REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
03-05-2018	Master's of Military Studies	SEP 2017 - APR 2018

4. TITLE AND SUBTITLE
ULS in Support of Disaster Recovery: Revisiting the 2010 Haiti Earthquake

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Wilson, Matthew, J, NGA

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USMC Command and Staff College
Marine Corps University
2076 South Street
Quantico, VA 22134-5068

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
Dr. Richard DiNardo

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Natural disasters, such as the 2010 catastrophic earthquake in Haiti, severely hinder governments, militaries, and humanitarian organizations from saving lives and delivering desperately needed goods. A deployable unmanned logistics system (ULS) could provide just-in-time last-mile deliveries of desperately needed medical supplies even in devastated environments such as Haiti in 2010. Commercial companies, federal agencies, and regulators are already developing the technologies and exploring the regulations that could be co-opted and modified to make a deployable ULS. This paper explores four main initiatives the United States government should champion to make this ULS a reality. 1) Modify regulations to allow autonomous systems to fly UAVs beyond-the-line-of-sight (BLOS) in the national airspace system (NAS). 2) Apply and advance existing UAV sensor, docking, and power technology. 3) Develop the mathematical algorithms that compose the flight management system. 4) Create global standards and interactive modular technology such as universal UAV docking stations, mobile apps for requesting ULS support, and standardized humanitarian loadouts. A standardized ULS flight management system with interoperable standards could deploy anywhere in the world and provide logistic services to any first responder when traditional services are either degraded or absent.

15. SUBJECT TERMS
Unmanned logistics system, ULS; Unmanned aerial vehicle, UAV; Flight management system; Disaster recovery

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UU	36	USMC Command and Staff College
Unclass	Unclass	Unclass			**19b. TELEPHONE NUMBER** *(include area code)* (703) 784-3330 (Admin Office)

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

United States Marine Corps
Command and Staff College
2076 South Street
Marine Corps Combat Development Command
Quantico, VA 22134-5068

MASTER OF MILITARY STUDIES

TITLE:
ULS in Support of Disaster Recovery: Revisiting the 2010 Haiti Earthquake

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

AUTHOR:
Matthew J. Wilson, NGA

AY 17-18

Mentor and Oral Defense Committee Member: Dr. Richard DiNardo,
Professor of National Security Affairs
Approved:
Date: 3 May 2018

Oral Defense Committee Member: Dr. Jonathan Phillips
Associate Professor of History
Approved:
Date: 3 May 2018

EXECUTIVE SUMMARY

Title: ULS In Support of Disaster Recovery: Revisiting The 2010 Haiti Earthquake

Author: Matthew John Wilson, National Geospatial-Intelligence Agency

Thesis: Using the Haiti earthquake as an operating scenario, it can be shown how regulation reform, the implementation of a mostly-autonomous unmanned logistics systems (ULS) air traffic control system, and a just-in-time delivery system can provide critical logistics in support of disaster relief efforts.

Discussion: The 7.0 catastrophic earthquake that devastated Haiti in 2010 severely damaged Haitian transportation, communication, and logistics infrastructure. First responders and humanitarian aid groups struggled to obtain the medical supplies they needed to save lives in the initial days of the earthquake. In this disaster and the numerous ones since, an alternative or complementary logistics system would have alleviated much suffering and improved the community's ability to respond. If a deployable unmanned logistics system (ULS) was available then, it would have provided the just-in-time last-mile logistic deliveries to first responders, hospitals, and refugee areas without the need of traditional infrastructure. With the commercial sector advancing unmanned aerial vehicle (UAV) technology, regulators realizing the inevitability of large numbers of UAVs sharing the national airspace system (NAS), and innovators developing related communication and visual algorithms and software, the prospects for the creation of a ULS is high. This study examines the regulations and technologies that can be employed to safety operate a ULS. It also recommends that the United States lead an effort to design an autonomous ULS flight management system and champion interoperable global regulations and standards.

Conclusion: The time to advance and develop ULS technology and global standards for disaster relief is now. With commercial businesses and militaries rapidly advancing UAV technology and regulators realizing that they must accommodate UAV usage into the NAS, the United States is in a position to posture its military, disaster support agencies, and humanitarian partners to take full advantage of ULSs and their networks.

DISCLAIMER

List of Illustrations

Table of Contents

PREFACE

The main aim of this study is to investigate the feasibility of an autonomous unmanned logistics system. The desire to conduct this research stemmed from what appeared to be an increase in devastating natural disasters and the difficulty in providing last-mile logistics to the survivors. The Haitian earthquake, Japanese tsunami, and the Puerto Rician hurricane demonstrated the difficulties and dangers of delivering humanitarian aid to a trapped urban population. Fortunately, governments, militaries, and businesses are developing UAV capabilities to solve numerous problems. The United States and its humanitarian partners could adapt this technology to support a wide variety of national disaster responses. Long-term development with an emphasis on communications, data management, and sensor sensitivity could make an unmanned logistics system a reality. UAVs have proven themselves in intelligence gathering, surveying, and conducting inspections. I am convinced with more development they can prove themselves in logistics as well.

I am deeply thankful to Dr. NiDardo and Dr. Phillips for their support and advice on this study.

I am also grateful to LtCol M. Byrne, Dr. A. Antonoff, and the LCSC staff for all the encouragement and advice they provided throughout the year.

In addition, I would be remiss if I did not also recognize my neighbor’s dog whose incessant barking got me out of the house and into the library on many cold and rainy days.

I. INTRODUCTION

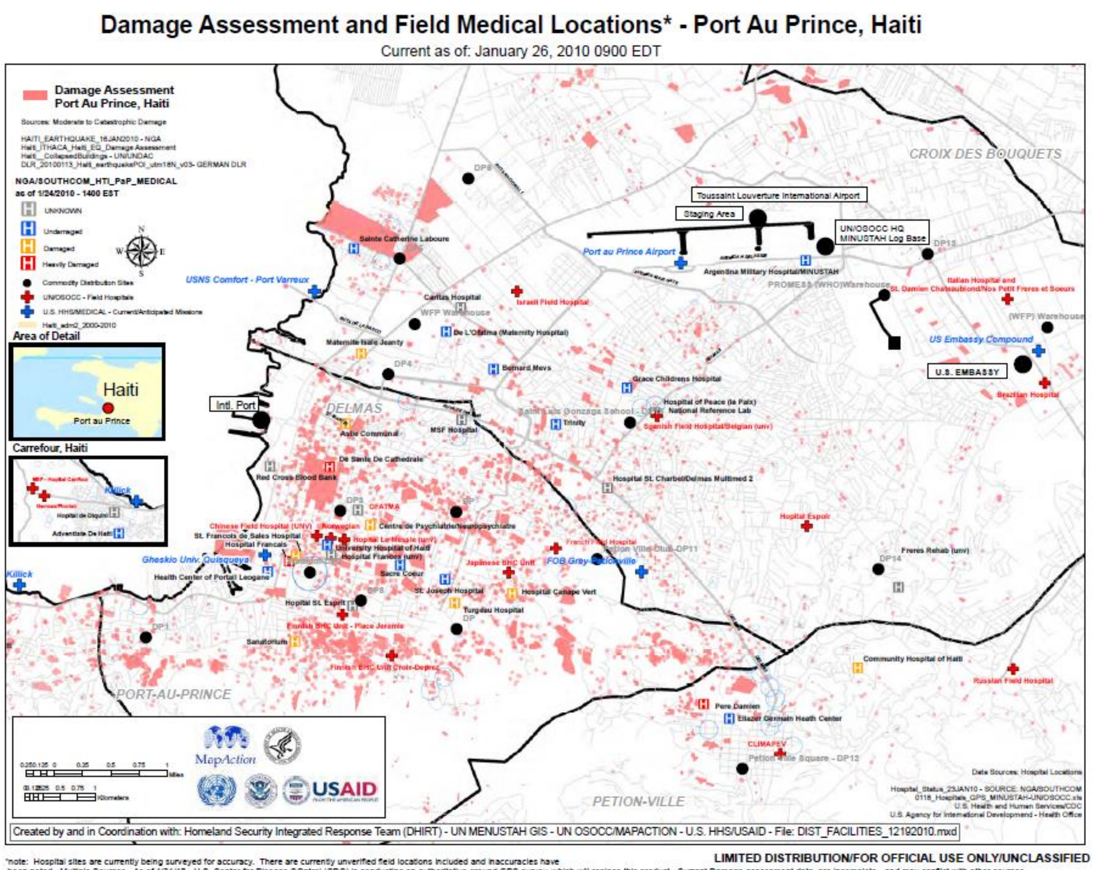
Catastrophic disasters, such as the magnitude 7.0 earthquake that devastated Haiti in 2010, place immense pressures on disaster response logistics. Humanitarian organizations must contend with a degraded government's ability to respond, the destruction of existing private-sector supply chains, damaged infrastructure limiting entrance and mobility, and the destruction of locally stored goods. To save lives and minimize suffering, governments and humanitarian organizations need to continually develop more dynamic and effective methods to transport critical supplies to a displaced populace. To that end, unmanned logistics systems (ULS) could be the next advancement in humanitarian logistics management. Using the Haiti earthquake as an operating scenario, it can be shown how regulation reform, the implementation of a mostly-autonomous ULS air traffic control system, and a just-in-time delivery system can provide critical logistics in support of disaster relief efforts.

