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E.S.C.A.P.E - Earthquake Safety & Coordinated Assistance for Public Evacuation

** All authors contributed equally to this memo. The names are listed alphabetically by surname.*

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November 2025

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Abstract

Every year, large-scale earthquakes result in thousands of injuries, communication blackouts, overwhelmed hospitals, and widespread panic. In these events, survivors may not have access to cell service and would be unable to navigate to safety, while first responders face delays in helping those in need. Current evacuation methods focus on transporting resources to injured patients; however, we propose a system to efficiently and safely move individuals away from the impact zone into safe areas and medical centers by incorporating aviation. Our interconnected system includes Wi-Fi drones providing hotspots to those without cell service, illumination drones equipped with color-coded beacons to guide people, eVTOLs for fast emergency response to the severely injured, and a cellphone app that optimizes user direction to ensure proper accommodations for occupants. Once an earthquake is detected, drones are sent from their local charging stations to the impact zone to provide Wi-Fi hotspots and guide people using color-coded beacons. At the same time, eVTOLs are sent to help those who are immobile or severely injured by providing a direct airlift to hospitals. Users are able to access the app through Wi-Fi provided by the network of drone hotspots and are given directions to safe areas (NSCs, Triage Centers, Hospitals, or Evacuation Zones) based on their injury severity. The system tracks users and gives updates to first responders to prevent overcrowding. Overall, our comprehensive system can reduce evacuation delays and help those who are immobile. This creates a model that can be used for future earthquakes and other natural disasters.

1 Introduction

Earthquakes remain one of the most devastating natural disasters, causing over 10,000 deaths annually and affecting millions more through structural collapses, communication failures, and overwhelmed emergency systems [1]. Globally, more than 100 earthquakes of magnitude 6 or higher occur each year. These threaten communities with limited time to respond [2]. Currently, emergency operations often prioritize transporting supplies, like food, water, and medicine, while the coordinated evacuation of people, particularly the injured or disconnected, remains insufficient. This causes life-threatening delays in rescue operations [3]. For example, in the 2023 Turkey-Syria earthquake, communication breakdowns and overwhelmed hospitals hindered aid delivery and led to thousands of preventable deaths[4].

One of the most urgent issues in disaster response is response time. Even a one minute delay in emergency medical response can significantly affect survival outcomes, potentially saving more than 140,000 lives per year if avoided [5]. However, many current evacuation protocols lack real-time insight into evacuee movement and injury status. FEMA's Hub-and-Spoke model instructs residents to shelter in place during shaking and then move to a Neighborhood Support Center (NSC), followed by transport to triage or evacuation zones as needed. Yet this method provides limited visibility into where people are, who needs help, or which zones are overburdened.

Moreover, earthquakes often disrupt telecommunications infrastructure. Damaged towers and power outages lead to widespread loss of cell service, leaving survivors unable to call for help or receive instructions [4]. Despite the scale of this problem, most tracking solutions focus on supply chains or responder coordination, not the people themselves.

To address this gap, we developed E.S.C.A.P.E.: Earthquake Safety and Coordinated Assistance for Public Evacuation, a system that integrates real-time tracking, aviation, and mobile technologies to prioritize the safe and efficient movement of individuals. The system includes Wi-Fi drones that restore connectivity, color-coded illumination drones to guide survivors visually, and eVTOLs to transport those who are severely injured or immobile. A centralized app links these technologies, directing users based on injury status and location while providing first responders with live data to prevent overcrowding and bottlenecks. By shifting focus from resource logistics to human movement, E.S.C.A.P.E. presents a scalable model for earthquake and disaster response.

2 Current Methods

We reviewed the existing infrastructure in place during earthquake evacuations. We focused on the FEMA "Hub-and-Spoke" framework. This model guides residents to shelter in place following an earthquake, then directs them to nearby Neighborhood Support Centers for safety, followed by transfer to triage or broader evacuation zones as needed [6].

We identified two significant shortcomings in this process. First, the system presumes evacuees can reliably reach their assigned centers and that hospitals have sufficient capacity, which may not be able to happen under strained conditions. Second, the framework does not incorporate mechanisms to monitor evacuees in real time; we lack visibility into who is injured, their arrival status at support centers, or which centers are nearing capacity [7].

Additionally, established disaster protocols have centered predominantly on logistics (ensuring access to essential supplies such as food, water, and medical support) rather than focusing on the evacuees themselves. Crucially, there remains limited attention on evacuee movement, injury status, or communication access [7].

3 System Overview

3.1 Aerial Mesh Network

Real-Time Kinematics (RTK) is a system that enables autonomous drones, decentralized scaling, and crash prevention. In E.S.C.A.P.E. It connects eVTOLs, Wifi Drones, and Color-Coded Drones to ensure real-time communication and crash prevention.

However, RTK connections need pre-established technologies within the drones: an RTK receiver, GNSS Antenna (L1/L2), Cellular Module (SIM), and FCI (Flight-Controller Interface). Each type of drone may need more customization to fit RTK dependent on size and autonomy, for instance, WiFi Drones only need a basic system since they are hovering in place whereas Color-Coded Drones need much more customization due to autonomy. Based on technologies currently on the market we chose were u-blox ZED-F9P (RTK Receiver), u-blox ANN-MB-00 (GNSS Antenna), Quectel EC25 (Cellular Module), and CubeOrange+ with CAN/GPS port (Flight-Controller Interface). With these technologies, the Color-Coded Drones, Wifi Drones, and eVTOLs will be able to maneuver without worry of crashing.

