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Introducing a Network of Emerging Commercial Technologies to Combat Wildfires on DoD Installations

December 2022

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Department of Defense Management

Naval Postgraduate School

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

ACQUISITION RESEARCH PROGRAM
DEPARTMENT OF DEFENSE MANAGEMENT
NAVAL POSTGRADUATE SCHOOL

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ABSTRACT

The purpose of this thesis is to analyze the fiscal, environmental, and health impacts of wildfires aboard Marine Corps Base (MCB) Camp Pendleton and the potential benefits of incorporating Project Vesta, a system of emerging commercial-off-the-shelf technologies, into Camp Pendleton's firefighting capabilities. The main objective of this report is to determine the cost of acquiring Project Vesta and the benefit of fielding it aboard Camp Pendleton and other DOD installations at risk from wildfires.

First, we determine the growing threat of wildfires to MCB Camp Pendleton and their fiscal, environmental, and health impacts. Second, we analyze current firefighting detection and suppression methods to determine shortfalls and potential costs derived from insufficient responses. Finally, we identify Project Vesta integration opportunities and conduct a sensitivity analysis of the cost-benefit to better combat wildfires aboard MCB Camp Pendleton.

This study determines how investing in Project Vesta will allow fire departments to detect fires sooner and suppress fires faster, leading to reduced costs by protecting people, resources, and training environments. Based on this research, we recommend that DOD facilities that are regularly impacted by wildfires acquire the Vesta system and integrate it into their fire departments.

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LIST OF ACRONYMS AND ABBREVIATIONS

AI	artificial intelligence
AUC	average unit procurement cost
BVLOS	beyond visual line of sight
CAL FIRE	California Department of Forestry and Fire Protection
CI	commercial items
COO	chief operating officer
COTS	commercial off-the-shelf
CPFD	Camp Pendleton Fire Department
CRADA	Cooperative Research and Development Agreement
DAU	Defense Acquisition University
DOD	Department of Defense
DODD	Department of Defense Directive
eTHOR	Electric Tactical Humanitarian Operations Response
EO	Executive Order
FUV	fun utility vehicle
FY	fiscal year
HAZMAT	hazardous materials
HEN	High Efficiency Nozzles
HVAC	heating, ventilation, and air conditioning
JIFX	Joint Interagency Field Experimentation
LTC	Local Technology Cluster
MILCON	military construction
MCAS	Marine Corps Air Station

MPS	mobile power system
NDI	non-developmental items
NPV	net present value
SME	subject matter expert
SoCal	Southern California
UAS	unmanned aerial systems
UAV	unmanned aerial vehicle
USDA	United States Department of Agriculture
USIR	unmanned systems integrated roadmap
VPD	vapour pressure deficit

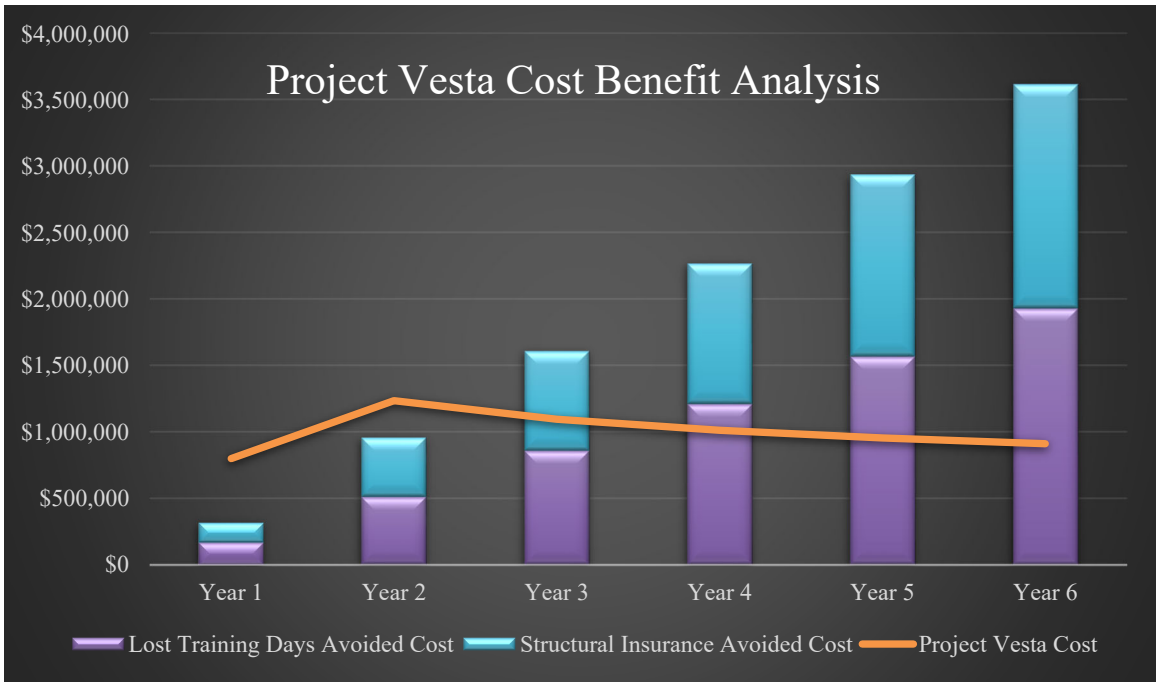
EXECUTIVE SUMMARY

The Department of Defense (DOD) has acknowledged that wildfires present a serious threat to the safety and security of DOD installations across the Continental United States and abroad. The traditional methods of fighting fires both on the ground and in the air have become overly expensive and unable to keep up with the pacing threat. We must change how we detect, deter, and prepare to combat wildfires in order to preserve human life and infrastructure. The challenges presented by wildfires cause an elevated cost burden to the taxpayer and increased risk to the public and the environment.

The commercial sector has been developing and testing a multitude of new technologies that can be incorporated into a synergistic network harnessing state-of-the-art wildfire fighting capabilities. Through the use of emerging commercial technologies, wildfires can be detected at an earlier stage and extinguished prior to presenting a serious threat to the population and infrastructure aboard DOD installations.

A team consisting of commercial partners, the Southern California (SoCal) Tech Bridge, and the Naval Postgraduate School formed a collaborative team creating Project Vesta. The intent of this cooperative team is "to reduce the impact of wildfires through the delivery of timely fire containment agents onto desired targets, persistent fire surveillance, robust analytics capabilities, and convenient interoperability" (SoCal Tech Bridge 2022).

As shown in the following figure, our research indicates that Project Vesta is a worthwhile intiative that the DOD should continue to invest in for further development and fielding. The cost of Project Vesta would quickly be outweighed in avoidance costs within 36 months of incorporation. The current estimate to purchase a local tech cluster is $568,126 when factoring the learning curve and acquisition of 11 units. Immediate benefits could be realized in the areas of recouped lost training days and a reduction in the costs of wildfire insurance premiums (shadow cost).



In addition to the calculated avoidance costs of lost training days and structural insurance displayed in the table above, our research also calculated avoidance cost for loss of military aircraft, associated health impacts, and economic disruption. These account for hundreds of millions of dollars of additional cost that are not factored in when analyzing the impacts of annual wildfires aboard MCB Camp Pendleton. Project Vesta may have the potential to significantly reduce the impacts of wildfires with a minimal investment garnering a large return. Upon full maturation and implementation, Project Vesta may have the ability to reduce the threat of wildfires aboard MCB Camp Pendleton by as much as 30 percent.

Reference

Southern California Tech Bridge. (May 2022). *Project Vesta.* https://www.socaltechbridge.org/project-vesta

I. INTRODUCTION

The Department of Defense (DOD) has acknowledged that due to climate change, wildfires present a serious threat to the safety and security of DOD installations across the Continental United States and abroad. On January 27, 2021, President Joseph Biden Jr. signed Executive Order (EO) 14008, "Tackling the Climate Crisis at Home and Abroad." This executive order required the DOD to submit a draft action plan to the National Climate Task Force and the Federal Chief Sustainability Officer within 120 days "that describes steps the agency can take with regard to its facilities and operations to bolster adaptation and increase resilience to the impacts of climate change."

Wildfires have become a growing threat to DOD installations throughout the country and abroad. The traditional methods of fighting fires both on the ground and in the air have become overly expensive and unable to keep up with the pacing threat. We must change how we detect, deter, and prepare to combat wildfires in order to preserve human life and infrastructure. The challenges presented by the wildfires cause an elevated cost burden to the taxpayer and increased risk to the public and the environment.

The commercial sector has been developing and testing a multitude of new technologies that can be incorporated into a synergistic network harnessing state-of-the-art wildfire fighting capabilities. Through the use of emerging commercial technologies, wildfires can be detected at an earlier stage and extinguished prior to presenting a serious threat to the population and infrastructure aboard DOD installations.

A team consisting of commercial partners, the Southern California (SoCal) Tech Bridge, and the Naval Postgraduate School formed a collaborative team creating Project Vesta. The intent of this cooperative team is "to reduce the impact of wildfires through the delivery of timely fire containment agents onto desired targets, persistent fire surveillance, robust analytics capabilities, and convenient interoperability" (SoCal Tech Bridge 2022).

A. PURPOSE

The purpose of this research is to begin evaluating the feasibility of incorporating Project Vesta onto DOD installations and what benefits it can provide in order to mitigate the damage of future wildfires. Marine Corps Base Camp Pendleton, California, will be the baseline model for the incorporation and evaluation of Project Vesta.

The first objective in our research is to conduct a comparative analysis of the Camp Pendleton Fire Departments current methods for prevention, detection, and response to wildfires against Project Vesta's capabilities. Our second objective is to conduct a cost benefit analysis on the incorporation of Project Vesta aboard Camp Pendleton versus costs related to historical wildfires.

B. SCOPE AND RESEARCH METHODS

This research examines the shortcomings of the current capabilities and techniques used by firefighters aboard DOD Installations utilizing Camp Pendleton as the baseline. First, we will evaluate the growing risk of wildfires along with their fiscal, environmental, and health impacts. Then, this study will introduce commercial off-the-shelf (COTS) technologies aiming to modernize firefighting techniques and capabilities. In the final step, we will conduct a cost benefit analysis and demonstrate the benefits of incorporating Project Vesta.

C. WHY PROJECT VESTA?

Current firefighting practices rely heavily on early detection and ideal weather conditions to help control the burn. Firefighting experts realize the need for the modernization of equipment and techniques, but there is significant hesitation over the cost and reliability of the items that may be leveraged to address this problem.

Project Vesta affords the DOD the opportunity to take advantage of emerging COTS technologies that can provide a network of wildfire fighting capabilities "intended to identify fire risk, reduce response time, and decrease firefighter engagement" (SoCal Tech Bridge, 2022). Currently, Project Vesta consists of eight commercially developed technologies focusing on improved capabilities networked together in order to better

prevent, detect, and suppress wildfires; see Figure 1. The use of autonomous systems is the key focus of the project through the utilization of unmanned, electric, air, and ground systems. These systems would all ideally communicate via ad-hoc mesh 5G networks allowing employment in the more desolate areas throughout the country.

The intent is for the "system" to operate independently of the energy infrastructure that is currently in place through the utilization of stand-alone alternate energy sources. This can be made possible through the use of purpose-built electric vehicles and mobile power plants. The end result that Project Vesta is focused on is the delivery of an autonomous "system of systems" that is able to identify, engage, and prevent wildfires within a five-acre area. Upon maturation, these systems can be deployed by the local, state, and federal firefighting agencies throughout the high fire risk zones.

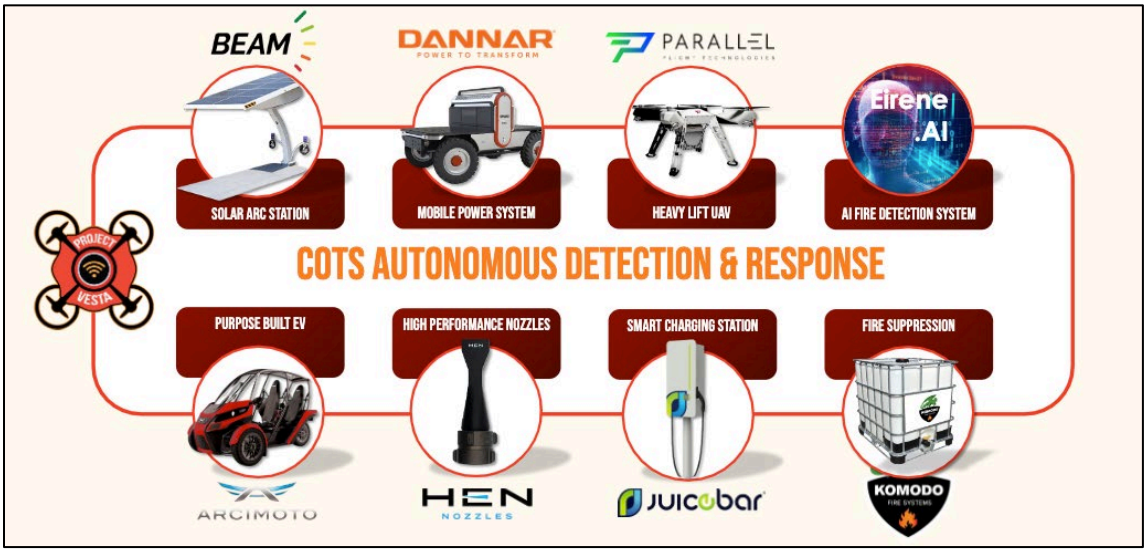


Figure 1. Project Vesta Consists of Eight Commercial-off-the-Shelf Partners. Source: SoCal Tech Bridge at www.socaltechbridge.org/project-vesta (2022).

D. RESEARCH QUESTIONS

Our primary research questions were:

1. What are the key technologies that can be utilized to form a network of wildfire fighting capabilities?
2. What type of field testing can be carried out to test the capabilities of the different technologies providing a proof of concept?
3. Can the different technologies in Project Vesta be utilized at different stages of the firefighting process: prevention, detection, and response?
4. How large of an area can a Local Technology Cluster (LTC) provide coverage for?
5. How many of each asset type is required to provide maximum effectiveness of the LTC?
6. How long does it take the assets to positively identify and locate a fire?
7. What is the accuracy detection rate of the artificial intelligence capability?

