Using AED-equipped UAV to enhance cardiac arrest response

EENA-Everdrone project: Final Report

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1 I INTRODUCTION

UAV technology is rapidly evolving. Improvements in aircraft autonomy, sensors for navigation, automatization of flights, air traffic management systems and connectivity are making UAV operations more reliable and UAV operations can expand to new use cases.

In 2021, EENA Published the Unmanned Traffic Management Report[1] with potential use cases rising in Public Safety thanks to those technology improvements. And this report aims to complement it with a real case that proves how public safety agencies can benefit from UAVs.

This report will explain the current status in Out of Hospital Cardiac Arrest (OHCA) and how the Everdrone Project in Sweden is helping in the OHCA response. In addition, this report includes a series of considerations and recommendations on how this case could be replicated in other regions within Europe. These insights have been gathered thanks to the contribution of public safety experts from Croatia, Spain, Germany, UK and Turkey.

In 2020, EENA and Everdrone launched a project to understand the possibility of using UAVs for emergency medical deliveries. This final report outlines the project's achievement and considers the contributions from different experts that helped foster knowledge in this field.

[1] *https://eena.org/knowledge-hub/documents/unmanned-traffic-management/*

2 l CURRENT CONTEXT: THE CHALLENGE OF OUT OF HOSPITAL CARDIAC ARREST

Annually some 275,000 individuals suffer from out-of-hospital cardiac arrest (OHCA) in Europe; survival is dismal, with a mortality of about 90%. A presumed medical aetiology is dominant (90%), and most OHCA (70%) occur in residential settings. (1,2)

Early interventions, as stated in the chain of survival, may increase survival significantly. (2) An early emergency 112-call for help may facilitate early recognition at the emergency medical dispatch centre (EMDC). (3) The American heart association (AHA) states that 75% of all OHCA should be recognised, that OHCA recognition should be made within a median time of 1 minute and that telephone assisted CPR (T-CPR) should be initiated within 120 seconds in high performing systems. (4) Early recognition at the EMDC may facilitate three components; Early T-CPR, early dispatch of appropriate emergency medical service resources as well as instructions to bystanders onsite to retrieve a nearby located AED.

The second link with bystander-initiated cardiopulmonary resuscitation (CPR) has been shown to increase survival 2-3 times as compared to no-CPR (5) and general awareness through basic life support (BLS) courses in the community is therefore of outmost importance. BLS courses, including an automated external defibrillator (AED), are essential for increasing 30-day survival rates. Early defibrillation during the first minutes of an OHCA has been associated with survival rates reaching 70% in cases of witnessed arrests presenting with a shockable rhythm. (6,7)

The EMDC is a key factor for facilitating early CPR and AED use prior to the arrival of EMS. However, although the potential with BLS-interventions is well known, bystander CPR is not always initiated, CPR quality may be poor, and the use of public AEDs is unfortunately rare. Publicly available AEDs are often placed in offices or public arenas where they are seldom used. (8) Public AEDs are as well most often inaccessible during non-office hours. (9) National validated AED-registries integrated at the EMDC displaying exact AED location is often non-existing or unavailable for the dispatcher at the EMDC.

OHCA-survival during the COVID19 pandemic has decreased, (10) guidelines from the ERC on CPR during this period exclude ventilation from the CPR-algorithm with unknown long-term effects on mortality. (11)

A novel method for facilitating early use of AEDs and early defibrillation is to use unmanned aerial vehicles, i.e. UAVs to deliver AEDs. By calculating optimal location using historical validated OHCA-data, AED-equipped UAVs may be placed in hotspots in the community. (12,13) Optimal locations are dependent on population density, OHCA incidence, EMS response time, geographical conditions, air traffic regulations and a cost-effectiveness perspective. Shortening the time to defibrillation in the early minutes of an OHCA is more important than during a later stage because the proportion (%) of shockable rhythm decreases rapidly after a collapse. Therefore, suburban communities with many residents and acceptable EMS response times may be optimal areas for placing AED-equipped UAVs.

Areas with an occasional high population, such as popular resorts during summertime, may also be of interest. These areas may have prolonged EMS response times and several cases of OHCA. Deploying AED-equipped UAVs is feasible in simulated settings (14,15), and a recent clinical feasibility trial in Sweden during 2020 has explored dispatch to suspected OHCA in a real-life setting.