II. BACKGROUND

On 12 January 2010, Haiti was struck by a 7.0 magnitude earthquake. According to the Haitian government over 220,000 people died, 300,000 were injured, 1.17 million people were displaced, and 1.5 million became homeless.[1] The challenges facing the initial relief effort were tremendous.

Damage to infrastructure was extensive, and it hindered the transportation of humanitarian assistance (see figure 1). Communication and electrical systems were destroyed. First responders had to contend with "soil liquefaction, landslides, and rockslides in cut slopes, and road embankment failures [that] contributed to extensive damage in Port-au-Prince and elsewhere."[2] The earthquake collapsed buildings in the downtown area of Port-au-Prince blocking many streets with rubble.[3] The Port was especially hard hit, which inhibited the delivery of relief supplies. The north wharf collapsed, the Varreux Terminal pier collapsed, a large portion of the south pier collapsed, and vehicle traffic was suspended on that pier after an aftershock caused additional damage.[4] The damage was so severe, that it took ten days to reopen the seaport.[5] In lieu of the port, humanitarian assistance travelled overland from the Dominican

Figure 1: AOR Damage Assessment and Logistics Nodes



United States Geological Survey, *The Mw 7.0 Haiti Earthquake of January 12, 2010: USGS/EERI Advanced Reconnaissance Team Report* (Reston, Virginia: U.S. Geological Survey, 2010), 53, https://pubs.usgs.gov/of/2010/1048/

Republic, but the roads were difficult to pass and congested. It took approximate eight-nine hours, instead of the regular two hours, to travel from Jimani, Dominican Republic to Port-au-Prince, Haiti.[6] This was during a crucial time when first responders and hospitals urgently needed medical supplies.

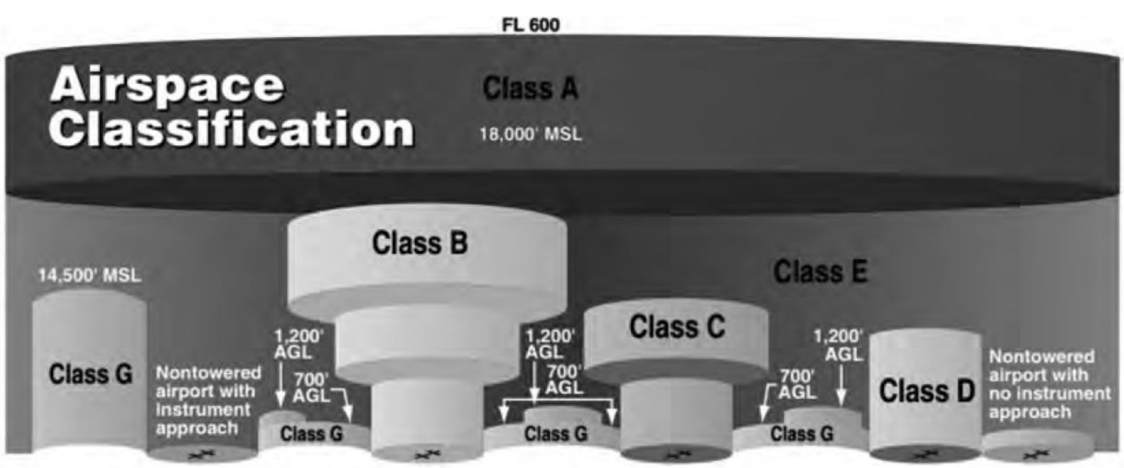
In addition to the physical damage, the earthquake incapacitated the government and destroyed the Haitian State's ability to respond to the disaster. Almost one third of Haiti's 60,000 civil servants died. Seventy-Seven Haitian National Police died with hundreds wounded or unaccounted for. Two senators died and many other senior political leaders were wounded. The United Nations also lost 101 staff.[7] Government buildings were also destroyed or heavily damaged.[8] The sheer damage to the Haitian personnel and infrastructure overwhelmed their ability to react.

The international community had to confront this environment: heavy damage, high casualties, low mobility, and few points of entry. The United Nations Stabilization Mission in Haiti (MINUSTAH), UN member states, the United States, and Canada deployed thousands of troops to restore key infrastructure, conduct search-and-rescue operations, and establish medical and relocation sites. At this early stage, a ULS network would have been invaluable in transporting key medical supplies to first responders and critical components to restore communications infrastructure. Unmanned aerial vehicles (UAVs) could have transported high value, low volume assistance instead of waiting for traditional ground delivery. The data the ULS network would acquire to route UAVs and the user requests for its services could be aggregated and displayed to support the overall logistical effort. Perhaps the most important aspect of a ULS network is to spare humanitarian responders' valuable time so they can focus on the needs of the populace.

III. REGULATIONS

To implement an unmanned logistics system in support of disaster relief, world regulators must first update regulations and doctrine. The current system of air traffic control is not optimized to track and manage small unmanned, and in some cases, autonomous aerial vehicles operating at ground-level. Humanitarian ULS operations will be especially challenging because their just-in-time deliveries cannot be planned and routed ahead of time. To overcome these challenges, the Federal Aviation Administration (FAA), the Joint Force, and international regulators must augment their regulations and doctrine to integrate a ULS navigation and control system into their current operations. This would require the creation of a new class in the National Airspace System (NAS), a relaxing of existing restrictions or the granting of exceptions for national disasters, and the willingness to defer operational control of UAVs to local municipalities or capable humanitarian entities.

Figure 2: Airspace Classification

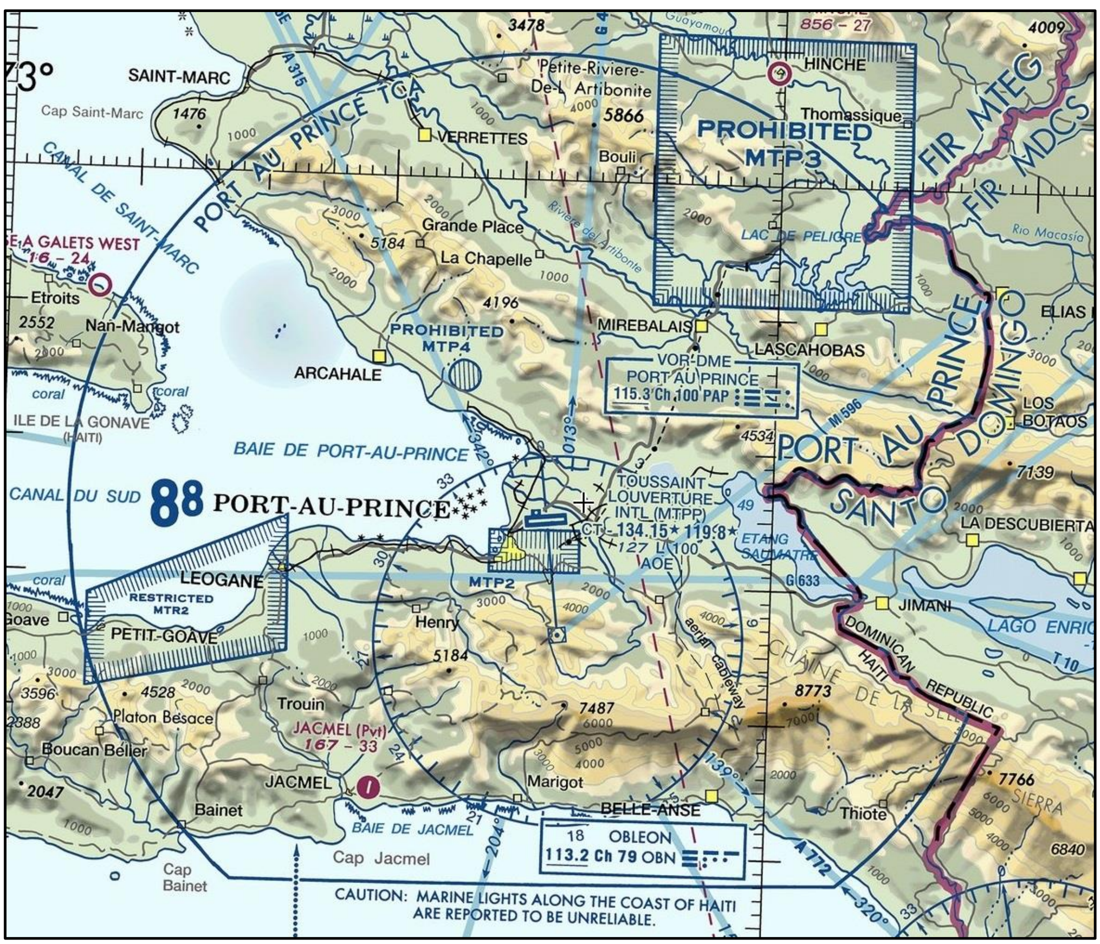


Timothy Ravich, *Evolving Law on Airport Implications by Unmanned Aerial Systems* (Washington: National Academy of Sciences, 2017), 12, https://www.nap.edu/download/24932

