	178	168	144	150	185	108	123	143	127	130
5–5.9	2074	1768	1896	2209	2276	1401	1453	1574	1419	1550
Estimated Deaths	708	88708	1790	226050	21942	689	1572	756	9624	

Figure 6: Worldwide Earthquakes from 2000 to 2016

Source: "Earthquake Statistics." *U.S. Geological Survey*,2018, earthquake.usgs.gov/earthquakes/browse/stats.php.

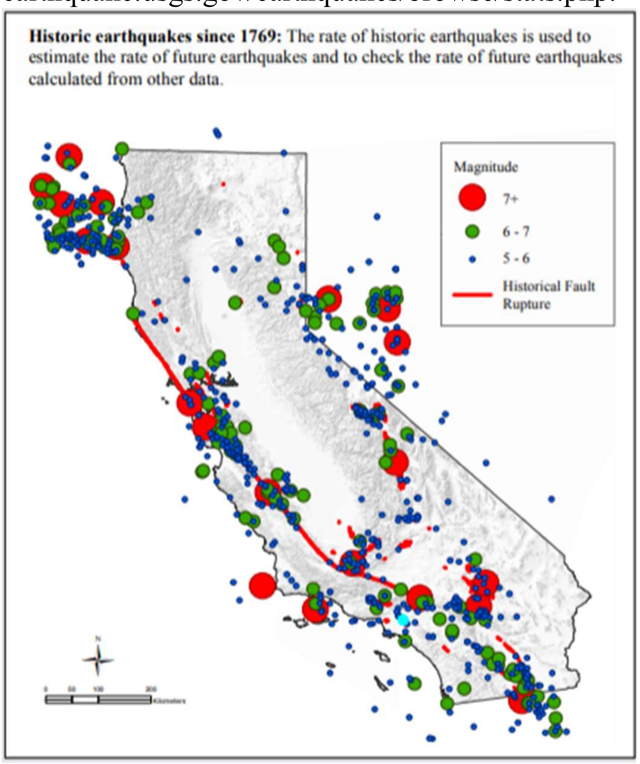


Figure 7: Map of historic earthquakes since 1769

Source: Branum, D., et al. "Earthquake Shaking Potential for California." *www.conservation.ca.gov*, California Geological Survey, 2016, www.conservation.ca.gov/cgs/Documents/MS_048.pdf.

Figure 8 below shows the map of the epicenter of the 2011 earthquake in Japan. The earthquake had a magnitude of 9.0 and was the largest recorded earthquake in Japan in over 100 years. The earthquake cost more than $300 billion which makes it the most expensive disaster.

Figure 8: 2011 Tohoku earthquake epicenter map

Source: Reid, Kathryn. "2011 Japan Earthquake and Tsunami: Facts, FAQs, and How to Help." *World Vision*, 19 Aug. 2019, www.worldvision.org/disaster-relief-news-stories/2011-japan-earthquake-and-tsunami-facts.

C. Tsunamis / Hurricanes / Floods

Subsection C provides data related to tsunamis, hurricanes, and floods, respectively.

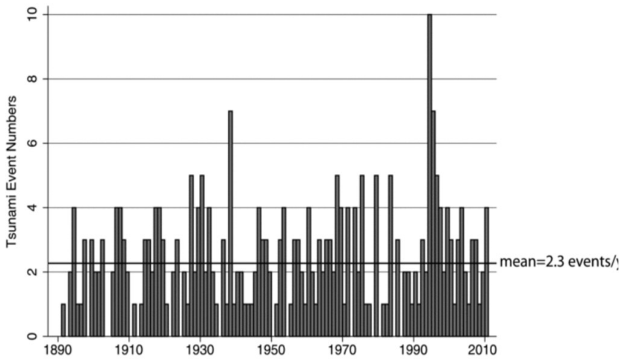


Figure 9: Global tsunami events from 1890 to 2010
Source: Geist, Eric L., and Tom Parsons. "Assessing Historical Rate Changes in Global Tsunami Occurrence." Geophysical Journal International, vol. 187, no. 1, 2011, pp. 497–509.