This research project is continuing in a follow-up clinical trial recruiting patients using five AED- UAV systems to complement the EMS study starting 21st April 2021 (study protocol is available at *https://clinicaltrials.gov/ct2/show/NCT04723368*).

THE OUTCOME OF THE 2020 CLINICAL STUDY

Abstract
Aims

Early defibrillation is critical for the chance of survival in out-of-hospital cardiac arrest (OHCA). UAVs used to deliver automated external defibrillators (AEDs) may shorten the time to defibrillation. However, this has never been evaluated in real-life emergencies. Therefore, this study aimed to investigate the feasibility of AED delivery by UAVs in real-life cases of OHCA.

Methods and results

In this prospective clinical trial, three AED-equipped UAVs were placed within controlled airspace in Sweden, covering approximately 80 000 inhabitants (125 km2). UAVs were integrated into the emergency medical services for automated deployment in beyond-visual-line-of-sight flights: (i) test flights from 1 June to 30 September 2020 and (ii) consecutive real-life suspected OHCAs. The primary outcome was the proportion of successful AED deliveries when UAVs were dispatched in cases of suspected OHCA. Secondary outcomes were the ratio of cases where AED UAVs arrived prior to ambulance and time benefit vs. ambulance.

Fourteen cases were eligible for dispatch during the study period. AED UAVs took off in 12 alerts to suspected OHCA, with a median distance to the location of 3.1 km [interquartile range (IQR) 2.8–3.4). AED delivery was feasible within 9 m (IQR 7.5–10.5) from the location and successful in 11 alerts (92%). AED UAVs arrived before ambulances in 64%, with a median time benefit of 01:52 min (IQR 01:35–04:54) when the UAV arrived first. In an additional 61 test flights, the AED delivery success rate was 90% (55/61).

Conclusion

In this pilot study, we have shown that AEDs can be carried by UAVs to real-life cases of OHCA with a successful AED delivery rate of 92%. In addition, there was a time benefit compared to emergency medical services in cases where the UAV arrived first. However, further improvements are needed to increase dispatch rate and time benefits.

Trial registration number

ClinicalTrials.gov Identifier: NCT04415398.

The full study can be found at *https://academic.oup.com/eurheartj/advance-article-abstract/doi/10.1093/eurheartj/ehab498/6358076*.

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3 I UAV AED DELIVERY CONCEPT IN SWEDEN

Based on previous theoretical studies, three organisations joined forces in the spring of 2019 to make AED delivery by UAV a reality in real-world emergency situations.

- The Center for Resuscitation Science at Karolinska Institutet (KI)
- SOS Alarm – Sweden's national PSAP
- Everdrone AB – a world leader in autonomous UAV technology and operations

The UAV operator Everdrone AB has extensive experience developing UAV systems for beyond visual line of sight flights (BVLOS). The company has conducted over 16,000 real-world autonomous UAV flights and more than 2.3 million simulated flights logged at the time of writing.

After 14 months of close collaboration between the parties, addressing technical, regulatory, and operational challenges, real-world operations were launched in the Gothenburg region, reaching some 80,000 residents.

Operational procedures

When an emergency 112-call is answered, it is indexed by the dispatcher depending on the patient's condition. For example, if an OHCA is suspected, the dispatcher indexes the event as a) "ongoing CPR" or b) "Unconscious with abnormal or absent breathing". In addition, an automated alert is sent to the UAV operator if an emergency call is identified within administrative areas AND indexed as "a" or "b". This triggers the following events:

- boot-up of the UAV
- UAV hangar gate opening
- route-planning of the mission
- weather condition confirmation
- remote pilot obtaining takeoff approval from Air Traffic Control via phone
- remote pilot accepts the mission