A question that came up during this decision was: Will the RTK system be able to cover all of San Francisco? Our answer was yes, with a couple of GNSS Base Stations/NTRIP Repeaters and an NTRIP Caster. To start, we need an NTRIP Caster to send out the signal to the aerial vehicles, picked up by the GNSS Antenna. However, if a vehicle flies out of the Caster's range (20km), we need GNSS Base Stations to repeat the signal. To cover all of San Francisco ($1915km^2$) we would need about 2 GNSS Base Stations. However, to ensure seamless communication and account for any damage or limitations due to urban debris, we would install 5 GNSS Base Stations for optimal communication. For our Base Station, based on current available technologies, we chose the Trimble R12i. These 5 GNSS Base Stations and NTRIP Caster would need to be pre-established prior to the earthquake.

3.2 Wi-Fi Drones

3.2.1 Aerial Wi-Fi Hotspot Drones

Earthquakes are caused by underground rock movement along fault lines and can result in significant structural damage in addition to mass casualties. Earthquakes, by their very nature, occur unpredictably although there are identifiable fault lines that place certain populations or urban areas at elevated risk, like along the San Andreas and Hayward Faults in the San Francisco area. Earthquakes do not only cause physical damage, but they can also damage cellular towers and powerlines, leading to data and voice communication outages just when rescue response services are needed the most. According to a 2017 United States Geological Survey (USGS) Analysis, if a major earthquake were to strike the Hayward Fault, data and cellular outages in the San Francisco area could last up to several weeks.[8] Data and voice communication outages following an earthquake could lead to significant delays in rescue response times and can contribute to widespread confusion among residents regarding recovery processes from timing of power restoration to the safety of drinking water.

One promising solution to such a catastrophic communication systems collapse in the event of an earthquake involves mobilizing a fleet of drones to emergently establish data connectivity in communication 'dead zones'. For deploying an emergency mobile data network, a drone fleet represents a more cost-effective and autonomous approach compared with helicopters, while also offering greater maneuverability and precision than high-altitude balloons. This fleet of drones would be equipped with components that could transmit and receive radio signals, convert radio signals into digital data, and manage network traffic. The E.S.C.A.P.E. drone fleet would be made up of a combination of tethered and non-tethered drones. Tethered 'hub' drones would be equipped with radio base stations and would deploy from fixed pre-determined locations. At the same time, these tethered drones could also be strategically moved along with mobile power generators nearer to disaster areas if needed. The tethered 'hub' drones receive continuous power with generator backup and remain airborne throughout an emergency period. Battery-powered non-tethered or 'mesh' drones fly within a radius of a few kilometers of the 'hub' acting as relay nodes extending data connectivity to affected areas. This combined network of continuously powered tethered 'hub' drones and battery-powered non-tethered 'mesh' drones would allow for quick and dynamic flight without having to constantly fly all of the drones back and forth for recharging.[9]

3.2.2 Wi-Fi Drone Platform Selection

To identify the optimal drone platform for E.S.C.A.P.E., we considered the following criteria and parameters: maximum flight time, payload capacity, battery life, and cost efficiency. The Aurelia X8 MAX, Draganfly Heavy Lift, and JOUAV PH-20 represented three drone platforms that met our initial screening criteria. After carefully considering these platforms, the Aurelia X8 MAX [10] emerged as the optimal choice for a variety of reasons. Firstly, its 24 lb payload capacity aligned most closely with our payload which primarily consists of a Tecore CoreCell-E LTE eNodeB [11] and a Starlink

Figure 1: 1915 sq km of coverage, dense areas within MMI 7 ring. Maps Data: Google, Landsat / CopernicusData, SIO, NOAA, U.S. Navy, NGA, GEBCOData, LDEO-Columbia, NSF, NOAAData, MBARIData, CSUMB, SFML, CA OPC. Imagery from the dates: 12/14/2015–1/1/2021.

Mini kit [12]. Additionally, the Aurelia X8 MAX's foldable airframe allows for efficient storage and transport. Finally, its unique mission planning software includes an integrated swarm mode that supports synchronized control of multiple units. These features make the Aurelia X8 MAX the most versatile and cost-effective option for coordinated deployment in the event of an earthquake.

3.2.3 Coverage

According to a simulated Richter scale 7 earthquake by USGS, these will be the areas most likely in need of immediate evacuation given that the epicenter is a few miles off the coast of San Francisco on the San Andreas Fault. This region is the densely populated areas that will experience an MMI shaking intensity of 7 [13], which is really strong shaking that will cause damage to most buildings. While other regions beyond this may experience power grid disruptions and reduced cell service, we decided to prioritize the area within the ring because they are more in need of a coordinated immediate evacuation. This area is about 1915 square kilometers, and according to the average population density of the bay area, we will need to cover about 1 million devices. We will be communicating using LTE instead of Wifi because it has a much longer range than Wifi, about 5 km in ideal conditions whereas Wifi only reaches a few hundred meters. Assuming each drone can serve this 5 km radius and using a hexagonal radius approximation, we will need about 30 drones. To allow one group of drones to charge while the other provides service, we will need double that. Although this could theoretically cover the whole region, it wouldn't be able to provide service to all 1 million devices. While people who aren't able to mobilize get unicast service, everybody else will get broadcasts. Although only a small amount of smartphone chipsets support it today, implementing eMBMS compatability across all smartphones would be a viable option for this system to work, as broadcast signal strengths aren't capped by user density and evacuees will still be able to get navigation and status updates.