The national airspace system is broken up into classes (see figure 2). For the purposes of UAV operations, operators must be especially cognisant of Classes B through D. These classes surround airports, and regulations impose restrictions within them to ensure the safety of arriving and departing air traffic. Class B airspace, like that surrounding Toussaint Louverture International airport (MTPP) in Port-au-Prince, has an upper ceiling of 10,000 feet above mean sea level (MSL) and a terminal control area (TCA) radius of approximate ten miles.[9]

ULSs will have to operate within these airspaces to be even remotely useful. The need for

Figure 3: Port-au-Prince Toussaint Louverture International Airport (MTPP) Airspace



U.S. Department of Transportation, *CJ-27*, world aeronautical chart (Silver Spring, MD: Federal Aviation Administration, 2016), https://skyvector.com/

this can be easily seen in the Port-au-Prince disaster area. In Figure 3, the outer blue circle around the Toussaint Louverture Intl airport is its terminal control area (TCA). Regulators impose restrictions on air travel within this area to ensure safety and the orderly arrival and departure of aircraft. This TCA covers the entire city of Port-au-Prince. The inner blue circle with hashes on the inside denotes the UAV restriction area. This restrictive area covers not only the airfield, but the Port-au-Prince seaport and the location where the *USNS Comfort* was anchored. If these areas are superimposed over the disaster assessment in Figure 1, then the vast majority of the city would be inaccessible to UAVs. The UAVs would not even have access to most of the commodity distribution nodes. Regulators would have to modify their regulations to prevent airports from creating ULS dead zones.

The first modification to existing regulation would be to create a new airspace class. This new class falls along the same lines as an Amazon proposition in 2015 to create a new class of airspace for low altitude small unmanned systems (UASs).[10] This "Class H" airspace would become a segment of the NAS no higher than 400 ft above ground level (AGL). In this segment, an air traffic control system could navigate, communicate, and deconflict routes of a constellation of beyond line of sight (BLOS) UAVs. While this airspace would still restrict UAVs from approaching runways and helipads, a ULS could be established near or at the airport. The FAA or international regulator would still retain "jurisdiction over the ULS aircraft and flight rules," but would defer the role of local aviation to the jurisdictions in which they fly.[11] For the purposes of disaster relief, the impacted jurisdictions would specify how ULSs operate provided their capability remains intact. If a disaster destroys the local UAV navigation and control system, a capable humanitarian actor would implement and administer an ad-hoc replacement system. Such a system will be explored in the next section.

The second modification would be a relaxation of restrictions within the radius of the Airport's airspace. The FAA's drone regulation enacted in 2016, 14 C.F.R. Part 107, would prevent UAV operators from flying within five nautical miles of any airport with a control tower.[12] While an operator may obtain a certificate of Waiver or Authorization (COA) under Part 107 or Section 333, it comes with additional restrictions.[13] The operator would have to obtain a remote pilot certificate, fly under the visual flight rules (VFR), remain in Visual Line of Sight (VLOS), and coordinate with the air traffic controllers of the airport. Controllers could reasonably manage one or two UAVs, but for disaster relief there would be hundreds of UAVs coming and going. To support just-in-time last mile delivery, controllers would need to use a fast and flexible autonomous system. A mostly autonomous ULS, with machine and human teaming capability, would have to be demonstrated and proven for the FAA and other regulators to accept it, but technology is advancing and systems are being tested that show promise. Governments, the Joint Force, and international humanitarian aid organizations should situate themselves to integrate these systems as soon as they are available in order to be prepared for the next disaster.

The third regulatory and policy change would require a willingness to relinquish UAV aircraft control to local municipalities, militaries, and international aid organizations. This is a pragmatic change to spare the FAA the extreme workload, improve flexibility, and improve responsiveness. As of 2013, the FAA had more than 46,000 employees. The FAA's air traffic controllers handle approximately 87,000 conventional flights a day, but despite their sophisticated avionics equipment, the FAA still lacks the technology, staff, and budget to track and deconflict drone use.[14] This will only get worse as FAA's own projections forecast an increase in drone purchases from 1.1 million in 2016 to 4.15 million by 2020.[15] The FAA and other NAS regulators need to make the cognitive leap that they will not be able to manage the rise in UAV traffic by manpower alone. They will need to set the stage for autonomous UAV flight management systems to handle the workload.

After the catastrophic earthquake, the workload spiked as the whole world rushed to Haiti. The Haitian aviation authority at Toussaint Louverture International Airport was quickly overwhelmed by the inbound airborne relief.[16] Hundreds of aircraft were stuck in uncoordinated holding patterns and many had to divert before their fuel ran out. Three days after the earthquake, the Haitian government signed a memorandum with the 601st Air and Space Operations Center/Air Mobility Division (AOC/AMD) Regional Air Movement Control Center (RAMCC) to coordinate airflow.[17] Renamed the Haiti Flight Operations Coordination Center (HFOCC), the experienced USAF air controllers were hard pressed to accomplish their mission. In two months, the HFOCC coordinated 3,940 international flights.[18] If a ULS was in operation during this disaster, it would have added hundreds of extra UAV flights a day that would have far outstripped their capacity to control.

IV. ULS INFRASTRUCTURE

To expect air traffic controllers to command and control hundreds of drones carrying small parcels at low altitudes is unrealistic. The international community should develop a mostly-autonomous system to provide the last-mile, just-in-time critical logistics. This ULS would need to rapidly deploy a mostly self-sufficient drone network, utilize a highly automated UAS traffic management system capable of managing the real-time airspace states of all the drones in the network, integrate drone operations with the air traffic controllers for manned aircraft, and provide interactive communication services to first responders and aid organizations. To do this, the ULS would have to address four main concerns: the entire structure would have to be deployable with little to no warning, be able to function in a chaotic environment, provide safety through airworthiness and redundancy, and be able to adapt in real-time.

First, the ULS operator will have to deploy an entirely self-sufficient ULS structure to the disaster zone. This is not just the UAVs themselves. It includes communications nodes outfitted with radio beacons, cellular network transceivers, mobile broadband modems, barometers, and GPS to maintain navigation and guidance for the UAVs in its network. Some communication nodes are stationary, which can be placed on roofs, while others are mounted on tethered dirigibles that can be dropped out of planes or helicopters and moved as necessary. These aerial nodes will also be equipped with visual optics and light detection and ranging (LIDAR) sensors to create updated 3D maps of the city to assist UAV navigation. The ULS operator will also bring docking stations, recharge stations, hundreds of spare battery packs, generators, ready-to-ship pre-packaged supplies, and empty UAV shipping boxes (both regular and refrigerated).

The ULS must be shipped as a self-sufficient whole because there is no guarantee that the local infrastructure survived the disaster or could have supported the system in the first place. The ULS is scalable, so the ULS operator could send the exact number of UAVs, beacons, and docking stations to appropriately address the disaster at hand. The Haitian earthquake, for example, collapsed buildings destroying Port-au-Prince's fiber optic communication nodes and knocked down many of their Global System for Mobile Communications (GSM) towers.[19] Private sector cellular networks and satellite-based Internet Service Providers (ISPs) fared better, but were degraded, suffered intermittent outages, and were quickly overloaded. The power grid was also lost, making the local infrastructure completely unusable. The damage was so extensive in this case, the humanitarian community would need to deploy a fully robust ULS.

The location for communication nodes is extremely important. Their location must take into account the capabilities of the ULS aerial platforms, location of the victims, location of the main distribution and receiving nodes, and the identification of any restricted air space. For the purposes of this analysis the notional ULS will use average commercial multirotor UAV technology available in 2017. For example, the Intel Falcon 8 has a maximum data link range of 1 km, average airspeed of 22 mph, and a max flight time of approximately 26 minutes.[20]

ULS communication nodes will be established along with the UAV base stations at hospitals, airports, distribution sites, and ships at sea. Additional communication nodes will have to be established within 1 km of every end destination the drone visits. The reason for this is to ensure safety and flexibility. For a UAV to travel from one place to another is easy, but when it descends into the "urban canyons" or approaches the delivery point for a package, the C2 network could augment GPS, update the drone with additional navigation instructions, provide updates if the recipient has moved, or place the UAV in hover mode until a human can assume beyond-line-of-sight control for those really difficult deliveries. (More information on machine-human teaming can be found in the ULS flight management system section) To completely cover the entirety of the Capital of Port-au-Prince, the ULS would need approximately 71 communication nodes, but this would almost certainly be more than what would be required. The devastation was not as intense on the eastern side of the city (figure 1), so the need for 100% coverage would not be necessary. The stationing of communication nodes at the regional hospitals and distribution sites might have been enough.

The communications nodes would guide UAVs from point to point. The ULS operator would establish base station points at hospitals, distribution sites, ports, refugee camps, aboard supply ships, and at transition points. One type of transition point would be locations along long routes that would typically be beyond the range of a single UAV charge. Others would be recharging

Figure 4: Digicel Building Next to Collapsed "Hopital de Turgeau" in Port-au-Prince

Benoit Boulanger, et al, "Analysis of a damaged 12-storey frame-wall concrete building during the 2010 Haiti earthquake Part I: Dynamic behaviour assessment," *Canadian Journal of Civil Engineering* 40, no. 8 (August 2013): 792

and staging locations where drones could land, recharge, and await new instructions while being out of the way. The roof of the Digicel building (Figure 4), in an almost completely destroyed neighborhood of Port-au-Prince, could be a good location to place a transition point. Its construction withstood the earthquake and numerous aftershocks with only minor damage.[21] Autonomous operation would also be possible at this location if access to the roof can be barred, which would prevent theft and tampering.