E. ASSUMPTIONS AND LIMITATIONS

Project Vesta remains in the developmental and testing phase. We assume that upon maturation, certain components of Project Vesta will be fully autonomous and able to operate remotely via a 5G mesh network. To date, two controlled burns have been carried out at Camp Roberts, CA, in order to test and evaluate the emerging commercial technologies. During this research, multiple prototypes produced by commercial entities were tested to collect data identifying validated effectivity and required areas of improvement. The major limitations technologies still in the prototype phase and the inability to mesh the technologies through a consolidated operating system.

F. BENEFITS

Project Vesta and the research associated with it allows the DOD to collaborate with commercial entities in identifying a solution to an emerging threat (wildfires) to

national security and DOD installations. This may prove to be the bridge that DOD can utilize to find a cost-effective solution to combatting wildfires in the future in order to protect the population and infrastructure aboard DOD installations. The commercial partners benefit by having the opportunity to test prototypes of emerging technologies aboard Camp Roberts with the potential of receiving an invitation into the DOD acquisitions process as the technology matures.

Project Vesta is an early stage technoloy; it is not yet ready for fielding, but the technologies that make-up Project Vesta are evolving very rapidly and may become mature enough to start deploying experimental units within the next five years. Therefore, it is not too early to start to understand the risk and costs that Project Vesta might mitigate for use on DOD installations. Our research will show that this is a worthwhile project for the DOD and Marine Corps to monitor and participate in which will assist in the matuaration of the technologies and capabilities.

When factoring the willingness to pay, there's a nationwide effort to invest in the prevention and advancement in capabilities to combat wildfires. According to the National Association of State Foresters, in FY 2020, the United States Department of Agriculture (USDA) Forest Service allocated $2.25 billion for wildfire suppression. This amount has increased annually and is scheduled to continue to increase by $100 million annually until the FY 2027 when it will total $2.29 billion. This is a clear signal of not only that the rise and devastation of wildfires is a real threat, but also that there is a genuine desire to provide resources to help combat the growing problem.

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II. BACKGROUND

A. DOD WILDFIRE ASSESSMENT

The number of wildfires aboard DOD installations have grown in number and size over the past several decades. The Center for Environmental Management of Military Lands conducted analysis on 145 DOD installations utilizing Level-1 Landsat data spanning a period of 11 years from 2004–2014 (Beavers, 2021). The DOD Wildfire Hazard Assessment was initiated in order to identify the growing threat of wildfires and potential solutions to mitigate the threat. Prior to this assessment being carried out, wildfires aboard installations were not being tracked in a consolidated database preventing the ability to conduct trend analysis of wildfires aboard DOD Installations. However, as shown in Figure 2, the amount of acreage burned from 1960 to 2018 in the United States has increased substantially and continues to trend in an upward direction.

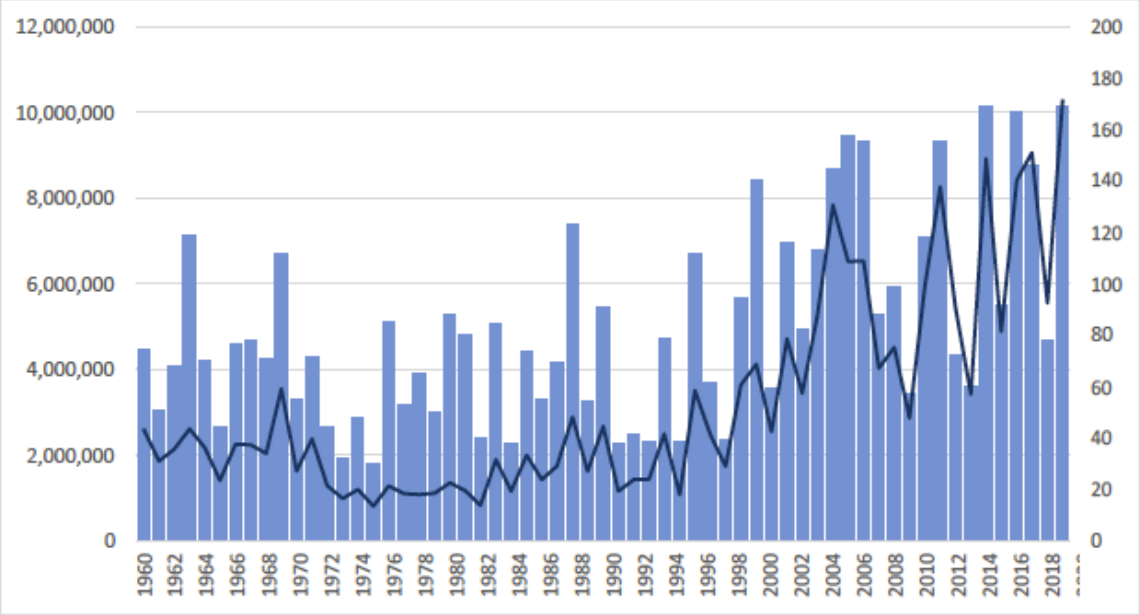


Figure 2. Annual Total and Annual Average Acres Burned in the U.S. from 1960 to 2018. Source: Beavers (2021).

According to CAL FIRE, 25 percent of the population in the state of California (approximately 11 million people), live in a high-risk area for wildfires (CAL FIRE, 2022). According to the Insurance Information Institute, "there were more than 2 million properties at high to extreme wildfire risk in 2021, the largest number of properties of any U.S. state" (iii, 2022). The DOD has 32 military bases located within California with many of those installations located inside a high-risk area for wildfires (Beavers, 2021).

As shown in Figure 3, the DOD Wildfire Hazard Assessment listed two United States Marine Corps bases as HIGH under their Wildfire Hazard Classification: Camp Pendleton and Camp Lejeune. Out of the 145 installations that the assessment conducted analysis on, only 13 installations were categorized as HIGH for wildfire hazard.

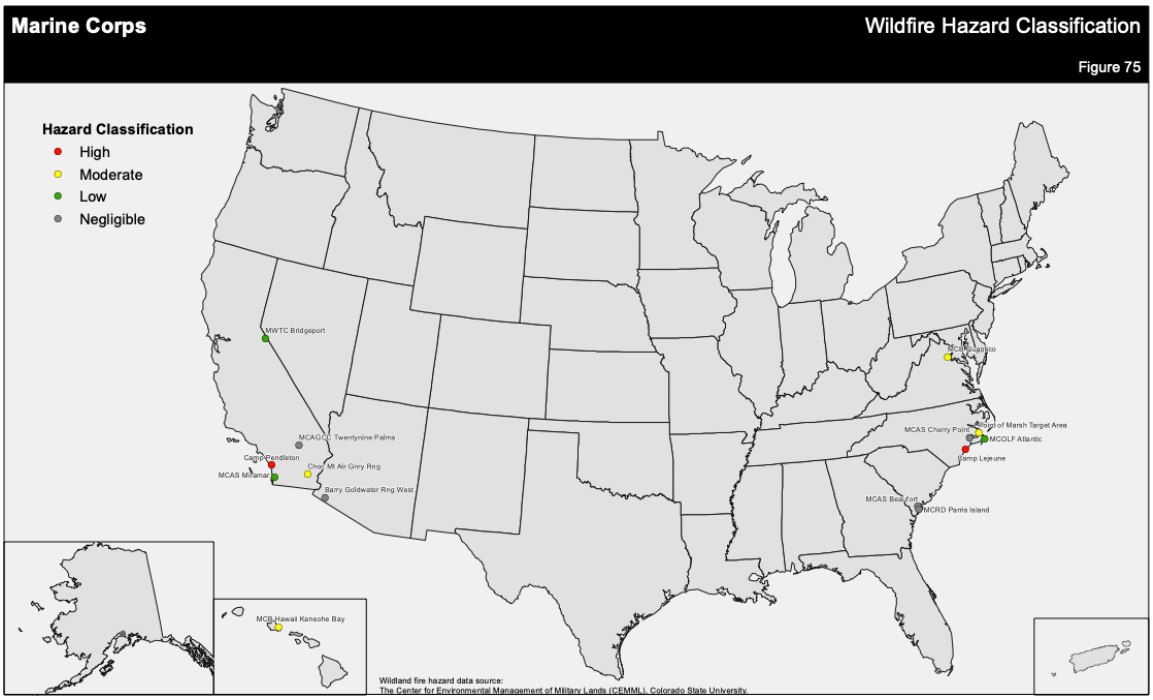


Figure 3. Center for Environmental Management of Military Lands Wildfire Hazard Classification. Source: Beavers (2021).

According to the DOD Wildfire Hazard Assessment, "installations with a HIGH fire hazard were found in particularly fire-prone locations and/or have an active training mission that produces many ignition sources, making wildfire hazard mitigation difficult

and expensive." The assessment conducted analysis on 14 Marine Corps bases and categorized them as HIGH, MODERATE, LOW, and NEGLIGIBLE as seen in Table 1.

Table 1. Center for Environmental Management of Military Lands Wildfire Hazard Classification. Source: Beavers (2021).

HIGH	MODERATE	LOW	NEGLIGIBLE
CAMP LEJEUNE	CHOC MT AIR GNRY RNG	MCAS MIRAMAR	BARRY GOLDWATER RANGE WEST
CAMP PENDLETON	MCB HAWAII KANEOHE BAY	MCOLF ATLANTIC	MCAGCC TWENTYNINE PALMS
	MCB QUANTICO	MWTC BRIDGEPORT	MCAS BEAUFORT
	POINT OF MARSH TARGET AREA		MCAS CHERRY POINT
			MCRD PARRIS ISLAND

B. CAMP PENDLETON FIRE DEPARTMENT CAPABILITIES AND PROCEDURES

According to the Camp Pendleton Fire Department (CPFD) webpage, their personnel consist of 175 firefighters and emergency service personnel based at 11 fire stations strategically located throughout the installation. Equipped with 7 Type I Engines, 10 Type III Engines, a 75-foot Aerial Ladder Truck and 105-foot Aerial Ladder Truck, the CPFD relies on California Department of Forestry and Fire Protection (CAL FIRE) for assistance if a wildfire is unable to be controlled. CAL FIRE is able to provide air assets to combat wildfires in support of the CPFD as they have no organic air assets available. On average, over 200 wildfires (approximately 185 training related) and 1,500 acres are burned aboard base annually, the fire department is consistently engaged in fire suppression and prevention. As seen in Figure 4, Camp Pendleton is home to approximately 114,000 acres of training areas for the Marines.

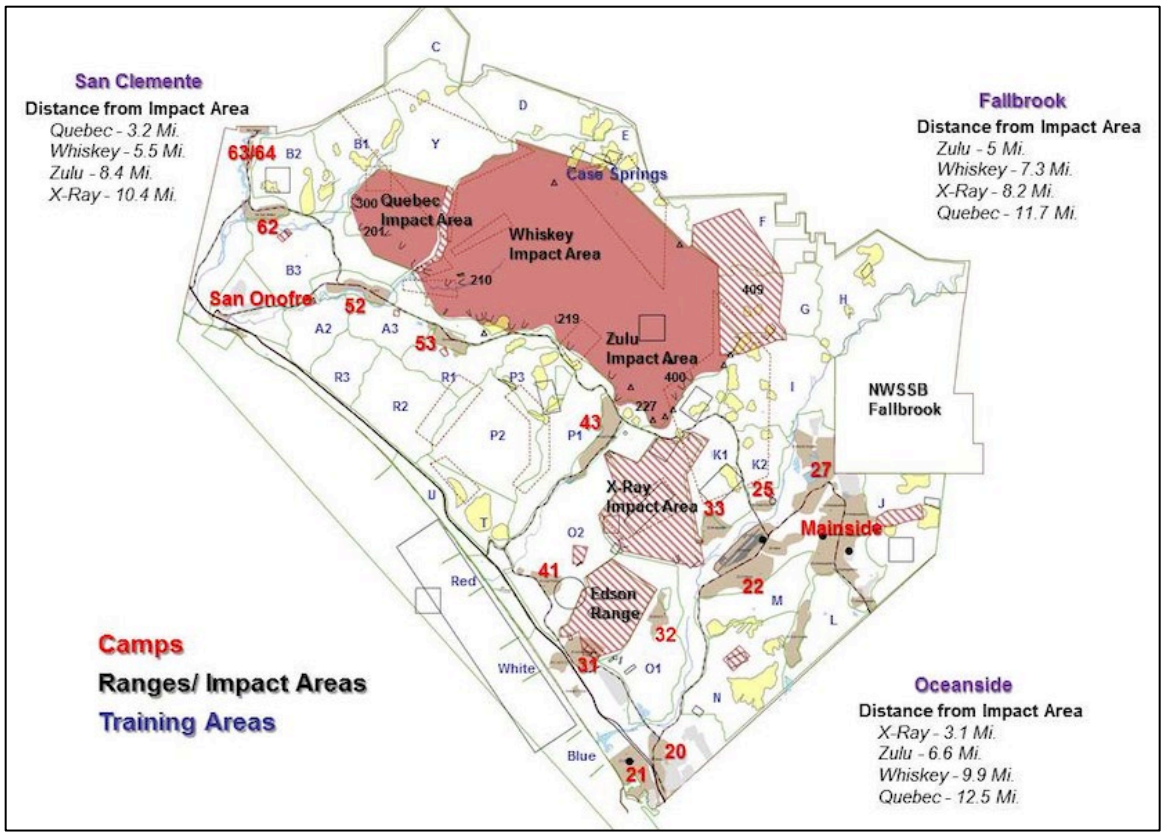


Figure 4. Marine Corps Base Camp Pendleton Training/Impact Area Map. Source: "MCB Camp Pendleton" at www.pendleton.marines.mil (2022).

With the constant employment of ordnance, primarily mortars and artillery in the training and impact areas combined with the wildfire fuel rich conditions, fire prevention and containment will continue to be a challenge going forward. The CPFD utilizes a variety of preventative steps to mitigate wildfires. First, they collect information on areas where fires are most likely to start. Second, they initiate prescribed burns to reduce the fuel load available. Lastly, they create fire breaks in order to cutoff fuel available for the fire to spread allowing for better containment. These actions are labor intensive requiring a significant number of resources and planning for the fire department.