3.3 Tactical Aerial Illumination Drones

3.3.1 Why Color-Coded Drones?

In the case of a MMI 6+ earthquake, power outages are common due to both physical and cascading damages to electricity infrastructure.[14] Without electricity, navigation is exceedingly difficult, especially for those who are unfamiliar with the urban area or who face the immediate destruction of buildings and other debris caused by the earthquake. Further, due to an increasing reliance on apps like Google Maps for navigation,[15] blackout conditions will decrease the efficiency of navigation through affected areas.

The Napa Earthquake, the most recent earthquake with a Modified Mercali Intensity Rating of VIII, occurred in 2014. Causing extensive damage, the earthquake rattled the electricity systems. At this time, Napa was powered by Pacific Gas and Electric, and according to GE Engineering Systems Inc. and LT Consulting, it took 38 hours and 236 people to recover the power grid system after the earthquake.[16] Yet, in comparison to San Francisco, Napa is ten times less populated and is much less developed. Thus, if an earthquake of this scale were to hit San Francisco, the damage would be much more extensive. As a result, a navigation system is necessary in lieu of the damaged electric system which can reduce visibility and navigation efficiency. Our solution is to leverage Tactical Aerial Illumination, Powered by drones with color-coded lightning, E.S.C.A.P.E. is able to lead civilians through the destruction caused by earthquakes.

3.3.2 Selecting a Color-Coded Drone from Existing Technologies

Types of Drones	Verge Aero X1 [4]	DJI Matrix 30T [5]	UVify-IFO-S [6]
Flight Time	20 minutes	41 minutes	26 minutes
Battery Capacity	5100 mAh	5880 mAh	5800 mAh
Brightness	900 lumens	6000 lumens	280 lumens
Price	$439	$13,907	$1500

Figure 2: Selecting a Color-Coded Drone from Existing Technologies

In our search for an optimal drone that can be used for Tactical Aerial Illumination, we set metrics for flight time, battery capacity, brightness, and price. Based on current technology, the closest drone that fits our metric specifications between the Verge Aero X1,[17] DJI Matrix 30T,[18] and Uvify-IFO-S,[19] was the Verge Aero X1.

We chose this drone because, though it had a low flight time of only 20 minutes, it enabled fast-swap battery charging which meant they were redeployable within 8 minutes, and also enabled mobile charging trucks which reduced the need for pre-established infrastructure. Though the lumen count was low, LED add-ons are possible for increased visibility, similar to the ones seen on ambulances and police cars. Lastly, the benefit of having a sub-500 dollar drone allowed more drones to be deployed at once, optimizing the navigation system.

3.3.3 System Overview of Tactical Aerial Illumination

E.S.C.A.P.E. uses these drones to provide beacons over our NSCs (Neighborhood Safety Centers), Triage Zones, Hospitals, and Evacuation Areas. In addition, they are color-coded to avoid color-blindness confusion and increase visibility during both day and night to provide an easy-to-follow evacuation route. The selected colors were green (NSC), purple (Triage Zones), orange (Hospitals), and white (Evacuation Areas). This helps avoid Deuteranomaly (red-green colorblindness) and Tritanomaly (blue-yellow) confusion, the two most common types of colorblindness.[20]

3.3.4 Challenges of Tactical Aerial Illumination

In developing this system, we ran into two main problems: What if there is a malicious actor who launches an imposter drone and will the drones still be visible if the earthquake occurs during the day?

To address the first problem, we turned to RTK (Real-Time Kinematics), a system that transmits aerial vehicle locations with accuracy down to the centimeter. This kind of system is traditionally used in light shows to prevent midair collisions and can also be used in this case to prevent drones from crashing into eVTOLS or other drones. To solve our problem, we determined that drones would have sensing capabilities to avoid urban debris in the aftermath of an earthquake. In this way, they would also sense rogue drones that are alien to the RTK system. Our solution was thathat once such a drone or similar flying object was detected, it would be physically intercepted by a rapid-deployment drone that would be able to neutralize the threat.

As for the second problem, our color choices (green, purple, orange, and white) are selected not only to avoid color blindness confusion but also to enhance visibility during the day and at sunset/sunrise times. However, to further ensure visibility, we chose a strobing pattern seen on bike lights or traffic lights which draw attention and added high-lumen strobe LED customizations seen on emergency vehicles.

3.4 eVTOLs: Electric Vertical Takeoff and Landing Vehicles

3.4.1 The Importance of eVTOLs

Earthquakes can cause severe damage to buildings and road infrastructure by blocking them with rubble and other materials from landslides. Such obstacles make it difficult for emergency vehicles, such as ambulances or fire trucks, to traverse and reach their necessary locations in a timely manner. Because of this, injured persons will not receive the care they need quickly and this can lead to more serious problems.[21]

Current solutions to this problem mainly rely on the usage of Medevac helicopters to find and rescue survivors and take them to the hospital or other corresponding safety centers. However, their large rotor diameter and need for helipads for deployment makes them unsuitable for high-speed emergency operations in urban settings. Main concerns arise from this lack of mobility and therefore a more versatile solution was needed.

