The Complexities of Integrating Drones into Urban Search and Rescue

Perfectly Balanced, As All Things Should Be

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It is important to draw wisdom from many different places… if we take it from only one place, it becomes rigid and stale. ~ Iroh

This thesis is submitted for obtaining the Master's Degree in International Humanitarian Action. By submitting the thesis, the author certifies that the text is from their hand, does not include the work of someone else unless clearly indicated and that the thesis has been produced in accordance with proper academic practices

Abstract:

There exists a schism between the humanitarian and technology sectors. While this can be seen in many different aspects of both fields, this thesis primarily focuses on one such manifestation; exploring the usage of drones in the context of urban search and rescue (USAR). There is extensive research and development being done investigating and developing solutions to improve how drones can be used for USAR. The research and development of drones are highly promising, and drones should be able to function as a great tool in the toolbox of USAR personnel. Despite the potential drones have, drone usage and adoption into USAR are found to be lacking. It was found not only is there a lack of understanding and background among those familiar with the technology in USAR, but in numerous situations, drone integration is faced with resistance.

The goal of the thesis is two-fold. First, the thesis aims to understand *'how can the lack of UAV integration into USAR be understood?'* It is found that integrating drones into USAR comes with various complexities and intricacies that must be carefully navigated. Various social issues arise when drones get introduced to USAR. One such social consideration that is vital to understand is the relationships that various groups of people have with drones. It is by understanding such relationships that it becomes possible to investigate the nuances of the social impacts that arise from drone usage in specific contexts. This gets further corroborated by legal concerns pertaining to drone usage in various states, each having different legislation prescribing how drones may or may not be used. Legal and ethical questions also arise due to data that gets collected, managed, and processed due to various sensors added to drones, such as cameras.

The second aim of the thesis is, '*Taking account of the complexities regarding drone usage in USAR, how can drones be constructively integrated into the USAR ecosystem for the benefit of both USAR teams and the victims the team is trying to aid?'* This is done by analysing the capabilities drones have by adding different sensors such as cameras, infrared cameras, and lidar units to the drone. Linking the capabilities of drones to the goals and tasks of USAR allows for the exploration of the benefits that can be gained. It is by combining the benefits that drones can provide whilst also

understanding the complexities and limitations earlier explored that enable the thesis to make two propositions.

The thesis proposes the creation of the Urban Search and Rescue Drone Framework. This framework is a set of guidelines and standardizations regarding the usage of drones for USAR. For this framework, six key sections have been identified: Drone Classification, Requirements for Drone Operation, Flight Constraints, Drone Tasks, Data Management Practices, and When Not to Use Drones.

The thesis also coins the term techno-social scientist and provides a classification system to differentiate between professionals based on their competencies. People can be identified as being either an 'II', 'TI', 'IT', or 'TT' professional. This classification system can not only be used to assist in bridging the gap between technology and the humanitarian field- and thus, with extension, drones and USAR- but also in the broader technology and social sciences fields.

Preface:

First and foremost, I would like to thank Dr Malcolm Campbell-Verduyn. Thank you for all your guidance and feedback. You always got back to me so quickly that I started to worry that you might not get enough sleep. I would like to thank my parents; without your unconditional love and support, I would not be where I am today. Last but not least, I would like to thank my friends for ensuring I kept sane after writing all day. Without you, I would not have made it through. Also, without you, I would not have friends to thank.

This thesis was inspired by my background in both the technology and humanitarian sectors. Technology has always been a significant part of my life. As such, it was unsurprising that I completed a Bachelor of Science in Creative Technology, a multidisciplinary study examining how various forms of technology work and develop and their interactions with other fields. Likewise, the development sector has been part of my life since a young age. Having family and family friends that worked in the development sector, I was exposed to both worlds. As I grew older, I became more aware of the broadness and nuances found in the development and technology sectors and noticed that often people did not have experience in both.

When I started in the direction of the humanitarian sector for my master's degree, I recognized the same gap existing between humanitarian work and technology. This was when I decided that I would want to build my career with a focus on bridging the gap between the humanitarian and technology sector. This is why I decided to pick drones and urban search and rescue as my focus, as I believed that it would be a good way of showing the nuances that apply to both fields.

While writing my thesis, I learned that bringing these two fields together has its own set of complexities. A desire to make my thesis accessible to those with a technology or a humanitarian background has been challenging. And while I believe that the thesis is a good starting point providing a perspective into both fields, more nuances exist in both disciplines that I was not able to fully address. Unfortunately, due to the scope of this thesis, I was unable to ramble on endlessly about minute details. Fortunately for readers, I was unable to ramble on endlessly about minute details.

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Abbreviations:

AED	Automated External Defibrillator
CDRP	[Florida State University] Centre for Disaster Risk Reduction Policy
GDPR	General Data Protection Regulation
ICAO	International Civil Aviation Organization
ICRC	International Committee of the Red Cross
IEEE	Institute of Electrical and Electronics Engineers
INGO	International Non-Governmental Organization
Lidar	light detection and ranging
NGO	Non-Governmental Organization
OMM	Ortho-mosaic Map
RPA	Remotely Piloted Aircraft
SAR	Search and Rescue
SCOT	Social Construction of Technology
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UCC	USAR Coordination Cell
UCD	User Centred Design
UDF	USAR Drone Framework
UN	United Nations
USAR	Urban Search and Rescue
VTOL	Vertical Take-Off and Landing

1 Introduction

The interdisciplinary nature of the humanitarian sector results in humanitarians having to navigate complex interconnected political, legal, and social landscapes whilst also considering various stakeholders such as the people humanitarians aim to help, funders, governments, and other international and local organizations. In recent years technology has started to become significantly more integrated into the humanitarian sector and, with it creating a rise in humanitarian technology (Picucci, 2017). While technology provides extensive new opportunities and opens various doors, it also comes with a host of ethical, legal, and socio-political considerations and complications (Cook, 2017; Jacobsen, 2015; Ortiz, 2020). The complex environment created by humanitarian technology often requires navigation by those who have experience in both fields, although people with these relevant backgrounds are often in short supply (Cook, 2017; Oerther, 2021).