C. DOD SHIFT TO EMERGING TECHNOLOGIES

The United States Military is well aware of the need to adopt, develop, and deploy state-of-the-art technologies in order to maintain strategic and operational advantages over adversaries around the globe. Since 2012, and the release of the Department of

Defense Directive 3000.09, the DOD has been focused on the need to provide oversight for such advanced systems. According to the Center for Strategic International Studies, "DODD 3000.09 formally defines what an autonomous weapon system is and requires any DOD organization proposing to develop one to either go through an incredibly rigorous senior review process or meet a qualifying exemption" (Allen, 2022). Although DODD 3000.09 is mainly focused on weapon systems and their employment, the use, and benefits of emerging technologies are not lost on senior leadership or those in support roles throughout the DOD. In 2021, the current Deputy Secretary of Defense Kathleen Hicks stated that "AI capabilities will have explicit, well-defined uses, and the safety, security, and effectiveness of such capabilities will be subject to testing and assurance within those defined uses across AI capabilities' entire life-cycle" in a memorandum on "Implementing Responsible Artificial Intelligence in the Department of Defense."

The use of autonomous systems allows for engaging in dangerous tasks or mission sets without endangering humans that were previously required to leverage specific capabilities. In a 2020 study conducted by the Rand Corporation, they found that "a minimally manned Army convoy put 28 percent fewer soldiers at risk compared to current practices. A partially unmanned convoy would put 37 percent fewer soldiers at risk, and a fully autonomous convoy would put 78 percent fewer soldiers at risk." The use of autonomous systems also has the capability of alleviating barriers that are frequently encountered by humans such as fatigue, darkness, and other natural conditions. Autonomous systems are capable of rapid response capabilities that can provide direct action and surveillance to areas previously inaccessible by outdated technologies and practices.

Artificial Intelligence (AI) is a force multiplier for the DOD. Algorithms designed for surveillance and detection can be applied through existing security devices or employed through airborne systems or newly installed hardware in strategic locations. AI reduces required manpower while increasing the amount of surveillance and depth for which it can be employed. Air Force Gen. Glen D. VanHerck, the commander for U.S. Northern Command, stressed the importance of AI during the 2022 Aspen Security Forum when he stated, "What I'm trying to do is create decision space; decision space

equals deterrence options," he said. "The way you do that is through analyzing that data and information – that domain awareness data — through the use of machine learning and artificial intelligence" (Lopez, 2022). There is a broad expectation among military analysts and leaders that the ability for rapid data collection and processing may unleash significant advantages for our military and supporting agencies.

The Defense Acquisition University (DAU) acknowledges the use of CI (Commercial Items) and NDI (Non-Developmental Items) otherwise known as COTS, "allows the military to take advantage of technological advances, cost savings and rapid procurement stemming from the competitive pressures of the commercial marketplace as well as developments in other DOD or government agencies" (DAU, 2022). Introducing COTS into non-combatant roles makes integration with supporting agencies even easier as there is less sensitive information to deal with.

Combining AI with autonomous systems that are both being produced by commercial industry allows significant advantages to be leveraged going forward. When looking at improving the capabilities for firefighting and the prevention of fires aboard DOD installations, the utilization of COTS technologies may make sense depending on the specifics of the location and technology maturity.

III. PROJECT VESTA

A. PROJECT VESTA CONCEPT

As the western part of the United States continues to struggle with below-average precipitation, rising temperatures, and sustainable methods of prepping the vast amounts of woodlands for fire prevention.

DOD installations have specific characteristics that make them challenging sites for wildfire suppression. On Camp Pendleton alone, over 200 wildland fires consume on average fifteen hundred acres annually (CPFD, 2022). When the fires occur in optimum fire conditions, they have the ability to spread widely and rapidly. This subsequently places the residents and visitors to Camp Pendleton in danger, as well as buildings, homes, and military facilities and equipment worth tens of billions of dollars.

Complicating things is the fact that many of these installations contain ordnance and hazardous materials (HAZMAT). The threat of unexploded ordnance makes it too risky for firefighters to enter the impact zone and extinguish the blaze before it has a chance to become unmanageable. When wildfires come into contact with ordnance and HAZMAT, it has the potential to pollute the air and contaminate drinking water far beyond the borders of the DOD installation. These negative impacts can take years to identify and treat, creating a public safety hazard.

Therefore a key issue for combating wildfires, especially on DOD installations, is early detection and rapid response. This has been an extremely difficult challenge that has been amplified by outdated means and problem-solving methods. Even if you observe the recent fires in the affluent area of Laguna Niguel, where firefighting is as well funded as you will find anywhere in the country, the limited detection, notification, and immediate response capabilities were obvious.

Early detection utilizing AI, rapidly deployed autonomous vehicles, and cutting-edge surveillance capabilities are possible new tools of the firefighter's trade. We believe the technology that currently exists would allow us to weave a formidable system of off-the-shelf products to combat wildfires safely, efficiently, and economically. Project Vesta

originated at the Naval Postgraduate School (NPS) with the belief that AI could be leveraged by firefighting agencies to detect and predict wildfires. It was quickly sponsored by the SoCal Tech Bridge, where the scope of Project Vesta was expanded to include the use of autonomous and semi-autonomous air and ground vehicles, renewable and transportable power supplies, and advanced firefighting systems. The concept envisioned the various technologies being meshed via a mobile 5G application into an Local Technology Cluster (LTC). The LTC then being capable of operating without outside power or communication grids. As the amount of area that requires coverage increases, the LTC can be linked to additional LTCs to ensure the proper amount of coverage. Shown in Figure 5 is a display of how to potentially position the LTCs throughout MCB Camp Pendleton. Alternatively, the LTC can scaled down by removing elements that are deemed redundant or unnecessary by the subject matter experts (SME) operating at the specific installation.

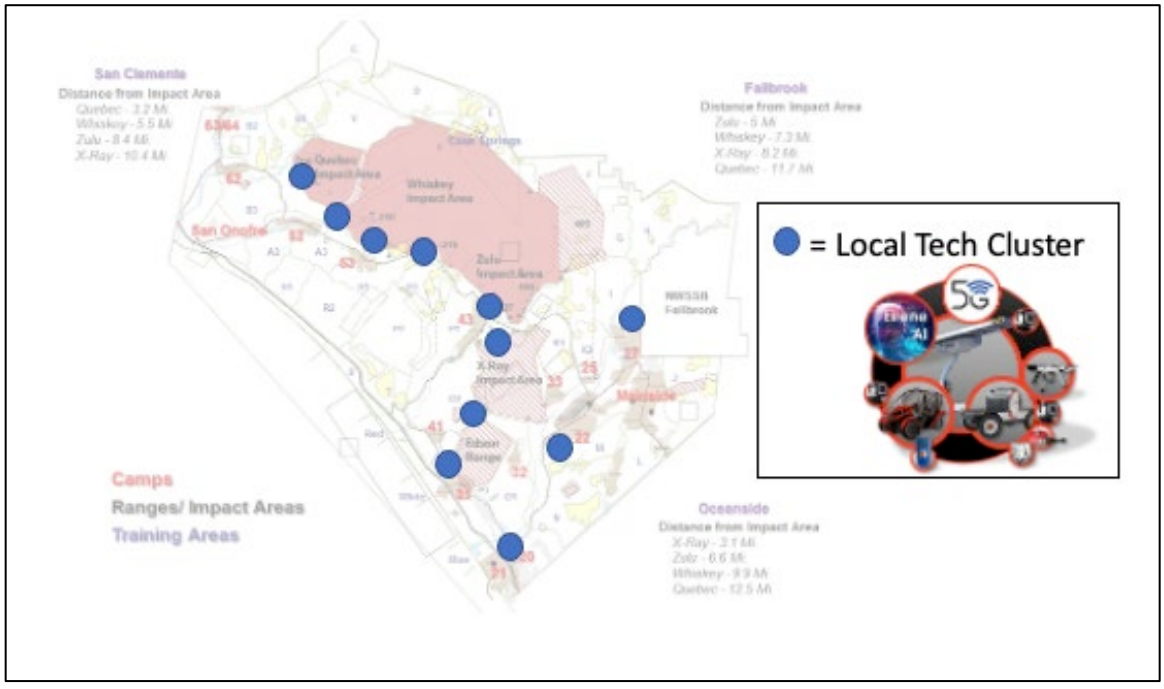


Figure 5. Potential Local Technology Clusters Distributed Throughout Camp Pendleton

B. CURRENT INDUSTRY PARTNERS

1. BEAM with JUICEBAR

Beam Global equipped with the JuiceBar Charger has developed EV ARC, capable of providing 100 percent renewable, off-grid charging capabilities. The EV ARC is capable of producing and storing all its own electricity and can conveniently be moved around from location to location. Project Vesta was interested in the EV ARC in order to provide off-grid recharging capabilities to support the DANNAR. The EV ARC technology has been tested and can already be observed in use at many of the rest stops along California's highways and interstates.

Figure 6. Beam Global EV ARC Stations Located at a Rest Stop along a California Highway. Source: Beam at https://beamforall.com (2020).

2. DANNAR

The Dannar Mobile Power System (MPS) is a fully autonomous work vehicle and generator platform that is capable of delivering capabilities to remote locations in order to support the firefighting effort through more than 250 hydraulic and electric work attachments such digging, lifting, or trenching. It is a rigid platform that can be modified to also fulfil logistical requirements and potentially act as an emergency evacuation

vehicle. The MPS can reach speeds up to 25 miles per hour and provide significant towing and lifting capabilities.

Figure 7. Base Configuration of a DANNAR 4.00. Source: DD Dannar at www.dannar.us.com/platforms/ (2022).

3. PARALLEL FLIGHT TECHNOLOGIES

Parallel Flight Technologies is capable of providing heavy lift and beyond visual line of sight (BVLOS) applications throughout the field. Testing was carried out in February 2022, at Camp Roberts observing its ability to transport and disperse 10 gallons of KOMODO fire retardant. One of the concepts behind the use of Parallel Flight Technologies Unmanned Aerial System (UAS) would be utilization of the "swarm concept" to deliver large amounts of fire retardant to a wildfire high risk area. As demonstrated in Figure 8, the technology could also be utilized to deliver necessary equipment to firefighters on the frontline.

Figure 8. Demonstration of the Parallel Flight Technologies UAS Transporting a Chainsaw that could Be Utilized for Fighting Wildfires. Source: Parallel Flight Technologies at www.parallelflight.com (2022).

4. EIRENE.AI

The brain behind Project Vesta is the Eirene Artificial Intelligence program being developed through the "Disaster Lab" at the University of California, Berkley. Utilizing Eirene, the team from the Disaster Lab will provide Project Vesta with early detection and notification by utilizing an advanced algorithm that is capable of being ran through a network of preexisting camera systems and/or mobile cameras mounted on UAVs and ground units. Utilizing its state-of-the-art algorithm, Eirene will be able to differentiate between smoke and fog with a 94 percent detection rate and provide firefighters and Project Vesta with the early notification required to prevent fires from spreading into much larger disasters. According to the Chief Operating Officer (COO) from Eirene, the average fire is detected and relayed to the emergency response units anywhere from 8 to 45 minutes. Eirene is capable of reducing the notification time to approximately 17 seconds from detection. The algorithm is continuously being improved to reduce the numbers of false detections and make it more reliable when being ran through a less than

optimal surveillance camera. The benefit of embracing AI goes beyond just the important tasks of detection and notification. In time, Eirene will be able to give accurate determinations of size, speed, and direction of movement along with potential solutions for combating the blaze. Eirene is also capable of providing a common operational picture to the firefighters by producing an eight-digit grid and number of firefighters on the ground.

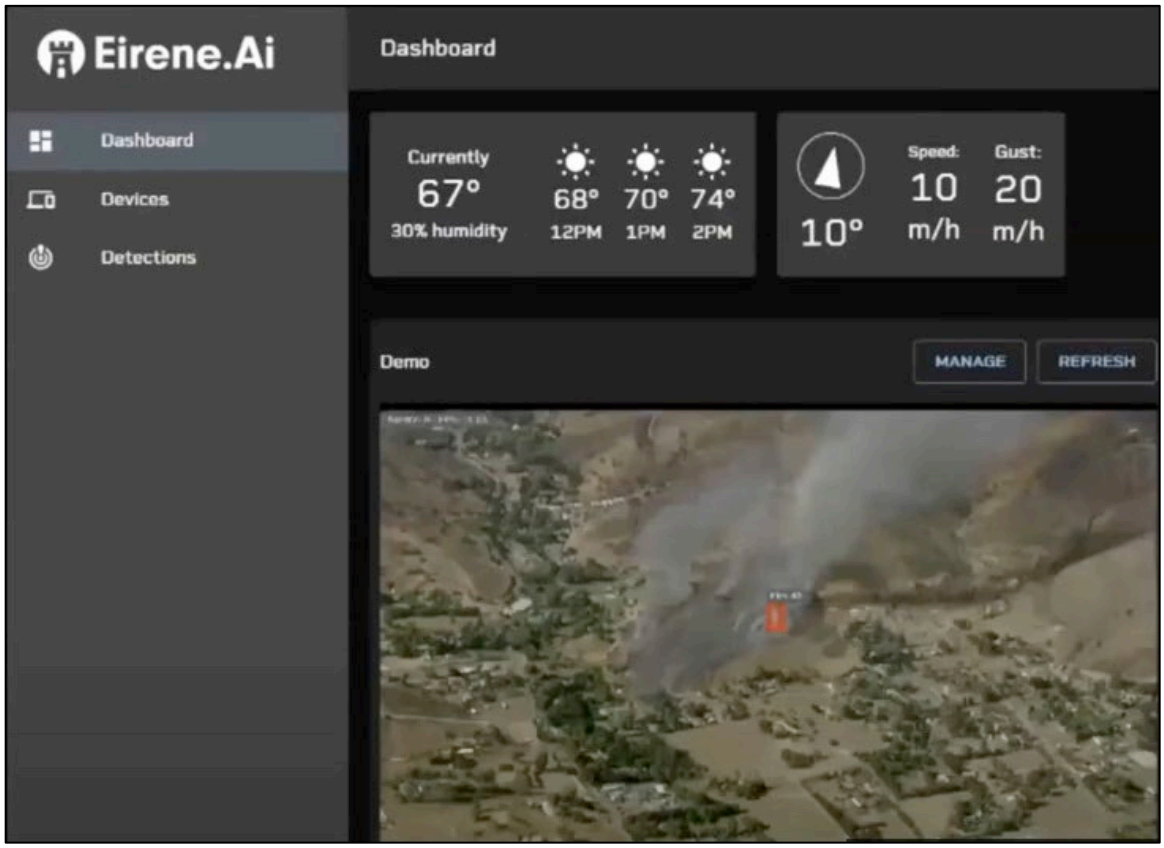


Figure 9. Demonstration of the Eirene.AI Dashboard Detection of a Fire. Source: Eirene.Ai at www.eirene.ai (2022).

