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Facilities Required for Search and Rescue Operations Using Unmanned Ariel Vehicles.

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Abstract: The study investigated the facilities required for search and rescue operations using Unmanned Aeriel Vehicles(UAV). The study considered a qualitative exploratory research design with a global reach of some selected search and rescue Institutes that use UAVs in emergency management through a Purposive and convenient sample. The study data was obtained through an open-ended recorded interview of UAV stakeholders of the selected search and rescue organizations. NVivo version 20.6.1 software application and an online interview transcription platform, otter.ai, were used as instruments for transcription. The transcribed data was presented in thematic tables with data Classified into themes and codes for analysis. Thematic analysis was applied through a thorough examination of the data to identify common themes, ideas, and patterns that appear repeatedly. The results from the analyzed data revealed Unmanned ariel Vehicles' search and rescue operations are highly influenced by the state and types of facilities used during emergencies. The finding provides empirical evidence to justify those facilities used in search and rescue operations with unmanned aerial vehicles influence the effectiveness of search and rescue missions. The study recommends sustainable and resilient UAVs' command and control structures in search and rescue missions.

Index Terms **-Unmanned Aeriel Vehicle, Drones, Search and rescue, Facilities.**

1. INTRODUCTION

The use of Unmanned Ariel Vehicles (UAVs) or drones in the search and Rescue (SAR) of victims in the state of disasters has been noted with remarkable significance. Unmanned Ariel Vehicles (UAVs) have been identified as a vital new resource in nearly all SAR services (Gotovac, Zelenika et al. 2020). According to the Alliance for Drone Innovation (ADI), at least 59 people were saved by drones from life-threatening situations in 18 different accidents globally in 2017 (Gotovac, Zelenika et al. 2020). According to Erdelj, Natalizio et al. (2017), during a crisis, disaster management personnel's response time is critical in rescuing the lives of victims. Aerial evaluation of the UAV network provides the most efficient situational awareness. The response time of disaster management personnel during a natural disaster is critical in saving the lives of those in the affected areas. Using UAVs, first responders can quickly understand the gravity of the material damage and the potential number of the affected victim in the disaster (Erdelj, Natalizio et al. 2017).

Depending on the Country, different restrictions apply to the use of UAVs; however, during a crisis, specific permissions are frequently granted to flying devices to assist first responders in assessing the situation as rapidly as possible (Erdelj, Natalizio et al. 2017). Unmanned Aerial Vehicles (UAVs) or Drones have recently emerged as a cost-effective solution for handling emergency scenarios for various reasons. UAVs can quickly approach difficult-to-reach sites such as devastated areas, cover large search areas, and can be rapidly deployed in disaster areas delivering on-demand mobile networks (Albanese, Sciancalepore et al. 2020). UAVs are of various sizes and configurations capable of flying without a pilot on board. An onboard computer controls the object's flight, and the drone is operated by

a pilot operating from the ground via radio (Pensieri, Garau et al. 2020). Drones are more widely employed to assist public safety personnel and first responders. Drones provide low-cost, simple-to-operate, and analytically complex remote sensing solutions in SAR, hazardous response, wildfires, medical supply delivery to remote regions, and many other applications. (Eyerman, Crispino et al. 2018). The use of drones for public safety is one of the most promising and wides pread applications for search and Rescue. SAR is a sophisticated procedure that varies widely based on the environment, weather, the experience and skill level of the searchers, and the missing individual.

The current standard procedure for SAR has been created, performed, and upgraded over many years of training and testing in diverse situations worldwide (Eyerman, Crispino et al. 2018). The successful operation of UAVs in Search and Rescue Missions has been influenced by an adequate coordinated architecture or command and control structures. The concept of Command and Control is derived from Military operation research. Military operations would never have succeeded in the past without effective command and control, especially the massive operations that have been performed. (Erdelj, Natalizio et al. 2017, Afina, Inverarity et al. 2020).