Base stations would have multiple docking stations, recharging stations, generators, solar panels, packaging services, and in some cases limited maintenance services. To charge the batteries of a typical UAV from empty would take approximately sixty to ninety minutes, so battery packs would be swapped out frequently. Additional UAV flights would be scheduled throughout the ULS network to pick up bins of expended battery packs and bring them to specified locations for mass charging. To put this into perspective, if a single UAV were to operate continuously for eight hours a day in optimal conditions, it would have to swap out batteries nineteen times.

Figure 5: H3 Dynamics Dronebox: Autonomous UAV Docking Station and Recharger

Malek Murison, "Dronebox – The Automated, Connected, Self-Charging Drone Platform," *Airnest*, accessed January 12, 2018, http://www.airnest.com/blog/2016/2/18/ dronebox-the-automated-connected-self-charging-drone-platform.

Power management is the biggest challenge in using an ULS today, but a lot of research and development is ongoing in the commercial sector to alleviate this burden. One such endeavor is H3 Dynamics' Dronebox (Figure 5). It seeks to be an all-in-one autonomous landing pad, automated recharger, and wirelessly connected platform that can be left unattended in hard-to-reach locations for months.[22] More research is needed in autonomous recharging technology, but the goal is to make them mass deployable.

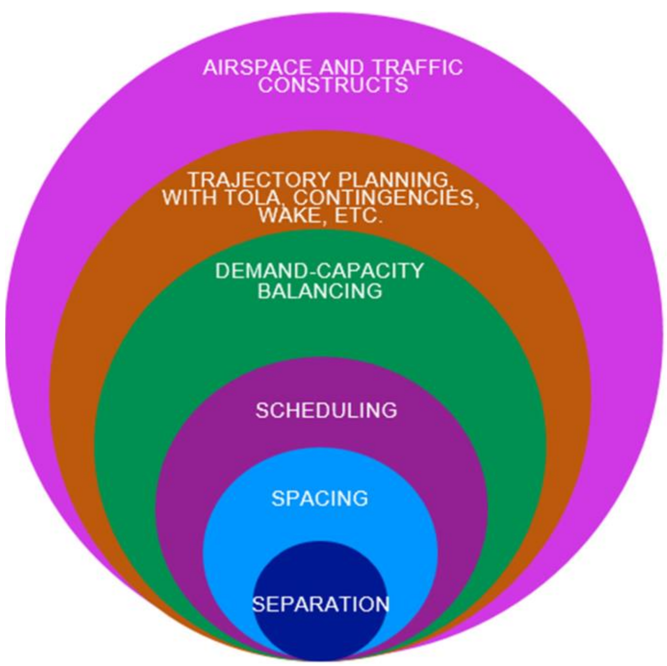
The physical nodes, UAVs, and power sources are important, but a ULS is more than the sum of its physical pieces. A ULS requires the ability to command and control an entire network of UAVs. This command and control system must do more than merely control its network safely and efficiently, it must also do so autonomously.

V. ULS FLIGHT MANAGEMENT SYSTEM

A ULS flight management system can achieve this though robust mathematical algorithms that are the nervous system that runs the network. They assess information, make decisions, and are crucial in any autonomous system. A ULS operating in a disaster zone, especially one as large and complex as Haiti, will have to address six main functions as seen in Figure 6.

The first three functions -- scheduling, spacing, and separation -- are so interrelated they should be covered together. A ULS flight management system would need to schedule the arrival and departure queues at each hub and delivery location, and then assign routes and departure

Figure 6: Layers of Airspace Integration Capabilities



Eric Mueller, Parimal Kopardekar, and Kenneth Goodrich, "Enabling Airspace Integration for High-Density On-Demand Mobility Operations," in *17th AIAA Aviation Technology, Integration, and Operations Conference* (Denver, CO: June 2017), 11, https://utm.arc.nasa.gov/docs/2017-Mueller_Aviation_ATIO.pdf times to individual UAVs. These systems are basically the same structures that air traffic controllers use today, the standard instrument departure (SID) process and standard terminal arrival routes (STARS) process, except that the ULS system would be completely automated.[23]

This may sound daunting, and it is, but agencies and commercial companies are conducting research into its development. The National Aeronautics and Space Administration (NASA) is developing something similar with its Unmanned Aircraft System (UAS) Traffic Management (UTM) program. NASA developed and "successfully flight tested an automated, centralized sequencing and scheduling algorithm" for its Small Aircraft Transportation System (SATS).[24] While SATS tested only a few UAVs simultaneously in a much less intense area than a natural disaster zone, the technology shows promise. This is a promising first step, but to operate in a fully automatic mode, ULS creators need to design algorithms that become air traffic controllers, instead of merely assisting them.

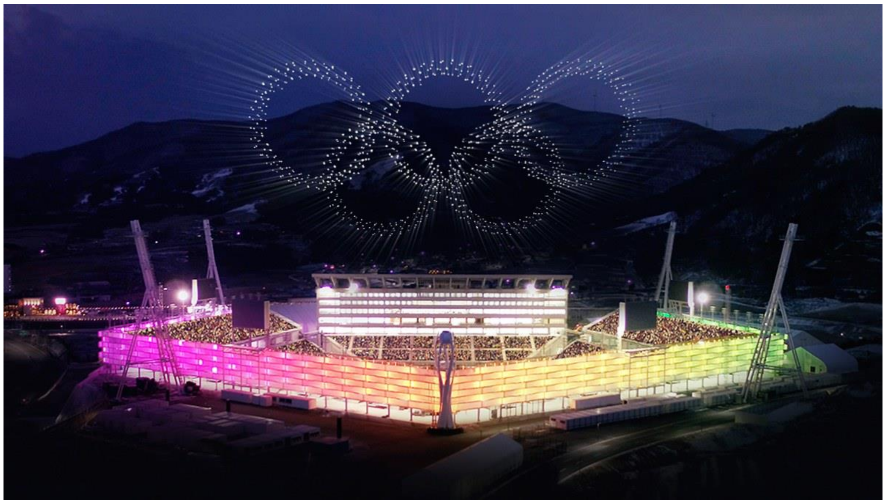
A ULS flight management system will space and separate UAVs, so they do not collide into each other and other aircraft. Spacing UAVs out by time and route will prevent collisions, but in a congested and chaotic airspace that may be a luxury the system does not have. To mitigate this challenge, the ULS flight management system will need to employ detect and avoid (DAA) system(s).

There are many options, so the ULS could mix and match the systems that best suit the cost and risk tolerance of the user. Reflective markings could be put on UAVs that communication nodes and other UAVs can identify. This information can then be sent to estimate control algorithms that would align trajectories of UAVs to enforce safe distances. GPS and radar beacon-based systems could track UAV', and provide that information to the flight management system, so it can make flight plan changes. UAVs should be equipped with optical and LiDAR sensors that can identify other aircraft and urban features such as high-voltage power lines, buildings, and terrain. GPS and Inertial Navigation Systems (INS) would then be able to calculate the UAVs' location and vector relative to those features and make the adjustments necessary to avoid a collision.

Automobile manufacturers have recently designed safety features that a flight management system could use in maintaining proper spacing and separation of its UAVs. Adaptive Cruise Control (ACC) could adjust the speed of UAVs as they encounter one another and then make slight adjustments to match the flow of traffic in the airspace. This would not only avoid collisions, but also enable the flight management system to string convoys of UAVs together in close formations. If a UAV sensor trips a fault or becomes confused, an autonomous emergency breaking (EAB) algorithm could force the UAV to hover or land and wait for human intervention. If the management system detects other drones or commercial aircraft entering the operating area, it would impose additional spacing and rerouting to avoid encounters. Ultimately, the flight management system would maintain positive control because it has surveillance data from all the communications relays and UAVs in the system.

Cars are not the only example of advancement in these kinds of technologies. At the 2018 Olympics in PyeongChang, Korea, Intel integrated and operated a drone swarm of over 1,200 Intel Shooting Star drones (see figure 7).[25] 3D design software treated each drone as a pixel in a 3D area. Anil Nanduri, general manager of Intel's drone group, commented that "with the animation in place, each drone operates independently, communicating with a central computer rather than any of the drones around it."[26]

Figure 7: Intel Shooting Star Drone Swarm at 2018 Olympics



Brian Barrett, "Inside the Olympics Opening Ceremony World-Record Drone Show," *Wired,* accessed on February 19, 2018, https://www.wired.com/story/olympics-opening-ceremony-drone-show/.

This is exactly what a ULS flight management system would attempt to do. The only difference is that the ULS system would react and adapt in real-time instead of running a pre-set routine. More technological development is needed to make the ULS flight management system viable, but the technology is well on its way.