5. ARCIMOTO

Arcimoto has developed three electric Fun Utility Vehicles (FUVs) for testing; one roadster for speed test and two first responders equipped with nozzle and pump attachments. The first responder FUV is capable of deploying rapidly with a 30-gallon

tank for suppressant or water equipped with a pump, hose, and nozzle. It has a 100-mile endurance and is capable of reaching speeds up to 85 mph.

Figure 10. Demonstration of the Arcimoto Rapid Responder. Source: Arcimoto at www.arcimoto.com/rapid-responder (2022).

6. HEN NOZZLES

High Efficiency Nozzles (HEN) is another commercial partner that is involved with Project Vesta. The firefighting nozzle has only seen two types of nozzle designs over the past 150 years of firefighting in the U.S.: the fog/combination nozzle and solid stream nozzle (Kaloz, 2013). The fog/combination nozzle is focused on projecting small droplets into a structure/room allowing the multiple droplets of water to convert into steam and lower the thermal temperature. Critics of this nozzle discuss how the steam produced by the small droplets can be hazardous to firefighters causing injuries. The solid stream nozzle if focused on placing uninterrupted volumes of water directly onto the source of the flame extinguishing the fire. Critics of this nozzle discuss how inefficient the solid stream can be due to the amount of water required. This can create logistical constraints of water availability when dealing with wildfires in rural areas without access to a sufficient water resupply. HEN has designed an adjustable high-efficiency water

nozzle that places solid droplets into a fire with a smoothbore nozzle. The HEN nozzle claims to be able to suppress fires up to three times faster while using 50 percent less water.

Figure 11. Demonstration of the HEN Smoothbore Nozzle vs. Conventional 3/8 Smoothbore Nozzle. Source: HEN at https://hennozzles.com (2022).

7. KOMODO

In June 2022, KOMODO participated in a controlled burn at Camp Roberts put on by Camp Roberts Fire Department. KOMODO was dispersed in three locations during the controlled burn to prove effectivity. Approximately 150 gallons of KOMODO was placed around a solar panel network and 25 gallons was placed around an oak tree in the middle of some grassland approximately 60 minutes prior to the controlled burn. During the controlled burn, KOMODO was able to display an effective level of fire protection. KOMODO also permeated a 25ft x 25ft area of grassland with 125 gallons for a future burn to support the proof of concept that areas can be pretreated in advance and leave an enduring level of protection.

Figure 12. Demonstration of KOMODO Being Utilized as a Fire Break in a dense Dry Environment. Source: Komodo at https://komodo-fire.com (2022).

8. BURNBOT

Burnbot is a promising technology that would deliver an semi-autonomous vehicle capable of burning fire breaks in a controlled manner in order to stem off advancing wildfires. The technology is still in the developmental phase, but the prototype that took part in the controlled burn aboard Camp Roberts in June 2022, demonstrating that the theory behind the design was sound and potentially valuable to Project Vesta. The design of Burnbot utilizes torches contained in a compartment that scorch the earth as it is pulled by a semi-autonomous tractor. Once the vegetation has been burned, the ground is saturated with water or flame retardant, and rolled with a water-cooled roller to ensure all embers have been extinguished.

Figure 13. Demonstration of Burnbot Being Utilized to Create a Fire Break in a dense Dry Environment aboard Camp Roberts, CA (2022).

C. COST BENEFIT ANALYSIS

1. Project Vesta Cost Structure

For the purpose of this analysis, we will look at the eight core partners involved in Project Vesta and their related costs. Since the concept of this "system of systems" is still in its infancy, we acknowledge that the price tag for each LTC is capable and likely to increase from what we have detailed in this writing. This is due to the fact that additional commercial technologies will be required to fully incorporate all of the capabilities of the system, such as 5G network meshing. With that said, it is reasonable to assume that the cost of an LTC would not be required to increase by more than 15 percent to still provide substantial benefit to the fire department aboard Camp Pendleton.

The Beam ARC Charger will have a procurement cost of $65,022.02. An additional $1,925.70 will be spent to provide an emergency power panel (6kW) with a 208V or 240V connection for resiliency or emergency power supply during disaster response. Each LTC will be procured with an ARC Mobility Trailer. The hydraulic-lift trailer system will provide the maneuverability required to position the ARC Charger where it will be best suited to support emergency operations and provide continuous power resupply for the firefighters. This trailer will cost $24,534.30 each. The JuiceBar charging station consists of the 48-amp dual unit which costs $7,636. This unit will

require a $250.00 mounting pedestal, and $1,000.00 in custom-length charging cords. The total cost for the BEAM ARC Charger and JuiceBar charging unit will be $100,368.02.

The DANNAR MPS base model 4.00 has a procurement cost of $294,630.00. Although the MPS has a wide array of attachments from numerous manufacturers we only priced out the attachments that we felt would be the most advantageous and provide the baseline for combating wildfires. The climate-controlled HVAC operator cab with joystick and touchscreen tool control will cost $33,075.00. The DANNAR Work Arms with universal quick attach mounting plate for additional attachments costs $22,459.50. The DANNAR carriage adapter is $4,347.00 and the pintle hitch rear bumper with 100,000-pound towing capacity is $3,150.00. The DANNAR front linkage 3-point hitch is $4,347.00 and the DANNAR 480 3-phase interconnect box is $49,995.00. The Guardian "Skid-Mount Fire Fighter" will also be acquired for each LTC procured. This attachment will allow the DANNAR to be outfitted with a 400-gallon tank, 8hp pump, and 150 feet of hose. This capability will cost $5,720.00. To provide training, servicing, and onsite repair, DANNAR Engineering services are estimated to be required for 120 hours at $300 per hour for a total of $36,000.00. The full cost of the DANNAR MPS will be $459,443.50.

Parallel Flight Technologies has yet to establish a base price for its Firefly hybrid drone. According to a product overview on startengine.com in 2019, Parallel Flight estimated that they would be selling the Firefly hybrid drone for an estimated $150,000.00. For our research we will utilize that dollar amount with a recommendation to reevaluate for future cost estimates (https://www.startengine.com/parallel-1).

The AI program Eirene.AI will be on a subscription basis and cost approximately $45,000.00 per year according to the company's COO. This cost will cover AI computing eight streams of video coverage from either stationary or mobile cameras. Additional cameras can be added for additional cost.

According to the Arcimoto website, the Arcimoto Rapid Responder vehicle starts at a base price of $24,900.00. An additional $5,000.00 will be required to outfit the vehicle with emergency lights and siren for a total of $29,900.00.

High Efficiency Nozzles will be utilized on the DANNAR vehicle at a cost of $545.00 per unit. These nozzles are extremely attractive because of their effectiveness and reduction in water consumption decreasing the amount of water required to fight wildfires in remote settings. A strong possibility exists for additional nozzles to be requested by the fire department for utilization outside of the LTC.

Komodo fire suppressant is available for purchase in various quantities. For the LTC we focused on, their largest unit for sale was 275 gallons of premixed fire suppressant. This amount will provide 55,000 square feet of coverage providing up to one year of protection. The fire department will determine strategic pretreating and how much suppressant to have on hand for actual firefighting operations. This unit of sale costs $10,000.00 and will need replenishing annually at a minimum.

Burnbot will be contracted on a per-use basis. According to the company, the fee for Burnbot is estimated to be around $5,000.00 per day. This includes two technicians that will coordinate with the fire department to identify and remove the wildfire's fuel from the desired areas. Burnbot can create fuel breaks in order to create perimeters within which fuel treatment can be done safely using either traditional broadcast burning or for instance, the Burnbot Air technology which can do 2,000 acres per day.

The total costs for Project Vesta will continue to fluctuate as additional partners and technologies are added, but the figures for the core-eight industry partners give us a strong starting point that we can hold up against what a wildfire costs Camp Pendleton.

a. Technology Learning Curve Model

To assess technology progress in the manufacturing of an LTC for Project Vesta, we measured technology improvement by calculating the decrease in the Average Unit Procurement Cost (AUC). The procurement cost of each additional LTC will decrease according to Equation 1. The cost-reduction parameter, w, is the rate of progress – unit

cost declines by a factor of 2^{-w} when cumulative production doubles, meaning that the AUC is reduced by a constant percentage as the number of units produced doubles.

$$y_{t=} Vx_t^{-w} \qquad (1)$$

where:

t = Time measured in years since year 0
y_t = Average unit cost per LTC procured in year t (all costs are in FY23 Dollars unless otherwise stated)
V = Unit procurement cost of first LTC (in year 0)
x_t = Cumulative number of LTCs procured through year t
w = Cost reduction parameter

We utilized a typical learning curve for a technology of 85 percent. This leads us to conclude that when total production doubles, the AUC will be reduced by 15 percent from the initial cost. For our formula w = ln(.85)/ln(2) which calculates an 85 percent learning curve to w = 0.234 as our base.

Table 2. Actual Unit Cost for Project Vesta Local Technology Custer.

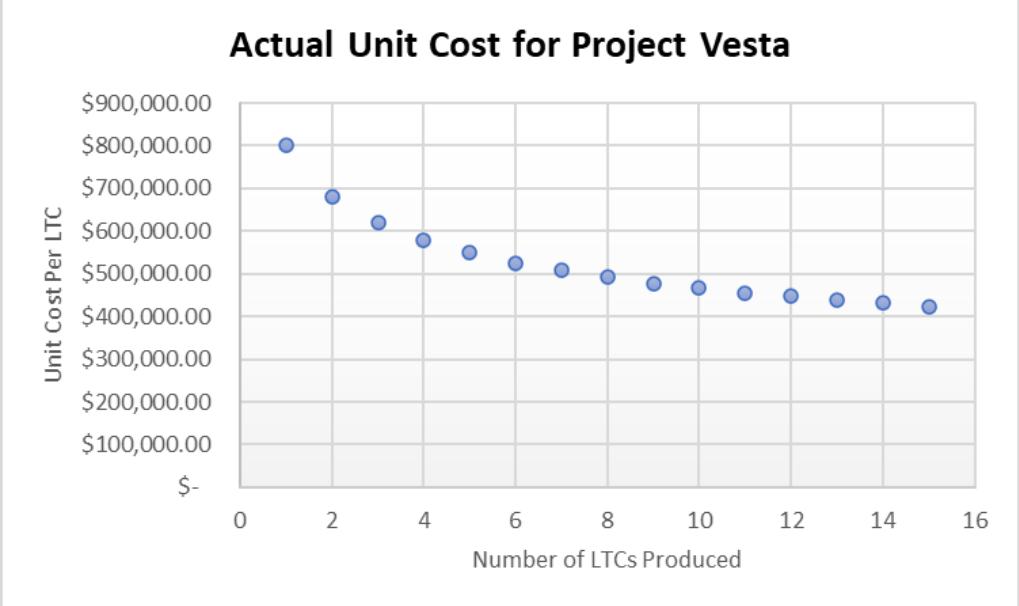


Table 3. Actual Unit Cost for Project Vesta Local Technology Custer by Quantity Produced.

Learning Curve Calculator		
Improvement Rate	15%	
Learning Rate	85%	
Quantity Produced	Unit Cost	Cum Tot
1	$800,256.52	$ 800,256.52
2	$680,218.04	$ 1,360,436.08
3	$618,530.14	$ 1,855,590.41
4	$578,185.34	$ 2,312,741.34
5	$548,712.74	$ 2,743,563.69
6	$525,750.62	$ 3,154,503.70
7	$507,087.72	$ 3,549,614.05
8	$491,457.54	$ 3,931,660.28
9	$478,071.12	$ 4,302,640.08
10	$466,405.83	$ 4,664,058.27
11	$456,098.69	$ 5,017,085.55
12	$446,888.02	$ 5,362,656.29
13	$438,579.38	$ 5,701,531.96
14	$431,024.56	$ 6,034,343.89
15	$424,108.22	$ 6,361,623.24

Table 4. Six Year Fielding Plan Average Unit Cost.

Year	LTCs Delivered to Camp Pendleton	Cumulative LTCs Delivered	Average Unit Production Cost	Total Cost
1	1	1	$ 800,256.52	$ 800,256.52
2	2	3	$ 618,530.14	$ 1,237,060.27
3	2	5	$ 548,712.74	$ 1,097,425.48
4	2	7	$ 507,087.72	$ 1,014,175.44
5	2	9	$ 478,071.12	$ 956,142.24
6	2	11	$ 456,098.69	$ 912,197.37
			AUC	$ 568,126.15
			Cost	$ 6,017,257.33
			Cost + 15%	$ 6,919,845.92

The individual cost for each LTC, in each year, is calculated using Equation 1, and based upon the total number of LTCs delivered to Camp Pendleton over a five-year fielding plan, the AUC is shown in Table 4. This is assuming the fielding of two units per year and that the commercial sector and/or other DOD installations are fielding similar units. This process would allow for an accelerated learning on how to assemble and field the technology. This plan will provide one LTC to each fire station aboard Camp Pendleton over the course of five years.

Potential exists for manufacturing discounts as the number of LTCs are sold as manufacturing and distribution is streamlined. These discounts should be negotiated and implemented as Project Vesta continues its development.

2. Camp Pendleton Wildfire Costs

The historical trendlines for wildfires have not necessarily spiked for Southern California, however a recent study published shows that a severe threat for Southern California in the coming decades persists (Wang et al., 2021). Modeling of an "emissions scenario" which assumes extensive use of coal globally could increase the number of high-risk fire days from the 36 averaged between 1970–1999 up to as many as 71 by the year 2100 (Wang et al., 2021). Even if the model is adjusted to only moderate use of coal globally, the number of high-risk days is expected to reach around 58 (Wang et al.,

2021). The increasing of temperatures and reduction of humidity creates a deficit of moisture in the air which in turn expedites the drying of the wildfire's fuel in the region. This is known as the Vapour pressure deficit (VPD). According to Wang et al., the vast amounts of tinder quality fuel, coupled with the seasonal Santa Anna winds will only compound the future wildfire problem in Southern California.

