# Preliminary Feasibility Study of a Simulated Overdose Antidote Delivered by an Unmanned Aerial Vehicle in an Urban Environment

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## Abstract

*Unmanned aerial vehicles (UAVs; 'drones') deliver time-sensitive health care tools to out-of-hospital environments. Many emergency response systems struggle to deliver antidote to victims of opioid overdose before respiratory depression results in morbidity or mortality; thus, UAVs may play a useful role in antidote delivery for out-of-hospital toxicologic emergencies. We tested the feasibility of dropping simulated antidote from a UAV to a bystander in an urban environment, measuring accuracy of drop, ease of recovery, and antidote survivability. A minimum flight altitude of 40m avoided any obstacles to accurately fly to specific coordinates. Simulated antidote drifted an average of 48 feet from the intended target, was discoverable on the ground, and survived the drop. These findings imply that UAV-dropped antidote may be a potential tool in emergency response to opioid overdose. Future research should focus on mechanisms for UAV integration within existing opioid overdose emergency response systems, human-UAV interactions, and payload design.*

**Keywords:** unmanned aerial vehicle, drone, emergency medical services, opioid, antidote.

## 1. Introduction

Opioid overdose is a time-sensitive emergency that may result in respiratory depression, hypoxemia, and cardiac arrest if not rapidly reversed with an antidote, such as naloxone (Boyer, 2012). Naloxone is commonly packaged in a pre-filled, single-use dose given intranasally or by injection. In the United States, emergency medical services (EMS) collectively respond to over 100,000 non-fatal opioid overdoses that require naloxone each year (NEMSIS, 2023). Goal response time to minimize adverse outcomes is less than five minutes; however, delays in EMS response (e.g. urban traffic congestion, workforce shortages, large rural catchment areas) result in a national average response time of 9.8 minutes, with delays of up to 30 minutes reported in some rural areas (Griffin & McGwin, 2013; Mell et al., 2017; NEMSIS, 2023). Although bystander-administered naloxone prior to EMS arrival increases the odds of survival, naloxone is often not readily available or the amount needed may exceed the available supply (Giglio et al., 2015; Klebacher et al., 2017; Nguyen et al., 2020; Wheeler et al., 2015).

Unmanned aerial vehicles (UAVs; 'drones') have served an important role in out-of-hospital emergency response through the timely delivery of critical equipment and/or medications to on-site personnel. Prior studies of UAV-delivered automated external defibrillators in response to out-of-hospital cardiac

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arrest provided patients with lifesaving equipment earlier than a simultaneously dispatched ambulance (Boutilier et al., 2017; Claesson et al., 2017; Schierbeck et al., 2022). Other preliminary work using UAVs has demonstrated that medication can survive the temperature changes associated with UAV flight, medication arrives faster than a simultaneously dispatched ambulance in an urban environment, and a simulated bystander could remove medication from the UAV and deliver it to a mannequin suffering from a simulated emergency condition (Beck S, 2020; Ornato et al., 2020; Tukel CA, 2020). These prior studies suggest that UAVs may be useful in antidote delivery during toxicologic emergencies in the community; however, these studies were limited by the need for the UAV to land at the site of the emergency. The requirement to land risks unnecessary time-delay, UAV damage, and bystander injury; additionally, it assumes that a bystander is willing to interact with the UAV to remove the antidote and that the UAV would not be damaged or stolen during this interaction. Thus the need for alternative strategies for UAV-based antidote delivery is highlighted (Buckland DM, 2019; Tukel CA, 2020).

We examined the feasibility, accuracy, discoverability, and survivability of simulated opioid antidote delivery by UAV in an urban environment.

## 2. Methods

### 2.1. Study Design

We conducted a series of flight scenarios to characterize the feasibility of a UAV carrying simulated antidote to an emergency response scene and dropping simulated antidote to a bystander below. The study was designed to quantify the accuracy of UAV flights to pre-defined coordinates at the study site, measure the accuracy of simulated antidote dropped from a standardized altitude above a pre-defined target on the ground, characterize the ease of recovery by a bystander, and determine the survivability of simulated antidote after striking the ground.

This study was categorized by The Ohio State University Office of Responsible Research Practices as not human subjects research. All UAV pilots in this study completed Federal Aviation Administration (FAA) required training.

### 2.2. Materials

We conducted the study using a SwellPro SplashDrone 4 UAV. (**Table 1**). The UAV can function in all weather, is waterproof, buoyant, and useable in both day and night conditions. We modified the UAV to carry a simulated opioid antidote payload. (**Figure 1**) The UAV was registered with the FAA via a Part 107 account on FAA DroneZone and we labeled the UAV with its unique identification number according to FAA regulations ("Part 107 - Small Unmanned Aircraft Systems," 2016). We calibrated the UAV according to the procedures defined in the operation manual (SwellPro, 2022).

