

# UAV Use in Disaster Management

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## ABSTRACT

Unmanned aerial vehicles (UAV) provide multiple opportunities to first responders and disaster managers, especially as they continue to improve in affordability as well as capabilities. This paper provides a brief review of how UAV capabilities have been used in disaster management, examples of current use within disaster management, as well as adoption considerations. Example disaster domains include fires, tornadoes, flooding, building and dam collapses, crowd monitoring, search and rescue, and post disaster monitoring of critical infrastructures. This review can increase awareness and issues when considering UAVs by those challenged with the management of crisis and disaster events.

## Keywords

Disaster Response, Emergency Management, Drone, Unmanned Aircraft System (UAS), Unmanned Aerial Vehicle (UAV).

## INTRODUCTION

A 1966 Welsh mining tragedy claimed 144 lives, mostly children, when a man-made mountain of liquefied coal waste moved at great speed in a “30-foot-tall tsunami of sludge” entombing the village’s Junior School (Solly, 2019, para. 11). Although UAVs did not then exist, their use might have anticipated a similar 2015 mining dam collapse in Brazil’s town of Mariana, and again in Brazil’s 2019 dam collapse in Brumadinho. The police report of the Mariana disaster stated that the mine’s emergency plan to warn nearby villagers was insufficient (Gallas, 2016). UAVs could have possibly saved lives by detecting a pending collapse or triggering early warning systems. UAVs have since been used to detect potential problems, such as structural building stability following Hurricane Katrina, and early intervention, such as forest fire and drowning victims (Karsten & West, 2018; Lopez-Fuentes, van de Weier, González-Hidalgo, Skinnemoen, & Bagdanov, 2018; Murphy, 2015; Ramirez-Serrano, 2018).

Monitoring for possible dam reinforcement to reduce the risk of collapse represents one opportunity for UAV aerial surveillance. Mine “tailings, or dams made from mining residue, are some of the largest engineered structures on earth. The tailings must be monitored constantly for structural stability, as they are vulnerable to excess water and seismic activity (Owen, Kemp, Lèbre, Svobodova, & Pérez Murillo, 2019).

This paper discusses the role of hazard modes in disaster management, describing UAVs and issues in applying them, providing cases of successful UAV use in disaster management, and presenting criteria for UAV adoption.

## HAZARD MODES IN DISASTER MANAGEMENT

Disaster Management encompasses the organization and management of resources and responsibilities for the humanitarian aspects of emergencies, as well as response and recovery, to lessen the impact of disasters (IFRC, 2020). In this paper the words disaster and crisis are used interchangeably.

All disasters stem from hazards, but effective risk management could control hazards to prevent a disaster. Further, hazards can be ranked into dormant, armed, and active modes (Glantz & Ritter, 2017; MacCollum, 2007), increasing in order from 0% to 100% probability of occurrence.

Risk management is primarily proactive by creating plans and interventions primarily for dormant hazards. Risk management also plans the disaster management response to active (i.e., occurring) hazards, including duties and tools for the disaster management teams (Glantz & Ritter, 2017).

The management of disasters enhances reactive response and is coordinated into three stages: (a) Pre-disaster planning and preparedness, (b) Ongoing disaster response and management, and (c) Post-disaster recovery (IFRC, 2020).

In the first stage, or pre-disaster planning, identification of threats or hazards is important along with the other risk management activities that identify and rank possible hazards. Thorough and proper identification of threats becomes a critical precursor in response planning to lower known risk likelihood and/or impact. UAVs can provide additional insight and alternative perspectives in this stage to identify threats and vulnerabilities. In the second stage, creating and preparing for ongoing disaster response and management is also important, including identification of tools, such as UAVs for surveillance and early warning. UAVs can also be used in the third stage to help build capacity to deal with future disasters.

Note that disasters stem from natural sources, such as earthquakes and tornados, or man-made sources, which may be intentional (e.g., armed conflict, sabotage), or unintentional (e.g., operator error, system or technological failure). The mining waste dams described in the introduction are of the more complex variety in that they represent the intersection of hazards from natural and man-made origins (Glantz & Ritter, 2017).

Ideally, risk management interventions will control known hazards and prevent escalation. However, a disaster may still arise from a hazard event that was (a) Unexpected, and thus lacking a planned response treatment or (b) Expected, but without a sufficiently planned response and treatment (Glantz & Ritter, 2017).

## UAV TERMS AND RELATED ISSUES

This paper uses the term UAV (unmanned aerial vehicle) and drone interchangeably to describe a rotary (i.e., multi-rotor) or fixed wing vehicle that is operated without an onboard pilot, including high altitude/long range vertical takeoff and landing (VTOL) aircraft. The term UAS (unmanned aerial system) more completely describes the system consisting of the aerial vehicle as well as necessary ground components, such as the remote pilot. UAS is preferred by the US Federal Aviation Administration (FAA) website that currently uses UAS and drone interchangeably. The FAA currently requires recreational flyers, for example, to include a remote pilot that maintains a visual line-of-sight on the UAV (FAA, 2020).