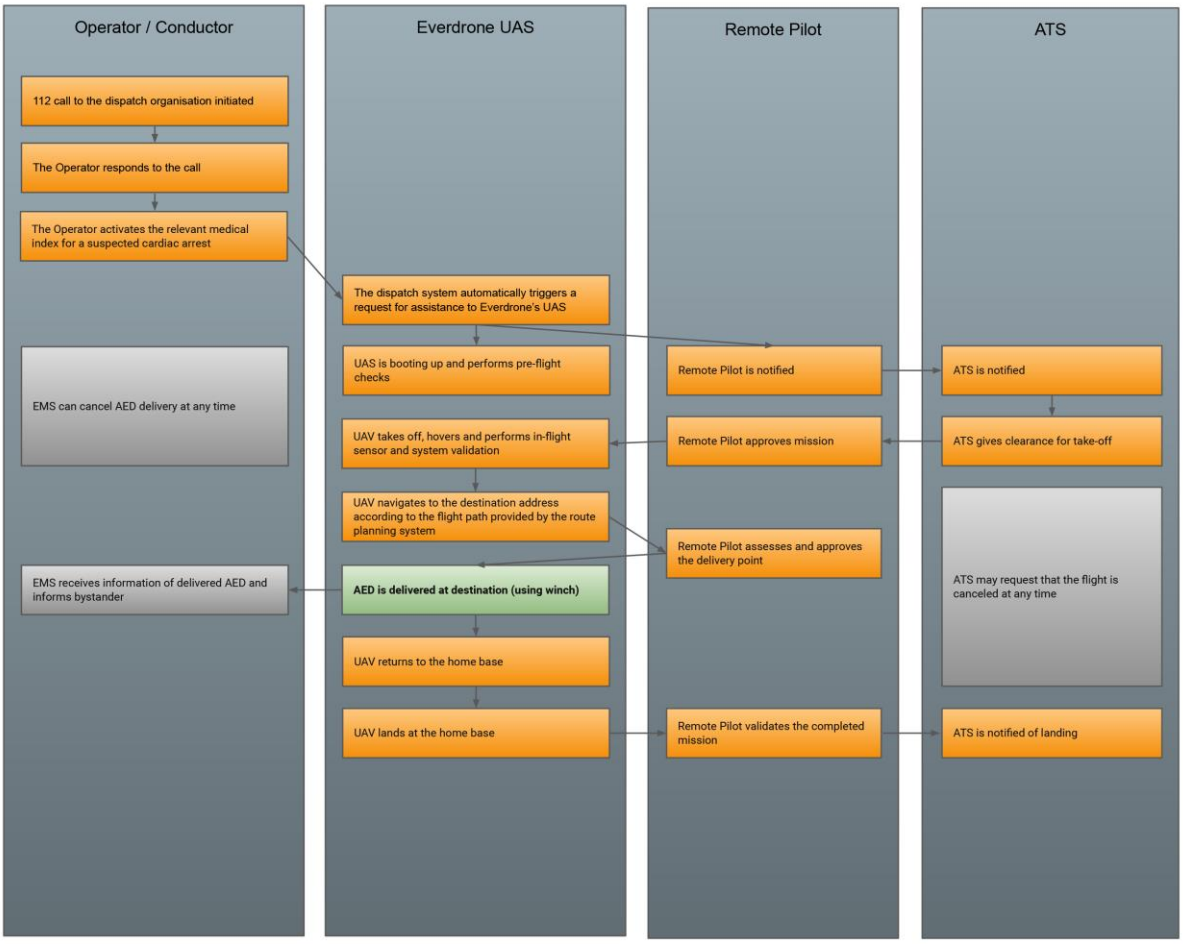
For safety reasons, all flights are performed within the controlled airspace of Säve airport and approval from Air Traffic Control is granted for each individual flight. The flight is carried out at a cruising altitude of 60-80 meters depending on terrain and at the average flight speed of 70 km/h. The maximum one-way range is 5 km. The flight operation is remotely monitored from Everdrone's mission control centre. The UAV is dispatched alongside an ambulance as a complement to standard care. The UAV systems are designed to operate in dry conditions with mean winds not exceeding 8 m/s. Operations are limited to daylight conditions only but are expanded to include non-daylight conditions soon.

Even if monitored by a remote pilot, the entire takeoff and flight procedure is fully autonomous. As the UAV approaches the delivery location, the remote pilot must ensure that the delivery location is safe and suitable. A preliminary survey of the area is performed before takeoff based on satellite images and a final survey is conducted through onboard cameras as the UAV descends from cruising altitude to the delivery altitude of 30 m. If needed, the remote pilot may manually adjust the UAV position before delivering the AED by releasing the winching mechanism.

Operations are highly autonomous but always monitored by a remote pilot.