Year	Total hurricanes (1)	Made landfall as hurricane in the U.S.	Deaths (2)
1999	8	2	60
2000	8	0	4
2001	9	0	42
2002	4	1	5
2003	7	2	24
2004	9	6 (3)	59
2005	15	7	1,518
2006	5	0	0
2007	6	1	1
2008	8	4 (4)	41
2009	3	1 (5)	6
2010	12	0	11
2011	7	1	44
2012	10	1 (6)	83
2013	2	0	1
2014	6	1	2
2015	4	0	3
2016	7	3	36
2017	10	4	147
2018	8	2	48

Figure 10: Number of hurricanes and hurricane related deaths.

Source: "Facts + Statistics: Hurricanes." *III*, 2018, www.iii.org/fact-statistic/facts-statistics-hurricanes.

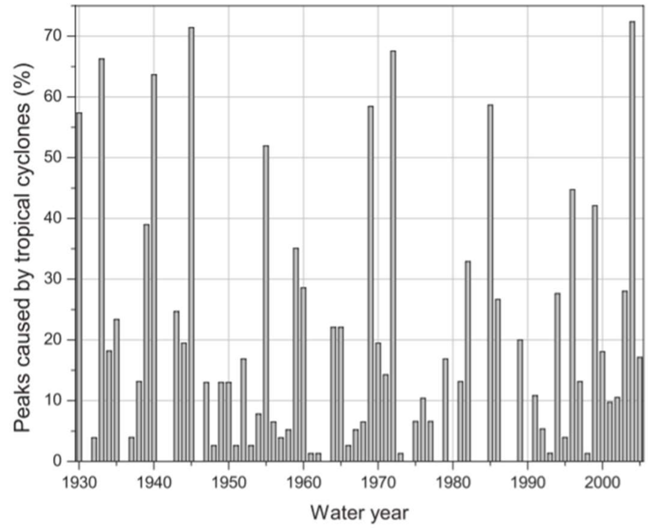


Figure 11: Annual percentage of flood peaks in the Easter United States
Source: Smith, James A., et al. "Mixture Distributions and the Hydroclimatology of Extreme Rainfall and Flooding in the Eastern United States." Journal Of Hydrometeorology, vol. 12, no. 2, 2011, pp. 294–309.

III. Search and Rescue Statistics (MARCUS)

People may go missing for a variety of reasons, which brings the need of various search and rescue groups. Search and rescue can be broken down into four different categories. The first being ground search and rescue. Ground search and rescue is the search for persons who are lost or in distress on land. The next is Mountain Rescue which is the search and rescue operations specifically in rugged and mountainous terrain. Urban Search and Rescue is the location and rescue of persons from collapsed buildings or other urban and industrial entrapments. Water search and rescue is the capability to coordinate and conduct water search and rescue response efforts for all hazards involving water. All of these include locating, accessing, medically stabilizing, and freeing victims from there specific areas.

A. Wildfires

Wildfires are a form of ground search and rescue, also other forms of fires can devastate urban areas to include them in urban search and rescue. A recent example would be “The Camp Fire” in Paradise, CA. They had to evacuate 52, 000 people throughout the city and surrounding area. The fire lasted for two weeks and burned across 153,000 acres. About 14,000 residences were destroyed and about 18,000 buildings in total. Multiple California Urban Search and Rescue (US&R) Task Forces and human remains canine search teams were deployed from across California to assist law enforcement with the search for, and recovery of, victims missing throughout Paradise and other towns devastated by the fire. Throughout the two week span, the wild fire killed 85 people. Even two weeks after the fire, search and rescue crews were still trying to find hundreds of people.

B. Earthquakes/ Tsunami

One of the most recent big earthquake was the 2011 Tohoku 9.0 earthquake which later caused a Tsunami to hit the city. The combined total of confirmed deaths and missing is more than 16,000. Due to the earthquake and tsunami, the japanese government ordered over 100,000 troops, a total of 236 aircrafts and 50 vessels/cargo planes were deployed to aid in the field. This incident is classified under the form of water and urban search and rescue.