Another option is to use a more specific term such as “quadcopter,” for example, to describe the popular recreational and civil rotary wing device that uses four propellers. When stationary flight is not required, fixed wing UAVs are popular for surveys, mapping, and agricultural use as they can fly a pattern at higher altitudes with more efficiency. **Figure 1** is an example of a craft that combines the maneuverability of a rotary craft with the speed and distance capabilities of a fixed wing vehicle.



**Figure 1. The xCraft x2Q (\$US7,995) is both a hybrid fixed wing and vertical takeoff and landing (VTOL) craft. Maximum flight time is 25 minutes. Speed range is from 0 to 100 km/hr. (0-62 MPH). Weight, without camera or another sensor, is 1.5 kg (3.3 lbs.). Wingspan is 84 cm (33 in.). Payload is 250g (0.55 lb.) (<https://xcraft.io/>)**

Beyond the scope of this paper are pilot-less or autonomous-UAVs common in defense (DeGarmo, 2004), as well as swarming networked devices capable of coordinating with each other (Dimitropoulos, 2019). Also not included in this paper are tethered UAVs that could provide a communications relay platform (Mottorn, 2014), unmanned ground vehicles (UGV), unmanned surface vehicles (USV), and unmanned underwater vehicles (UUV), as well as their autonomous counterparts, such as autonomous underwater vehicle (AUV). See also Oury and Ritter (2019/accepted) for suggestions for building such systems.

There are several issues associated with implementing the use of UAVs. The first is the lack of standards, or consensus on operational concepts, definitions, and classifications. This includes minimal certification standards and regulations addressing operations and operator qualifications. Coordination is also an issue due to lack of effective and affordable collision avoidance systems that could detect non-transponder equipped aircraft. UAV systems have a rather poor record of reliability, and there is limited availability of protected frequency spectrum. Finally, insurance and liability costs may seem high, as well as acquisition and operational costs (DeGarmo, 2004).

Another possible issue is evolving coordination between local and federal response agencies. In 2013 a UAV manufacturer had volunteered its services to the Boulder, Colorado, Emergency Operations Center to surveil areas of extensive flooding. Falcon UAV manufactures a hand-launched, fixed-wing UAV equipped with GPS and cameras to autonomously generate highly accurate ground maps. This worked for several days until the U.S. Federal Emergency Management Agency (FEMA) took control and abruptly and without explanation grounded Falcon (Ackerman, 2013). This early and unwarranted conflict seems to have smoothed in more recent incidents, such as Hurricane Florence, when the FAA encouraged authorized private sector drone operators (i.e., FAA Certificate of Authorization, or flying under Part 107) to coordinate activities with the local incident command (DHS, 2018).

#### **UAV USE EXAMPLES—DISASTER MANAGEMENT**

As UAVs continue to evolve, so have the use-cases for disaster management. UAVs can gather information, provide communications infrastructure, and improve situational awareness of affected areas. Valuable first responder information examples include whether roads are passable, surface-type of roads/paths, possible collection points, contamination results, and other necessary first responder information.

New York police monitored 2019 New Year's Eve Times Square crowds using drones, supplementing 1,200 security cameras and helicopters. Visual flexibility to move silently as needed while not disrupting activities is seen as the primary benefit. Drones are outfitted with thermal-imaging, 3D-mapping, and high-power camera lenses. UAVs have been used previously for New York crowd events, among other uses, such as crime scene investigation. They are small, mostly unseen, and for safety can be tethered or otherwise not permitted to fly directly over crowds (Paybarah, 2019; Sisak, 2018).

Rajant Corporation, a company in Malvern, PA, provides wireless mesh networking technology that can be outfitted on drones. In October 2019, Rajant partnered with Santa Barbara County fire fighters for a trial run of the mesh networked drones. The trial quickly changed from a simulation to a crisis application when a fire broke out near El Capitán Canyon, forcing closure of Highway 101 and the evacuation of campers from nearby campgrounds. Firefighters kept the fire from spreading beyond the 420 acres already burned by using aerial views provided by drones to support active hazard mitigation (Rajant, 2019).

Researchers propose integration of Wireless Sensor Networks (WSN) with UAV systems for disaster management, such as search and rescue. Erdelj, Król, and Natalizio (2017) also include a detailed overview of related research efforts combining disaster management and UAV use. WSNs are spatially dispersed sensors dedicated to centralizing data collection of recorded physical environmental conditions such as temperature, sound, pollution levels, humidity, and wind. In this case, researchers propose use of a fixed wing UAV to quickly survey the disaster area for an overall situational view—including people detection—followed by rotary-wing UAVs gathering real-time information from critical locations. Other researchers adopt UAVs in WSNs to deploy ground sensors, as well as carry embedded mobile sensors, especially in dangerous and/or inaccessible regions (Erman, Hoesel, Havinga, & Wu, 2008).