Our solution to this problem focuses on the addition of electric Vertical Takeoff and Landing (eVTOL) vehicles that can sustainably and quickly transport the injured to hospitals without being required to land on unstable ground or consume large amounts of time charging. eVTOLs work similarly to helicopters in their ability to take off vertically and their usage of rotors for movement. However, they are primarily charged electrically and can offer autonomy capabilities.

In our plan, eVTOLs will be used as an additional tool alongside ambulances and other emergency medical vehicles to provide a more comprehensive search that extends to areas not accessible from the ground. By doing so, ambulances can focus on easier-to-reach areas whereas eVTOLs will be able to assist survivors trapped across broken bridges or similar situations. Not only can eVTOLs be used to carry passengers, but they also serve use cases for resource and tool deployment.

3.4.2 eVTOL Aircraft Selection

Types of eVTOLs and Manufacturers	Joby S4	Jump Aero JA1 Pulse	Vertical Aerospace VX4
Range of Movement	150 miles (241 km)	31 miles (50 km)	100 miles (161 km)
Flight Time	3 hours	10 minutes	Estimated 2 hours
Cost	$1.3 million	$1.8 million	$4 million
Capacity	1 pilot, 4 passengers	1 pilot, 1 passenger	1 pilot, 4 passengers

Figure 3: Selecting an eVTOL from Existing Technologies

Out of the existing technologies, 3 major eVTOL producers have been analyzed in regards to their range of movement, flight time, cost, and capacity. The three technologies, the Joby S4 [22], the Jump Aero JA1 Pulse [23], and the Vertical Aerospace VX4 [24] all have varying specifications that were considered.

Originally, we had selected the Jump Aero aircraft due to its existing performance in an emergency response capacity given the company's dedication towards improving medical response rates specifically to rural environments. However, we found numerous drawbacks that would limit its capacity to function over a multi-hour urban disaster. Primarily, the low flight time of only 10 minutes, combined with the need for transportation to a helipad for launch, would make it difficult for the JA1 Pulse to perform a multitude of operations and have sustained air time. Furthermore, its capacity to store only one additional passenger to the pilot would make it difficult to transport numerous people from a severely wounded area in quick succession.

Therefore, we settled on the Joby S4 aircraft for our earthquake response system. The most attractive features included its long range allowing it to cover a substantial portion of our analyzed area, the extended flight time allowing the aircraft to function at 3 hours without charging, and the ability to gather up to 4 passengers per trip. This aircraft combined all the necessary features we needed, however its larger wingspan at 50 feet would make it troublesome to navigate safely throughout an urban city. To combat this, we introduce certain eVTOL attachments.

3.4.3 Additional Attachments for Improved Rescue Performance

One of the main problems that earthquakes cause is the uneven terrain and damage to infrastructure. For eVTOLs, this can be a major problem given their reliance on helipads and flat areas for both takeoff and landing. Specifically for emergency operations in an urban setting, it would be beneficial to incorporate existing attachments to the selected Joby S4 eVTOL for enhanced performance in such metrics. Currently, this aircraft is commissioned primarily for passengers as a form of public transportation, and therefore the following attachments are recommended for earthquake response: a winch system and a rescue hoist.

The winch system is a technology that currently allows drones to hover above the ground and drop resources and other cargo [25]. This would help hasten resource supply to different parts of the city during an earthquake without wasting time as the eVTOL does not have to land. For example, if a hospital or triage center runs out of an important medical supply such as surgical stitches, an eVTOL could simply drop this package from above the hospital rooftop for immediate access.

A rescue hoist is a common attachment found on Medevac helicopters that allows emergency personnel to rappel down a wire and transport injured passengers back into the aircraft in an aerial manner. This is a well-tested technology that would prove invaluable for earthquake rescue operations for an eVTOL. In combination with the winch system, these two technologies solve the issue of eVTOLs being unable to land on insecure terrain in a low-cost yet reliable manner. [26]

3.5 Phone Based Tracking and Guidance System

The primary purpose of having a phone-based tracking and guidance system that all users would already have downloaded is so that they would get instructions as to where to head after the effects of a severe earthquake and so that they can be accounted for during the process. Additionally, the system would focus on keeping households together or routing them back together. The system relies on the technology mentioned before in order to send information and aid its users.

3.5.1 Before Earthquake

Upon installing the phone-based system, users will be prompted with a first question asking them whether or not they would like their location to be tracked by the system, as seen in Figure 4. If the user selects “Yes,” then the system will reference their direct location throughout the duration of the evacuation. This allows the system to give them direct mapping and addresses to NSCs, triages, etc., while also being able to seamlessly track and account for the user. This mapping would be optimized and would use real-time data to ensure that road closures and traffic are accounted for. If the user selects “No” to location tracking, then they will be given instructions on where to go, but no specific directions. In addition, they will be asked whether or not they have reached a certain location in order to keep track of where the user is.