Next, the ULS flight management system must balance demand with the capacity of the ULS. In many industries the first-come first-served model is used to determine the order people are served in, but in disaster relief efforts this cannot be used. The first responder who desperately needs a tourniquet should have priority over the person who needs two flashlights and a portable phone charger. The flight management system would weave hundreds of flights together in a densely crowded airspace and dynamically reassess the priorities of cargo and flight plans as first responders submit time critical requests for support.

Prior to a national disaster, the ULS operator would set the priorities of goods and the order in which they would be shipped. Priorities would be determined based on numerous factors. A subset of them would be the criticality of the item, whether the item is perishable, does it require special handling like refrigeration, is it required for second order effects, and so on. In a perfect world, the global community of humanitarian aid organizations, governments, and militaries would have deliberated the issue and agreed on a common framework. Regardless of a universal framework, the priorities for categories of goods would be modifiable in order to be responsive to the natural disaster at hand. For non-standard loadouts, such as 3D printed components, rare medicines, etc., the priorities could be inputted individually into the system on a case-by-case basis. So long as the flight management system remains aware of the items in the network and the items awaiting entry into the network, it can make fair decisions in scheduling.

Demand will almost certainly outstrip capacity in the early hours and days of a catastrophic disaster, so the algorithms must be as efficient and flexible as possible to deliver life saving goods to first responders. Artificial intelligence would ensure that capacity is not exceeded and would predict the demand for services. The algorithms would then incorporate that information into traffic flow management.[27] Initially, most requests will be for immediate lifesaving items like emergency medical services (EMS) drugs, plasma, and tourniquets, so capacity will be maximized at the start. But once the network is finally capable of servicing all its highest priority requests, the flight management system should keep some capacity in reserve in the expectation of more top tier requests coming in.

Data management is critical for a ULS. It is even more critical for the disaster response effort as a whole. After the Haitian earthquake, the civil-military response was enormous and the chaos was nothing less. The noise across communications platforms created challenges to "quality and dissemination control that resulted in responders receiving duplicate, conflicting, and sometimes outdated information."[28] The ULS could minimize that confusion by providing aggregate aid request information, UAV pictures, and 3D LiDAR models to military, joint, and international coordination centers and headquarters. In addition to providing situational awareness, it could also highlight locations with large numbers of casualties. Instead of repeatedly sending dozens of drones to the same location, the flight management system could recommend a helicopter be dispatched with the specific items needed by that area. If agreed to, the flight manager would then reassign those UAV missions to other requirements once the helicopter departs. The ability of a ULS to balance demand and capacity can expand far beyond itself if it is incorporated into the planning and situational awareness tools of the community.

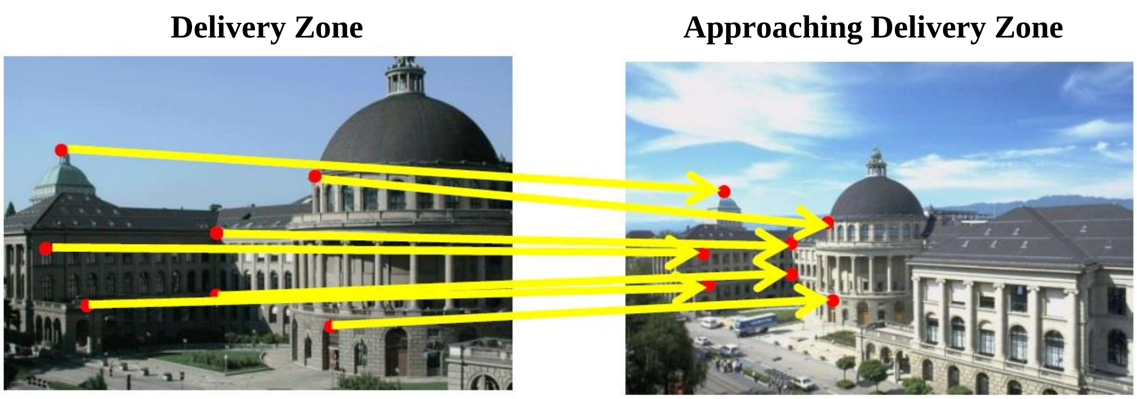
The ULS navigation system is responsible for trajectory planning and contingency management as well. Dirigibles and stationary communications/relay nodes would be equipped with anemometers to measure the speed and direction of the wind. Mathematical models would incorporate this weather data with UAV specifications and the UAV's current reported battery capacity to calculate the UAV's maximum range speed, maximum endurance speed, and optimum cruise speed.[29] The navigation system may instruct a UAV with an unwieldly parcel to operate at the maximum range speed, which maximizes distance travelled while keeping the drag force and fuel consumption to a minimum. This would improve in-flight stability through areas of turbulence. At other times, the ULS would instruct UAVs to just operate at their optimum cruise speed, which maximizes fuel consumption per unit of airspeed. Each communications/relay node would conduct these calculations and continuously update each UAV as they progress through their routes. Maximizing stability improves safety and maximizing fuel consumption reduces down time.

The navigation system may also dynamically change a UAV's route if there is a shift in wind direction, the wind speeds increase significantly, or the weather changes. A UAV scheduled to fly between two buildings and land might be forced to expend an exorbitant amount of energy to fly against the wind if a shift in the wind direction occurred. In this case the navigation system would modify the route to bring the UAV in perpendicular to the wind or with the wind to preserve its battery life. ULSs will occasionally encounter cases of temporary squalls or passing heavy rain. These obstacles might be severe enough to make flights infeasible. They could be either dangerous to the platform or would require the UAV to expend more energy to conduct the flight than it has left. In these cases, the navigation system could reroute the UAV to another path that was more favourable, redirect the UAV to a hub where it can swap out battery packs and continue on, or have it land to wait out the storm. If a UAV mission had to be scrapped, the navigation system might be able to reassign the task to a UAV on the other side of island or transmit the request to human logisticians to find another way to meet the need.

Trajectory planning is fairly simple when UAVs fly above the roofline. The ULS flight management system uses GPS to set waypoints. UAVs then fly from one waypoint to the next until they arrive at their ultimate destination. Unfortunately, this becomes much harder when UAVs descend into the "urban canyons" of a city.[30] Urban canyons are places in urban environments where tall buildings and structures block satellite signals or reflect them in ways that lead to inaccurate navigation. For last mile delivery, the ULS's UAVs would require at least four satellite sources, which they almost certainly will not have, to be accurate. Therefore, other systems will be necessary to provide redundancy and accuracy in GPS deprived areas.

Visual odometry is an approach that could assist in the degradation or absence of GPS-based capabilities. Visual odometry estimates UAV motion by tracking features taken with its visual sensors.[31] As seen in Figure 8, the optical sensor would identify discernible features over multiple subsequent images and then triangulate those 3D points to compute relative distances. The UAV's inertial navigation system, a wireless update from one of the communications relay nodes, and/or whatever GPS signal that could sneak through the terrain would be incorporated in its calculations to reduce the accuracy error. Instead of depending solely on GPS, it would determine its location based largely on its surroundings.

Figure 8: Visual Odometry: Feature-Based Method to Assess Relative Motion



Davide Scaramuzza, "Tutorial on Visual Odometry," *University of Zurich Department of Robotics and Perception Group*, 33, accessed February 12, 2018, http://rpg.ifi.uzh.ch/docs/ Visual_Odometry_Tutorial.pdf

Another method that could be used is 3D LiDAR simultaneous localization and mapping (SLAM). 3D LiDAR SLAM uses a LiDAR sensor to "simultaneously build a map of a previously unknown environment while also localizing itself within this map."[32] The LiDAR uses a pulsed laser to measure ranges to make a 3D map. The UAV's INS measurements, and GPS data if available, help estimate velocity and position within that map. With lightweight LiDAR sensors, such as YellowScan's Surveyor Ultra, that was designed specifically for UAV's with a range of 100m, constant motion and velocity are much less of a concern than before.[33] If airborne platforms, UAV or other, image the disaster zone with LiDAR ahead of time, that overall 3D map can be synchronized with the UAV map for even more fidelity.

Both of these systems provide the UAV with positional information to help it reach its destination, but they also help with collision avoidance too. UAVs must understand and react to their surroundings for autonomous systems to function safely and effectively. Algorithms and passive and active sensors plan a significant role in ULSs, but they are not advanced enough to handle every scenario yet. For this reason, human/machine teaming should still be an option, even if it is used only in limited occasions.

While the ULS will autonomously control the UAV network, there will be times where humans will have to intervene. Air traffic controllers will input flight/time restriction bans into the ULS as a matter of routine when helicopter rescue or deliveries are conducted in its AOR. Numerous situations could also confuse the UAV. The delivery zone might not have any distinguishing features for the visual odometry to latch onto, or it might be getting dark, which obscures them. LiDAR might construct a high-fidelity 3D map of a causality collection point, but detects so much movement beneath it that it cannot land, drop, or deploy its parcel via tether safely. The UAV might arrive at a location specified by the first responder, only to find out that he or she had to evacuate. In cases like these, safety and responsiveness require human judgment.