According to Leonhard, Buchanan et al. (2010), the setup of personnel, training, information management, equipment, and facilities required for a commander or other decision-maker to carry out an operation is command and control. The command-and-control aspect fit nicely into an Industrial Age perspective that assumed organizations and events could be adequately portrayed as machines, although complicated. Results might be controlled if machines functioned according to a known set of rules (Afina, Inverarity et al. 2020). The command and Control research concept is proving to be practically relevant in providing adequate solutions to many public safety challenges (Erdelj, Natalizio et al. 2017, Eyerman, Crispino et al. 2018)

According to Govindaraj, Chintamani et al. (2013), a Command control system architecture consists of a central mission planning and coordination system (MPCS), field-portable robot command and control subsystems, a portable force feedback exoskeleton interface for robot arm telemanipulation and mobile field devices. The command and control system provides different UAV search and rescue management functions regarding identifying victims in crisis quickly and efficiently (Govindaraj, Letier et al. 2017). According to ICARUS, the command and control structures of SAR define its various actors and their interactions with other systems (Govindaraj, Chintamani et al. 2013). The significant stakeholders that constitute the C2 systems: Disaster victims, local emergency management authorities, crisis data providers, Search and Rescue first-responders, Search and Rescue Mission planners, SAR UAV operators, SAR Field team, and crisis stakeholders, among many significant partners.

The present study focuses on the command-and-control structures and their impact on SAR operations using drones in crisis management. A pictured presentation of SAR drone and C2 systems is shown in figure.1, 2, 3 and 4.

Understanding the various facilities and stakeholders that constitute the command-and-control structures for search and Rescue (SAR) drones' operation is relevant during a crisis or disaster management. Functional knowledge of facilities, information management, infrastructures and stakeholders that constitute the C2 structures of SAR drones' operations are relevant factors for the efficient Rescue of victims during disaster periods. Unmanned Aerial Vehicles' SAR operations are complex and challenging due to inadequate coordination among entities, limitations of functions among stakeholders, operations skills, regulation hurdles among personnel, deficient infrastructures, technological failures, and abusive actions at various levels of Search and Rescue operations. Understanding the different architectural plans, communication management, facilities and mission planning protocols helps define the rescue process of SAR drone operations. The paper, therefore, aims to answer the following research question; What are the appropriate facilities required for Search and Rescue (SAR) operations using drones and their significance?

The paper is organized as follows; Firstly, the research gives a background on Command-and-control structures for SAR operations, followed by related literature. The method followed the results with a discussion of the study findings. Lastly, the limitations and perspectives for future research were highlighted.

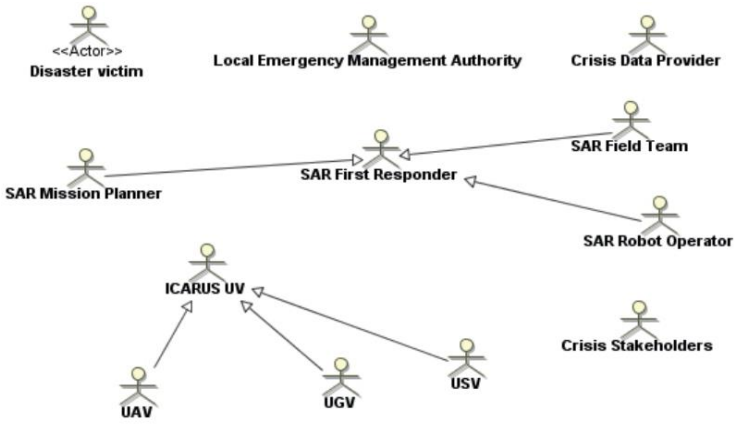

Figure 2*.Actors involved in Command-and-Control Systems in SAR with UAV; (Govindaraj, Letier et al. 2017)).*

Figure 1*, DJI Matrice 210 V2 SAR/LE/Fire Drone, source: lblasting.com*

Figure 3*. C2 systems deployment and communication framework; (Govindaraj, Letier et al. 2017)*