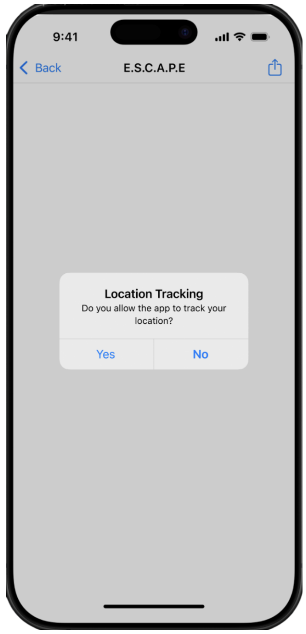

Figure 4: Location Tracking

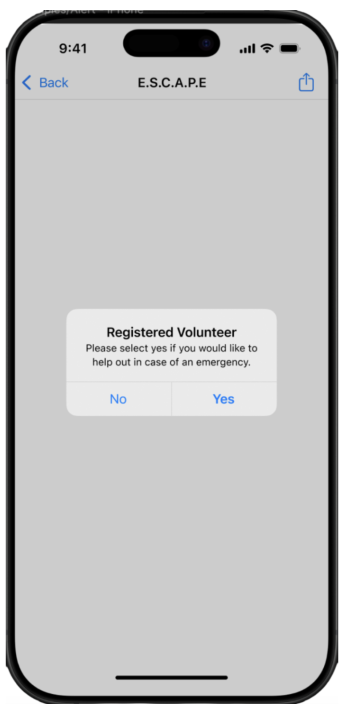

Figure 5: Registered Volunteer

After responding, users will be asked if they are registered volunteers, as depicted in Figure 5 below, allowing triage centers to better allocate assistance. Their answer will impact where they are sent after the earthquake occurs. Finally, the phone based system will ask users if they would like to add members of their household via phone number (see Figure 6). Once added, users become part of a Group. In the event of an earthquake, they will receive updates about other Group members and be routed to the same final evacuation zones as them.

Once all of the user's preferences are set up. The system will tell users what to expect in an earthquake scenario. This is so users have some idea of how to use the system and also know that they should be looking out for color coded drones (Figure 7).

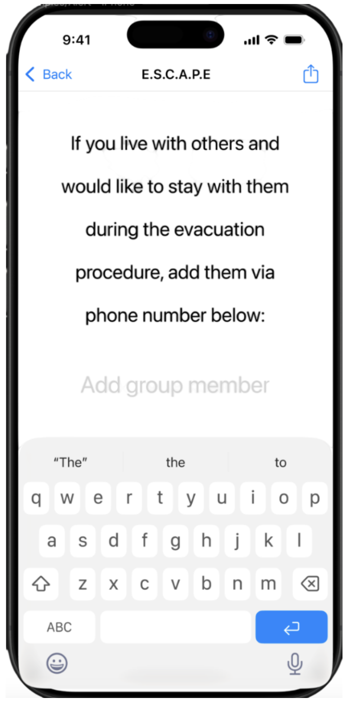

Figure 6: Creating a Group

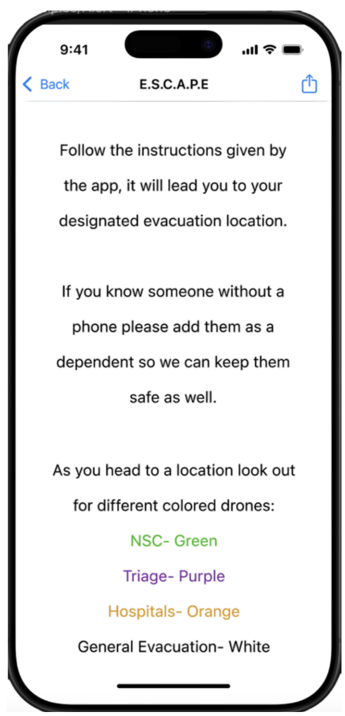

Figure 7: UI Instructions

3.5.2 Earthquake Occurs

When an earthquake strikes, all users will receive an alert notifying them of the event and providing guidance on how to protect themselves, as shown in Figure 8.

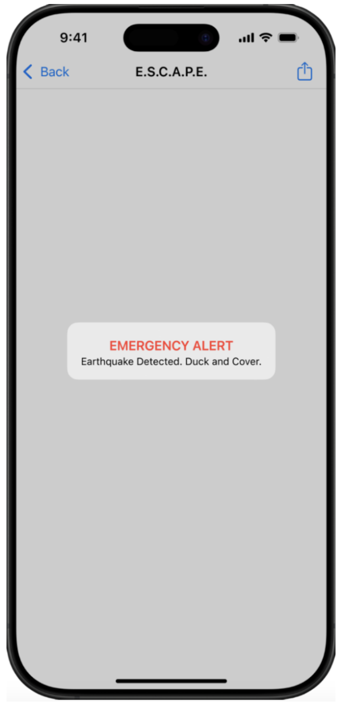

Figure 8: Emergency Alert

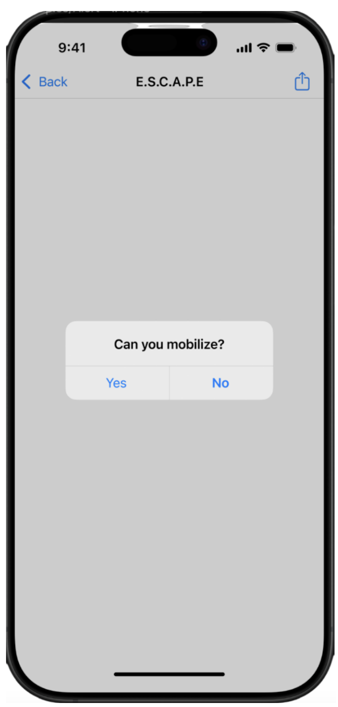

Figure 9: Major Injury Assessment

3.5.3 User Cannot Mobilize

After the initial shock is over, users are asked by the system if they are able to mobilize, Figure 9; This is to account for major injuries. If users are unable to mobilize due to serious injuries, the phone based system will immediately instruct them to remain in place and provide reassurance that help is on the way, as illustrated in Figure 10. If location services are enabled, the eVTOL will use this information to locate the individual and deliver aid. If the user does not have services enabled, they will have to type in their address or consent to location tracking (see Figure 11). People receiving aid from eVTOLS will be taken directly to hospitals, and Groups will be alerted of what hospital they are receiving care at.