C. Flood

Recently, Texas has been hit with record breaking rainfall during the Tropical Storm Imelda which has caused flash flooding. They have seen up to 42 inches of rain within a three day period. This storm has left at least two people dead and has had rescue crews with boats scrambling to reach stranded drivers and families trapped in their homes during the relentless downpour. There has been a combination of about 1,000 high-water rescues and evacuations to get people to shelter. The classification of the Tropical Storm Imelda falls under the categories of urban search and rescue as well as water search and rescue.

D. Avalanches

Avalanches are a form of mountain search and rescue. The largest avalanche in history was on May 30th, 1970 off the coast of Peru. An earthquake caused the north slope of Mt. Huascaran to collapse. The avalanche ran for almost 11 miles and estimates that 20,000 people were killed in the event. Statistics show that about 25% of victims were killed by the trauma of the event. Of those that survive the trauma, the first 15 minutes is crucial for survival. The search for victims must start immediately if they are buried. In present day, ski patrols, helicopters and mountain rescue teams are sent out to search and rescue the buried victims. For avalanche rescue teams, they usually have a first team that can travel light and move quickly to locate and uncover buried victims. After that depending on the severity, they will transport the victim via the ski patrol or by helicopter. Overall the plan for search and rescue teams has evolved tremendously.

IV. Current Safety Equipment Needs (EDGAR)

With an increasing number of deployment missions by search and rescue personnel, the need of equipment and supplies has also seen a jump in demand. For instance, the year 2017, was the most destructive year in California in terms of property loss/damage, as more than 9,133 fires burned across the state. That year alone saw an unprecedented number of search and rescue deployments; which utilized so much of California’s Fire and Rescue resources, that it required additional assistance from 10 other states. Having said that, this section aims to discuss the most common problems that SAR personnel face when deploying on missions; as well as, the resources needed by workers and victims.

A. A Closer Look into the Needs and Risks of California Firefighters

The majority of the largest fires in California have taken place within the past 20 years. These frequent occurrences has lead to the need of more fire combatant equipment. When dealing with wildfires, firefighters must come equipped with fire resistant pants and shirts, a helmet, eye protection, gloves, leather boots, and fire shelter. On the ground, they must be prepared to contain the spread of the fire by common means such as digging "fire lines", cutting down trees and bushes, or creating "backfires" to deprive the main fire of fuel.

Even with all this equipment aimed to protect and maintain the safety of firefighters, firefighters still run the risk of developing respiratory or carcinogenic issues in the future. The International Agency for Research on Cancer (IARC) classified occupational exposure as a firefighter as possibly carcinogenic to humans. In Fent et al.'s article,"Contamination of Firefighter Personal Protective Equipment and Skin and the Effectiveness of Skin decontamination," he analyzed the health effects associated with contaminated fire equipment utilized by firefighters. Due to the low maintenance of fire suits, as laundering them is only commonly performed once or twice a year, toxins are able to accumulate on the suits and could transfer onto the skin of firefighters.