This thesis investigates one such schism between technology and the humanitarian sector by analysing the usage of drones for urban search and rescue (USAR). Drones can be highly beneficial in USAR, providing new opportunities by creating up to date maps of environments, allowing for more extensive damage assessments that are otherwise not possible, and providing teams with a literal top-down perspective of the situation. As a result, drones can make finding and rescuing people safer, quicker, and more efficient. Similarly to other technology in the humanitarian sector, drones create numerous political, social, legal, and ethical challenges with their use in USAR. These challenges get further exacerbated by the lack of individuals with experience with both drones and USAR (Custers, 2016; Greenwood, Nelson, & Greenough, 2020; Półka, Ptak, & Kuziora, 2017; Rejeb, Rejeb, Simske, & Treiblmaier, 2021; Sandvik & Lohne, 2014). Before an in-depth analysis of drones in USAR commences, the aims and objectives of the thesis, such as understanding the lack of drone adaptation in USAR, and proposing the creation of a USAR drone framework, shall be expounded upon. The state of the art of research on drone usage in USAR is examined and is followed by a justification of the research, an explanation of the research methodology, and lastly, an explanation of the structure of the thesis.

1.1 Aims and Objectives

A drone, often also called an unmanned aerial vehicle (UAV), is an aircraft that is operated remotely. Coming in various shapes and sizes, ranging from smaller than a person's hand to the size of a passenger plane, and, when combined with other technology such as cameras, allows for the mapping of areas or the creation of 3D models of an environment (Vergouw, Nagel, Bondt, & Custers, 2016). While drone usage is becoming more commonplace for various emergency services (Braverman, 2021), and despite USAR having integrated various technological tools to help with completing its missions (International Search and Rescue Advisory Group, 2020c), the inclusion of drones in USAR is still lacklustre (Greenwood et al., 2020). Adoption is lacklustre despite the benefits that the drones could provide in information gathering potential, relative ease of use, lower cost to alternate methods of gathering similar data, and the extra safety it provides to USAR teams. This chasm is in large part due to the hurdles that arise from drone usage (Rejeb et al., 2021; Swiss Foundation of Mine Action & CartONG, 2016a). Combined with academic debate on the moral and social implications of drone usage (Jacobsen, 2015; Madianou, 2019) results in drones not being adopted more actively into international USAR.

As a result, the thesis investigates two research questions. The first is, *'How can the lack of UAV integration into USAR be understood?'* When looking at the benefits drones provide USAR teams, such as mapping and damage assessments, helping in locating people, and making USAR safer for rescuers, it would be expected that drone integration would be more common. This dissonance between the expectation of drones being more adopted and their lack of usage shall be investigated by analysing the specific contexts in which drones get used. In doing so, uncovering the nuances and limitations that are less evident (some more so than others) than when simply looking at what the technology can provide. By analysing drone integration from a social constructionist perspective, investigating the relations between people and UAV technology, and looking at the relationship of drones to other facets such as the legal and ethical structures of a society, one thing becomes abundantly clear. The context is a significant element not to be overlooked. Context can provide extensive challenges and hurdles that need to be overcome in order to constructively integrate drones into USAR for the benefit of both USAR teams and the victims the team is trying to aid.

With the understanding of the difficulties that arrive with the usage of drones and the intricacies that need to be navigated, it becomes possible to investigate the second research question, *'Taking account of the complexities regarding drone usage in USAR, how can drones be constructively integrated into the USAR ecosystem for the benefit of both USAR teams and the victims the team is trying to aid?'* This question is a separate yet explicit follow up from the previous question. It aims to apply the theoretical understanding of the situation to provide practical recommendations for USAR teams on how to proceed with drone integration. Importantly, it should be mentioned that the question does not presuppose drone integration as inherently good, leaving space for nuances and situations where drone integration, or at least drone usage, is recommended against. In doing so, it recognises the hurdles earlier identified as more than just complexities that need to be navigated, but concerns that need to be adequately considered. Showcasing that when properly considering the limitations in a specific context, there are situations in which drones should be avoided and not used.

To further answer the second research question, this thesis proposes the creation of a framework specifically for drones in USAR, including providing insight into what this framework should include and why. To provide practical recommendations, the thesis needs to consider more than just the hurdles; it needs to analyse the USAR ecosystem and the capabilities of drones in-depth. In doing so, it becomes possible to not only look at the benefits drones provide to USAR teams and see what potential gaps UAVs can fill but also how, when, and if drones should be integrated.

It is important to emphasise that while the thesis aims to answer the above questions, it also aims to contribute toward the more significant issue, which is the divide between the humanitarian and technology sector- of which drones and USAR is one such manifestation. In order to do so, the thesis also proposes the term techno-social scientist. The term comes with a methodology to identify people's competencies in both the technology and social sciences fields. For the chasm between the two fields to be bridged, it is vital to take an inherently multidisciplinary approach that takes the background of both the technology sector and humanitarian sector into account (Cook, 2017; Greenwood et al., 2020; Ortiz, 2020; Rejeb et al., 2021). To further investigate the gap between drones and USAR, a state-of-the-art analysis is done, which reflects the existing schism.

1.2 State of the Art

The technology/humanitarian divide and, more focused, the drone/USAR divide, exists not only pertaining to the lack of integration in the field; it is also reflected in literature. Zurli, Bravo, and Leiras (2015, p. 12) comment on this divide, noting that a large part of literature pertaining to drone usage in USAR comes from a "robotic and mechanical engineering" background with the aim to "improve the equipment's performance". Such publications are often found in IEEE Xplore databases and often are published by IEEE, the Institute of Electrical and Electronics Engineers. Cacace et al. (2016) developed a new method to control numerous drones simultaneously for USAR. In a similar vein, Cao, Sun, Gaelle, and Su (2021) developed a platform to help with drone control and data gathering for search and rescue purposes. Selim and Kamal (2018) looked at how drones could be used and improved upon to solve mobile data network issues after a disaster. Rudol and Doherty (2008) developed a method of detecting human bodies using thermal imagery. Lee, Har, and Kum (2016) explore how lidar (light detection and ranging) and thermal imaging can be used to find victims after a disaster. Sources other than IEEE also produce engineering heavy focused papers, as seen in Burgués and Marco (2020), analysing how smaller UAVs could be used for sensing chemicals and Chatziparaschis, Lagoudakis, and Partsinevelos (2020) investigated the use of drones and robots for mapping in search and rescue. Often times such research is done as part of a competition, as can be seen by Deleforge, Carlo, Strauss, Serizel, and Marcenaro (2019) and Cui et al. (2015).