Figure 10: eVTOL Aid with Location Tracking Enabled

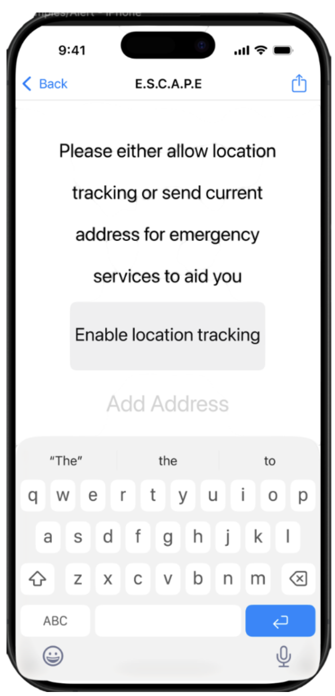

Figure 11: eVTOL Aid with Location Tracking Not Enabled

3.5.4 Dependents

Users who select "Yes" are then asked if they have any dependents, see below in Figure 12. A dependent would be a child who does not own a phone, or a person whose phone is either dead or broken. This question accounts for all those who cannot be independently tracked, and are therefore accounted for along with the person they are dependent under.

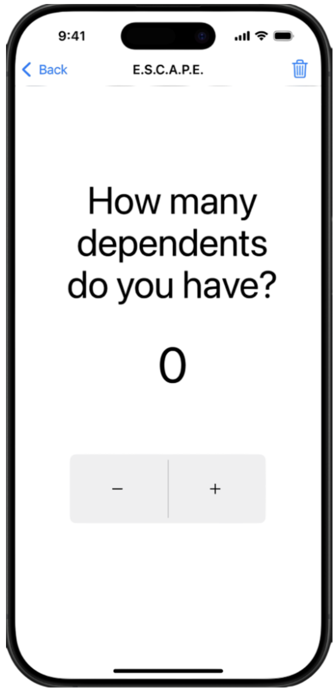

Figure 12: Adding Dependents

3.5.5 User Can Mobilize: Volunteer

Volunteers who are able to mobilize will then be instructed to head to a specific triage, either based on the one closest to them or the one that is low on aid. If the volunteer has location tracking on, they will see a screen similar to Figure 13. If the volunteer does not, they will see a screen like Figure 14 in which they will only be given an address and are responsible for finding a route there. Additionally, as depicted in Figure 15, once they reach the triage, those without location services activated will be asked if they have reached their designated location.

Figure 13: Volunteer Routing to Triage With Location Tracking

Figure 14: Volunteer Routing to Triage Without Location Tracking

Figure 15: Location Tracking: Triage

3.5.6 User Can Mobilize

Users who can mobilize will be given directions to go to their nearest NSC, either with direct mapping (Figure 16) or by being told to go to an open area such as parks or schools (Figure 17). Once again, users with location services disabled will be asked if they have reached (Figure 18).

Figure 16: Routing to NSC With Location Tracking

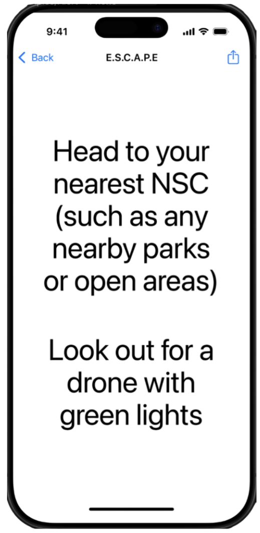

Figure 17: Routing to NSC Without Location Tracking

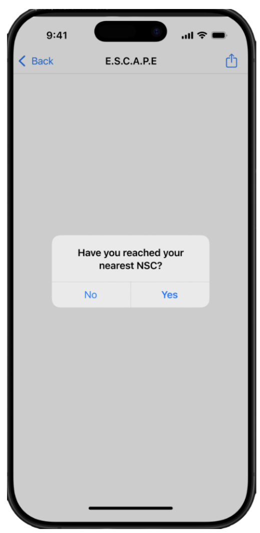

Figure 18: Location Tracking: NSC

3.5.7 Routing After NSC

Once at the NSC, users will be given directions based on their injuries or injuries in the Group. Users will be asked if they are injured, as shown in Figure 19. If the user responds "Yes," then they will be given directions to their nearest triage while also being prompted to keep a look out for a drone with purple lights to help them find it (Figure 20); users with location tracking not enabled will be told the addresses of triages near the impact zone of the earthquake and will also be told to look out for the drone (Figure 21). Users who respond that they have no injury will be directed to head to their nearest general evacuation center, either with direct mapping or an address to a few near the impact zone; while also being told to seek out a drone with white lighting (see Figure 22 and Figure 23). Once users who do not have location services have reached their designated location, they will again be asked if they have been reached in order to keep track of the number of people in an area (Figure 24).