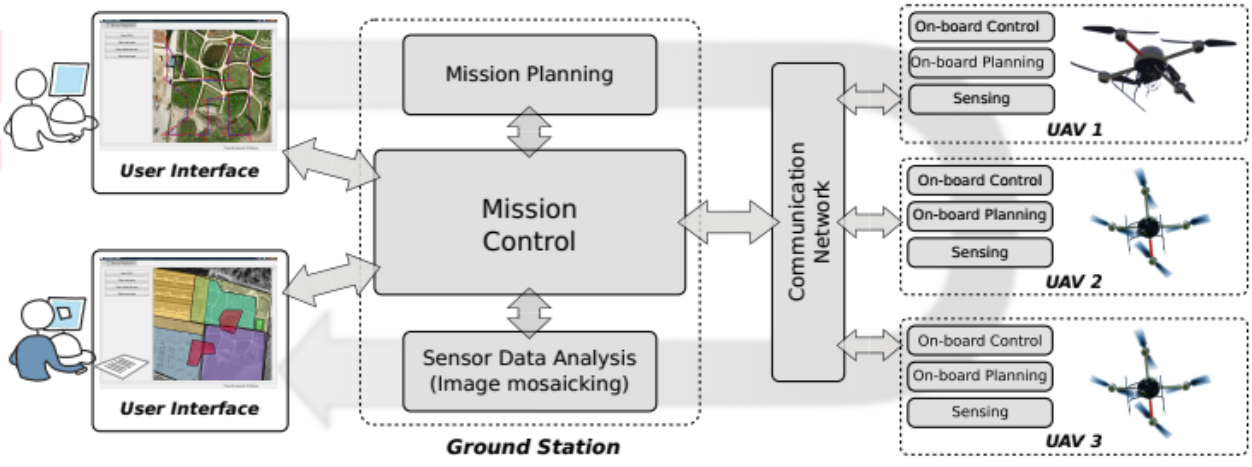

Figure 4*.. A C2 System Architecture. Source:(Yanmaz, Yahyanejad et al. 2018).*

2. LITERATURE REVIEW

Unmanned Aerial Vehicles s or drones in disaster management and search and rescue operations have gained significant attention globally (Yanmaz, Quaritsch et al. 2017, Surmann, Worst et al. 2019). Research studies have drawn more attention to drones in search and rescue operations. Unmanned aerial vehicles (UAVs), popularly known as drones, are becoming the most promising and powerful technology in improving disaster response and relief operations. UAVs are frequently depicted as game-changers in disaster relief, gathering data and delivering aid (Washington 2018). UAVs equipped with imaging sensors can capture timely and usable data for making more informed judgments in post-disaster situations, allowing for more effective and prompt responses (Htet and Htet 2016).

Time is vital in search and rescue efforts, and any delay can have disastrous effects on human lives. Search and rescue operations can benefit significantly from unmanned aerial vehicles (UAVs). UAVs are agile, swift, and capable of autonomous behaviour, allowing them to carry out actions that would be challenging for humans to carry out at minimal costs (Waharte and Trigoni 2010). Drones or UAVs can be used to deliver medical kits, vaccines, and blood supplies quickly in an emergency and help medical professionals, increasing victims' survival rates. It is a preferable alternative to providing humanitarian relief in naturally afflicted areas because it saves lives in a much shorter period (Konert, Smereka et al. 2019). Amongst the valuable advantages drones offer is high definition (HD) aerial imaging, which makes it simple to obtain live photographs and videos during a disaster such as floods or forest fires and take fast action. The ability of UAVs to quickly reach a crisis-affected area makes them highly beneficial for disaster management and life-saving (CHAVAN 2021). With new technological advancements, drones can potentially alter the healthcare and medical industries and increase their application in various fields (CHAVAN 2021).

Drones can give 3D geographic mapping a significant advantage for reaching isolated locations quickly and operating in hazardous areas if necessary (CHAVAN 2021). Even in low-vision areas, Unmanned Aerial Vehicles can find their way. Drone technology uses thermal imaging to provide a vision unavailable to the naked eye. Some modern drones feature sensors that can distinguish between living and dead things. A major advantage of Unmanned Aerial Vehicles is their ease of maintenance and low cost of operation (CHAVAN 2021). We can have a safe and successful drone flight if proper rules and regulations are followed and adequate capacity and capability tests are conducted (Konert, Smereka et al. 2019). The safety and Security of drones is the major problem concerning the technology as errors in operation can lead to collisions, accidents, hacking, and other undesirable consequences. Paying more attention to UAVs' safe operation during emergencies provides the efficiency of its operations.