Other researchers combine UAVs with unmanned ground vehicles (UGV) to leverage strengths in a symbiotic fashion. Together they can quickly search for and localize targets in a specified area. While unmanned ground vehicles can accurately locate ground targets, the UAVs offset the UGV disadvantage of slow movement and obscured views. The benefit of UAVs with low-cost embedded devices improves reliability while saving time during the response and recovery phases (Grocholsky, Keller, Kumar, & Pappas, 2006).

A disaster communication architecture coordinates communication between sensors embedded in the area, on users, and on vehicles. Although not citing UAV-use specifically, the vehicles could include UAVs, while ground sensors could be deployed using UAVs. Collaborative and distributed sensing improves the command and control information required to maintain situational awareness (George et al., 2010).

Combining networked and collaborative UAVs together overcomes single-use UAV limitations such as shorter flight times, smaller payloads, and reduced operating ranges. In a large-scale fire service drill, system setup was accomplished under five minutes before providing aerial surveillance of the entire area with a few additional minutes. Fire fighters were able to assess the situation and plan next steps using aerial images. Operating a multi-UAV system, however, must be intuitive and efficient so that a single individual can operate the entire fleet. In this case, the operator does not “steer” individual UAVs, but instead defines high-level tasks on a digital map such as area to be observed, as well as restricted areas to avoid (Quaritsch, Kuschnig, Hellwagner, & Rinner, 2011).

Rescue efforts have been impeded in Taiwan’s natural disasters, such as the 1999 Chi-Chi Earthquake and the 2009 Morakot Typhoon, from recurring flooding, dam failures, road and bridge failures, landslides, and water contamination. Following the Morakot Typhoon, efforts to prevent secondary disasters included mapping disaster areas using UAVs in conjunction with the Soil and Water Conservation Bureau. Affected areas were identified for disaster follow-up analysis and disaster restoration and reconstruction efforts (Chou, Yeh, Chen, & Chen, 2010).

**Table 1** presents a variety of sensors payloads for UAVs along with use case examples. Sensors include specialized cameras that detect different wavelengths, such as visible light for remote site inspection during flooding, or infrared (IR) heat signatures. Another sensor is LiDAR “point clouds” that create a 3D representation of ground topography by creating a “cloud,” or collection of points, from different angles to generate an X, Y, and Z coordinate for each point. LiDAR point clouds assist wildfire prevention by evaluating forest fuels in across topographies (Fernández-Álvarez et al., 2019). Particle sensors that detect radiation and chemicals, for example, are useful to inspect environmental disaster areas.

**Table 1. UAV sensor payload use case examples (<https://www.droneii.com/>)**

Sensor	Optical Camera	Thermo-Graphic Camera/IR Camera	Multispectral/Hyperspectral Camera	LiDAR	Particle Sensor
Feature	Visible light rays	Heat signatures	Combine visible, heat, and UV light	Light Detection and Ranging “point clouds”	Radiation, Gas, Electro-magnetic, Vapor, Other
Use Case	Site/Structure inspection	Search & Rescue	Earthquake, Agriculture, Mining	Wildfire mapping	Environmental disaster

**Table 2** summarizes use cases reviewed so far. Most application cases do not use all of these. Most of these uses are inspection activities, but (a) and (j) provide electronic and physical support. Some tasks are continuous monitoring, and some tasks are essentially mapping. Some monitoring would be done automatically by tools, and some would be done with a human observer.

**Table 2. UAV uses in man-made and natural disasters**

a) Network and communication support
b) Visual inspection, structural stability (e.g., dams, buildings)
c) Visual inspection, search and rescue (e.g., survivors, navigation)
d) Crowd monitoring
e) Fire (e.g., smoke detection, spread)
f) Chemical and radiation detection
g) Crime scene and accident reconstruction (e.g., orthomosaic mapping)
h) Photography and anomaly detection (e.g., still, video, infrared)
i) Weapon and threat detection
j) Deploying rescue materials (e.g., drowning victims)

**UAV POLICY AND FUNDING CONSIDERATIONS**

Adopting UAVs into emergency and disaster management operations should begin with a high-level review of the mission and goals to be accomplished, as executive support is required to establish the program. To make informed decisions, these officials should receive comprehensive programmatic information of the UAV program. This includes an understanding of information needs, historical perspective of conventional methods for aerial missions in disaster response, awareness of comparative programs, potential uses of UAVs in disaster response, and barriers to formal integration of UAVs into the national airspace system (Price, 2016; Thamm, Ludwig, & Reuter, 2013).