It is the humans on the ground that should be the first to provide this judgment and to provide updates as needs change. To convey this judgment to the ULS, there should be a universal application that first responders can use. After the Haiti earthquake, a free phone number was set up for the Haitian people that used short message service (SMS) technology. Haitians could “text their requests for medical care, food, water, and shelter from any Digicel/Comcel-Voila Device.”[34] Unfortunately, this was an ad-hoc measure established after the fact. Not everyone knew the number at the outset, the texts were transferred to translators, and it worked on only certain devices. The universality of the ULS application is important because host nation responders, international aid organizations, and militaries will be using different equipment, communicating in different languages, and if a common line of communication is not set up ahead of time, different communication channels. The application should be universally implemented across all disaster ULSs and have different language versions that are compatible. If first responders and aid workers are familiar with this application and have ready access to it from any device, they can immediately task the ULS as soon as it is deployed.

The application must provide other methods than GPS to direct deliveries. Final delivery to hospitals, distribution nodes, and refugee sites are fairly simple. UAV docking stations placed at these locations will have radio beacons directing UAVs specifically where to land, but first responders in the field will not have that luxury. Urban canyons can reflect GPS signals giving UAVs incorrect landing coordinates. If a first responder is in a partially collapsed building when he or she submits a request, the UAV may attempt to drop the parcel far out of reach on the roof. The first responder might have to change locations for a variety of reasons, such as a gas leak or the establishment of a casualty collection point a block or two away. Two ways the application could clarify a delivery point is through an interactive map function and/or a photo interpretation function.

The interactive map function would display a simplified 3D or 2D map of the disaster zone generated by the ULS flight management system. The map would stay current as new satellite, UAV, or LiDAR imagery is taken over the zone. The phone's GPS would orient the user to its approximate location on that map. From there, the user could zoom in or out, click a position on the map for the drop or landing, and provide delivery instructions, warnings, or situation updates as they deem fit. This information would then be discoverable by other first responders, humanitarian aid coordinators, and other algorithms that would aggregate that data into a whole-of-effort analysis. This data could also be sent to human UAV pilots on standby with a time frame of arrival and a breakdown of the situation if intervention is expected.

If the simple map does not provide the fidelity needed, the first responder could use the photo interpretation function. He or she could take a photo of the landing zone and upload the photo to the ULS flight management system. The photo could be anything from a stone bench next to a toppled fountain, to a sidewalk across from a bakery. It would work so long as the photo captures distinctive features. That picture would be processed alongside the phone's approximate GPS location, the ULS's 3D LiDAR map of the area, and an optical map of the city by recognition software. The algorithms would identify features on the picture and then direct the UAV to approach the disaster zone from a vector that would allow the UAV's sensors to recognize those features. The UAV would then approach the landing zone and deposit the goods or land at the location at the center of the picture.

These methods are nothing more than an evolution in the already existing technologies behind the WAZE traffic and navigation application and face recognition software[35]. These two applications, provided their algorithms were advanced enough to identify more objects, would solve the majority of the situations UAVs would encounter. Luckily for disaster recovery organizations, commercial enterprises have already begun conducting this research for domestic ULS delivery.

UAVs may still encounter a situation they are not prepared for, so they should be programmed to go into a hover state and wait for human intervention should such a situation occur. UAV pilots would be on standby to complete the delivery as needed. The assuming pilot would be given the same simple map as the first responder, location of delivery, delivery instructions if provided by the first responder, phone number of the first responder (and the ability to conference call with a translator), location of the UAV as best as it can determine, and updated imagery of the area, most likely satellite imagery or airborne imagery. The optical sensor can then operate in full-motion video or rapid single frame shots as needed to help the pilot navigate the UAV. The communication node, whether it was placed on a nearby building or on a dirigible aerostat, would provide the wireless connection. The UAV pilot would also be able to communicate with the air traffic controllers and/or humanitarian aid coordinators to either pass on or receive relevant information.

This ULS is not a be-all and end-all system. It will assist the humanitarian effort as best it can, but when it cannot, humans can guide its operations. It could provide last-mile just-in-time deliveries anywhere it is deployed and would make an outstanding initial logistics system or complementary logistics system once the traditional logistics system has been established.

VI. ULS INTEROPERABILITY

The disaster relief ULS should not be an American only endeavor. Disasters, both natural and man-made, occur throughout the world. America cannot afford, nor would be welcome, to position itself everywhere just in case a disaster occurs. Therefore, a multi-national and multi-international aid organization arrangement should be created. This arrangement would not only be able to share the cost among a variety of partners, but would be diffuse, interoperable, and scalable.

America could pre-position entire ULSs with its maritime forces, in the contiguous United States (CONUS), or in an allied nation, but that would still leave American ULSs days away from most disaster zones. If that was not enough, these initial days are the critical days that a ULS would be most valuable. If other nations and international aid organizations had their own ULSs, they could stage them closer to the areas most likely to experience a natural disaster. There would also be more ULSs in total that could be spread out to service more areas. In 2010, the Haitian government would not have been able to afford its own ULS, but the United Nations could have. The United Nations Stabilization Mission in Haiti was already established and operating when the earthquake occurred. MINUSTAH officials knew that Haiti, and its capital, lies along the Enriquillo-Plantian Garden fault zone and had a history of catastrophic earthquakes, so storing a full ULS in the region would be prudent. The ULS would be stationed at a location off the fault line, but still within a reasonable range such as Puerto Rico, the Dominican Republic, or Cuba.

With multiple countries and organizations operating their own ULSs, command and control, policy, and doctrine must be interoperable. The reasons for this are legion. When the international community descended on Haiti following the earthquake, their activities were uncoordinated chaos. There was no shared situational awareness, no focal point of coordination, and no common equipment. This made managing response activities extremely difficult.

The United Nations Office of the Coordination of Humanitarian Affairs (UN OCHA) attempted to coordinate information activities by establishing the Emergency Telecommunications Cluster (ETC), but by the time it stood up it was too late to prevent the chaos. NGOs and aid organizations flooded the region with independent satellite terminals and radios. This caused an unprecedented demand for “satellite bandwidth and the potential misuse of spectrum and satellite capacity."[36] The ETC resolved some spectrum issues, but the NGO community largely found it ineffective because the ETC was not collocated with them in the Petionville area.[37] Unable to attending meetings, NGOs continued with their ad-hoc methods causing interference in communications, hindering online services, and decreasing responder confidence in the reliability of life saving services. The ULS will depend on a segment of the EMS spectrum to maintain command and control, so the international community should reserve a segment of the EMS for it. Once solidified and communicated, NGOs and other aid organizations would refrain from interfering with that band. This would resolve at least one piece of chaos.

The international community should implement standards for modular humanitarian aid boxes and loadouts. These standards should be set to maximize flight performance such as range, speed, and power efficiency by minimizing drag. By balancing the cargo weight distribution, UAVs will experience less structural stress which could cause long term damage. The benefits of modular UAV boxes extend to logistics as well. Organizations, especially international aid groups, would have only one set of standards to contend with no matter where they are located. Aid supplies could be pre-packaged anywhere or by anyone in the world and be ready for UAV delivery as soon as they arrived in theater. This is not to say that non-standard items could not be shipped by the ULS, but this would add speed and consistency to the most requested disaster items.

Another benefit of ULS international interoperability is scalability. Before the earthquake Haiti was already facing a humanitarian crisis. If the UN Stabilization Mission in Haiti possessed a ULS prior to the earthquake, they probably would have kept their ULS in storage or deployed only a modest number of UAVs to handle routine shipments. MINUSTAH could tailor the ULS capabilities to the situation. Alternatively, the 7.0 magnitude earthquake was so powerful it probably would have dwarfed all UAV capacity that mission possessed. The ULS would need scalability to accommodate as many UAVs as needed to meet the surge in demand.

The UN would undoubtedly activate its ULS within hours of the earthquake to support the residents of Port-au-Prince. When the United States arrived two days later, the United States' ULS could bolster the one already there. The ULS from America could be established in the nearby cities and then connect to the Port-au-Prince grid. If the UAV infrastructure such as aerial models, docking station, and recharging stations were compatible, then they could even be deployed within the umbrella of the UN ULS. The ULS grid could seamlessly command and control itself, any extension nodes, and the different platforms.

There may be reasons for the hardware to be different, but that should not impose too big a problem so long as the software and mathematical algorithms are compatible. A ULS supporting Willington, New Zealand for instance would require UAV platforms capable of navigating stronger winds than UAVs in Haiti. Platforms operated in colder climates would almost certainly have different battery configurations to prevent battery drain in the cold. These platforms will have different specifications, which could impose new distance constraints between docking and charging stations, or different charging stations entirely. Even with these constraints, there is still value in having one overarching ULS command and control network. If both ULSs remain completely separated, then goods from one network would not be identified and scheduled to meet the needs of the other. With time being of the essence, lives on the line, and the possibility of medical supplies being just a mile or two away in the other network should be the rationale to integrate them together. The establishment of a distribution node to transfer goods from one network to the other would satisfy the needs of the different hardware sets while keeping the universal command and control intact.

VII. CONCLUSION

An unmanned logistics system would have been invaluable in the aftermath of the 2010 Haiti Earthquake. The damaged infrastructure impeded traditional logistics entry into the disaster zone and hindered its efforts once there. Uncoordinated and disparate efforts, while well intentioned, often impeded the synergies of various humanitarian capabilities. A ULS could have projected its reach right into the heart of the devastation and provided dependable, life-saving support.