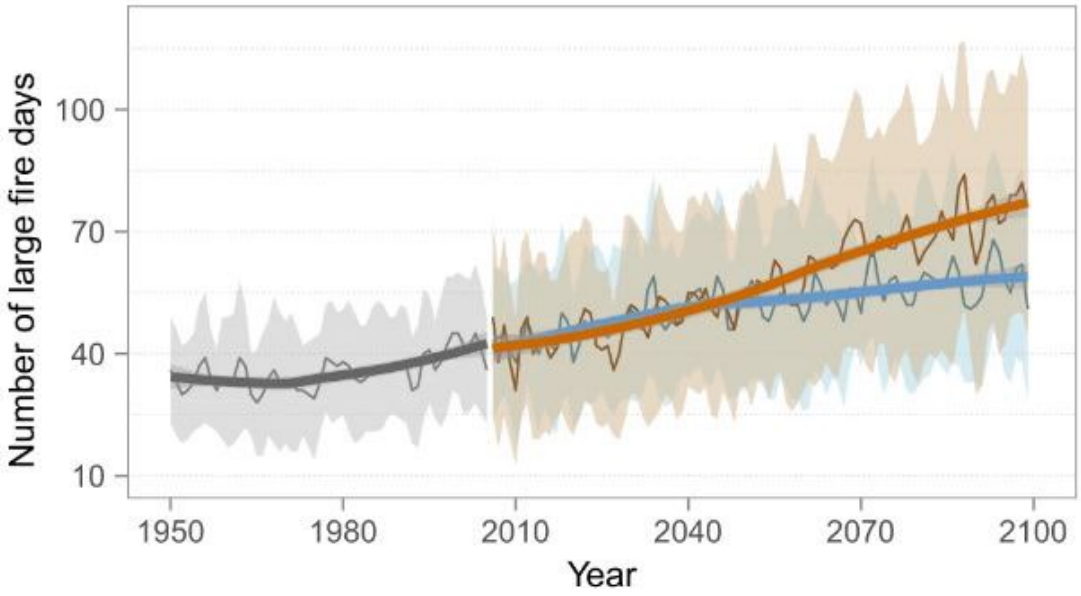


Figure 14. Southern California Large Fire Days Earth System Model. Source: Nature Portfolio at www.nature.com/articles/s43247-022-00344-6 (2022).

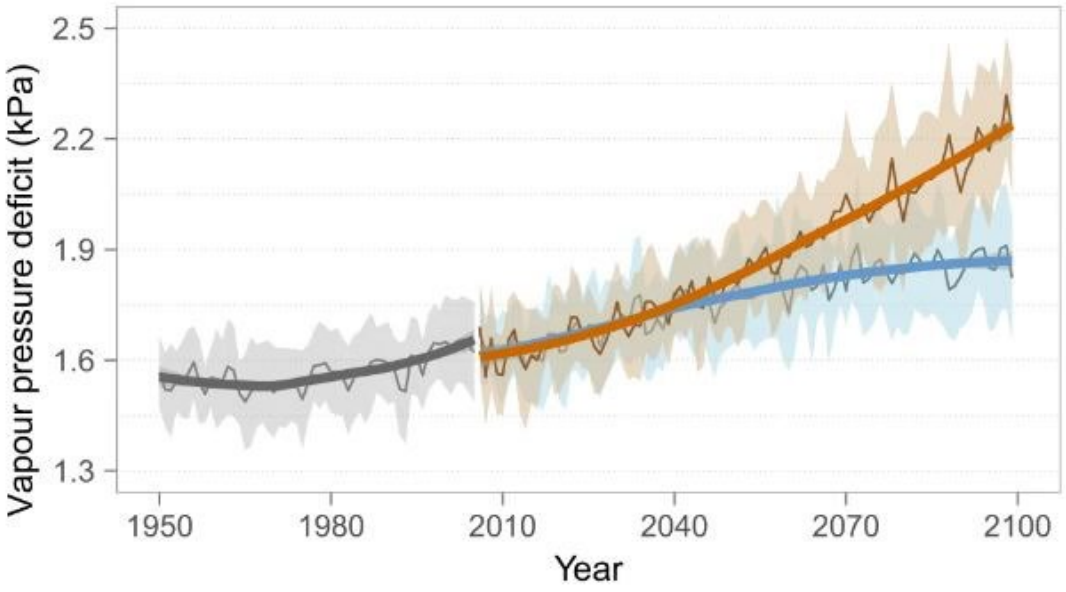


Figure 15. Southern California Vapour Pressure Deficit Earth System Model. Source: https://www.nature.com/articles/s43247-022-00344-6 (2022).

In order to determine the historical number of fires aboard Camp Pendleton, we contacted the Camp Pendleton Fire Chief, Range Control, and Base Safety. According to these sources, there is no historical data for the number of wildfires aboard the base due to the overwhelming number of fires each year. It is estimated that there are over 200 wildfires annually board Camp Pendleton that ignite outside of the live-fire ranges and their impact areas (CPFD, 2022). If you include the fires inside of the impact areas, the number of wildfires is increased by multitudes.

Due to the lack of formal data from Camp Pendleton, we will utilize past fires that occurred recently to help demonstrate the considerable cost placed on Camp Pendleton and potential catastrophes that exist because of wildfires.

The Fiscal Year (FY) 2023 Fire Dept Budget for Camp Pendleton is $970,000.00. According to the CPFD Fire Chief, an estimated four percent of the budget is dedicated to training and preparing for wildfires. That equates to only $38,800 directly focused on wildfires. From this, we concluded that the direct cost of training and preparing for wildfires would not be a major factor in our cost-beneifit analysis. Due to the

unpredictable expenses in fighting wildfires, the CPFD utilizes a supplemental funding request when they require external resources and/or the wildfires exceed the programmed budget. For example, the Creek Side wildfire in 2020 required the CPFD to submit a supplemental funding request for $1.6 million to cover expenses related to the suppression of the fire over a four day period.

Aerial firefighting is highly effective against wildfires however it comes at a steep price to the customer and is typically only enacted once the wildfire has begun to spread. Large firefighting aircraft called Very Large Aircraft Tankers cost approximately $65,000 per drop plus over $20,000 per flight hour. Military aircraft are commonly utilized to combat out of control wildfires aboard DOD installations. The costs can range between $2 thousand dollars to upwards of $20 thousand dollars per flight hour depending on the airframe in use.

Next we turn to indirect costs. One cost that is important is lost training time. There is significant loss when Marines are unable to execute their scheduled training due to wildfires. Even if a fire is ignited in an impact area, and the Marines are not required to cancel their training, they are often placed into a "check fire," which could mean hours of idle time for the Marines. Even if training is allowed to resume, the training will often be altered to compensate for lost time and value will be lost. We use the average daily pay of an E-4, which is $82.68, to create a benchmark cost and apply that across the population of an average infantry company of 150 personnel. Using this metric, the USMC incurs a $12,402 loss for every day of missed training. When compounded by over 200 fires aboard the base that happen every year and the fact that there are over 72,000 active-duty and reserve service members that rely on Camp Pendleton to execute their required training, the cost of lost training increases drastically. We conservatively estimated that Camp Pendleton would lose on average 75 to 125 days of training across five ranges annually. We can confidently assume that based off of the current rate of over 200 wildfires annually, 100 days of missed training is a reasonable measure. As shown in Table 5, a Net Present Value (NPV) benefit of $34,419,781 can be achieved over a thirty year period by incorporating Project Vesta aboard Camp Pendleton. This value was determined by utilizing the OMB real discount rate of 0.5 percent for projects with a

30-year life cycle. This is assuming that five units requiring training areas/ranges are impacted 100 days out of the year due to wildfires. With Project Vesta fully functional with 11 LTC's in place, we then estimated that Camp Pendleton may be able to reduce training days lost by 30 percent.

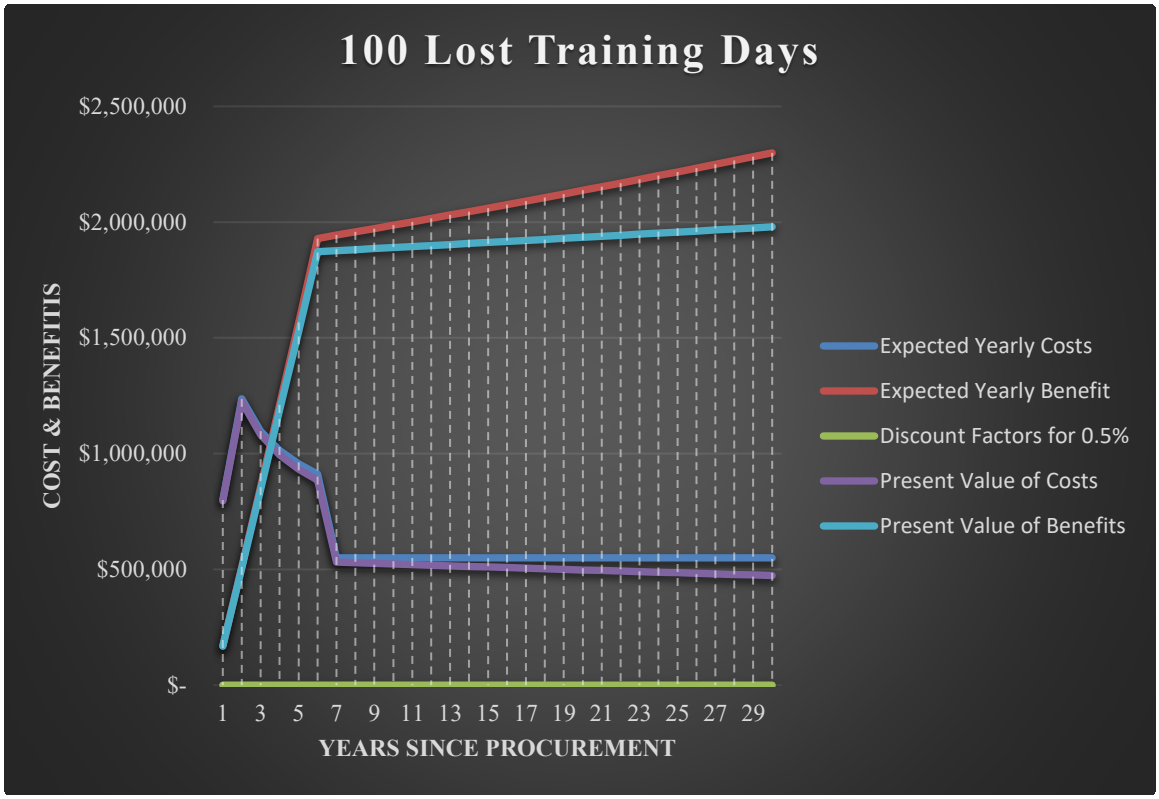
Table 5. Net Present Value of 100 Lost Training Days. Source: OMB (2022).

Year Since Procurement	Expected Yearly Costs	Expected Yearly Benefit	Discount Factors for 0.5%	Present Value of Costs	Present Value of Benefits
1	$ 800,256.52	$ 169,118.18	0.9950	$ 796,275.14	$ 168,276.80
2	$ 1,237,060.27	$ 511,074.98	0.9901	$ 1,224,781.83	$ 506,002.30
3	$ 1,097,425.48	$ 858,037.82	0.9851	$ 1,081,127.35	$ 845,294.89
4	$ 1,014,175.44	$ 1,210,061.73	0.9802	$ 994,142.96	$ 1,186,160.01
5	$ 956,142.24	$ 1,567,202.29	0.9754	$ 932,593.10	$ 1,528,603.14
6	$ 912,197.37	$ 1,929,515.60	0.9705	$ 885,304.04	$ 1,872,629.77
7	$ 550,000.00	$ 1,943,664.74	0.9657	$ 531,129.30	$ 1,876,976.88
8	$ 550,000.00	$ 1,957,917.63	0.9609	$ 528,486.86	$ 1,881,334.08
9	$ 550,000.00	$ 1,972,275.04	0.9561	$ 525,857.57	$ 1,885,701.40
10	$ 550,000.00	$ 1,986,737.73	0.9513	$ 523,241.37	$ 1,890,078.85
11	$ 550,000.00	$ 2,001,306.48	0.9466	$ 520,638.18	$ 1,894,466.47
12	$ 550,000.00	$ 2,015,982.06	0.9419	$ 518,047.94	$ 1,898,864.27
13	$ 550,000.00	$ 2,030,765.26	0.9372	$ 515,470.58	$ 1,903,272.28
14	$ 550,000.00	$ 2,045,656.86	0.9326	$ 512,906.05	$ 1,907,690.52
15	$ 550,000.00	$ 2,060,657.66	0.9279	$ 510,354.28	$ 1,912,119.02
16	$ 550,000.00	$ 2,075,768.46	0.9233	$ 507,815.21	$ 1,916,557.80
17	$ 550,000.00	$ 2,090,990.07	0.9187	$ 505,288.76	$ 1,921,006.88
18	$ 550,000.00	$ 2,106,323.30	0.9141	$ 502,774.89	$ 1,925,466.30
19	$ 550,000.00	$ 2,121,768.97	0.9096	$ 500,273.52	$ 1,929,936.06
20	$ 550,000.00	$ 2,137,327.90	0.9051	$ 497,784.60	$ 1,934,416.20
21	$ 550,000.00	$ 2,153,000.93	0.9006	$ 495,308.06	$ 1,938,906.74
22	$ 550,000.00	$ 2,168,788.89	0.8961	$ 492,843.84	$ 1,943,407.71
23	$ 550,000.00	$ 2,184,692.62	0.8916	$ 490,391.88	$ 1,947,919.12
24	$ 550,000.00	$ 2,200,712.97	0.8872	$ 487,952.12	$ 1,952,441.00
25	$ 550,000.00	$ 2,216,850.79	0.8828	$ 485,524.50	$ 1,956,973.39
26	$ 550,000.00	$ 2,233,106.96	0.8784	$ 483,108.95	$ 1,961,516.29
27	$ 550,000.00	$ 2,249,482.33	0.8740	$ 480,705.42	$ 1,966,069.74
28	$ 550,000.00	$ 2,265,977.79	0.8697	$ 478,313.85	$ 1,970,633.76
29	$ 550,000.00	$ 2,282,594.20	0.8653	$ 475,934.18	$ 1,975,208.38
30	$ 550,000.00	$ 2,299,332.47	0.8610	$ 473,566.35	$ 1,979,793.61
				$ 17,957,942.68	$ 52,377,723.67

LTCs	% per LTC	$ Saved	NPV of Benefit
1	2.727272727	$ 169,118.18	**$ 34,419,780.99**
3	8.181818182	$ 511,074.98	
5	13.63636364	$ 858,037.82	
7	19.09090909	$ 1,210,061.73	
9	24.54545455	$ 1,567,202.29	
11	30	$ 1,929,515.60	

As shown in Table 6, the benefit of incorporating Project Vesta outweighs the cost of lost training days after 3.5 years.