Once the AED lands on the ground, the dispatch centre is informed about the successful delivery and the dispatcher then instructs the caller to retrieve the AED and attach it to the patient.

The time from call centre alert to takeoff is typically between 60 and 90 seconds and the shortest time from takeoff to delivery is 2 min 14 seconds to date.



Flowchart of an AED delivery mission by UAV.

System

The UAV

The UAV system is built around an off-the-shelf airframe enhanced with additional hardware components and Everdrone's proprietary software – altogether enabling safe and highly autonomous operations.

The airframe is a DJI Matrice 600 Pro and enhancements include the following components and features.

- LTE modem enables command & control links with military-grade encryption over the mobile network. This means that the distance between the UAV and the remote pilot is not limited to signal range but rather to areas where satisfactory mobile network coverage can be obtained.
- Dual stereo vision cameras enable automated sense & avoid capability to ensure that the UAV does not collide with obstacles even in unexpected environmental conditions or human error.
- GPS system for automated navigation during normal operation at cruising altitude.
- Visual positioning works as a fall-back to the GPS and ensures mission safety in case of GPS loss.
- Visually guided precision landing to ensure safe and precise landings inside the hangar at the home base.
- Onboard ADS-B IN to enable, detect & avoid capabilities towards cooperative manned aircraft
- Automated route planning software enables the system to calculate the optimal flight patch considering safety and response time.
- Onboard safety parachute to minimise ground risk in case of critical motor failure or bird strike.
- Predictive failure detection enables the system to identify potential motor issues before they become critical and avoid potential accidents.
- The onboard and remote black box records detailed flight and telemetry data that is used for analysis and future system improvements.
- Winching mechanism enables the AED to be lowered to the ground safely while the UAV remains airborne 30 m above ground.

Furthermore, the UAV backend system is fully integrated with the emergency call centre, enabling extremely fast and reliable dispatching routines.

Enhanced DJI Matrice 600 Pro custom built for AED delivery operations.

The Home Base

The UAV is placed on standby in a hangar – an industrial tent building where temperature and humidity are controlled between missions. For safety reasons, the hangar is surrounded by a fenced area that protects the facility from theft and sabotage.

The hangar is equipped with an automated roller door and weather monitoring system.

The home base location is established by analysing the response time to historical OHCA incidents within the flight sector while also considering ground safety. This normally means that the hangars are placed in locations where the public usually is not present.

UAV on standby at home base.

Integration with the dispatch centre

The UAV backend system is fully integrated with Sweden's national emergency call centre, SOS Alarm, via the Swedish TETRA public safety network called RAKEL. The UAV system has been assigned a unique RAKEL number (i.e. radio unit) so that the UAV and UAV operator can be identified, alerted and communicated within the same way as regular ambulances. However, all mission-critical communication between the PSAP and the remote pilot is electronic, i.e. nonverbal.

To ensure the best possible integration with emergency dispatch a web training covering the UAV dispatch routine was created and made mandatory for all relevant dispatch personnel. As a result, all in all 460 dispatcher did undergo the web training.

The UAV system is active within selected geographical regions which have been integrated into the CoordCom dispatch system. The dispatcher can thereby see the coverage of each UAV visually on a map. Furthermore, in case of a suspected OHCA, the UAV system and remote pilot are alerted in an automated fashion to optimise mission speed and reliability.

The AED

The AED used is an ultra-light AED (FRED Easyport from Schiller), weighing 800 grams, including casing, basket and siren. The AED has pre-attached pads to simplify handling by untrained laypersons. Upon arrival at the delivery location, the basket with the AED is lowered from the UAV to the ground while the UAV remains airborne at 30 m altitude. The AED is typically delivered within 10 meters from the object, i.e. the front door of the caller's home.

4 I KEY LEARNINGS

From the interviews done with Public Safety experts, several items are to be considered when evaluating deploying a UAV AED Delivery capability.

a) Urban vs. rural coverage:
The effectiveness of the system will be directly influenced by the geographical area it covers. Both Urban and Rural environments offer advantages and disadvantages to the usage of UAV AED delivery.