Figure 19: Minor Injury Assessment

Figure 20: Routing to Triage With Location Tracking

Figure 21: Routing to Triage Without Location Tracking

Figure 22: Routing to General Evacuation Center With Location Tracking

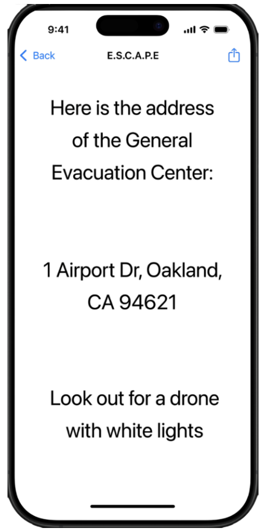

Figure 23: Routing to General Evacuation Center Without Location Tracking

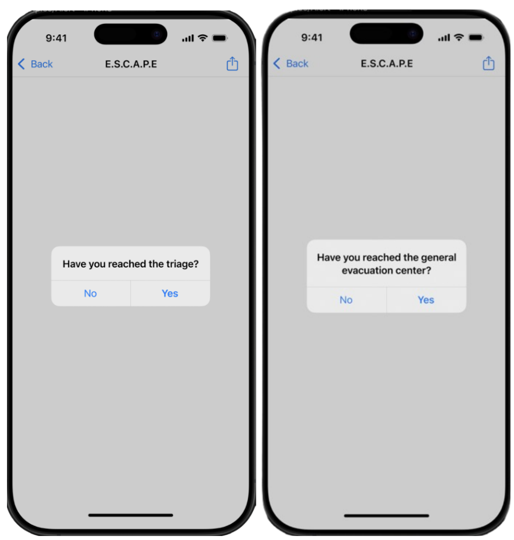

Figure 24: Location Tracking: Triage and General Evacuation Center

3.5.8 Group Routing

If a member of a group reports injury, either they were immobile to begin with or are sent to triage after heading to an NSC, others in the Group will be alerted when they are at the NSC being routed for their next steps. Users will be informed of all who are injured and will be given the option to follow or meet up with a member of the Group where they are receiving care, see below in Figure 25. If the member is at a triage, the button is colored yellow to show that the injury is not as severe; if a member is at a hospital the button is colored red to highlight severity.

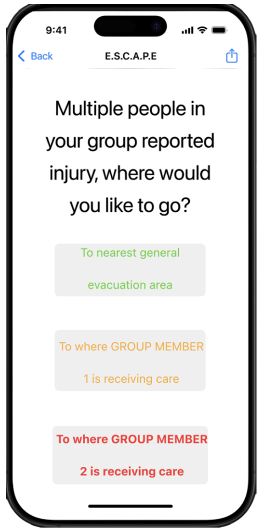

Figure 25: Group Routing

3.5.9 Rerouting

In the case that a triage or general evacuation area that the user was heading to is full before they get there, the system will alert its user and either reroute its map or give them the address to the new location (Figure 26 and Figure 27).

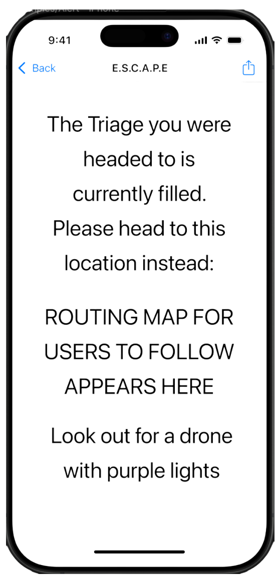

Figure 26: Rerouting With Location Tracking

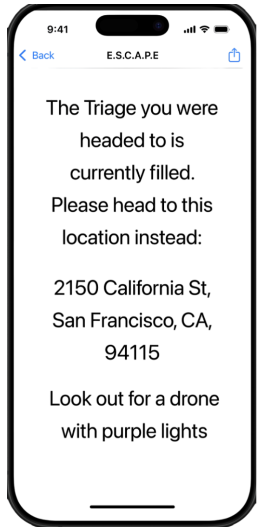

Figure 27: Rerouting Without Location Tracking

4 Costs

4.1 Cost of Wifi Drones

The proposed E.S.C.A.P.E. Wi-Fi hotspot drone fleet consists of 60 drones, each priced at approximately $10,000. Each drone would be equipped with an LTE eNode B, a Starlink Mini terminal, a Raspberry Pi, and a directional antenna. The estimated cost of these additional hardware components is $5,800 per unit. When combined, the total per-unit cost is approximately $15,800, resulting in a final budget of $948,000 for the 60-drone fleet.

4.2 Cost of Tactical Aerial Illumination Drones

The Verge Aero X1 drones were selected for use given their optimization of both visibility and cost. Furthermore, their ability to have precise movement (capable of correction to the nearest centimeter) and fast-charging battery swapping capabilities as low as 7.5 minutes projects them to be a leading drone for quick redeployment. The Verge Aero X1 drones are also ideal for their circling abilities around NSCs, triage zones, and hospitals. In total, 495 drones will be needed with a 300% redundancy given the need for a large number to cover a metropolitan area and surrounding neighborhoods. Given an individual price point at $440 per drone, the total cost will come out to $217,800.

4.3 Cost of eVTOLs

In the initial state and short-run economy, it is expected that around 100 Joby S4 eVTOL units will be produced per year. In this situation, the price per unit of each eVTOL is at 1.3 million USD. However, as annual production increases to approximately 5,000 units per year it is expected that this price point will drop to $\approx 200,000$ USD [27]. In comparison to the current commercially available R-44 helicopters (well-known for their reliability in both passenger transport and rescue operations) priced at $\approx 475,000$ USD, the incorporation of Joby S4 eVTOLs would have less financial burden in the long term.