There is an extensive body of research dedicated to improving technology for humanitarian purposes; likewise, extensive research improving drone technology for search and rescue. Both of these are illustrated by initiatives such as the IEEE Global Humanitarian Technology Conference (Oerther, 2021). It should be noted that while there is no lack of enthusiasm and dedication toward improving the technology, most of these developments remain primarily theoretical. That is to say, the improvements, be it software or hardware, get developed but do not get used in the field. Testing of the equipment is likewise usually only done in the form of simulations.

Conversely, there exist various forms of criticism towards technological integration into the humanitarian sector as a whole. Madianou (2019) explores the topic of techno-colonialism, stipulating that technology is another element that enforces Western imperialistic power structures on non-Western states. It also notes how an extensive amount of technology gets developed, often in the form of a competition, and how these competitions are not actually about humanitarian work. Similar resistance towards technology can be found by authors such as Jacobsen (2015), referencing the unintended consequences technology can have. It should be noted that the critical nature of these questions is not inherently wrong, often raising important arguments and concerns that do need to be considered. This is well reflected by later work by Jacobsen and Fast (2019), showcasing how technology adds a level of unclarity to the humanitarian sector that was not present prior.

There is likewise research that is more open but not bereft of criticism towards drone integration in the humanitarian and USAR sector. It should be noted that many concerns about drones in the humanitarian field also apply to USAR, such as the legal, ethical, and social implications of their usage. Notably, the Swiss Foundation of Mine Action and CartONG (2016a) conducted a series of case studies on using drones in various humanitarian and development settings. Investigating the potential that drones have in improving various tasks such as mapping and cargo delivery, but also examining the shortcomings such as legal and ethical concerns. Further, Custers (2016) analyses the numerous possibilities drones have in various fields, as well as extensively explores the legal and ethical challenges that arrive with their usage. Ning Wang, Christen, and Hunt (2021) and Emery (2016) likewise explore the ethical challenges that arise with using drones in the humanitarian field. Greenwood et al. (2020) note that while drones are starting to get used more by emergency services in the United States of America, it is still lacking in USAR. Meanwhile, Li and Hu (2021) note there has been a rise in using of drones in China, including for search and rescue.

1.3 Justification of Research

The research related to drones in USAR is varied, extensive, yet also divisive. From the engineering and science side, there are a plethora of papers examining and investigating how the technology can be improved. Likewise, there exists in-depth analysis of problems that do or potentially can arise from integrating drones into the humanitarian sphere, much of which also applies to search and rescue. There is, however, a gap in research identified. A gap in providing recommendations on steps to take if an organization wants to integrate drones further. Likewise, while numerous papers recognize the issues that arise with integrating drones into USAR, the research fails to provide insight into how drone usage can be adopted. Instead, papers tend to conclude more research needs to be done.

While this thesis agrees with the sentiment that more research needs to be done, it goes further by calling for the creation of a USAR Drone Framework, a framework specifically designed to address the issues that arise with drone usage in the USAR ecosystem. While the thesis does not create the framework itself, it does include the minimum topics that must be covered in such a framework, as well as explaining why they are needed and how including these topics can permit drone integration into USAR. This is compounded by also providing steps organizations need to take to start integrating drones.

Further, to address the divide between the humanitarian and technology sector, this thesis proposes the concept of a techno-social scientist- someone who has experience in both the technology and social science fields. While the thesis does not claim that people with such backgrounds do not already exist (as they do exist), it proposes the term techno-social scientist in conjunction with the development of a model that refers to different types of techno-social scientist professionals based on their competencies in the technology and social science sectors. Classifying peoples' skillsets and knowledge in various disciplines in both of these sectors will help facilitate the bridging of the technology and social science gap, including the technology and humanitarian gap. The proposed classifying framework yields a method to identify what kind of professionals should be needed for different positions in an organisation. It is an original idea created by the author of this thesis to better help understand how drones can be better integrated into USAR by highlighting what type of professionals are needed for such endeavours. It can also be used to help address the technology-humanitarian divide, as well as address other technology-social science sectors. The model builds off existing literature, and it is well possible that prior research devised a similar or likewise approach.

1.4 Research Methods

For this thesis, the conducted research was done by referencing publicly available documents and tools. Articles were found by searching various online databases, namely but not limited to Google Scholar, WorldCat, ReliefWeb, IEEE Xplore, and Elsevier. Due to the nature of the topic, on several occasions deviation from scholarly articles was required. Multiple sources are web pages belonging to organizations to INGOs, non-profits, and at times government. Often information pertaining to drones is easier to find on websites in blog format. While at times this was necessary, this has been avoided as much as possible.

Another aspect to note about this research is that it makes as little reference as possible to individual drones models. This was a deliberate choice. Drone technology is developing quickly and since the goal of the thesis is to contribute towards the integration of drones into the USAR ecosystem, as well as contributing to the humanitarian-technology divide, staying relevant for as long a period as possible seemed vital. The author believes that for such purposes, it would be counterproductive to mention individual drone models. This is seen in studies such as by the Swiss Foundation of Mine Action and CartONG (2016a), where several references were made to drone models. Some of these are no longer sold due to being outdated. An example would be references made to the DJI Phantom 2 and 3 series drones (of which various models exist). When comparing those to the more modern DJI Mavic 3 series, the Mavic 3 series outperforms the DJI Phantom 2 and 3 series in most ways. The DJI Mavic 3 has about double the maximum flight time, is significantly smaller, lighter, and more portable, has a better camera, and many other features (DJI, n.d.-a, n.d.-b, n.d.-c). Granted, the Mavic 3 series is not better in every way; the Phantom 2 and 3 series will still outperform the Mavic 3 series at tasks such as lifting cargo. And even though the Mavic 3 cannot do all the things a USAR team would use a drone for (a USAR team could potentially use different drones for different purposes), it does showcase that there have been vast strides in the capabilities of drones.

Drawing conclusions based on old research relating to drones can become more complex, as the research would be misrepresentative of the current status quo of the technology. To prevent this thesis from falling into such pitfalls, referencing individual models has been avoided as much as possible. This is also the reason why the costs of drones were mainly avoided in this thesis. Due to the evolving nature of the technology, any included costs could become outdated within a few years.