Urban areas	
Pros	**Cons**
Larger populations and more OHCA cases -Having more people concentrated in one area means more OHCA cases, which the system would serve. This would mean a higher return on investment for the health authority.	**Response times are already low** -The broad coverage of ambulances makes the response times already relatively low. -The presence of public AEDs, other co-responders, or even trained citizens would also reduce the response time. **Complex environment to operate UAVs** Urban environments are complex and risky for flight operations and aerial delivery (i.e. obstacles to land or winch payload). This is even more significant in cities with historical urban setups, small and narrow roads.

Usage in urban environments would make extra sense in regions where the ambulance service is stretched and cannot ensure a short response time. For instance, cases where ambulances are stuck in hospitals waiting for patients to be picked up, because the Emergency Room doesn't have enough capacity. In these cases, the busy ambulance cannot respond to OHCA, and an additional UAV AED delivery could prove useful.

Rural areas	
Pros	**Cons**
Long response times -Ambulances or alternative OHCA response measures are scattered or have more trouble reaching the patient due to the geography and infrastructure available. **Better environment for flight operations** -Open and wide areas or the lack of agglomerations of buildings or people makes it technically easier to operate the system and reduce risks.	**Less number of cases of OHCA** -Due to the lower population of these regions, the system tends to be less cost-effective. **Longer distance to cover** -Meaning a higher number of stations might be needed to service a particular region. **Regulatory barriers** -Operating UAVs over large areas in so-called uncontrolled airspace may, in many cases, come with regulatory challenges that are hard to overcome considering today's air traffic management systems. Future systems are, however, expected to facilitate such operations.

Rural areas are an ideal environment for UAV's AED delivery services. Although the population is much lower than in urban environments, a UAV delivery system could help reduce the OHCA response times much more efficiently than increasing the ambulance coverage. EMS response times in Urban environments are fast, but there is a pressing need to improve the response times in rural areas. And this could be a much more efficient way than increasing the number of ambulances.

From the Swedish experience, the semiurban environments are the ideal type of area to cover when considering the cost-effectiveness of the system, the operational conditions, and today's regulatory landscape. The population levels are high enough to justify the efficiency of the system. And the openness of the environment makes it relatively easy for the UAV operation to deliver the AEDs. Also, limiting the operations to a few kilometres radius makes the regulatory challenge manageable.

<u>b) Integration with wider response system: current Dispatch & response systems</u>

Apart from ambulances, there are several mechanisms that health authorities are using to reduce the OHCA response time:

- **Public AEDs**

These are AEDs deployed strategically in permanent sites with high traffic of people or areas of high risk. They can also be temporal, for example, during events.

- **Co-Responders**

Non-EMS staff from Fire Services, Law enforcement, or other agencies trained on using an AED or applying CPR. These co-responders could arrive before the ambulance and start treating the patient.

- **Community Responders**

Citizens trained and registered to help in the case of OHCA in their area. They can also be organised with apps to activate them.

These mechanisms are not competing but rather complementary. The approach is different depending on the region, but in general several of these mechanisms are activated to ensure the response gets as fast as possible to the patient.

For UAV AED delivery to make sense, it must be properly implemented in such a response system. A few examples would be:

- Integration with the CAD system. To unify the activation of the UAV together with the other response mechanisms.
- Create & train EMS staff, co-responders, or community responders on how an operation supported with the UAV would be.

c) Citizen Perception

The usage of UAVs by government agencies may have a negative perception from citizens. There is a public image of UAVs used in wars or as a threat to privacy.
However, several experts agree that the use of UAVs for healthcare purposes and their benefits is a cause that citizens would accept easily. The agency working with this type of capability should have a clear communication plan to transmit this message.

d) Legislation

Legislation is one of the main concerns of Public Safety agencies and one of the main barriers to implementing UAVs in emergency response.

Specifically, in this case, the operation has certain aspects that make the procedure riskier in the eyes of legislators, for example flying in urban areas, over people, winching payload to the ground, and flying BVLOS. This typically requires numerous risk mitigation measures to obtain approval for the operation.

In the Swedish pilot program, flight permission was obtained by Everdrone from the Swedish Transport Agency (Transportstyrelsen). Permission was granted within the national UAV regulations applicable to Sweden through 2020 (and extended through 2021). Operations are expected to be fully compliant with European UAV regulations by early 2022. Preliminary, the process will fall under the “specific category”, SAIL III.