Table 6. Net Present Value of 100 Lost Training Days. Source: OMB (2022).

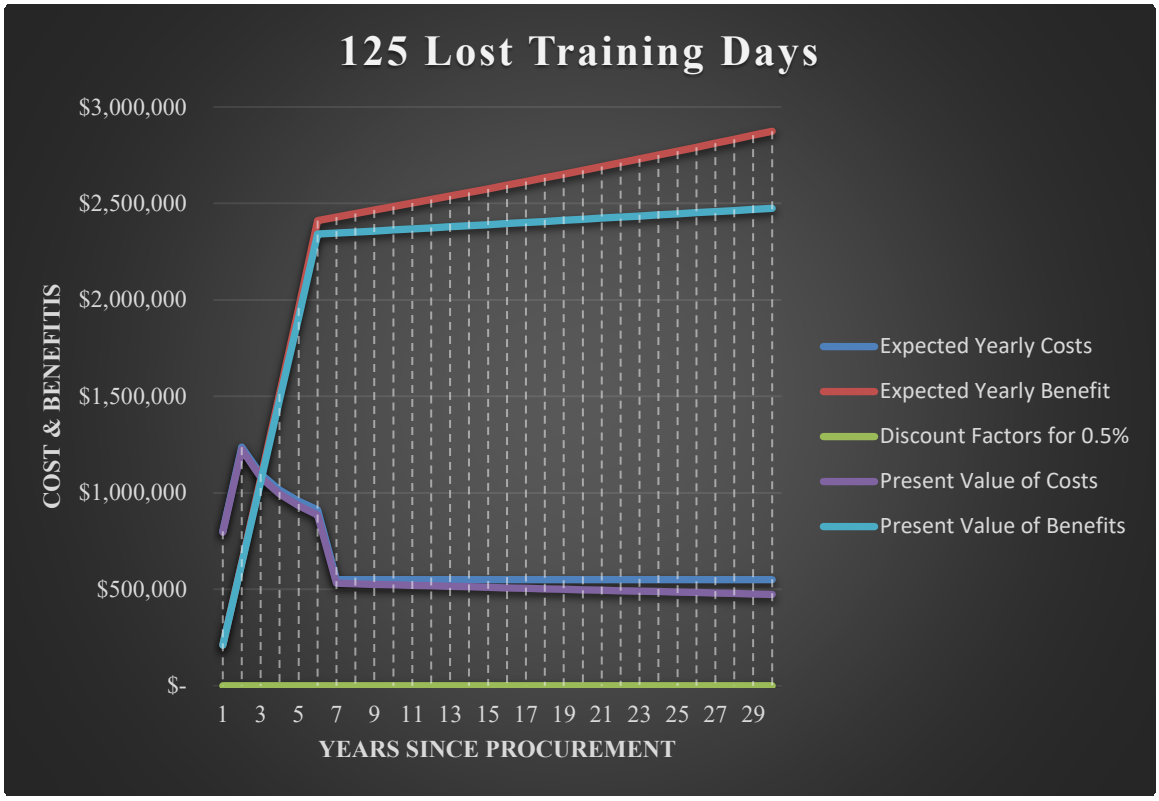


Next we examine the risk wildfires create for Camp Pendleton's facilities and equipment. Table 7 shows the low end range of 75 lost training days. The benefit of incorporating Project Vesta outweighs the cost of lost training days after 4.5 years and return a NPV benefit of $21,325,350.

Table 7. Net Present Value of 75 Lost Training Days. Source: OMB (2022).

Next we examine the risk wildfires create for Camp Pendleton's facilities and equipment. Table 8 shows the high end range of 125 lost training days. The benefit of incorporating Project Vesta outweighs the cost of lost training days just over 3 years and return a NPV benefit of $47,514,211.

Table 8. Net Present Value of 125 Lost Training Days. Source: OMB (2022).



It has been very fortunate that Camp Pendleton has avoided any major structural losses or military equipment loss due to wildfires aboard the base. The 2020 Military Construction (MILCON) inventory for Camp Pendleton valued the structures aboard the base at $18,565,721,000.00. Most of this value resides in the housing developments and business districts aboard the base. These areas tend to be insulated from wildfires due to the natural firebreaks from pavement and reduced vegetation to burn. However, as the wildfires increase in frequency and size, the threat to housing areas and offices will become elevated. This will lead to additional cost in evacuations and disruptions in operations. Of the MILCON inventory, Camp Pendleton has 6,880 residential homes. The current average cost of fire insurance for a 2,000 square foot home in San Diego County, CA is $1,575 annually (Policy Genius, 2022). As shown in Table 9, a NPV of

$27,806,048 can be achieved assuming a 15 percent policy reduction rate over 30 years with Project Vesta fully incorporated.

Table 9. Net Present Value of Residential Wildfire Insurance Premiums. Source: OMB (2022).

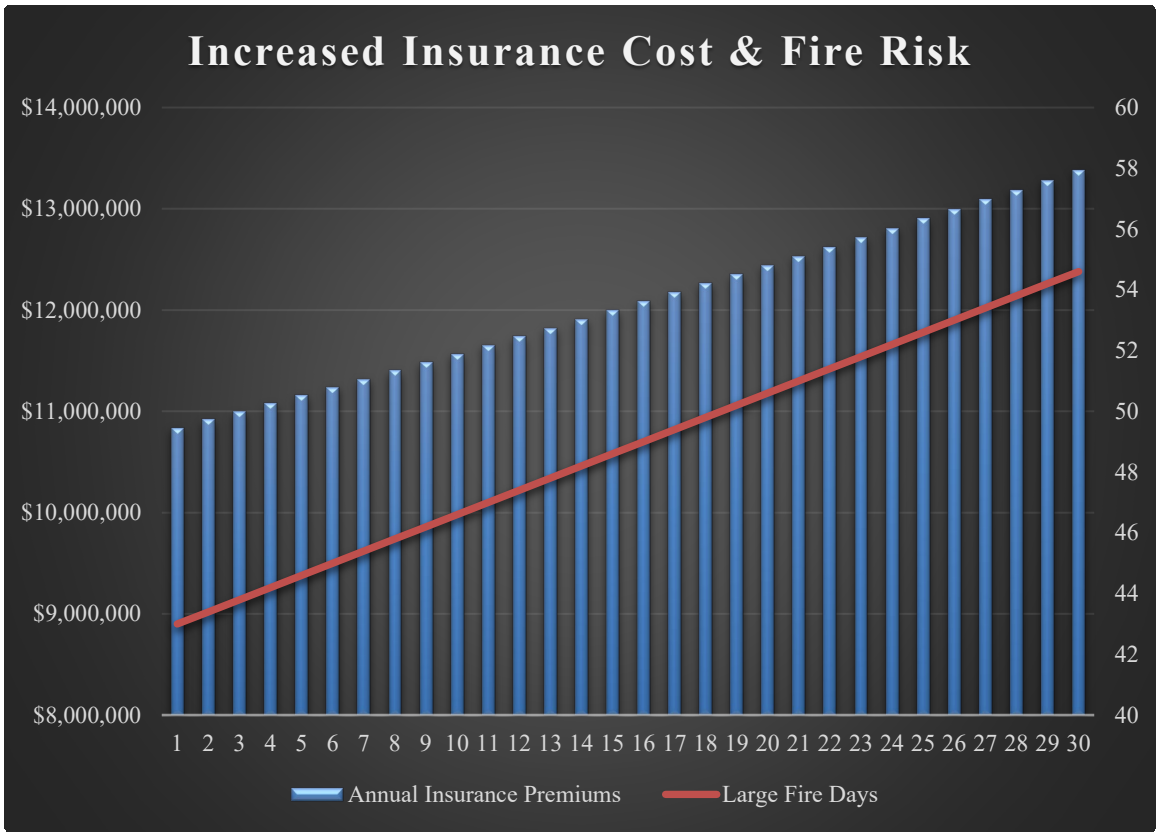
Year Since Procurement	Expected Yearly Costs	Expected Yearly Benefit	Discount Factors for 0.5%	Present Value of Costs	Present Value of Benefits
1	$ 800,256.52	$ 147,763.64	0.9950	$ 796,275.14	$ 147,028.49
2	$ 1,237,060.27	$ 446,541.56	0.9901	$ 1,224,781.83	$ 442,109.41
3	$ 1,097,425.48	$ 749,693.42	0.9851	$ 1,081,127.35	$ 738,559.54
4	$ 1,014,175.44	$ 1,057,267.29	0.9802	$ 994,142.96	$ 1,036,383.64
5	$ 956,142.24	$ 1,369,311.72	0.9754	$ 932,593.10	$ 1,335,586.49
6	$ 912,197.37	$ 1,685,875.75	0.9705	$ 885,304.04	$ 1,636,172.89
7	$ 550,000.00	$ 1,698,238.28	0.9657	$ 531,129.30	$ 1,639,971.09
8	$ 550,000.00	$ 1,710,691.46	0.9609	$ 528,486.86	$ 1,643,778.11
9	$ 550,000.00	$ 1,723,235.96	0.9561	$ 525,857.57	$ 1,647,593.96
10	$ 550,000.00	$ 1,735,872.45	0.9513	$ 523,241.37	$ 1,651,418.68
11	$ 550,000.00	$ 1,748,601.60	0.9466	$ 520,638.18	$ 1,655,252.27
12	$ 550,000.00	$ 1,761,424.09	0.9419	$ 518,047.94	$ 1,659,094.76
13	$ 550,000.00	$ 1,774,340.62	0.9372	$ 515,470.58	$ 1,662,946.17
14	$ 550,000.00	$ 1,787,351.86	0.9326	$ 512,906.05	$ 1,666,806.52
15	$ 550,000.00	$ 1,800,458.51	0.9279	$ 510,354.28	$ 1,670,675.84
16	$ 550,000.00	$ 1,813,661.27	0.9233	$ 507,815.21	$ 1,674,554.13
17	$ 550,000.00	$ 1,826,960.85	0.9187	$ 505,288.76	$ 1,678,441.43
18	$ 550,000.00	$ 1,840,357.95	0.9141	$ 502,774.89	$ 1,682,337.75
19	$ 550,000.00	$ 1,853,853.30	0.9096	$ 500,273.52	$ 1,686,243.12
20	$ 550,000.00	$ 1,867,447.60	0.9051	$ 497,784.60	$ 1,690,157.55
21	$ 550,000.00	$ 1,881,141.60	0.9006	$ 495,308.06	$ 1,694,081.07
22	$ 550,000.00	$ 1,894,936.01	0.8961	$ 492,843.84	$ 1,698,013.70
23	$ 550,000.00	$ 1,908,831.57	0.8916	$ 490,391.88	$ 1,701,955.46
24	$ 550,000.00	$ 1,922,829.04	0.8872	$ 487,952.12	$ 1,705,906.36
25	$ 550,000.00	$ 1,936,929.14	0.8828	$ 485,524.50	$ 1,709,866.44
26	$ 550,000.00	$ 1,951,132.64	0.8784	$ 483,108.95	$ 1,713,835.72
27	$ 550,000.00	$ 1,965,440.30	0.8740	$ 480,705.42	$ 1,717,814.20
28	$ 550,000.00	$ 1,979,852.87	0.8697	$ 478,313.85	$ 1,721,801.92
29	$ 550,000.00	$ 1,994,371.13	0.8653	$ 475,934.18	$ 1,725,798.90
30	$ 550,000.00	$ 2,008,995.86	0.8610	$ 473,566.35	$ 1,729,805.16
				$ 17,957,942.68	$ 45,763,990.79

LTCs	% per LTC	$ Saved
1	0.014	$ 147,763.64
3	0.041	$ 446,541.56
5	0.068	$ 749,693.42
7	0.095	$ 1,057,267.29
9	0.123	$ 1,369,311.72
11	0.150	$ 1,685,875.75

NPV of Benefit
$ 27,806,048.11

As shown in Table 10, the cost of wildfire insurance premiums are expected to rise in correlation with the projected increase in the number of large fire days. According to the research data, "climate change has significantly increased the frequency of large fire days from 34 in 1950–1979 to 43 days in 2000–2019. Both scenarios are expected to increase the annual frequency of large fire days to 55 days by 2050" (Wang et al., 2021). The research projects a 22percent increase of large fire days over the next 30 years increasing the annual insurance premium by 0.0073 percent. The estimated annual insurance cost is currently $10,800,000 with it increasing to $13,381,000 by 2050.

Table 10. Increased Insurance Cost Associated With Increase in Large Fire Days. Source: Wang et al. (2021).



Camp Pendleton is home to another significant financial consideration when accounting for the number of aircraft stationed aboard the base. Currently, the base has seven flying squadrons permanently assigned with approximately 150 aircraft valued at

$4.962 billion. Historically, when a natural disaster such as a hurricane or wildfire is approaching a base, squadrons are able to fly off all operational aircraft to prevent loss. Unfortunatley, not all aircraft are operational and must be left behind. In 2018, Tyndall AFB was struck by Hurrican Michael and 31percent of the F-22's were non-mission capable requiring them to shelter in place. When the hurricane struck, 17 of 55 aircraft were damaged which led to a damage assessment of more than $1 billion (Leone, 2018). If a similar scenario were to take place aboard Camp Pendleton with a wildfire, the damage costs to aircraft could exceed $1.5 billion. As the large fire days are expected to increase over the next 30 years, the risk to these assets also increases.

In addition, we studied the cost of bringing in firefighting assets to deal with major blaze. When a wildfire is not contained quickly and rapidly spreads, it is not uncommon to incorporate military aircraft stationed aboard Camp Pendleton and Marine Corps Air Station (MCAS) Miramar. This was the case during a wildfire that broke out in 2014. Over the course of five days, for approximately ten hours per day, 22 aircraft were mobilized to help combat the blaze. From personal observations, the "cost per flight hour" can vary between $2,000 for a UH-1Y and $20,000 for a CH-53E. Utilizing the low end of $2,000 per hour, the cost for military aircraft alone for one fire in 2014, was $2,200,000.