1.5 Structure

The thesis is divided into three main sections. The first section starts with analysing the concept of drones in USAR from a social constructionist perspective. Integrally, it frames the research into an existing body of literature and provides commentary thereof. Analysing techno-colonial perspectives as presented by Madianou (2019) and Jacobsen (2015) and showcasing both shortcomings of their work as well as highlighting several essential concerns raised. Further analyses is done by investigating drones using the social construction of technology framework. An updated version developed by Humphreys (2005) is used to explore how drones and USAR can be investigated from that perspective.

An analysis of what it means to combine the technology and humanitarian sector follows in which the thesis introduces the term 'techno-social scientist'. The thesis then develops a methodology to identify someone's capabilities as a techno-social scientist. By building on the work of Oerther (2021), this thesis further proposes a model to categorize (including already existing) techno-social scientists on their competencies, skills, and knowledge in the technology and social scientist sector, respectively.

The first section continues with the investigation of the legal limitations that arise from the use of drones in the context of USAR, analysing how the legislation of different states impacts drone integration. Similarly, the legal and ethical challenges that arise from the different equipment that can be attached to drones are discussed. This is followed up by examining electrical limitations to drone usage pertaining to flight time and battery capacity.

The second section of the paper is more straightforward and examines the USAR ecosystem in-depth, exploring the various phases that exist within USAR as well as analysing the five USAR Teams a USAR mission employs. It likewise identifies USAR Team Search as the best potential candidate to integrate drones into. This section likewise delves into further depth, investigating the definition of drones and different classifications thereof.

The second section starts by analysing the USAR ecosystem, exploring what USAR consists of and how its various tasks and responsibilities are divided. After this, the thesis investigates the various sensors that can be added to drones. The benefits of cameras are explored, analysing their ability for mapping and photogrammetry purposes. Infrared cameras are analysed for their heat-sensing capabilities and utilization for multispectral images when combined with a camera. Another sensor analysed is lidar, and how the photogrammetric models lidar units produce are superior to those of cameras, albeit coming with some more complications to set up. Using drones as a tool for payload delivery is also explored.

The third and last section of the body aims to combine the aspects that have been learned from the previous two sections. It forms an intersection of the technology and humanitarian field, as well as the intersection between drones and USAR fields. By recognizing the benefits drones can at times provide whilst understanding the realities and complexities with which USAR teams and humanitarians are faced. The section provides recommendations that can be used in order to help facilitate the adoption of drones in USAR where feasible and beneficial. It does this by recommending the creation of a USAR Drone Framework, stipulating the most critical elements that need to be included in such a framework. The last section provides insight into what is needed for drone technology to be constructively integrated into USAR activities.

The thesis is rounded off with a conclusion summarizing the findings of the conducted research and providing recommendations for further research. It examines the lessons learned, providing final comments and key takeaways.

2 Understanding the Complexities of Drones in the USAR Sector

The perception that different stakeholders such as USAR personnel, humanitarians, and beneficiaries have of drones is vital in understanding the role the technology could potentially play in the humanitarian and USAR sector. While the thesis argues that drones should be another tool in the toolbox for USAR teams, understanding the contextual complications that arise with drone usage requires stepping away from perceiving drones as merely a tool. Instead, it is essential to analyse relationships between drones, the operators, and the affected people. To investigate the underpinning of political, social, economic, legal, cultural, and technological power structures and decipher the impact drone technology has on this landscape. Accordingly, this section of the paper aims to provide a critical outlook on drone technology from these some of these various perspectives and the issues that come with it.

This will be done by firstly analysing drones from a social constructionist perspective. Showing that relations of various stakeholders, such as those of the people receiving aid, have towards drones is vital in understanding the applicability of their usage. This is further analysed by applying the social construction of technology framework to drones, specifically an updated version proposed by Humphreys (2005).

This is followed up by the creation of the techno-social scientist identification model. It showcases a classification system that was developed to help with describing people's competencies in the technology and social science fields.

A legal analysis of using drones is conducted, investigating how legislation is an integral contextual element pertaining to how drones may be utilized. Another legal and ethical analysis is considered relating to the data that USAR teams would collect using drones and how that complicates drone adoption. Lastly, limitations regarding drones' flight time and ability to be recharged are analysed as possible limiting factors for seeing them more broadly adopted for USAR.

2.1 Social Constructionists

Social interpretations of what a drone is can both aid and hamper its effective use in specific contexts. An integral part of deciding whether to use a drone is the locals' stance toward drones, a stance that is reflective of how UAVs have been presented to the community in question. It is not a static and predefined view; instead, it is devised from the experiences individuals have and the meanings that get ascribed to those experiences. Failing to properly account for the local disposition could have potential negative impacts on the entire USAR mission. Illustrated well by recognizing that while section 3.2 showcases various ways to define and qualify a drone, such as by the configuration of the drone: fixed-wing, multi-rotor, or hybrid[1]; or as is often done delineating drones based on weight, it should be noted that these different categories are arbitrary distinctions made from a specific perspective. Presupposing that drones are viewed with the same definitions and distinctions in two separate cultures would run counter to a social constructionist approach. Demonstrated well by Somalia, Yemen, Pakistan, and, importantly, Afghanistan. The listed countries have been hit by a considerable number of drone strikes from the United States of America between the years 2004 and 2020. The countries were hit 202, 336, 430, and 13,072 times respectively (The Bureau of Investigative Journalism, 2020a, 2020b, 2020c, 2020d). As such, one can presume that people coming from a society that is used to drone strikes would have its population react significantly different than the population of a country that has not suffered similar strikes. In fact, "civilians describe feeling severely stressed, depressed, anxious, and being constantly reminded of deaths in prior strikes" (Hijazi et al., 2019, p. 1291) when seeing drones hover for a prolonged period of time, at times resulting in conditions similar to PTSD (Hijazi et al., 2019).

The nature of drones thusly is no longer composed simply of the factors of its creation- the specifications of the drone's capacity such as flight time, fly speed, max payload, and sensor functionalities. Instead, a drone becomes a representation of the interpretation of the local constituents, whose interpretation is based on their shared experiences. Perception of the drone thus shifts the reality in which people live accordingly (Benjamin, 2020). In the previous example, it might even be apt to refer to a drone as an 'angel of death'. In such settings, if USAR personnel were to fly a drone, for the locals it would be a symbolic representation of the oppression faced by the Western

[1] The different configuration of drones are explained in more depth in section 3.3. Briefly, fixed-wing drones fly similarly to a plane and have fixed wings. Multi-rotor drones have multiple rotors and flies similarly to a helicopter. Hybrid drones combine fixed-wing and multi-rotor designs, able to fly like a plane and helicopter, akin to a Boeing Osprey.

military. Reminding those whom the USAR team is supposed to help of death, destruction, and suffering. It instils fear and a sense of danger and creates distrust; it comes with implications such as military ties. As such, it can be counterproductive for USAR teams to use drones in certain regions. For USAR teams it is vital to establish a level of trust from the community. Creating close bonds with locals enables better teamwork, local cooperation, and integration. Failing to do so can hamper the team. Locals might refuse to be helped by the team or even become hostile toward them (N. Wang, 2020).