**Table 1. SwellPro SplashDrone 4 manufacturer specifications.**

| Variable | Specification |
|---|---|
| Weight (including battery and propellers) | 2.18kg |
| Propellers | #1242 carbon fiber |
| Battery | 14.8V, 84W, 6600mAh |
| Axis Diameter | 450mm |
| Maximum Ascend/Descent Speed | 4m/s |
| Hovering Precision | +/- 0.5m (vertical)<br>+/- 0.5m (horizontal) |
| Maximum Flight Speed | 22m/s |
| Maximum Wind Speed Resistance | 14m/s |
| Maximum Payload Capacity | 2.0kg |
| Waterproof Rating | IP67 |
| Operating Frequency | 4180-5875 MHz |
| Maximum Flight Time | |
| No Payload | 30 minutes |
| Maximum Payload | 15 minutes |
| Working Temperature | -10C – 40C |
| Video Stream | 64 mbps |
| Video Latency | 200 ms |


**Figure 1. SwellPro SplashDrone 4 with diagram of pertinent features.**

## 2.3. Setting

We conducted all flight scenarios in a 47-acre urban park, which included a river, tree cover, buildings, streetlights, and powerlines (**Figure 2**). We registered each flight scenario with the FAA using the B4UFly App and followed the Code of Federal Regulations Part 107 § 107.130 Category 3 (including restrictions preventing nighttime flight) and local altitude restrictions ("Part 107 - Small Unmanned Aircraft Systems," 2016). Each flight scenario had a UAV pilot and UAV spotters, as required by the FAA; flights that utilized automated flight paths to pre-programmed global positioning system (GPS) coordinates included a UAV pilot who actively monitored the flight and had the ability to manually overtake the flight path, if necessary. We conducted flight scenarios on different days to include various common weather conditions: freezing and non-freezing temperatures, sunny and overcast/cloudy skies, precipitation and no precipitation.

## 2.4. Methods and Measurements

We conducted a series of three flight scenarios to meet the study objectives.

Scenario One (feasibility, minimum altitude): We designed a flight path that encountered a building, bridge, powerline, and trees. (**Figure 2**) We first calibrated the UAV to an altitude of 0.0m on the ground. The UAV was manually turned on and the pilot flew to an altitude of 20 meters (m) and continuously measured altitude using real-time feedback from the UAV's altimeter. The pilot flew along the pre-defined flight path until an obstruction was encountered; the pilot paused flight, the obstruction was documented, and the pilot increased the UAV's altitude by 5.0m meters and continued to fly using the same procedure until the entire circular flight path was flown without encountering an obstruction.

Scenario Two (flight path accuracy): We chose three sites within the park as hypothetical emergency response sites to test the accuracy of the UAV's GPS-guided flight path. (**Figure 2**) Scenario 2a used pre-programmed GPS coordinates within the park. We placed the UAV at an origin point and manually turned it on; the UAV then automatically ascended to a height of 40m after which it flew to three pre-programmed GPS coordinates (one open space, one shelter, and one wooded area) without direct pilot guidance before returning to the flight origin, at which point the pilot manually landed the UAV. While the UAV flew this route, a spotter used identical GPS coordinates from GoogleMaps and stood at each target location on the flight path and reported if the UAV flew directly over-


**Figure 2. Park map with annotated flight paths (star: flight origin; white line: flight scenario 1; black line: flight scenario 2a; orange line: flight scenario 2b; red line: flight scenario 3).**

head; we confirmed this outcome using the UAV's real-time video feed to verify that the spotter was in the center of the screen as the UAV flew directly over each set of GPS coordinates. Scenario 2b used similar methods, but instead of flying to pre-programmed GPS coordinates, the UAV flew to a pre-programmed street intersection. (**Figure 2**) In this scenario, if the spotter reported that the UAV was not directly overhead, the pilot manually maneuvered the UAV until it was overhead, and the distance flown manually was recorded (in meters) using real-time flight distance recording.

Scenario Three (drop accuracy, discoverability, survivability): We manually equipped the UAV's payload with a simulated antidote (a sealed, pre-filled 10 milliliter normal saline syringe, measuring 19 x 2 centimeters and weighing 18 grams) using a plastic cable tie. (**Figure 3**) We manually turned on the UAV, which then automatically ascended to a standard altitude of 40m and flew to pre-programmed GPS coordinates in the park, which were also marked on the ground using identical GPS coordinates via a spotter with GoogleMaps. (**Figure 2**) Once the UAV arrived at the pre-programmed coordinates and hovered, the UAV pilot ensured the field of view was clear of obstructions and manually released the simulated antidote; the spotter observed the simulated antidote until it hit the ground and used a tape measure to quantify the amount of drift (in feet) between the marker on the ground and the site that the simulated antidote was discovered on the ground. Discoverability was defined as the ability of the spotter to find the simulated antidote for the above measurement. This procedure was repeated three times each for four different simulated antidote packaging materials (a single syringe cable tied to payload, two syringes cable tied to payload, a single syringe wrapped in bubble wrap, and a single syringe wrapped in paper batting). To characterize survivability, each syringe was opened, and the plunger was depressed to determine if the syringe remained functional (i.e., that the plunger completely depressed and flushed out normal saline).