An interoperable and fully autonomous unmanned logistics system will take years to develop, but innovations and applications of UAV technology have made significant advancements over the past decade. During the 2010 Haiti earthquake, the United States military used RQ-1 Predator UAVs to gain situational awareness.[38] Full motion video was used to assess damage, monitor food distribution efforts, and IDP movements. In 2015, a ScanEagle UAV assessed fire intensity over the Olympic National Park in Washington state utilizing infrared sensors.[39] The ScanEagle was smaller and less than a quarter of the cost of a Predator, but could still fly in adverse weather. In 2017 rescuers used a UAV to find two stranded hikers and their dog in Colorado's Pike National Forest. Bruce Fosdick, a Douglas County search and rescue incident commander from Colorado praised the use of UAV by saying, "Instead of an all-night search we were done in about four hours."[40] January 2018, a small UAV delivered a flotation device to save two swimmers who were stuck in heavy surf in Australia.[41] These recent applications of UAVs demonstrate their use in disaster surveillance, search and rescue, and even just-in-time last-mile logistics. They also demonstrate that research and development of a ULS does not have to be a singular herculean effort. Development can take the form of incremental applications on a state or local level to gain expertise and trust.

The time to create ULS global standards and interactive modular technology is now. The FAA understands that UAV usage is expanding and that the NAS will have to accommodate their use. Commercial businesses are rapidly advancing UAV technology for a wide variety of applications, most notably home delivery. The internet has permeated the globe, giving most people access to the same online applications. As these technologies and regulations converge to make unmanned logistics a reality, the United States should posture its military, disaster support agencies, and humanitarian partnerships to take full advantage of unmanned logistics systems (ULSs) and their networks.

NOTES

---

1 United Nations Security Council, *Report of the Secretary-General on the United Nations Stabilization Mission in Haiti* (2010), 1, http://www.un.org/ga/search/view_doc.asp?symbol=S/2010/200; Sean Hussey M., et al, "The 2010 Haiti Earthquake: A Pathology Perspective Aboard the USNS Comfort," *Archives of Pathology & Laboratory Medicine* 135, no. 4 (April 2011): 417-421. EBSCO*host* (accessed January 12, 2018).

2 United States Geological Survey, *The Mw 7.0 Haiti Earthquake of January 12, 2010: USGS/EERI Advanced Reconnaissance Team Report* (Reston, Virginia: U.S. Geological Survey, 2010), iii, https://pubs.usgs.gov/of/2010/1048/

3 Ibid, 37.

4 Ibid, 41.

5 United Nations Security Council, *Report of the Secretary-General on the United Nations Stabilization Mission in Haiti* (2010), 3, http://www.un.org/ga/search/view_doc.asp?symbol=S/2010/200.

6 Melina Yingling, "Help Arriving," ReliefWeb, U.S. Geological Survey, http://www.mcclatchydc.com/news/politics-government/article24571306.html

7 United Nations Security Council, *Report of the Secretary-General on the United Nations Stabilization Mission in Haiti* (2010), 2, http://www.un.org/ga/search/view_doc.asp?symbol=S/2010/200.

8 Ibid, 1.

9 Timothy Ravich, *Evolving Law on Airport Implications by Unmanned Aerial Systems* (Washington: National Academy of Sciences, 2017), 11-12, https://www.nap.edu/download/24932; U.S. Department of Transportation, *CJ-27*, world aeronautical chart (Silver Spring, MD: Federal Aviation Administration, 2016), https://skyvector.com/

10 Juliet Van Wagenen, "Amazon Proposes New ATM Model for Commercial UAS Ops," *Aviation Today*, July 2015, http://www.aviationtoday.com/2015/07/30/amazon-proposes-new-atm-model-for-commercial-uas-ops/#.VyemqfkrJhF

11 Timothy Ravich, *Evolving Law on Airport Implications by Unmanned Aerial Systems* (Washington: National Academy of Sciences, 2017), 11, https://www.nap.edu/download/ 24932

12 Ibid, 15.

13 Ibid, 11-16.

14 Ernest C. Brown, and John A. Jarrell, "Local Management of Small UAS Traffic: A Path to Efficient Drone Operations," *The Air and Space Lawyer* 29, no. 4 (2016): 2. ProQuest (1879064058).

15 Federal Aviation Administration, *FAA Aerospace Forecast Fiscal Years 2017-2037*, (Washingtion, DC: Federal Aviation Administration, 2017), 31-32, https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2017-37_FAA_Aerospace_ Forecast.pdf

16 Michael Morales and Doral Edward Sandlin, "Managing Airborne Relief during International Disasters," *Journal of Humanitarian Logistics and Supply Chain Management* 5, no. 1 (2015): 19, https://search-proquest-com.lomc.idm.oclc.org/docview/1673079959?accountid=14746.

17 Ibid, 13.

18 Ibid, 14.

19 Larry Wentz, *Haiti Information and Communications Observations*, Washington, DC: Center for Technology and National Security Policy, 2010, p4. https://my.nps.edu/ documents/105738171/0/Haiti+Summary+Observations+%28V9%29_Larry+Wentz_PDF.pdf/f29221df-c49f-41c9-b009-f645de7b8b60

20 Intel Corporation, *Intel Falcon 8+ Unmanned Aircraft System User Manual*, (2017), Ch 7, https://www.intel.com/content/dam/support/us/en/documents/drones/IF8P_User-Manual.pdf

21 Benoit Boulanger, et al, "Analysis of a damaged 12-storey frame-wall concrete building during the 2010 Haiti earthquake Part I: Dynamic behaviour assessment," *Canadian Journal of Civil Engineering* 40, no. 8 (August 2013): 792. EBSCO*host* (accessed January 12, 2018).

22 Malek Murison, "Dronebox – The Automated, Connected, Self-Charging Drone Platform," *Airnest*, accessed January 12, 2018, http://www.airnest.com/blog/2016/2/18/ dronebox-the-automated-connected-self-charging-drone-platform.

23 Eric Mueller, Parimal Kopardekar, and Kenneth Goodrich, "Enabling Airspace Integration for High-Density On-Demand Mobility Operations," in *17th AIAA Aviation Technology, Integration, and Operations Conference* (Denver, CO: June 2017), 14, https://utm.arc.nasa.gov/docs/2017-Mueller_Aviation_ATIO.pdf.

24 Ibid, 14.

25 Brian Barrett, "Inside the Olympics Opening Ceremony World-Record Drone Show," *Wired*, accessed on February 19, 2018, https://www.wired.com/story/olympics-opening-ceremony-drone-show/.

26 Ibid.

27 Eric Mueller, Parimal Kopardekar, and Kenneth Goodrich, "Enabling Airspace Integration for High-Density On-Demand Mobility Operations," in *17th AIAA Aviation Technology, Integration, and Operations Conference* (Denver, CO: June 2017), 11, https://utm.arc.nasa.gov/docs/2017-Mueller_Aviation_ATIO.pdf

28 Larry Wentz, *Haiti Information and Communications Observations*, Washington, DC: Center for Technology and National Security Policy, 2010, 9. https://my.nps.edu/ documents/105738171/0/Haiti+Summary+Observations+%28V9%29_Larry+Wentz_PDF.pdf/f29221df-c49f-41c9-b009-f645de7b8b60

29 Abhishake Kundu and Timothy I. Matis, "A Delivery Time Reduction Heuristic using Drones Under Windy Conditions," in *IIE Annual Conference Proceedings*. (Norcross, 2017). https://search-proquest-com.lomc.idm.oclc.org/docview/1951124029?accountid =14746.

30 Ian J. Douglas, "Improving GPS Global Navigation Accuracy for Connected Vehicles in an Urban Canyon," (master's thesis, University of Windsor, 2016), 10, ProQuest Dissertations Publishing. Order No. 10172932

31 Davide Scaramuzza, "Tutorial on Visual Odometry," *University of Zurich Department of Robotics and Perception Group*, 31, accessed February 12, 2018, http://rpg.ifi.uzh.ch/docs/ Visual_Odometry_Tutorial.pdf

32 Sebastian Hening et al, "3D LiDAR SLAM Integration with GPS/INS for UAVs in Urban GPS-Degraded Environments," in *17th AIAA SciTech Forum*, 1-10. (Santa Cruz, CA: January 2017) https://utm.arc.nasa.gov/docs/2017-Hening_SciTech_2017-0448.pdf.

33 Close-Up Media, "YellowScan Introduces Surveyor Ultra High Density, Long-Range LiDAR for UAV," *Professional Services Close – Up*, February 7, 2018, https://search-proquest-com.lomc.idm.oclc.org/docview/1994805999?accountid=14746.