Techno-imperialism or techno-colonialism are other concepts that are relevant in this situation. A concept that basically stipulates that the integration of technology into the development and humanitarian sector propagates a system of dependency on imperialistic powers. Even going in so far to claim that further colonization happens under the guise of emergencies (Madianou, 2019). Such interpretations of techno-colonialism are further predicated by Jacobsen (2015), making references to technology being used for experimental purposes in humanitarian contexts on vulnerable populations. It should be noted that Jacobsen (2015) does reference the greater humanitarian sphere. Indicating that the issue of experimentation is not only limited to technology but is strongly present throughout humanitarian history; technology is another form in which this manifests. Also, further aiming to highlight that even when not intentional, there are possible unintentional consequences that arise with the integration of technology.

2.1.1 Social Construction of Technology

It is essential to look at social construction of technology (SCOT), as explained by Bijker (2015), a theory used to analyse technology from a social perspective developed in 1984. The drone strike example earlier is a perspective one would get utilizing the SCOT framework. When technology gets developed, what constitutes said technology is not some predefined natural aspect; instead, it is precisely the dynamic social interpretations and implications thereof that form the identity of the technology. The vast interpretations that can be applied to a given technology are referred to as ‘interpretive flexibility’. ‘Interpretive flexibility’ is seen in the above examples. One view interprets drones in a techno-colonial nature and UAVs as a potential oppressive force.

This can be contrasted to the interpretation used by the technology sector, where drones are defined and seen based on capabilities, size, and form, as seen in sections 3.2 and 3.3.

According to SCOT, research and integration of the technology progress in three phases. Firstly, different groups of people will find specific ways of relating to said technology (technology being referred to as an artefact). A way a group relates to an artefact is called 'interpretive flexibility'. The second stage is when some 'interpretive flexibilities' become more prominent whilst other relations weaken. Eventually, a state of 'closure', also known as 'stabilization', is reached. A point where one 'interpretive flexibility' to the artefact has become established as the de facto relation to said artefact. The last and third phase in the SCOT model would be to analyse the process the technology undertook to reach closure and analyse it with other broader frameworks (Bijker, 2015).

There exists a significant weakness in the closure phase, however, namely pertaining to the presupposition that closure is an end state. This could be problematic as technology is in a constant state of development, as can be seen with recent drone developments drastically changing how UAVs are used. Such developments create new discussions on the artefact's usage and, in doing so, create more 'interpretive flexibilities' to the artefact. While it is possible to apply the SCOT model to a more recent drone innovation, doing so fails to cover the complexities and nuances that are inherent to development. That is to say, while the SCOT model works well when there is a significant innovation, such as when comparing the first iPhone to previous phones. The SCOT model falls short when analysing technology that changes gradually over time because interpretive flexibilities, closure, and stabilizations are not reached in the same fashion.

There are potential possible ways in which the SCOT limitations could be addressed. Humphreys (2005) addressed this by making a distinction between closure and stabilization. Closure is used to refer to the social groups, whereas stabilization is used to refer to the artefact. Not only is that distinction made, but further sub distinctions are also likewise generated. The proposed concept of 'temporary closure' indicates that closure is not a permanently reached state but has the potential to become relevant again depending on contexts, as seen when comparing drone usage in the United States of America to Afghanistan. Stabilization is further divided into three sections, pertaining to uses, well demonstrated by how drones can be used (further explored in section 3.4) in different settings such as for surveillance, drone strikes, or photography; language as showcased with the definition of drones (further explored in section 3.2); and structure, exploring the shapes an artefact can potentially take and be divided or subdivided into (further explored in section 3.3). In this updated SCOT model, developments in an artefact could destabilize 'stabilizations' in use, language, and structure. For example, by using drones for cargo delivery instead of bombing other states alters the 'interpretive flexibility' of the artefact. It becomes possible to change the opinion and discourse on drones by altering the way in which they are used, named, and designed. The question for humanitarians and/or USAR teams becomes, should this discourse be opened to begin with, or should this attempt at rekindling the closure (temporary or otherwise) or (use/language/structure) stabilization be encouraged?

By opening up such dialogue, it is possible to apply Humphreys (2005) updated SCOT framework. The 'use stabilization' of drones has caused drones to become associated with the military and surveillance. Rightfully so, since drones have been used extensively for both purposes. If people associate drones with military and surveillance and a humanitarian team start using drones, it can cause the humanitarian organization to be seen as no longer impartial and too militaristic, and this can have negative consequences for involved stakeholders. The use of drones in other settings and scenarios will reopen the 'use stabilization', causing a potential shift, opening up the closure that once was. At such stages, it becomes pertinent to ask questions such as, '*is this an environment in which the use case shift can be safely and properly be explored*?'. In Afghanistan, the answer would be no, due to the interpretive flexibility of the local population and the likely negative consequences (Hijazi et al., 2019). In the United States of America, where 94% of people approve of using drones for USAR purposes (Sakiyama, Miethe, Lieberman, Heen, & Tuttle, 2017). By changing the language used to refer to drones, the 'language stabilization' element gets addressed. This could cause further distinctions between combat drones and humanitarian drones. Referring to one as a humanitarian drone whilst the other as an unmanned aerial combat vehicle could cause even further distinction between the two.

2.1.2 Talking Past Another

The crux of one of the problems when it comes to the integration of technology into the humanitarian sector (and thusly, drones into international USAR) is that the two sectors fail to properly understand one another. As a result, the people within talk past one another. Humphreys (2005) mentioned the idea of language stabilization and how interpretations of what words mean shape how technology is seen. This is exceptionally well demonstrated by Madianou (2019)- noting the use of the term 'disruption' in the technology sector as a metric to measure how successful a product is. This is followed up by statements such as: "The emphasis on the "level of innovation and disruption" speaks volumes about how the shiny cart of technology is put before actual social and political problems. It is striking that "disruption" is one of the success criteria: how can the Silicon Valley mantra "move fast and break things" be applied to politically sensitive and potentially fragile situations?" (Madianou, 2019, p. 6).