Rather than dealing with the European UAV legislation, it should be noted that some member states still offer national laws for emergency response organisations that want to operate UAVs. This may open for a somewhat easier regulatory model for emergency response organisations.
Key components to ensure mission safety in the Swedish project are listed below:

- Overall qualitative risk assessment according to the SORA methodology

- Separate quantitative risk assessment regarding the ground risk
- Separate risk assessment regarding payload (i.e. AED and winching device)
- Functional Hazard Assessment covering ~40 different safety-related failure scenarios and corresponding mitigations
- Comprehensive test documentation covering all system components and features (Key components and features are described under the section "System").
- Third-party validation of the Parachute Recovery System
- Operations Manual including checklists for normal and non-normal operations, including an Emergency Response Plan
- Documentation of crew training and service and maintenance routines

Overall, the application argues that Everdrone's operations meet and exceed the TLS (target level of safety) established for general aviation. This is accomplished through the concept of functional safety that aims to eliminate potential single points of failures in the flight system – meaning that no individual technical error, internal or external, should result in a serious incident or accident.

The regulatory process for the 2020 pilot project lasted for just over one year. However, it should be emphasised that the successful outcome also benefited from Everdrone's previous projects and documented capabilities ranging back to 2017.

On top of the UAV operations' legislation, there are other legal aspects to bear in mind, like legislation on who can operate AEDs. In certain regions, AEDs can only be operated by trained personnel, like, for example, in Andalucia (Spain).

e) Evidence & Funding

As a tool to be used in medical response, evidence of its effectiveness is key for EMS & Healthcare decision-makers to support the implementation.

The work done by KI, Everdrone and SOS Alarm in Sweden is great to prove the benefits of UAV AED delivery. This, in addition to the availability of national databases on OHCA for research purposes and a new European regulatory framework for UAV operations, makes it a great moment to collaborate in deepening the work KI & Everdrone to validate its benefits:

- Faster response times, meaning higher survival rate
- Improvement of service quality in non-urban regions
- Save resources
- A UAV delivery system could escalate to provide further support, like being the first eyes on-scene

Another way of justifying the investment is by looking at UAV interoperability. If this system could be used in other use cases, this would make it easier to obtain the required funding. As stated in previous EENA work on UTM Public Safety Cases, some examples could be:

- Using the UAV as the first eyes on-scene to help people in the control room better assess the situation and adapt the response (i.e. activating more units or calling back and decreasing the response).

- Delivery of other medical supplies. This can be useful for remote areas that may need medical supplies or support Search & Rescue operations. Supplies could include Medications, Insulation, Blankets, Food, Water, Comms devices.

5 I CONCLUSIONS

UAV AED delivery is showing great potential as a way to improve OHCA survival rates, especially in suburban residential areas, where EMS may take longer, and public AEDs are not available.

The research and real-world pilot carried out by Everdrone, SOS Alarm and Karolinska Institutet is an excellent example of how the UAV platform and operations could look like and the results that can be achieved.

After running several interviews with public safety experts, there are still no standards for applying this concept in different regions. However, many of them agree on its relevance for non-urban areas or situations where the EMS cannot arrive on time. Also, to enhance the service with other non-medical use cases to increase the effectiveness of the investment in such platform.

The major conclusion is that more pilots and research are needed to really understand how this concept could be scaled to other regions. And now is the perfect moment for it. The technology has evolved enough to operate in real environments, and the new legal framework is allowing it. Again, the Sweden Case is a great reference.

Like the one done in Sweden, continuous research is a great example to follow to pass from UAV AED delivery pilots to make this service mainstream and permanent.

PROJECT PARTNERS

EENA

EENA, the European Emergency Number Association, is a non-governmental organisation with the mission to contribute to improving the safety and security of people. How can citizens get the best help possible if they find themselves in an emergency? This is the question we continuously try to answer.

Today, the EENA community includes 1500+ emergency services representatives from over 80 countries world-wide, 100+ solution providers, 100+ researchers. EENA is proud to be a platform for everyone involved in the public safety community and to provide a space for collaboration and learning.

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Everdrone AB

Everdrone is a global leader in autonomous UAV technology and provider of integrated UAV services. The company focuses on civil applications for commercial UAVs, with a string focus on healthcare and emergency response. Everdrone also actively works with regulatory issues associated with UAVs, specialising in urban operations. The company holds a unique permit for UAV operations in urban areas conducted beyond visual line of sight from the pilot.

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