The European Union has supported several SAR projects, including the SHERPA project, which created ground and aerial robots to aid alpine SAR (Marconi, Leutenegger et al. 2013). The ICARUS projects also have contributed much to Unmanned technology in SAR processes, focusing on reducing long deployment time and improving coordination and integration of devices used during the SAR operation. (Govindaraj, Chintamani et al. 2013).

Many lives have been lost due to natural catastrophes such as earthquakes, tsunamis, volcanoes, landslides, and avalanches (geophysical). Many initiatives are underway to anticipate and forecast natural disasters to respond promptly and efficiently, assess the damage, repair the outages, and restore normalcy (Erdelj, Natalizio et al. 2017). Erdelj, Natalizio et al. (2017) recognizes the need to improve disaster resilience with the use of advanced wireless sensor network (WSN) technology and unmanned aerial vehicles (UAVs) to improve network-assisted disaster prediction, assessment, and response capabilities. The most important thing to do in a crisis is to save as many people as possible (Hábermayer and Horváth 2020). Search and rescue (SAR) efforts must be carried out rapidly and efficiently in the first 72 hours after a disaster strikes. During a crisis, the main challenge is communication and situational awareness, which causes first responder teams to improvise, reducing the efficiency of the rescue mission. (Erdelj, Natalizio et al. 2017). The response time of disaster management personnel during a natural disaster is critical in saving the lives of those in the affected areas. UAV aerial assessment networks provide the most efficient situational awareness. Different restrictions apply to UAVs; however, specific authorizations are frequently issued to flying devices during disasters to allow first responders to analyze the situation as rapidly as possible. (Erdelj, Natalizio et al. 2017, Washington 2018).

Time is essential in search and rescue situations since lives are at stake. The time factor is frequently linked with uncertainty because the location of the people involved is unknown. As a result, search and rescue personnel are forced to explore a broad area fast (Mayer, Lischke et al. 2019). SAR operations' most common essential aspects are time and vast space, but natural disasters frequently create limits that people cannot surmount. Natural disasters such as avalanches, floods, and wildfires are among the most prevalent natural calamities that make human search and rescue missions extremely difficult(Mayer, Lischke et al. 2019). In search and rescue scenarios, UAVs have several benefits over humans. For example, they may be dispatched to any location without the operator knowing the exact conditions in the target area. The rescuers' risk of injury or death is reduced during the operation. UAVs can also scan a big land area in a short time using the newest tracking and communication techniques (Mayer, Lischke et al. 2019). The various command and control base stations are illustrated in figures 5 and 6.

***Figure** 5. Portable command and control base station. Source:(Balta, Bedkowski et al. 2017)*

***Figure 6.** Transportable C2 base station. Source: https://www.kratosdefense.com/products/uav/air/uav-command-and-control.*

3. METHODOLOGY

The present study is an exploratory qualitative research design. Qualitative research allows ways to explore or investigate the quality of relationships, activities, situations, or resources(Creswell and Poth 2018, Islam and Aldaihani 2022). The study explores the appropriate facilities required for Search and Rescue Operations using drones and their significance. An exploratory study is applicable when understanding a context seems relevant in knowing the success and failures of an intervention (Thurmond 2001, Creswell and Poth 2018, Goodrick 2020). The study considered organizations or stakeholders from different continents, the United States of America, Europe, Australia, Asia, and Africa. Countries within these study areas are active in SAR rescue missions and have integrated the use of UAVs in their operations. The study observes a convenient and purposive sampling technic. Research information was obtained from professional agencies or stakeholders with SAR experience at their convenience. Participants in the study were selected based on the convenience of the researchers' access to their available schedule by soliciting interview consent at their convenience. Purposively, participants who are active in SAR operations with UAVs and understand the phenomenon under investigation were identified. The study observed Search and Rescue Agencies from the United States, Germany, South Africa, New Zealand, Belgium, Britain, and France based on professional knowledge in using UAVs in SAR and active involvement in national and international relief missions or disaster management. These organizations considered the use of UAVs service as an integral structure in their operations. The study assessed a global coverage to help understand the various stakeholders involved in SAR using UAVs, their experiences, and thoughts regarding the phenomenon under investigation.