The argument is that since the people humanitarians aim to help are already highly vulnerable, the last thing those people need is disruption. The problem is that Madianou (2019) fails to properly analyse what disruption actually means. A disruption is an innovation that is great enough to completely and utterly change how that field operates (Smith, 2020). At the time of discovery, penicillin was an enormous disruption, forever changing how the medical field operated (Ligon, 2004). Another example of disruption? The internet. It changed forever how people, different sectors, and the world operates. Assume a hypothetical situation in which a near cure-all drug is created that can be produced cheaply (costing less than a bottle of water). It cures malaria, HIV/AIDs, and dengue, as well as many other afflictions. It is safe to use and has nearly no side effects, and only needs to be taken two times over a span of two weeks. This drug would be highly disruptive, as it would drastically change how the medical field would operate, as well as the humanitarian sector. Madianou (2019) argues against the use of this drug under the pretext of the disruption it would cause. This example makes it clear that disruption is not inherently bad if one uses it in the same context as it was intended.

Such misunderstandings are not uncommon, however. Both Madianou (2019) and Jacobsen (2015) denounce the use of experimentation of new technological products on vulnerable populations, failing to understand why or how it is done.

Experimentation on vulnerable people is due to a process called user-centred design (UCD). As is explained by Abras, Maloney-Krichmar, and Preece (2004), one of the core tenants of UCD is, usurpingly, designing with a focus on the user. The goal is to make products that address the needs that the user has and fill existing gaps. To properly execute UCD, a bottom-up approach is required; and for that, the designers need to engage with the actual users of the product. By collecting data, such as background interviews, questionnaires, focus groups, and onsite observations, designers are able to see the needs of the user and design solutions for those needs. Using the same methods, the designer can see how the targeted group interacts with the created designs and how these can be adjusted to better fit the user and address shortcomings that might have been overlooked. It involves testing the product to ensure it properly covers the needs and wants of those it aims to help, including by asking the people what is wanted and needed. One of the reasons UCD goes through this process is to prevent top-down design, resulting in people being given products and being told how to use them and for what. Even if the product does not fulfil a need. Coincidentally, this is reflective of humanitarian development, where a constant focus should be put on integrating the local population more into the design and execution of humanitarian missions. In many ways, the requirements of UCD overlap with the core humanitarian principles as laid out in The Sphere Handbook, namely “humanitarian response is based on communication, participation and feedback”, as well as “Complaints are welcomed and addressed” (Sphere Association, 2018, p. 50).

Up to this point, this thesis might seem rather critical of technological criticisms. This is because the material challenged up to this point was mainly consisting of arguments in which the analysed criticism failed to take account of the nuances of the field it was criticising; highlighting the technology/social science gap the thesis aims to bridge. That does not mean that the scepticism provided against technology is without warrant, though. Madianou (2019) explores the problematic nature of tech giants and the impact that these organizations can have, worries that are well-founded. Jacobsen (2015), whilst being critical of technology, does raise significant concerns about unintended consequences echoed by authors such as Sandvik, Gabrielsen Jumbert, Karlsrud, and Kaufmann (2014).

A shortcoming in much literature critical of technology in the humanitarian sector is that technology gets analysed as an optional addendum. It analyses the humanitarian sector and then analyses the technology and showcases the issues that arise. The question becomes, ‘then what?’. Problems and issues are identified almost as the end goal. But research should be done to address the issues that are raised. This thesis aims to do just that, address the issues that arise from integrating drones into USAR. To highlight the importance of finding solutions where possible. In order to do this, there needs to be a shift of disposition towards technology in the humanitarian sector.

2.1.3 The Importance of Disposition of the Humanitarian Sector Towards Technology

There are various stakeholders involved in any USAR mission, such as the USAR team, local and international governments, institutions, those affected by a crisis, and those onlooking from afar. While different considerations need to be taken for each of the partiers, stakeholders should not be seen as separate, independent, non-associated entities. Instead, different stakeholders are a complex interwoven web, with each party impacting the other to some degree. Likewise, humanitarian work is inherently intersectoral, connecting various sectors together– international law, geopolitics, sociology, anthropology, psychology, medicine, management, governance, and ethics, to name some prominent examples. A humanitarian needs to carefully balance the impact and interplay it has with relevant stakeholders and sectors. In return, humanitarian organizations play a vital role during any humanitarian crisis and are, to a large part, able to shape the direction of the humanitarian field.

The humanitarians’ disposition towards other stakeholders and sectors thusly becomes an integral part of the functioning of the humanitarian field. In recent years this has manifested with a focus on the Triple Nexus, looking at the intersectionality between the humanitarian field, the development sector, and peace (Howe, 2019). There is a shift from seeing the three elements within the triple nexus as separate to more interconnected. Humanitarians changing their disposition towards the triple nexus, seeing it as three interconnected elements, resulted in a likewise shift in disposition in the entire humanitarian field.

Relating this back to drones in USAR and technology in the humanitarian field as a whole, with new technology comes new problems. Problems that need to be addressed, one way or another. Several authors point in the right direction, taking the initiative regarding technology. Hunt et al. (2016) conclude that technology raises new ethical questions that need to be answered and that simply because the technology exists does not mean it should be implemented recklessly. Also, referencing that there are several initiatives that address such concerns, such as the Humanitarian UAV Code of Conduct, which is also referenced further on in this thesis (Hunt et al., 2016; UAViators, 2022). Jacobsen and Fast (2019, p. 13) state, "a research agenda on this topic should include additional and detailed explorations of the ways that aid agencies use technologies, the foreseeable and unintended consequences (such as requests for data) of these uses, and how agencies have attempted to address some of these issues." Likewise, Sandvik et al. (2014) note the risk associated with careless integration of technology and the potential consequences thereof, concluding with "we invite the scholarly community and those who implement, develop and invest in humanitarian technologies to carefully evaluate the dynamics that those technologies engender" (Sandvik et al., 2014, p. 242).