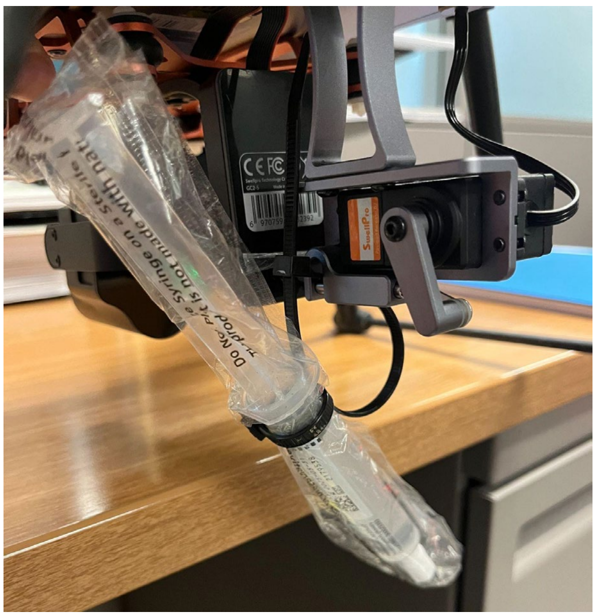

**Figure 3. Example of simulated antidote (10 milliliter normal saline syringe) attached to UAV payload by plastic cable-tie.**

### 2.5. Statistical Analysis

We calculated descriptive statistics for each objective, including frequency, percentage, mean and range.

## 3. Results

Scenario One (feasibility, minimum altitude): The minimum altitude for unobstructed flight was 40m. Trees were the most common obstruction between 20m-40m; trees, powerlines, and buildings did not interfere with the flight path above 20m. (**Table 2**)

Scenario Two (flight path accuracy): The GPS coordinate based flight path flew directly over the observer during 100% of flights (n=6). The GPS street intersection based flight path was accurate to within 3m of the observer (n=3). (**Table 2**)

Scenario Three (drop accuracy, discoverability, survivability): The single normal saline syringe drifted an average of 47 feet (') from the target (range 20'-60'). The double syringe drifted an average of 33' from the target (range 20'-50'). The syringe in bubble wrap drifted an average of 57' (range 30'-80'). The syringe in paper batting drifted an average of 53' (range 32'-80'). We observed 100% (n=5) survivability of syringes after hitting the ground. In all cases we recovered the payload (100%, n=12). (**Table 2**)

**Table 2. Flight Scenario Outcomes**

| Flight Scenario | Description | n | Outcome |
|---|---|---|---|
| 1 | Minimum Altitude | 1 | 40m |
| 2 | Flight Accuracy | | |
| | (a) GPS Coordinate Based | 6 | 100% |
| | (b) Street Address Based | 3 | 100% |
| 3 | Drop Accuracy | | |
| | (a) Single Syringe | 3 | 47' (20-60') |
| | (b) Double Syringe | 3 | 33' (20-50') |
| | (c) Bubble Wrap | 3 | 57' (30-80') |
| | (d) Paper Batting | 3 | 53' (32-80') |
| | Syringe Survival | 5 | 100% |
| | Syringe Discoverability | 12 | 100% |

## 4. Discussion

We demonstrated that a hovering UAV carrying simulated antidote can successfully air drop the simulated antidote near an individual on the ground, the simulated antidote survives the drop, and is discoverable by an observer on the ground.

Our observed results are similar to those of Tukel, et al (2020), which demonstrated the ability of a UAV carrying an antidote package to fly unobstructed at an altitude of 45m. Our study builds upon this previous work by demonstrating the ability to release and deliver the antidote to the scene from this altitude. The observed mechanical survivability of the syringe in our study also builds upon the results reported by Beck, et al (2020), which demonstrated that epinephrine retained its pharmacologic potency after exposure to UAV-like conditions (including humidity and temperature changes). Finally, the observer's ability to find the simulated antidote that was dropped to the ground in this study was equivalent (100%) to that of the direct-to-bystander delivery method described by Ornato, et al (2020), implying that multiple modes of delivery may be feasible.

In addition to building upon the prior literature base, this study's results add five key systems observations for consideration in future research: UAV integration with emergency response systems, human-UAV interactions, payload design and delivery, human-payload interactions, and regulatory environment.