The size, type, and quantities of UAVs also need to be determined, with an opportunity for expansion following a successful start. Features such as GPS, cameras, and infrared capabilities need to be considered, as well as auto-return to home-base during low battery or loss of pilot signal. **Table 3** presents price points for a few sensors. Consider also the organizational structure and support needed, as well as other significant investment in personnel, equipment, training, and funding. As stated above, there must be support for a UAV program at the highest levels of the organization to succeed (Price, 2016), which is similar to what is required for human factors and usability interventions to succeed (Booher & Minniger, 2003).

**Table 3. Various drone sensor costs (<https://www.pobonline.com/>)**

<b>Built-in Camera</b>	<b>Small Independent Camera</b>	<b>High-end Independent Camera</b>	<b>LiDAR (Light Detection and Ranging)</b>
Small multi-rotor w/built-in camera	Fixed wing or Small/medium multi-rotor	Large multi-rotor	Large multi-rotor
\$1,500	\$2,000 – \$40,000	\$20,000+	\$7,500 - \$150,000

Funding sources could also be considered, such as Emergency Management Performance Grant (EMPG), State Homeland Security Program (SHSP), and Urban Area Security Initiative (UASI). Consider also training and maintenance expectations and requirements, and experience needed such as pilot in command or visual observer to earn and maintain certification (Price, 2016).

A policy outlining the parameters of the program is needed before formally beginning and procuring a UAV. Policy sections should include the topics in **Table 4**. These are derived from the review of the above and related publications (DeGarmo, 2004; Price, 2016).

**Table 4. Policy considerations for procuring a UAV**

<ul style="list-style-type: none"> <li>a) Standard terminology and program definitions,</li> <li>b) Purpose of the program,</li> <li>c) Types of UAVs used by the agency,</li> <li>d) Specifications for the UAVs and capabilities,</li> <li>e) System and data cyber security,</li> <li>f) Outline of the flight crew roles and responsibilities,</li> <li>g) Operating guidelines,</li> <li>h) Flight requirements,</li> <li>i) Process for notifying local air traffic control; and</li> <li>j) An emergency management dashboard.</li> </ul>
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Thamm et al. (2013) have created a process model for implementing UAVs, based on research with police and fire agencies, with an emphasis on power outages as the disaster scenario. This process takes into account organizational requirements with theoretical findings. Similarly, researchers at the University of Cincinnati have formed the SIERRA project (Surveillance for Intelligent Emergency Response Robotic Aircraft) as a resource uniting academia with emergency responders working with UAVs. Their work is based on research conducted with West Virginia forestry to improve situational awareness and prevent loss of life by providing firefighters a view of the fire in real time, as well as its progression (Brown, Wei, Ozburn, Kumar, & Cohen, 2015). Perhaps the largest UAV/UGV group is at Texas A & M (<https://unmanned.tamu.edu/>).

Legislative considerations are often managed by each country's national aviation authority and tend to evolve regularly. Safety as the primary concern requires the UAV to be part of a system (UAS) connecting the UAV to a remote pilot station, often maintaining line of site, and a command and control system. An example of an online directory tracking legislation is <https://droneregulations.info/index.html>.

Training and certifications are other considerations, especially for advanced operation such as remote piloting. Training is available online can be completed through a variety of providers. For example, Drone Pilot Ground School (<https://www.dronepilotgroundschool.com/pricing/>) charges around \$300 to meet the FAA's Small UAS Rule (Part 107) knowledge requirements. Inexpensive flight simulators are also available for less than \$250 to build experience without risking damage to expensive drones.

Finally, reviewing earlier robotics applications can be beneficial, even when not UAV-based, such as search and rescue in the World Trade Center (Casper & Murphy, 2003), or victim detection and navigation competitions (Murphy, Casper, Micire, & Hyams, 2000).

## CONCLUSION

UAVs represent a powerful tool for first responders and crisis managers. Capabilities and features are wide-ranging, and include GPS mapping, infrared photography, and chemical sensors among others. UAVs may be operated solo or even in swarms. Detailed aerial views are possible from an integrated array of sensors, as well as sensor or cargo deployment, or functioning as a communication platform. UAVs offer alternative views of disaster scenes that may improve response and recovery, and expand capabilities to observe, inspect, and react. These views might otherwise be difficult, dangerous, or expensive to obtain.

Disaster managers and researchers should be aware that UAVs are an increasingly easy and affordable tool to assist gathering information and managing disasters. Adopting UAVs begins, like most infrastructure improvements, with the creation of a business case that articulates the goal and purpose of the UAV system. Cost preparation includes upfront and ongoing, acquisition, operation, maintenance, training, and certification considerations.

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