This paper argues that there is a technological permanence prevailing through society, the implication being that regardless of what humanitarians wish of technology, it will only become more permeated throughout both society and the humanitarian sector. That said, it can be difficult to predict what technology will coevolve and what will die out. In the context of drones, it is possible that funding diminishes, and drones get phased out in much the same way cassettes have been. Regardless, keeping up with technology has been seen as pivotal for decades to ensure that an organization can grow (Tushman & Anderson, 1986). And if it will not be drones that catch on, it will only be a matter of time before another technology does.

While it might not be possible to predict what technology makes it big, it is imperative to ensure that the humanitarian field stays up to date with technology. As such, a proactive approach is needed, stepping away from purely reactive measures and proactively taking steps to mitigate possible future and unfrozen dangers whilst also making space to embrace the benefits the technology can provide. Often technological developments happen at rates at which other sectors are not able to keep up. This is often seen in regulation, where technology develops at a pace that prevents proper regulation withholding the potential dangers of technology, often resulting in either no regulation taking place or poorly executed legislation (Fenwick, Kaal, & Vermeulen, 2018). The proposed solution for this, similarly to what Fenwick et al. (2018, p. 153) proposed, a “more proactive, dynamic and responsive” approach.

There is a paradigm shift that needs to happen from ‘should we integrate more technology into the humanitarian sphere?’ to ‘technology is here to stay, and it will keep developing. How can it be ensured that the technology used in the humanitarian sector benefits the various stakeholders, remains ethical and safe, and helps accomplish the various mandates of organizations as much as possible?’ To do this, while extensive critique is needed, it needs to be a critique that understands the technical nuances of what is being critiqued. To do this requires professionals and academics with a background in both technology and social sciences.

2.1.4 The Techno-Social Scientist

One element this thesis proposes as an approach to the problem of integrating technology into the humanitarian sector, and likewise drones into USAR, is to put a focus on what is aptly named the techno-social scientist. A techno-social scientist is someone with a background in both technology and the social sciences and has skillsets that are ideal for bridging the gap between technology and the social sciences field.

To further explore the concept of a techno-social scientist, it is essential to understand different types of professionals. Oerther and Glasgow (2021) reference two types of professionals ‘I’ and ‘T’. ‘I’ professionals are people who are fully dedicated to their profession, and their knowledge reflects that. Someone whose professional knowledge base mainly consists of one discipline, for example, case law in a specific country. ‘T’ shaped professionals are professionals who have a base in various disciplines and then specialize more in one. This is more common among humanitarians, who need an understanding of international law, public health, anthropology, management, and world politics (Heintze, Thielbörger, & Network on Humanitarian Action, 2018) and could then specialize in a specific direction, such as by dedicating themselves to more towards public health. A humanitarian working in public health, however, does still need the familiarity of the other mentioned fields to be notable.

Oerther and Glasgow (2021) propose an additional type of professional, namely the ‘V’ shaped. The ‘V’ professional is created by taking two ‘I’ shapes and directing those to the same goal. In their paper, nursing and engineering are used, two disciplines that combined to make a ‘V’ shaped nurse+engineer professional. In the presented paper, nurse+engineer professionals are seen as a solution to “Two of the greatest challenges for nurses […]: “(a) the integration of new technologies into practice; and (b) managing the human technology interface” (Huston, 2013, table 3)” (Oerther & Glasgow, 2021, p. 4). In another paper (Oerther, 2021) presents humanitarian technologists and proposes it as another ‘V’ shape professional.

The issue with the proposed ‘V’ shape professional is that it is too narrow to address the nuances of humanitarian technologists and the broader techno-social scientists. While it would hold up for some positions, for example, a USAR drone operator trained in both USAR techniques and drone operation could potentially be considered a ‘V’ shape professional. There are not many professionals with those skillsets; “There appeared to be few individuals operational in the response who were equally conversant in both UAV operation and in the disaster response system.” (Greenwood et al., 2020, p. 26). Conversely, it could well be argued that someone flying for a USAR team needs familiarity with national and international law, drone operation and upkeep, and international search and rescue standards and procedures.

If not the drone operator, there is quite a chance that an organization needs someone versed with both extensive general knowledge related to various technology-based disciplines and, likewise, extensive general knowledge of the humanitarian sector. A humanitarian technologist would be a ‘T’ shaped professional in two fields. From the technologist’s side, understanding of various types of technology such as drones, information technology, remote sensing, and data security. On the humanitarian side, the professional would need to know about world politics, international law, anthropology, and management, and then specialize in the field of integrating technology. This professional would then be required to link their broader knowledge in both fields together. The specialization can then become the exporting of the various types of technology and the relevant knowledge of the technology to the different fields within the social sciences.

As such, this paper proposes that for techno-social scientists, a two-letter classification for types of professionals is introduced. The first letter refers to the technology part and the second letter to the social scientist part. This enables the creation of 'II' professionals, those who are the same as 'V' professionals and are specialised in one technology and one social science discipline and focus on their intersectionality. 'TI' professionals are 'T' shaped in technology, with a broad focus on technology disciplines, and are highly specialized in a social science field. 'IT' professionals are 'I' shaped in technology and 'T' shaped in social sciences. Lastly, 'TT' professionals are those who are 'T' shaped in both the technology and social science element, able to focus on various technologies and how those interlink with various elements in the social sciences side.

Different situations call for different types of professionals. A firm that wants to investigate how different technologies can be used by psychologists would want a 'TI' professional, someone with an extensive background in various technologies and a focus on psychology. Conversely, a thinktank wanting to analyse the possibilities blockchain will have on various social science fields would want an 'IT' professional, heavily involved in blockchain and aware of various social science fields. A humanitarian organization that wants to explore options for how more technology can be integrated into various of their humanitarian operations would want to utilize a 'TT' professional, aware of various technologies and able to navigate the multidisciplinary nature of the humanitarian operations.

While it is possible to question the requirement of having either an 'I' or 'T' professional skillet in both technology and the social science sector when wanting to bridge the two fields, this paper believes it is imperative. This is due to the different approaches and frameworks used in the technology and social science sectors, and one needs to be aware of both to properly integrate and consider each side. Without an understanding of how each sector works, one becomes highly prone to misunderstanding and misattributing different elements of the sector one lacks experience with. As was illustrated in section 2.1.2, which showcased how UCD shared several core tenants of humanitarian work and how disruption in vulnerable settings is potentially a good thing.