34 Larry Wentz, *Haiti Information and Communications Observations*, Washington, DC: Center for Technology and National Security Policy, 2010, p10. https://my.nps.edu/

documents/105738171/0/Haiti+Summary+Observations+%28V9%29_Larry+Wentz_PDF.pdf/f29221df-c49f-41c9-b009-f645de7b8b60

35 Waze Mobile Ltd., “Waze,” *Waze*, accessed February 16, 2018, https://www.waze.com/

36 Larry Wentz, *Haiti Information and Communications Observations*, Washington, DC: Center for Technology and National Security Policy, 2010, p16. https://my.nps.edu/documents/105738171/0/Haiti+Summary+Observations+%28V9%29_Larry+Wentz_PDF.pdf/f29221df-c49f-41c9-b009-f645de7b8b60

37 Ibid, 14.

38 David R. DiOrio, *Operation Unified Response, Haiti Earthquake 2010*, Joint Forces Staff College, 2010, 13, http://jfsc.ndu.edu/Portals/72/Documents/JC2IOS/

39 National Park Service, “Aviation Program, Unmanned Aircraft Systems,” *National Park Service*, accessed April 25, https://www.nps.gov/orgs/aviationprogram/unmanned-aircraft-systems.htm

40 Jennifer Smith, “The Moment Drone Finds Stranded Hikers and Their Labrador Who Got Lost in Colorado Forest,” *DailyMail*, accessed April 25, 2018, http://www.dailymail.co.uk/news/article-4615500/Drone-finds-stranded-hikers-Colorado-forest.html

41 Joseph Hincks, “Watch the World’s First Ever Drone Surf Rescue,” *Time*, accessed April 25, 2018, http://time.com/5109269/surf-drone-rescue-worlds-first-australia/

BIBLIOGRAPHY

Betson, Andrew P. "The Case Against a Cargo Unmanned Aircraft System." *Army Sustainment* 44, no. 5 (September 2012): 28-29. EBSCO*host* (accessed January 12, 2018).

Bjork, A., et al. "Geographic distribution of blood collections in Haiti before and after the 2010 earthquake." *ISBT Science Series* 12, no. 2 (May 2017): 291. EBSCO*host* (accessed January 12, 2018).

Boulanger, Benoit, et al. "Analysis of a damaged 12-storey frame-wall concrete building during the 2010 Haiti earthquake Part I: Dynamic behaviour assessment." *Canadian Journal of Civil Engineering* 40, no. 8 (August 2013): 791-802. EBSCO*host* (accessed January 12, 2018).

Brown, Ernest C. and John A. Jarrell. "Local Management of Small UAS Traffic: A Path to Efficient Drone Operations." *The Air and Space Lawyer* 29, no. 4 (2016): 9-14. ProQuest (1879064058).

Capitta, G., et al. "Structural and Operational Design of an Innovative Airship Drone for Natural Gas Transport over Long Distances." *Engineering Letters* 25, no. 3 (September 2017): 247-254. *Academic Search Complete*, EBSCO*host*(accessed January 12, 2018).

Close-Up Media, "YellowScan Introduces Surveyor Ultra High Density, Long-Range LiDAR for UAV," *Professional Services Close – Up*, February 7, 2018, https://search-proquest-com.lomc.idm.oclc.org/docview/1994805999?accountid=14746.

Department of Defense. *Joint Airspace Control*. JP 3-52. Washington, DC: February 13, 2014. https://jdeis.js.mil/jdeis/new_pubs/jp3_52.pdf

Department of Defense. *Joint Logistics*. JP 4-0. Washington, DC: October 16, 2013. https://jdeis.js.mil/jdeis/new_pubs/jp4_0.pdf

Douglas, Ian J. "Improving GPS Global Navigation Accuracy for Connected Vehicles in an Urban Canyon." Master’s thesis, University of Windsor, Canada, 2016. ProQuest Dissertations Publishing. Order No. 10172932.

Federal Aviation Administration. *FAA Aerospace Forecast Fiscal Years 2017-2037*. Washington, DC: Federal Aviation Administration, 2017. https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2017-37_FAA_Aerospace_Forecast.pdf

Federal Emergency Management Agency. *National Response Framework, 3rd Edition*. Washington, DC: Department of Homeland Security, 2016. https://www.fema.gov/media-library/assets/ documents/117791.

Gazal, Fuad. "Optimized Endpoint Delivery Via Unmanned Aerial Vehicles." Master's thesis, Minnesota State University, Mankato, 2017. ProQuest Dissertations Publishing. Order No. 10269624.

Hening Sebastian, Corey Ippolito, Kalmanje Krishnakumar, Vahram Stepanyan, and Mircea Teodorescu. "3D LiDAR SLAM Integration with GPS/INS for UAVs in Urban GPS-Degraded Environments." In *17th AIAA SciTech Forum*, 1-10. Santa Cruz, CA: January 2017. https://utm.arc.nasa.gov/docs/2017-Hening_SciTech_2017-0448.pdf.

Holguin-Veras, Jose, Miguel Jaller, and Tricia Wachtendorf. "Improving Postdisaster Humanitarian Logistics: Three Key Lessons from Catastrophic Events." *TR News*, July-August 2013. http://onlinepubs.trb.org/onlinepubs/trnews/trnews287.pdf

Hussey, Sean M., et al. "The 2010 Haiti Earthquake: A Pathology Perspective Aboard the USNS Comfort." *Archives of Pathology & Laboratory Medicine* 135, no. 4 (April 2011): 417-421. EBSCO*host* (accessed January 12, 2018).

Intel Corporation. *Intel Falcon 8+ Unmanned Aircraft System User Manual.* February 16, 2018. https://www.intel.com/content/dam/support/us/en/documents/drones/ IF8P_User-Manual.pdf

Kapoor, Rohan, et al. "UAV Navigation Using Signals of Opportunity in Urban Environments: An Overview of Existing Methods." *Energy Procedia* 110. (December 2016): 377-383, http://www.sciencedirect.com/journal/energy-procedia.

Kundu, Abhishake and Timothy I. Matis. "A Delivery Time Reduction Heuristic using Drones Under Windy Conditions." In *IIE Annual Conference Proceedings*, 1864-1869. Norcross, 2017. https://search-proquest-com.lomc.idm.oclc.org/docview/ 1951124029?accountid =14746.

Morales, Michael and Doral Edward Sandlin. "Managing Airborne Relief during International Disasters." *Journal of Humanitarian Logistics and Supply Chain Management* 5, no. 1 (2015): 12-34. https://search-proquest-com.lomc.idm.oclc.org/docview/1673079959?accountid=14746.

Moshref-Javadi, Mohammad and Seokcheon Lee. "Using Drones to Minimize Latency in Distribution Systems." In *IIE Annual Conference Proceedings*, 235-240. Norcross, 2017. https://search-proquest-com.lomc.idm.oclc.org /docview/ 1951120446?accountid=14746.

Mueller, Eric, Parimal Kopardekar, and Kenneth Goodrich. "Enabling Airspace Integration for High-Density On-Demand Mobility Operations." In *17th AIAA Aviation Technology, Integration, and Operations Conference*, 1-24. Denver, CO: June 2017. https://utm.arc.nasa.gov/docs/2017-Mueller_Aviation_ATIO.pdf.

Neuberger, Briana. "An Exploration of Commercial Unmanned Aerial Vehicles (UAVs) through Life Cycle Assessments." Master's thesis, Rochester Institute of Technology, 2017. ProQuest Dissertations Publishing. Order No. 10618409.

Nolte, Isabella M., Eric C. Martin, and Silke Boenigk. "Cross-Sectoral Coordination of Disaster Relief." *Public Management Review* 14, no. 6 (September 2012): 707-730. *Business Source Complete*, EBSCO*host* (accessed January 12, 2018).

Ravich, Timothy. *Evolving Law on Airport Implications by Unmanned Aerial Systems*. Washington: National Academy of Sciences, 2017. https://www.nap.edu/download/24932.

United Nations Security Council. *Report of the Secretary-General on the United Nations Stabilization Mission in Haiti.* (2010). http://www.un.org/ga/search/view_doc.asp?symbol=S/2010/200

United States Geological Survey. *The Mw 7.0 Haiti Earthquake of January 12, 2010: USGS/EERI Advanced Reconnaissance Team Report*. Reston, Virginia: U.S. Geological Survey, 2010. https://pubs.usgs.gov/of/2010/1048/

U.S. Department of Transportation. *CJ-27*. world aeronautical chart. Silver Spring, MD: Federal Aviation Administration, 2016. https://skyvector.com/

Vanian, Jonathan. "How Stanford Plans to Prevent Drones from Colliding." *Fortune.Com* (January 21, 2016): N.PAG. *Business Source Complete*, EBSCO*host* (accessed January 12, 2018).

Versluis, Anna. "Formal and informal material aid following the 2010 Haiti earthquake as reported by camp dwellers." *Disasters* 38, (April 2, 2014): S94-S109. *International Security & Counter Terrorism Reference Center*, EBSCO*host* (accessed January 12, 2018).

Wagenen, Juliet Van. "Amazon Proposes New ATM Model for Commercial UAS Ops." *Aviation Today*, July 2015. http://www.aviationtoday.com/2015/07/30/amazon-proposes-new-atm-model-for-commercial-uas-ops/#.VyemqfkrJhF

Williams, Martyn. "NASA plans major test of drone management system." *Cio (13284045)* (April 19, 2016): 8. *Business Source Complete*, EBSCO*host* (accessed January 12, 2018).

Yingling, Melina. "Help Arriving." ReliefWeb, U.S. Geological Survey. http://www.mcclatchydc.com/news/politics-government/article24571306.html