An interview guide with semi-structured open-ended questions was designed and used as the instrument for data collection by interviewing stakeholders actively involved in SAR operations using drones as a tool for relief assistance. Stakeholders' interview was preferred as this allows the researcher to have first-hand data from experienced professionals involved in crisis management and SAR operations, considering UAVs as an integrated technology considered valuable in emergencies. The interview guide consisted of open-ended questions directed at SAR stakeholders regarding the research variables of command-and-control structures of search and rescue drones' operations. Questions were asked about the appropriate facilities for SAR missions using UAVs and their significance. The data gathered from in-depth interviewing stakeholders of SAR Organizations using UAVs was transcribed using NVivo version 20.6.1, a transcription software application, and an online interview transcription platform, otter.ai. The transcribed interview data was organized into a meaningful form. The data was coded for easy description and development of themes to understand the phenomenon of C2 structures for SAR operations with UAVs. Thematic analysis was preferred as the researcher needed a close inspection of every word and sentence to capture specific quotes and the meaning of respondent views.

4. RESULTS

The name of the individual respondents interviewed and the various search and rescue organizations were not disclosed. The transcribed interview data were classified into themes for comprehensive analysis. The interviewed respondents of the different search and Rescue Organizations (SARO) are presented in thematic tables coded and identified as SARO 1, SARO 2, etc.

Table 1. General information about Respondents and Organization for SAR operations with Unmanned Aerial Vehicles.

UAV Org in SAR	Involve in SAR missions?	Number of interviewees	Interview mode	Interview time	Position held	Years of Experience	Country
SARO 1	Yes	**1**	Google meet	51 min	Cluster Manager-SAR	4	Belgium
SARO 2	Yes	**1**	Google meet	1hr 27min	Senior officer (USAR)	4	Germany
SARO 3	Yes	**1**	Microsoft teams.	48min	Drone pilot	6	France
SARO 4	Yes	**1**	Google meet	43min	Chief Remote Pilot (USAR)	5	New Zealand
SARO 5	Yes	**1**	Google meet	42min	Battalion Chief for technical operations	4	USA
SARO 6	yes	**1**	Google meet	54min	Team leader; drone pilots.	5	United Kingdom
SARO 7	yes	**1**	Google meet	56min	Team leader USAR	3	South Africa

The general observation of all the search and rescue organizations recognizes UAVs for search and rescue missions involve using established facilities for effective operation. A general observation from all the seven SAROs considered in the study acknowledges the establishment of command centres, communication assets, Drones or UAVs models, Training Institutions, working knowledge of U-space, and availability of relevant transportation facilities for an effective search rescue operation. All seven respondents accepted the use of UAV base stations for effective UAV search rescue missions. Two respondents (SARO2 and SARO5) accept the command tents as among the facilities they considered when performing a SAR operation with a UAV in the disaster zone.

All the respondents accepted satellite communication networks as a valuable asset relevant for an effective SAR operation using UAVs. Mobile phone gadgets were also assistive, as observed by all the respondents. Three respondents (SARO2, SARO3, SARO5) accept the incident management dashboard when performing SAR operations using UAVs. All respondents admit Satellite networks for fast data transfer with UAVs in search and rescue operations.

All seven respondents accepted using DJI drones as a reliable model for SAR operation. The use of different models of DJI drones was observed from the responses of all the respondents. DJI 600, DJI, 300, DJI 310. The various SAROs observed DJI inspire and DJI quantum four as models frequently used for search and rescues. Mavic and matrices were other additional models regarded by (SARO2 and SARO6) as among the model employed in their SAR missions. All the respondent observes the relevance of mobile vehicles or mobile incident command vehicles as a reliable resource considered by responders when carrying out SAR operations with UAVs in the disaster zone. It was also observed that all respondents agreed to have a working knowledge of U-space regarding UAVs in search and rescue missions. All respondents agree to understand flight restrictions and control in air traffic zones. Also, SARO 6 observed the 400feets as the maximum flight Hight the UAV is permitted to fly along with air space restrictions with the help of National and air traffic. Training for Drones pilots are observed to be conducted in training Institution, police (SARO1, SARO2), civil protection Institutes (SARO 3, SARO4, SARO5), and Drones service providers (SARO 6, SARO7). Finally, it was observed that all the respondents accept the position of Facilities as an essential structure for search and rescue with UAVs.

Table 2. Facilities perceived by respondents for UAVs in Search and Rescue operations.