Next, we consider the costs of wildifes for health impacts. The "true" total cost for a wildfire is very difficult to determine due to the varying degrees that specific variables affect individuals and that effects such as medical problems may not appear until after the fire is over. Often, government agencies, insurance companies, and political organizations simply calculate wildfire costs on the loss of life and destroyed physical assets. In 2021, researchers published a study in Nature Sustainability that attempted for the first time to capture a total cost of a wildfire (Wang et al., 2021). The researchers examined wildfires in the state of California for 2018, which is notably one of the worst wildfire years in history. What the study showed was that wildfires caused an estimated $148.5 billion in damage. With $27.7 billion in capital losses, $32.2 billion in health costs, and $88.6 billion in indirect losses due to broad economic disruption in supply chains and productivity in multiple industry sectors throughout the state.

According to CAL Fire, the state of California had 1,063,414 acres burn due to wildfires in 2018. When calculating the total acres burned in California versus Camp Pendleton which has approximately 1,500 acres burned annually, we're able to assume that Camp Pendleton wildfires contributed to approximately 0.14percent of the health impacts due to wildfires. This figure totals approximately $45,419,752 in health impacts. Each LTC may be capable of reducing health costs by 2.7 percent. Over a 30 year period, Camp Pendleton may see an average of $13,928,112 in reduced annual health costs from wildfires as shown in Table 11.

Table 11. Net Present Value of Avoided Health Costs (Camp Pendleton Area). Source: Wang et al.(2021)

Year Since Procurement	Expected Yearly Costs	Expected Yearly Benefit	Discount Factors for 0.5%	Present Value of Costs	Present Value of Benefits
1	$ 800,256.52	$ 1,238,720.51	0.9950	$ 796,275.14	$ 1,232,557.72
2	$ 1,237,060.27	$ 3,743,412.14	0.9901	$ 1,224,781.83	$ 3,706,256.91
3	$ 1,097,425.48	$ 6,284,770.91	0.9851	$ 1,081,127.35	$ 6,191,434.26
4	$ 1,014,175.44	$ 8,863,200.05	0.9802	$ 994,142.96	$ 8,688,129.89
5	$ 956,142.24	$ 11,479,106.45	0.9754	$ 932,593.10	$ 11,196,383.73
6	$ 912,197.37	$ 14,132,901.00	0.9705	$ 885,304.04	$ 13,716,235.91
7	$ 550,000.00	$ 14,236,537.71	0.9657	$ 531,129.30	$ 13,748,076.83
8	$ 550,000.00	$ 14,340,934.24	0.9609	$ 528,486.86	$ 13,779,991.52
9	$ 550,000.00	$ 14,446,096.31	0.9561	$ 525,857.57	$ 13,811,980.29
10	$ 550,000.00	$ 14,552,029.53	0.9513	$ 523,241.37	$ 13,844,043.33
11	$ 550,000.00	$ 14,658,739.57	0.9466	$ 520,638.18	$ 13,876,180.79
12	$ 550,000.00	$ 14,766,232.10	0.9419	$ 518,047.94	$ 13,908,392.86
13	$ 550,000.00	$ 14,874,512.88	0.9372	$ 515,470.58	$ 13,940,679.71
14	$ 550,000.00	$ 14,983,587.69	0.9326	$ 512,906.05	$ 13,973,041.51
15	$ 550,000.00	$ 15,093,462.33	0.9279	$ 510,354.28	$ 14,005,478.43
16	$ 550,000.00	$ 15,204,142.69	0.9233	$ 507,815.21	$ 14,037,990.65
17	$ 550,000.00	$ 15,315,634.67	0.9187	$ 505,288.76	$ 14,070,578.34
18	$ 550,000.00	$ 15,427,944.22	0.9141	$ 502,774.89	$ 14,103,241.68
19	$ 550,000.00	$ 15,541,077.34	0.9096	$ 500,273.52	$ 14,135,980.85
20	$ 550,000.00	$ 15,655,040.06	0.9051	$ 497,784.60	$ 14,168,796.02
21	$ 550,000.00	$ 15,769,838.46	0.9006	$ 495,308.06	$ 14,201,687.36
22	$ 550,000.00	$ 15,885,478.69	0.8961	$ 492,843.84	$ 14,234,655.06
23	$ 550,000.00	$ 16,001,966.91	0.8916	$ 490,391.88	$ 14,267,699.29
24	$ 550,000.00	$ 16,119,309.33	0.8872	$ 487,952.12	$ 14,300,820.23
25	$ 550,000.00	$ 16,237,512.22	0.8828	$ 485,524.50	$ 14,334,018.05
26	$ 550,000.00	$ 16,356,581.90	0.8784	$ 483,108.95	$ 14,367,292.94
27	$ 550,000.00	$ 16,476,524.72	0.8740	$ 480,705.42	$ 14,400,645.08
28	$ 550,000.00	$ 16,597,347.07	0.8697	$ 478,313.85	$ 14,434,074.63
29	$ 550,000.00	$ 16,719,055.42	0.8653	$ 475,934.18	$ 14,467,581.79
30	$ 550,000.00	$ 16,841,656.25	0.8610	$ 473,566.35	$ 14,501,166.74
				$ 17,957,942.68	$ 383,645,092.43

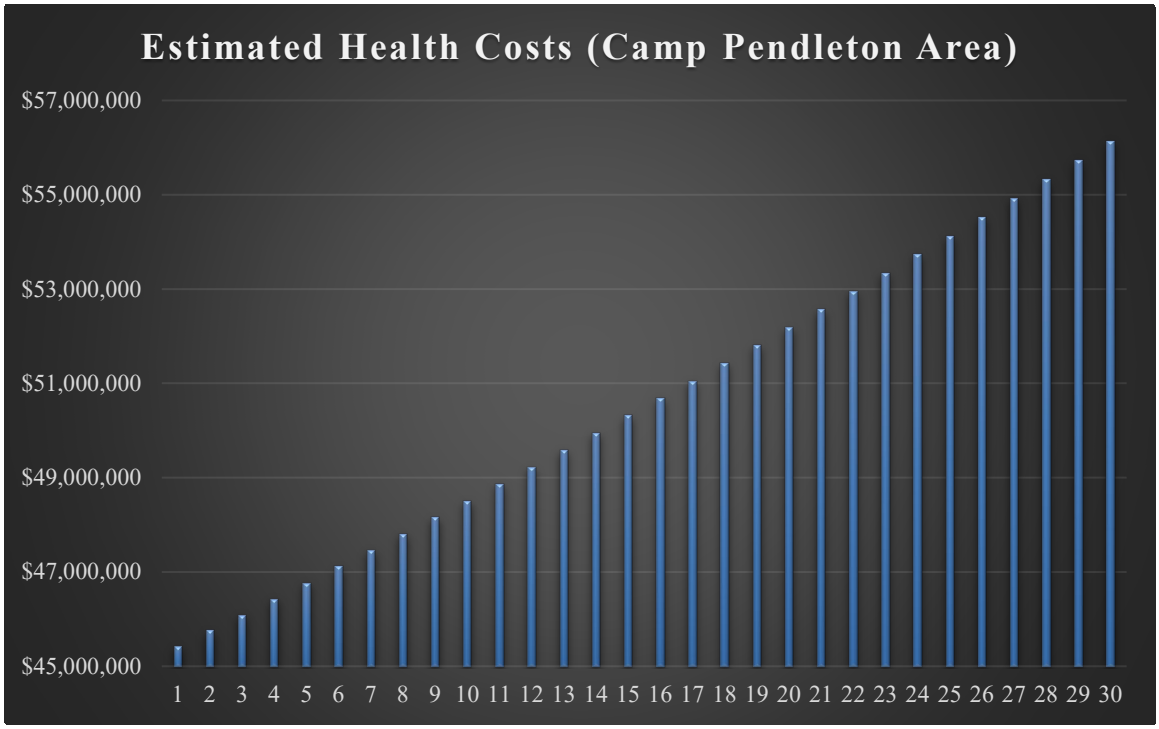
LTCs	% per LTC	$ Saved
1	2.727272727	$ 1,238,720.51
3	8.181818182	$ 3,743,412.14
5	13.63636364	$ 6,284,770.91
7	19.09090909	$ 8,863,200.05
9	24.54545455	$ 11,479,106.45
11	30	$ 14,132,901.00

NPV of Benefit
$ 365,687,149.75

As shown in Table 12, health costs due to wildfires in the San Diego region are expected to rise over the next 30 years by 22 percent. This study demonstrates there are significant costs to the Marine Corps when wildfires are ignited aboard Camp Pendleton but also to the local community living and working in the shadow of MCB Camp Pendleton. The health costs of service members and their families, mandatory

evacuations, and disruption in the civilian workforce aboard Camp Pendleton are substantial. Perhaps far more than we have previously considered, and these should be factored into our considerations for fire prevention and response spending.

Table 12. Estimated Health Costs Due to Wildfires in the Camp Pendleton Area over the Next 30 Years. Source: Wang et al. (2021)



Southern California is densely populated and is subject to severe economic disruption due to wildfires. This may include the shutting down of supply chains and mandatory evaucuations. The 2021 study conducted by Wang et al., estimated $88.6 billion in indirect losses due to broad economic disruption in supply chains and productivity in multiple industry sectors throughout the state. In 2018, Camp Pendleton accounted for approximately 0.14percent of the economic disruption due to wildfires. This figure totals approximately $124,974,845 in broad economic disruption. Each LTC may be capable of reducing economic disruption costs by 2.7 percent. Over a 30 year

period, Camp Pendleton and the surrounding area may see an average of $38,323,935 in reduced annual economic disruption costs from wildfires as shown in Table 13.

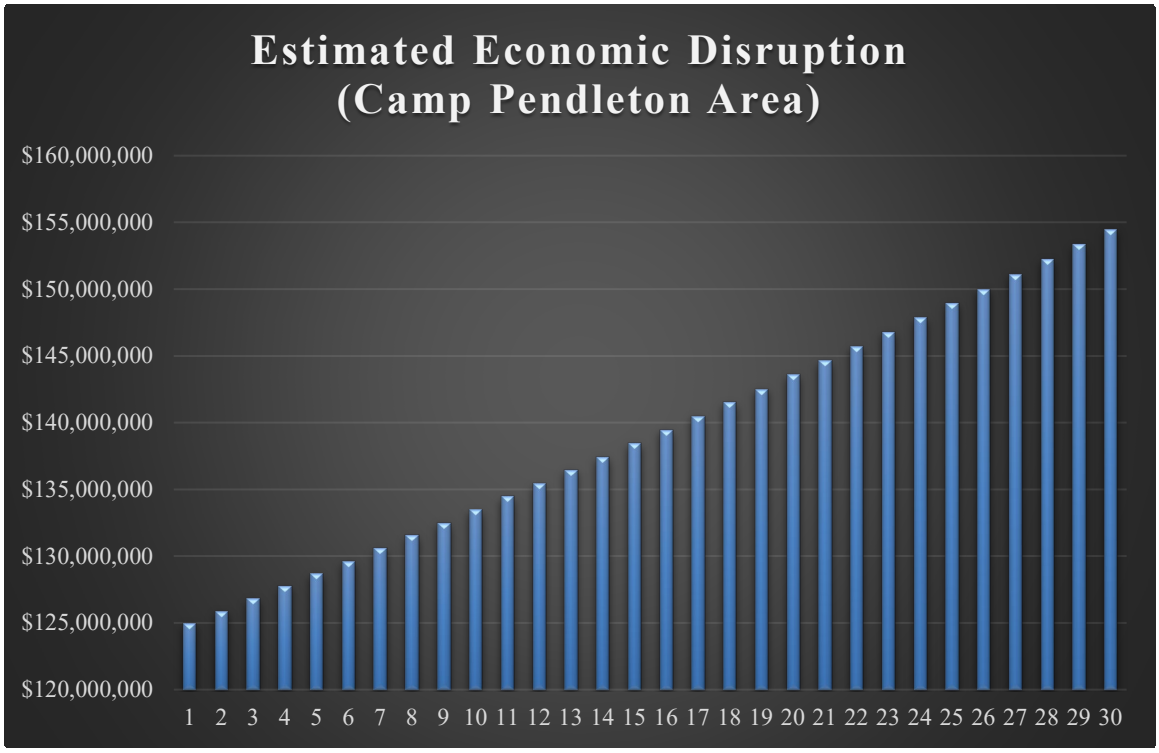
Table 13. Net Present Value of Avoided Economic Disruption (Camp Pendleton Area). Source: Wang (2021)

Year Since Procurement	Expected Yearly Costs	Expected Yearly Benefit	Discount Factors for 0.5%	Present Value of Costs	Present Value of Benefits
1	$ 800,256.52	$ 3,408,404.86	0.9950	$ 796,275.14	$ 3,391,447.63
2	$ 1,237,060.27	$ 10,300,196.09	0.9901	$ 1,224,781.83	$ 10,197,961.53
3	$ 1,097,425.48	$ 17,292,879.05	0.9851	$ 1,081,127.35	$ 17,036,058.34
4	$ 1,014,175.44	$ 24,387,562.82	0.9802	$ 994,142.96	$ 23,905,848.01
5	$ 956,142.24	$ 31,585,367.34	0.9754	$ 932,593.10	$ 30,807,440.85
6	$ 912,197.37	$ 38,887,423.46	0.9705	$ 885,304.04	$ 37,740,947.48
7	$ 550,000.00	$ 39,172,584.94	0.9657	$ 531,129.30	$ 37,828,559.05
8	$ 550,000.00	$ 39,459,837.51	0.9609	$ 528,486.86	$ 37,916,374.00
9	$ 550,000.00	$ 39,749,196.49	0.9561	$ 525,857.57	$ 38,004,392.81
10	$ 550,000.00	$ 40,040,677.35	0.9513	$ 523,241.37	$ 38,092,615.94
11	$ 550,000.00	$ 40,334,295.64	0.9466	$ 520,638.18	$ 38,181,043.88
12	$ 550,000.00	$ 40,630,067.03	0.9419	$ 518,047.94	$ 38,269,677.09
13	$ 550,000.00	$ 40,928,007.31	0.9372	$ 515,470.58	$ 38,358,516.05
14	$ 550,000.00	$ 41,228,132.39	0.9326	$ 512,906.05	$ 38,447,561.24
15	$ 550,000.00	$ 41,530,458.28	0.9279	$ 510,354.28	$ 38,536,813.14
16	$ 550,000.00	$ 41,835,001.13	0.9233	$ 507,815.21	$ 38,626,272.23
17	$ 550,000.00	$ 42,141,777.20	0.9187	$ 505,288.76	$ 38,715,938.99
18	$ 550,000.00	$ 42,450,802.85	0.9141	$ 502,774.89	$ 38,805,813.90
19	$ 550,000.00	$ 42,762,094.59	0.9096	$ 500,273.52	$ 38,895,897.45
20	$ 550,000.00	$ 43,075,669.03	0.9051	$ 497,784.60	$ 38,986,190.11
21	$ 550,000.00	$ 43,391,542.91	0.9006	$ 495,308.06	$ 39,076,692.38
22	$ 550,000.00	$ 43,709,733.09	0.8961	$ 492,843.84	$ 39,167,404.74
23	$ 550,000.00	$ 44,030,256.56	0.8916	$ 490,391.88	$ 39,258,327.68
24	$ 550,000.00	$ 44,353,130.44	0.8872	$ 487,952.12	$ 39,349,461.69
25	$ 550,000.00	$ 44,678,371.94	0.8828	$ 485,524.50	$ 39,440,807.26
26	$ 550,000.00	$ 45,005,998.44	0.8784	$ 483,108.95	$ 39,532,364.87
27	$ 550,000.00	$ 45,336,027.43	0.8740	$ 480,705.42	$ 39,624,135.03
28	$ 550,000.00	$ 45,668,476.52	0.8697	$ 478,313.85	$ 39,716,118.22
29	$ 550,000.00	$ 46,003,363.46	0.8653	$ 475,934.18	$ 39,808,314.94
30	$ 550,000.00	$ 46,340,706.12	0.8610	$ 473,566.35	$ 39,900,725.69
				$ 17,957,942.68	$ 1,055,619,722.23