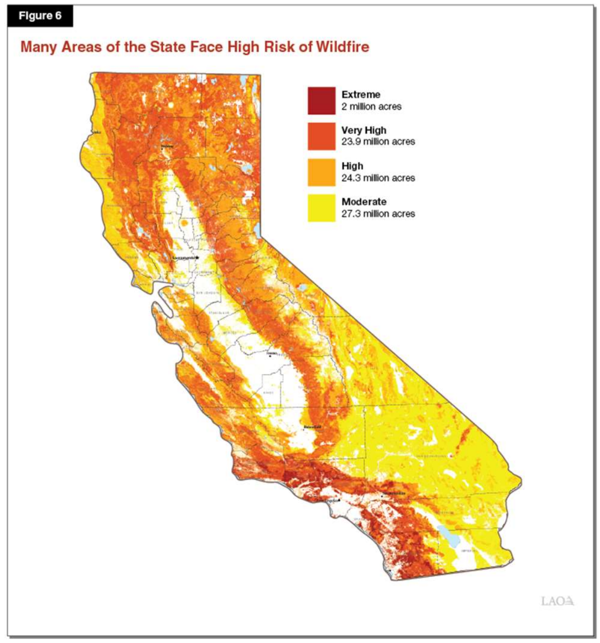


Figure 11: Potential Areas with High Risk of Wildfires.
Source: loa.ca.gov

	Reference		
Material	*Gold et al*[23]	*Treitman et al*[24]	*Lowry et al*[26]
Carbon monoxide	3–1000	15–5000	0–15 000
Hydrogen chloride	18–150	1–200	0–40
Hydrogen cyanide	0·02–5	0·1–5	0–40
Formaldehyde acetaldehyde	NA	NA	1–15
Nitrogen dioxide	0·02–0·89	0·2–10	NA
Carbon dioxide	NA	1000–60 000	NA
Benzene	NA	0·2–150	500–1200*
Particulates	4–750	20–20 000	NA

All concentrations in ppm except particulates which are in mg/m^3.
*Reported as total hydrocarbons.
NA = Not available.

Figure 12: Table demonstrating the most common
chemical substances firefighters are exposed to.
Source: British Journal of Industrial Medicine

As the upward trend in natural disasters continues, disaster relief individuals will be more susceptible to becoming exposed to hazardous materials. With this in mind, new risk management techniques need to be developed and implemented;in order to maintain the health and safety of SAR workers.

B. Quantifying the Disaster: The Health and Economical Effects Influenced By Natural Disasters in the General Population.

Often times, when a natural disaster occurs such as a catastrophic storm, flood, hurricane, wildfire etc. the priority many times is to act upon the current situation. Similarly, this is more or less the same when researchers analyze the health consequences of natural disasters; as the research focuses primarily on the populations impacted and the immediate aftermath. Prohaska and Peters (2019) argue that there has been very little research done on the health effects of natural disasters in older adults over a long period of time. The article proposes correlations between exposure to these events and the long term development of cancerous diseases in older adults. As discussed before, the current trends show an increase in occurrences of severe weather events in the United States; with that being said, this increase has also led to an increased exposure to natural disasters by the general population.

Figure 13: Number of Natural Disasters from 1900-2018

Some of the most common natural disasters that Americans are exposed to are flooding and wildfires. In the case of wildfires, potential risks of cancer can be associated with the exposure of particulate matter in the air. For instance, smoke of wildfires contain high levels of ash and particulate matter (PM2.5) that remains suspended in the air. The specific health concern is the harmful airborne PM associated with forest fires. These smaller airborne particles, specifically PM2.5, have been found to embed and accumulate in the lungs resulting in respiratory diseases such as lung cancer. When it comes to flooding, there can be a variety of toxins and carcinogens that become present in the water. Storm surges can create situations where water comes into contact with hazardous materials; which in turn, may flow into bodies of water used by people.

Economic strain may also be an apparent consequence of a natural disaster. For instance, according to Munich Re, in 2018 the US saw an 82 billion dollar loss due to natural disaster events that had occurred.

Natural Catastrophe Losses In The United States, 2018

(Based on perils)

As of March, 2019	Number of Events	Fatalities	Estimated Overall Losses (US $bn)	Estimated Insured Losses (US $bn)*
Severe Thunderstorm	56	66	18.8	14.1
Winter Storms & Cold Waves	9	26	4.2	3
Flood, Flash Flood	20	49	2.6	1.2
Earthquake & Geophysical	2		0.5	0.4
Tropical Cyclone	5	107	30.4	15.6
Wildfire, Heat Waves, & Drought (ongoing drought condition without loss estimation for the half year)	16	107	25.4	18
Totals	108	355	$81.9	$52.3

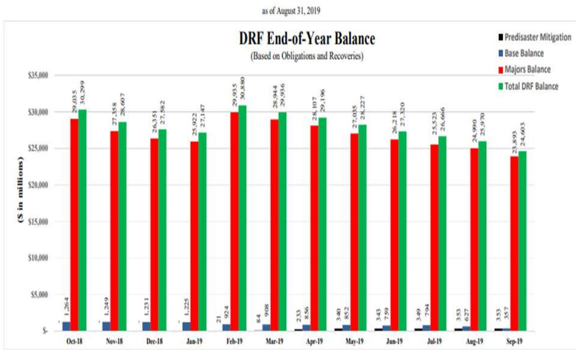
Source: © 2019 Munich Re, NatCatSERVICE; Property Claim Services (PCS®)*, a Verisk Analytics® business. As of March 2019.