Themes	SARO1	SARO2	SARO3	SARO4	SARO5	SARO6	SARO7
Command centres.	Mobile Base stations for C2.	Base stations are established. C2 Tents	Command and control base stations	Command and control base stations	Command tents, mobile base stations.	Base stations,	Mobile base stations.
Communication assets	Available satellite network, 4G network., Mobile phones.	Available Satellite network, Incident management dashboard. mobile phones	Available Satellite network, 4G network., mobile phones, Incident management dashboards.	Available Satellite network. Mobile phones	Public Satellite network, Mobile phones, 4G network, Incident management dashboards.	Available Mobile server, Satellite network, Handsets,	Available Satellites network. Mobile phones
Drone types/models	DJI 600, Mavic enterprise.	DJI 310	DJI phantom 4, Matrices 300, Mavic.	DJI300, DJI 310, Quantum trinity, quadcopter	DJI 300	DJI300, Mavic. DJI Inspire,	DJI 300
Transport facilities	Mobile vans.	SAR mobile Vans	Field vans	Mobile incident command vehicles.	Field vehicles	Field vehicles	Mobile incident command vehicles
Knowledge of U-space	UAV flights are restricted and controlled in air traffic zones.	UAV flights are restricted and controlled in air traffic zones,	Networked with civil aviation to understand restricted air zones.	U-space is highly regulated with advanced technological software that monitors field UAV operations	Flight is bound and controlled in air traffic zones,	-UAV Cannot fly above 400feets. -communicate with National air traffic (NAT).	Flights are restricted and controlled in air traffic zones.

Training Institutes.	Training and certification from drone Institutes.	Available Training Institute for UAV operators.	Firemen institute, Drones Institute	Fire Emergency Institute.	Fire Institutes. Drones Institute	Trained by drone service providers, Inservice training, and trained by the police for capacity building.	Training is provided by tech providers and organized workshops for capacity building.

5. DISCUSSION

The findings obtained from the study through thematic analysis from respondents interviewed show the relevant Facilities that support effective search and rescue operations using UAVs. The use of command centres or base stations, communication assets, drone models for SAR, transport facilities, an understanding of the U-space, mobile phones, and training Institutions for capacity building were considered very relevant infrastructures or facilities for search and rescue operations with UAVs. The study results are in line with Balta, Bedkowski et al. (2017), who says ground control stations should consist of a GPS receiver which provides a global position for network management, a computer system which hosts the software for the unmanned vehicle, and a modular battery slab with an onboard power control units. The finding also reflects Si-Mohammed, Bouaziz et al. (2020), who said, Communication technology is the key enabler to unlocking the potential of UAV operations. The 5G mobile network is envisioned as the communication standard for various UAV operations and applications. Si-Mohammed, Bouaziz et al. (2020) further says U-space services can assist in processing UAVs' flight authorizations and offer operators the tools and information needed to plan safe flights and avoid collisions with other aircraft, and comply with each member state's environmental, Security, and privacy standards. The findings also accept the importance of Training Institutions as a relevant structure for search and rescue operations with UAVs. The result supports De Cubber, Doroftei et al. (2013) and Balta, Bedkowski et al. (2017), who say a practical UAV operation needs extensive training and support infrastructure.

6. CONCLUSION.

The present study is based on global UAV search and rescue experts from reputable relief organizations. The study is supported by literature observing a decisive impact of command-and-control structures on UAVs' effective SAR operations and has empirically investigated the concept of command and control through its facilities and their significance. The results confirmed command and control structures as reliable structures for effective search and rescue operations using drones. The study generally reveals and answers the research question through the identification of facilities and stakeholders with relevance that command-and-control structures for UAVs in SAR provide effective coordination of relief management, increase the speed and quality of intelligence to decision-makers, and less time spent mapping and assessing a disaster zone, among many advantages.

7. LIMITATIONS AND FUTURE RESEARCH DIRECTION

The present study, though observed to feel research gaps but was also challenged in some respects; considering the small sample size of respondents that was limited in some few countries without having a full operational experience of other countries, challenges the strength of generalization. The study recommends a more comprehensive scope at the global level with SAR organizations from the various continents due to variations in regional regulation and approach.

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