LTCs	% per LTC	$ Saved	NPV of Benefit
1	2.727272727	$ 3,408,404.86	**$ 1,037,661,779.55**
3	8.181818182	$ 10,300,196.09	
5	13.63636364	$ 17,292,879.05	
7	19.09090909	$ 24,387,562.82	
9	24.54545455	$ 31,585,367.34	
11	30	$ 38,887,423.46	

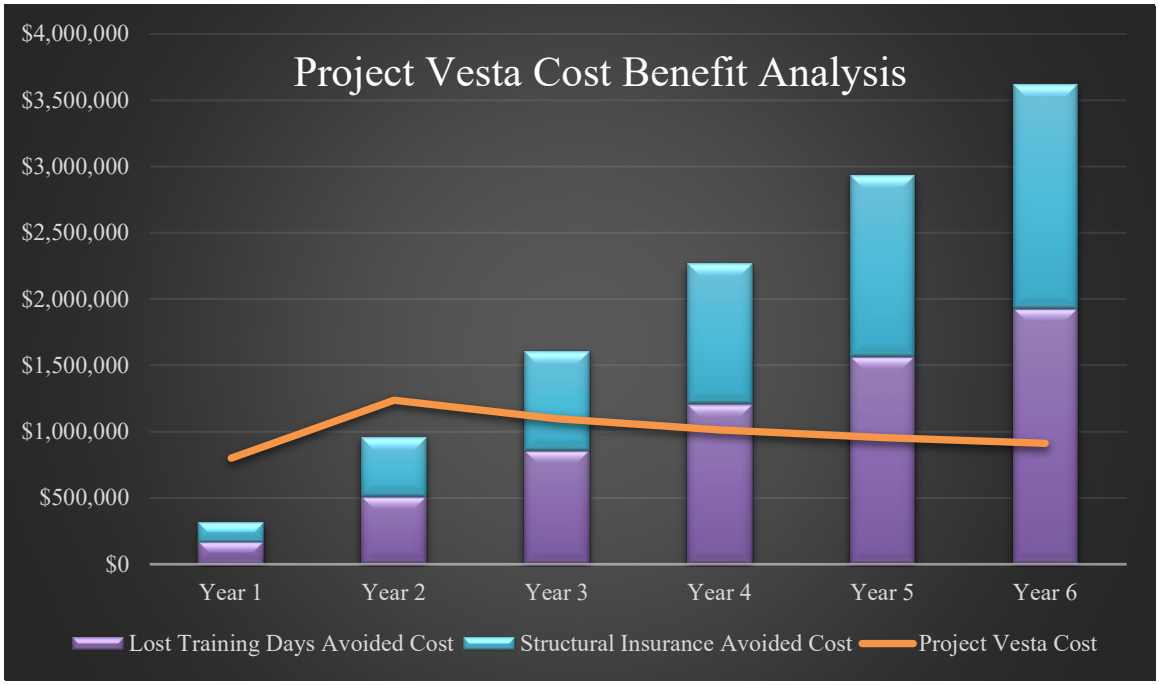
As shown in Table 14, the estimated economic disruptions in the Camp Pendleton area are expected to rise over the next 30 years by 22 percent due to wildfires (Wang, 2021).

Table 14. Estimated Economic Disruption Due to Wildfires in the Camp Pendleton Area over the Next 30 Years. Source: Wang et al. (2021)



As shown in the Table 15, our research indicates that Project Vesta is a worthwile intiative that the DOD should continue to invest in for further development and fielding. The cost of Project Vesta would quickly be outweighed in avoidance costs within 36 months of incorporation. The current estimate to purchase a local tech cluster is $568,126 when factoring the learning curve and acquisition of 11 units. Immediate benefits could be realized in the areas of recouped lost training days and a reduction in the costs of wildfire insurance premiums (shadow cost).

Table 15. Project Vesta Cost Benefit Analysis with Lost Training Days and Structural Insurance Avoidance Costs



In addition to the calculated avoidance costs of lost training days and structural insurance, we also calculated avoidance cost for loss of military aircraft, associated health impacts, and economic distruption. These account for hundreds of millions of dollars of additional cost that are not factored in when analyzing the impacts of annual wildifires aboard MCB Camp Pendleton. Project Vesta may have the potential to significantly reduce the impacts of wildfires with a minimal investment garnering a large return. Upon full maturation and implementation, Project Vesta may have the ability to reduce the threat of wildfires aboard MCB Camp Pendleton by as much as 30%.

Although we focused on MCB Camp Pendleton for our research, there are an additional 24 DOD installations categorized as "High" risk for the threat of wildfires encompassing 9,536,140 acres (Beavers, 2021). MCB Camp Pendleton has a total acreage of 125,000 with shared characteristics that cause the installations to be identified as high risk; causal factors such as high explosive impact areas, dry climate, or fuel rich environments. MCB Camp Pendleton is a high side case due to the nature that the

surroundings of the installation are densely populated with multiple service members and families living aboard the base. Although other installations are larger in acreage, the dollar value of benefits will likely be less due to the sparse populations and remoteness of the installations. It is likely that Project Vesta would still generate net positive returns for these installations.

IV. RESEARCH AND VIGNETTE

A. CONCEPT OF EXECUTION

Project Vesta enhances firefighting agencies through all phases of the firefighting process. The AI and autonomous vehicles allow firefighters to safely monitor and combat fires during hours of darkness and in remote locations. Although the LTC is modular and scalable, a potential example of a basic employment of one LTC would be the following:

Prior to wildfire season, the LTC would proactively assist firefighting agencies with prevention efforts. The fire-retardant spray, Komodo, would be strategically applied to high-risk areas and structures such as power line poles and the vegetation below transmission lines, ditches along highly traveled routes in training areas, in designated impact areas, and along roadways. Burnbot would be deployed throughout impact areas to remove wildfire fuel and create additional firebreaks where desired. Its remote operation keeps all personnel safe from the hazard of unexploded ordnance. The Dannar utility vehicle will assist bulldozer teams with the creation of firebreaks and is also capable of assisting in the application of Komodo to desired areas.

Detection of wildfires may be the most important aspect of preventing catastrophic events. Eirene can run through preexisting surveillance cameras or new cameras that are strategically placed in areas deemed to be high threat. Eirene will also be run through Parallel Flight's heavy-lift Firefly aircraft. The high-definition camera aboard the aircraft can utilize Eirene to sweep impact areas once training has been completed to ensure no fires have ignited or are smoldering.

Once Eirene has detected fire or determined conditions are ideal for ignition of a fire, it will que the LTC and alert first responders. The Parallel Flight Aircraft, armed with Komodo retardant and suppressant, will immediately respond to the eight-digit grid provided by Eirene. It will apply the Komodo to the fire and live-stream the fire to a quick response force aboard the Arcimoto vehicle. The Dannar vehicle will also be dispatched to provide additional fire suppression for the quick response team if they require.

If the fire is unable to be extinguished by the initial response of the LTC, then all of Project Vesta will be activated. The Beam Solar ARC and JuiceBar charging stations will be established at a secure location where they can ensure that not only the COTS technologies of Project Vesta remain charged, but that the firefighting agencies have any electrical requirements for legacy equipment satisfied. Firefighters armed with HEN nozzles attached to all water dispensing equipment will be able to engage flames more effectively while using significantly less water which is crucial when most locations will require water to be trucked in and conserved. Parallel Flight will continue to provide live overhead situational awareness for the firefighters on the ground, and also be able to refill its extinguishing capability or move medical supplies or firefighting tools up to (100 pounds) to areas of need. The Dannar vehicle will also continue to aid as a fire engine and mobile power supply for the firefighters. It can also be tasked with creating ad hoc firebreaks to turn the fire or cut it off. The Arcimoto vehicle's role can shift to rapidly moving personnel in and out of the fight, or rapidly relocating personnel to gain a better vantage point on the fire.

B. EXPERIMENTATION EVENTS

In February 2022, the SoCal Tech Bridge conducted its first experiment for Project Vesta in during the NPS Joint Interagency Field Experimentation (JIFX) 22–2 at Camp Roberts, CA. Professional firefighters, industry experts, and interested stakeholders spent four days envisioning and working to merge potential technologies into a feasible and value-added system capable of detecting wildfires, responding to them, and suppressing them. Participating COTS technologies were individually evaluated to determine value and identify potential gaps that were not addressed within the LTC.

The promise and excitement produced by the first experiment drove a second experiment in June 2022, again aboard Camp Roberts, CA. Additional commercial partners were identified from learning points during JIFX 22–2, and the second experiment leveraged a scheduled controlled burn being conducted by the Camp Roberts Fire Department and CAL FIRE. Project Vesta experimented with fire retardant sprays,

advanced firefighting tools, creating fire breaks, and additional data gathering for the AI software. A new fire-mitigation prototype, Burnbot, was also demonstrated during this experiment.

Future experiments will be required to continue the refinement of the LTCs and potentially integrate additional technologies as they become available. The core technologies are identified and capable of providing meaningful improvements to firefighting capabilities.

C. SUMMARY

Professional firefighters testing the Project Vesta technologies aboard Camp Roberts provided positive feedback and expressed optimism on the value-added benefits that can be produced by the LTC concept. Users voiced concern over the potential cost related to the purchase of the technology and their lack of technical knowledge capabilities to implement the technologies. Ensuring user friendly and intuitive interfaces would facilitate a smoother integration plan with the fire departments.

The initial demonstration event at Camp Roberts provided some early stage support for the vignette presented in the research concept of execution. In principle, the future employment of Project Vesta or elements of the LTC ought to be able to provide the advanced capabilities needed to assist firefighters in the prevention, detection, and suppression of wildfires. Like all new technologies, the path to this is still to be proven, but the possibility exists of using autonomous systems in an aggressive way to mitigate wildfire risks. Multiple compononts of Project Vesta are rapidly advancing to a viable state that upon incorporation, will ehance the capabilities. It is a matter of working out a feasible way of incporating all COTS into Project Vesta in the coming years, at which point the pressure for wildfire mitigation solutions will likely have grown.

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V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The growing threat of wildfires cannot be ignored and investments in future technologies are imperative. In order to combat the growing threat, firefighting capabilities of the future must be rapid, integrated, and efficient. Although firefighting agencies continue to expend resources to combat wildfires, gaps in current capabilities persist presenting an ongoing economic, environmental, and health threat to the population. In an effort to address these gaps in capabilities, firefighting agencies will need to leverage cutting edge technologies and unfamiliar tools. Project Vesta fits within the guidelines of the DOD requirement to research, develop, and field unmanned systems as defined in the Unmanned Systems Integrated Roadmap (USIR). It's possible that resilient, viable LTCs may become critical to thwarting the impacts of future wildfires in the United States. With many wildfires occurring in remote locations with rugged terrain, the LTCs present a self-sustaining capability providing a rapid response during the initial onset of a wildfire. Project Vesta has demonstrated value that can be utilized in the DOD to combat wildfires and provide additional capabilities to the firefighter that are already stretched thin on resources. Upon maturation, Project Vesta may afford interoperability between the DOD and other government firefighting agencies. Additional testing and fielding will allow for the continuous improvement and scaling of the AI and autonomous systems.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

Project Vesta as a whole still requires additional testing and maturation before becoming a fully deployable LTC. With only two experimental events to test the LTC concept at Camp Roberts, CA in 2022, additional analysis and development is required in order to collect the required quantitative data validating the feasibility of operation. Additional technology partners should be added to the LTC if Project Vesta is going to be a capable solution to predict, prevent, detect, and suppress wildfires. The incorporation of 5G Network Integration is essential to creating an autonomous LTC which can also

provide enhanced communication and coordination capabilities for the firefighters. The SoCal Tech Bridge is working with a product called eTHOR (electric Tactical Humanitarian Operations Response). This unit provides the capability to produce a mobile, low latency communication at high bandwidths. During the testing at Camp Roberts, the Project Vesta team was in coordination with the company Anduril that is fielding an operating system called Lattice. This operating system is able to link the technologies of Project Vesta, the command centers, and firefighters engaged in combatting wildfires.

Continued engagement with the Camp Pendleton Fire Department is recommended allowing the exposure and buy-in for Project Vesta employment. Camp Roberts, CA remains a viable testing ground for Project Vesta partners to continue testing technologies. Future research should be dedicated to determining a realistic timeline for concept maturation and accurate cost forecasting for the commercial technologies involved. Currently, the Naval Postgraduate School and Camp Roberts have a Cooperative Research and Deveopment Agreement (CRADA) in place that allows testing aboard Camp Roberts. Also, the Camp Roberts Fire Department has expressed interest in the Project Vesta technologies allowing their experimental use during controlled burns. Future research should be focused on the applicability of Project Vesta across additional DOD installations threatened by wildfires.

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