Figure 14: Natural Catastrophe Losses in the US 2018

However, the worst loss for the United States' economy was in 2017 where the US saw a total loss of 307 billion dollars due to 16 events that cost more than $1 billion each(Amadeo, 2019). Economical impacts like these have a tremendous impact on low-income communities as it takes much longer for them to recover; due to the fact that they have less access to resources.

C. Relief Efforts

During search and rescue operations, the main objective of a team is to rescue the largest number of people in the shortest time, while also mitigating the risk factor. The immediate priority after a natural disaster is providing emergency first aid and medical services to injured persons. In most cases first responders consist of doctors, emergency workers, and police units. Currently, the United States has provided a total of 270 billion dollars in disaster relief efforts as of August 2019.



DRF End-of-Month Balance	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Predisaster Mitigation	$ -	$ -	$ -	$ -	$ 21	$ 84	$ 233	$ 340	$ 343	$ 349	$ 353	$ 353
Base	1,264	1,249	1,231	1,225	924	908	856	852	759	794	627	357
Majors	29,035	27,358	26,351	25,922	29,935	28,944	28,107	27,035	26,218	25,523	24,990	23,893
Total DRF Balance	$ 30,299	$ 28,607	$ 27,582	$ 27,147	$ 30,880	$ 29,936	$ 29,196	$ 28,227	$ 27,320	$ 26,666	$ 25,970	$ 24,603

Figure 15: End of Year Cost of Disaster Relief

V. Possible Solutions (ALFRED)

Currently, Rescue Teams and Firefighters are put into highly stressful and erratic environments. The proposed, main solution to this problem is to add more robotic technology to help analyze dangerous situations, speed up the searching processes when disasters do happen, react to fires more rapidly and from more dynamic approaches, and give all this information to the teams in the situations so that they can help people in need with better assurance of their own safety. Currently, robotic models are used as live streams that feed information to a remote location out of danger. Eventually, the goal would be to allow autonomous or semi-autonomous robots to replace workers and to allow greater environmental control over any disaster type situation. This requires highly intelligent robotics as well as teams that are trained to operate them.

A. Search and Rescue Robot

Modern search and rescue workers are equipped with a multitude of tools to evaluate and interact with the dangerous situations they are placed in. Robotic technology is a broad topic on its own, but in general most current robots are limited to searching and not so much rescuing. This is caused by robots not having the level of sensitivity and dynamic motion control needed to analyze and transport victims in an efficient and safe manner. Many robots in use will be sent out to locate and send visual/audio feed to an operator that can then send that information to rescue workers. This alone is still a vital piece to rescue situations when victims have a limited time to be rescued. Thermal cameras, range finders, location tracking systems, and 3D mapping systems are all currently being used to varying degrees and being constantly improved.

One example of a current SAR robot is Japan's KOHGA3. This tracked robot is built to analyze damaged buildings whenever Japan is hit with an earthquake. The aim being to protect inspectors and workers as well as provide rescue workers with more eyes and, therefore, greater efficiency.

Figure 16: KOHGA3 Ground Robot for Search and Rescue and Vacant Building Inspection

Another example of current robotic technology falls under the snake-like robotics. These newer designs are light, thin, and can fit into narrow areas rescue workers cannot readily access. These types of robots, still being developed, could one day help rescue workers locate victims trapped under rubble piles in broken down buildings or miners stuck in caves and mines.

Figure 17: Robot Snake, Biorobotics Laboratory Carnegie Mellon University

Likely the most difficult of all the forms of robotics is the walking/running type robots that emulate humans and walking animals. It is very easy to imagine the usefulness of futuristic walking robots. Dogs, cats, horses, and mules have all been worked alongside humans for millennia and having robotic counterparts to match these aspects is not simply science fiction. Robotic quadrupeds have the ability to traverse rough terrain quickly, evermore efficiently, and can relay data just the same as any of the other robots discussed. Quadrupeds are being thoroughly researched and developed; many companies and universities are developing their own walking robots under different specifications which leaves hundreds, possibly thousands, of design ideas across the globe. Boston Dynamic, Honda, MIT, Stanford, and many others have customized prototypes.