Furthermore, eventual autonomy of eVTOLs would reduce labor operating costs (one of the major charges) and increase space in the eVTOL for both passenger transport and more EMS personnel during emergency response. Moreover, the capability of eVTOLs to function as everyday transportation would further amortize their purchasing and upkeep cost.

For our analyzed area, we concluded that 5 Joby S4 eVTOLs would need to be purchased in order to maximize area covered while still providing zones of overlap. These zones of overlap are necessary for high density population areas where risk of injury increases given the urban landscape. However, there is a 0% redundancy factor given that the eVTOL has a minimal charge time at less than 10 minutes and an extended flight time at 3 hours without charging, which would likely be enough to perform most high-danger rescues during the time immediately subsequent to an earthquake. Therefore, the total cost of 5 eVTOLs at 1.3 million USD per eVTOL comes out to 6.5 million USD.

4.4 Total Costs and Current Comparison

Tech	Number Required	Individual Cost	Total Cost	RTK Connections
Color-Coded Drones: Verge Aero X1	495	$440	$217,800	$148,500
Wifi Hotspot Drones: Aurelia X8 Max	60	$10,000	$600,000	$24,000
Radio Base Station	60	$5,800	$348,000	Not Applicable
GNSS Base Stations	5 + 1 Caster	$15,000	$77,500	Not Applicable
eVTOLs: Uber Elevate	5	$1,200,000	$6,000,000	$30,000

Total Cost: $7,424,200 (Bay Area)

Figure 28: Total Costs

The total cost of the three compartments (WiFi drones, Tactical Aerial Illumination drones, eVTOLs) will constitute total expenses needed for deployment in the short and long-term. In total, the cost comes out to approximately 7 million USD. While this is a substantial sum of money, it is important to note that current rescue operations can reach beyond tens of millions of dollars. Furthermore, our system is both sustainable and readily available aside from charging requirements that will need electricity. Given such additional benefits, we believe that this price point is reasonable and can be implemented for emergency use in many urban environments.

5 Analysis

5.1 Potential Challenges

The implementation of the E.S.C.A.P.E. system faces several challenges. One of them is compliance with Federal Aviation Administration (FAA) regulations governing the flight of unmanned aerial systems (UAS). Current FAA rules prohibit autonomous drones from operating beyond visual line of sight (BVLOS) without special waivers, limiting the system's ability to autonomously operate across large urban or rural environments. Since our concept depends on drone swarms and eVTOLs responding in real-time across expansive disaster zones, such constraints would hinder autonomous coordination and delay aid.

Another potential issue is connectivity and battery constraints. While Wi-Fi hotspot drones can provide emergency service coverage, their effectiveness is limited by battery life and bandwidth restrictions. Charging and deployment logistics, especially in areas where infrastructure is damaged or inaccessible, may require mobile charging stations and frequent drone replacements, which could increase operational costs and complexity.

Data privacy is also another major problem. Our system includes live user tracking, injury status, and evacuation routing: data that must be securely stored and processed. While users can opt-in to sharing their location, their trust in the system will depend on strong privacy protections.

Finally, the cost is another challenge. The estimated budget for initial deployment is over 10 million dollars, with much of the expense coming from eVTOL acquisition and RTK-enabled drone networks. While scalable in the long term, the upfront cost may limit this system spreading to regions with limited disaster funding.

5.2 Future Implementations

Looking ahead, the E.S.C.A.P.E. system could be adapted for a wide range of natural disasters beyond earthquakes, including floods, wildfires, hurricanes, and large-scale search and rescue operations. By refining the modular payloads on drones and optimizing the app interface for different hazards, the system could serve as a unified response tool across multiple emergency scenarios.

Integration with municipal emergency response networks, such as police, fire departments, and EMTs, would improve the deployment efficiency. For instance, enabling direct API connections between the E.S.C.A.P.E. dashboard and local dispatch systems could streamline triage and hospital routing in real time.

Another future goal is to increase autonomy and AI capability within the system. Machine learning algorithms can be used for automated triage prioritization, route optimization, and real-time crowd monitoring. Additionally, adaptive drone flight paths could be developed to avoid blocked roads, collapsed infrastructure, or hazardous zones.

5.3 Conclusions

Earthquakes frequently occur with little warning, leading to mass panic, communication failures, and overwhelmed emergency services. Traditional disaster response models often prioritize supply delivery, while the movement and safety of individuals, especially the injured or disconnected, remain under-addressed. The E.S.C.A.P.E. system remodels evacuation by integrating aviation, connectivity, and real-time user tracking into a unified response network. With Wi-Fi drones restoring communication, illumination drones guiding evacuees, eVTOLs transporting the severely injured, and a mobile app coordinating movement, our system dramatically reduces response times.

Although challenges such as airspace regulation, privacy, and cost must be addressed, the potential for saving lives is immense. By shifting the focus from static aid delivery to dynamic evacuee movement, E.S.C.A.P.E. offers a scalable model for disaster response, one that can adapt to both urban and rural settings, and evolve with emerging technologies. With continued development and collaboration with emergency agencies, this system has the power to transform how we prepare for and respond to earthquakes and beyond.

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