This study, and prior similar studies, are predicated on scenarios in which a UAV will outpace traditional modes of emergency response (e.g., ambulance, police vehicle, or fire apparatus). Future studies should consider developing ways to predict *times* (e.g., urban areas during certain traffic conditions), *locations* (e.g., specific rural catchment areas or urban mass gathering events), and *weather conditions* (e.g., temperatures above the minimum needed for UAV battery function or winds slower than maximum UAV speed) where this may occur. One potential area for innovation includes the development of information technology applications that can simultaneously consider time, location, weather conditions and local emergency resources to determine if a UAV would outpace other more traditional modes of response. In doing so, the emergency system may consider developing a UAV delivery network, similar to prior modeling studies for UAV-delivered automated external defibrillators (Ye JJ, 2019).

This study also highlighted conceptual questions regarding the necessity of human interaction with the UAV during simulated antidote delivery. In this study, due to FAA regulations, a UAV pilot observed and was able to overtake the flight (even on pre-programmed paths). Additionally, the UAV pilot manually verified that there was a clear path to drop the simulated antidote prior to manually releasing the payload (per UAV operating guidelines). While not technically difficult tasks, they do raise a question regarding the role of human oversight in UAV-based antidote delivery and if information technology (such as artificial intelligence) could be used to confirm an unobstructed drop before automatically releasing the payload. Future work should examine the potential benefits and pitfalls of a completely automated delivery system and the role that technology can play in assessing scene suitability for drop.

We observed variability in the accuracy of simulated antidote dropped from our UAV. It is important to acknowledge that the simulated antidote in this study was a saline syringe (due to local regulatory requirements) and that the aerodynamics of naloxone may differ. However, we expect the issue of accuracy to remain, and future consideration should be given to payload designs that maximize precision and accuracy of antidote delivery. Based on our results, increasing the weight of the payload (e.g., dropping two syringes tied together, rather than one) may increase drop accuracy. In addition to increasing weight and possibly drop accuracy, dropping multiple doses of antidote may be useful in delayed emergency responses where a victim requires more than one dose of antidote and/or scenarios where there are multiple victims requiring antidote prior to EMS arrival. Similarly, while this study supports the feasibility of dropping an unprotected antidote to the ground, prior studies by Tukel, et al (2020) and Ornato, et al (2020) used high-visibility packaging, which would both increase the weight of the payload and potentially improve discovery in low-visibility situations (e.g., adverse weather conditions, nighttime). However, potential drawbacks of increased payload weight for accuracy include decreased flight speed, increased battery use, and the possibility of the payload becoming a dangerous projectile when dropped. An alternative response to this problem that should be considered is designing new applications or leveraging artificial intelligence to account for payload weight, altitude, and current conditions (e.g. wind) and calculating the ideal GPS coordinates from which to drop the antidote in order for the antidote to land at specific GPS coordinates on the ground.

Although air-dropped simulated antidote negates the threats of time delay, damage, and theft associated with the UAV landing process, it does require consideration of important human-UAV payload interactions that have yet to be described. For example, the air drop method assumes that a bystander who activated emergency response has remained at the site of the emergency, is willing to leave the victim to recover the dropped antidote and is both capable and willing to administer it to an overdose victim. Unfortunately, very little is known about these critical variables in the human-UAV payload interaction and should be the subject of future investigation. Additional design considerations should specifically address bystander needs for administration instructions, whether that is printed on the payload itself, provided by 9-1-1 dispatcher via phone, or broadcasted via a speaker on the UAV itself.

A fifth important consideration for future research is the regulatory environment in which studies are conducted. The federal regulation of UAVs is administered through the FAA; however, additional regulations can be added by local governments and may be more restrictive in densely populated areas with frequent flight path obstructions (e.g., tall buildings, critical infrastructure, or restricted airspace over stadiums, hospital helipads and airports). Additional pertinent non-UAV regulations, including those limiting which antidotes can be delivered to a bystander in the community (i.e., over the counter antidotes only vs antidotes requiring prescription) and regulations regarding proper storage and transportation of the antidote, are also pertinent considerations for study implementation. Finally, consideration should be given to regulations surrounding antidote access in the surrounding community: in municipalities with over-the-counter antidote and/or publicly available antidote (e.g., Naloxbox) there may be non-UAV distribution methods that are more efficient or cost-effective.

Future research efforts should improve identification of emergency responses that would benefit from UAV-delivered antidote; consider the utility of human-machine interactions during response versus a fully autonomous UAV; investigate the impact of payload design on precision, accuracy, and discoverability; and describe human-UAV payload interactions to better optimize the operational aspects of a UAV delivery system for antidotes in out-of-hospital emergencies.

In conclusion, these results imply a potential role for UAV-based antidote delivery in the out-of-hospital setting and represents a promising area for further investigation of human-machine interactions during emergency response.

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