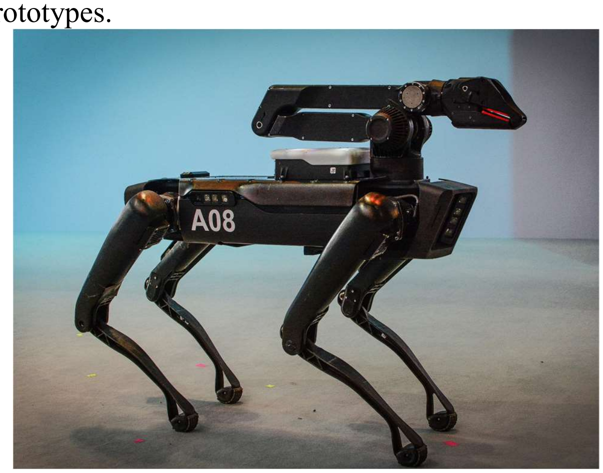


Figure 18: Boston Dynamics' SpotMini

Figure 19: Honda's Asimo

These robots can be highly versatile in the future working in all areas of society not exclusively search and rescue.

B. Firefighting Robots

Robotic Firefighting Systems typically entail a remote controlled vehicle with fire suppression technology attached to it, like a water hose. They are able to travel into areas deemed unsafe for humans such as a collapsing building or closer to a fire that would be too hot for a firefighter. They also have the added benefit of being able to detect voices, body signatures and map out hotspots to avoid walking over collapsable spots.

Figure 20: Thermite Fire Fighting Robot

Adding Autonomy to these robots would free up Firefighters to worry about people in rooms and trapped in various locations while the Robots analyzed and hosed down the fires.
In the future, fire fighting robots could be deployed in wildfire locations with teams of "Hotshots" to automate ditch digging, logging, setting backfires, or carrying addition equipment.

Figure 21: Prescribed fire in eastern Washington, United States

C. Drone Technology

Aerial drones can be used as stand alone units or in a mini-fleet to record terrain and battle fires from above. Currently, drones are being tested to track wildfire movement in large areas that are incredibly difficult to navigate, but, in the future, it is possible to have a team of drones dropping mapping hot zones and movement while other drone drop water and extinguishing material over the flames while firefighters tackle other angles. The same approach could be used in large buildings and skyscrapers to attack fires from the winds using hoses carried by drones.

Figure 22: Firefighting Drone

A group of aerial drones could be set up to map the progress of a fire and track its movement.

Figure 23: Disaster Relief Drone

A disaster relief drone could be useful after a natural disaster that blocked or damaged roads, especially in remote locations in other parts of the world.

VI. Conclusion

Natural Disasters are a consistent issue across the globe especially for impoverished communities. This report's aim was to study common forms of natural disasters and their statistical side effects including fatalities, suburban devastation, and economic impact on specified regions. Following this, the report aimed to find solutions to these disaster situations by improving safety standards for firefighters, rescue workers, and disaster relief workers through the use of robotics. The general notion being that creating safer conditions for rescue workers is tantamount to improving rescue effort efficiency as well and increasing relief effort responses. By looking at firefighting robots and drones, it is fairly clear that adding a small, well-trained team to a wildfire effort could increase overall coordination, tracking, and possibly aid in stopping wildfires and saving thousands of acres of forest. Estimated with increased performance over the next few decades and higher agility robots, one day, perhaps, only a small team of robotic technicians could be putting out entire forest fires with no personnel in direct conflict with the flames.

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Glossary

S.A.R. - Search and Rescue

Robot - a machine able to replicate certain human movements and perform a function(s) autonomously

DISASTER RELIEF WORKER - AN INDIVIDUAL WHOSE JOB IS TO ASSIST THOSE AFFECTED BY A NATURAL DISASTER. MANY TIMES ARE VOLUNTEERS

FS - FOREST SERVICE

DOI - DEPARTMENT OF INTERIOR