According to this framework, this paper is leaning towards an 'IT' focus, looking at drones and relating them to various social science fields. Having discussed the social implications of drones, the following sections will explore drones from legal, ethical, and electrical perspectives, then do a deep dive into the drone technology itself. Both the 'I' and ‘T’ elements of the paper are related to USAR as a whole and will be used to provide recommendations on drone integration into USAR and the greater humanitarian sector.

2.2 Legislation

The first element to be analysed and showcasing the ‘IT’ nature of integrating drones into USAR is the legal framework in which drones operate. Legislation in place pertaining to drone usage can have drastic ramifications on the usability of the technology. Similarly, how cars might have a top speed higher than the speed limit, the top speed of a car becomes irrelevant if one wants to work within the established legal paradigm.

There are numerous ways in which such legislation can be interpreted. As SCOT illustrated, ‘interpretive flexibilities’ are, in large, shaped by peoples’ experiences with the technology in question (Bijker, 2015). Legislation prescriptive to a specific technology can determine how said technology may or may not be used in various settings and contexts. Consequently, it impacts how people interpret the technology and, thusly, what the technology is. Similarly, legislation can be seen as a force that counters the techno-colonial nature by imposing restrictions on the appropriate applications of the technology, preventing misuse. Conversely, it can be argued that legislation can be utilized to push for a colonial nature, such as by passing laws that force organizations to share data with governments (Madianou, 2019). Legislation for new technology needs to find the right balance between punitive and flexible. In the case of drones, legislation errs on the side of caution (Ravich, 2016). Avoiding the possibility of injuring people, protecting peoples’ privacy, and preventing drones from interfering with the day-to-day operation of society- such as prohibiting drone flight close to airports and preventing interference with aeroplanes.

While it is possible to apply various interpretations for analysing legal frameworks, it is likewise essential to understand the consequences legislation can have on drone usage in USAR. Existing legal frameworks can create a severe bottleneck for drone usability by establishing constraints and prerequisites for their usage. While different countries stipulate different requirements for drone usage, the question arises as to what standard USAR teams would be held. Given that the various USAR guides published by the International Search and Rescue Advisory Group (INSARAG) strongly encourage adhering to local standards and laws and to abide by instructions provided by local authorities (International Search and Rescue Advisory Group, 2020a, 2020b, 2020c, 2020d, 2020e) unless these authorities state otherwise, civil use of drones can be considered a metric for the regulation to which USAR teams must comply.

The legislative analysis will be divided into two main categories. The first of which analyses the use of drones itself, examining legal issues that arise and possible solutions to them. The second category (section 2.3) will delve into legal and ethical limitations arising based on the data drones collect and provide insight into how that can be resolved.

2.2.1 Limitations Regarding Drone Operations

Civil legislation is an essential factor to prevent drones from being abused. By creating a legal framework stipulating how drones can be used in a manner to not overstep the rights to safety, security, and privacy of other people. Further to prevent disturbances to their surroundings. To understand why drones are not adopted further in USAR, one needs to understand the legal paradigm in which drones operate. Notably, the distinction between theoretical operational limits and practical operational limits. A drone that is not allowed to go higher than 100 meters above ground level will be limited by that elevation, presuming the USAR team adheres to local laws. 100 meters becomes the max flight altitude regardless of how high the drone can theoretically go.

In order to further understand the impacts such legislation has on drones in USAR, different aspects of such laws are analysed. While it is not possible to analyse every country and their requirements within the scope of this thesis, it is possible to look at overarching patterns. From these patterns, it becomes possible to glean the insight and promote a separate set of guidelines to which USAR operates. Similarly to ambulances, which need not adhere to typical traffic laws. According to Ravich (2016), most legal frameworks for UAVs have been made within recent years and tend to be critical of drone usage. With UAV legislation being new and the laws in place being strict, results in using drones for USAR purposes becoming more challenging.

2.2.1.1 Line of Sight

A requirement that is often established for flying drones is that drones must remain within line of sight of the operator (Agência Nacional de Aviação Civil, 2017; Ghana Civil Aviation Authority, 2018; National Civil Aviation Agency - Brazil, 2017; The Civil Aviation Authority of Thailand, 2017). In some countries, a visual line of sight includes a maximum operating distance. In Singapore, it is within 400 meters of the pilot (Civil Aviation Authority of Singapore, 2019).

Requiring having the drone within the operator's vision drastically limits the effectiveness of the drone for multiple reasons. Flying a drone around a building would likewise require the operator to move to dangerous or difficult to reach areas. Further, when wanting to navigate a complex destroyed urban environment, it is not always possible to keep the drone within line of sight. In such cases, using the onboard camera would work better. If a drone is needed to deliver supplies, flying the drone between or over buildings would cause a line of sight to be lost. Instead, the operator will need to go with the drone, defeating the purpose of using the drone to begin with.

2.2.1.2 Height Limits

Often limitations are placed on how high the drone may be flown. The exact height differs per country but is usually 150 meters or less (above ground level). This can cause problems depending on the use case. Attempting to do damage assessments on large buildings or structures can become a difficulty. Specific sensors require a certain flight height. Lidar setups require an altitude between 50 and 100 meters (heliguy, 2021), while for mapping, a flight height of 90 and 120 meters is recommended (DroneDeploy, 2017). While for many countries, flight height limit will not cause too many issues, exceptions do exist. In Thailand, the flight limit is 90 meters (The Civil Aviation Authority of Thailand, 2017), which could cause problems for lidar and mapping. Singapore does not allow drone flight above 60 meters (Civil Aviation Authority of Singapore, 2019).

2.2.1.3 Proximity to Others

Some states have legislation in place prohibiting drones from being flown close to other people. Thailand prohibits drone flight within 30 meters (horizontally) next "to any person, vehicle, construction or buildings" (The Civil Aviation Authority of Thailand, 2017). Brazil has a similar 30-meter requirement for people and buildings (Departamento de Controle do Espaço Aéreo, 2020; National Civil Aviation Agency - Brazil, 2017). While not all countries have such strict requirements, it is relatively common to find laws preventing drone flight above populous areas or crowds of people. Both terms often fail to provide specifics of when a populous area is considered populous enough or when a crowd is crowded enough. Worded vaguely enough to be interpretable in ways that are problematic for accomplishing USAR purposes.

2.2.1.4 No-fly zones and Airports

No-fly zones are regions in which flying drones (or other aircraft) is prohibited altogether and can hamper UAV usage significantly. A great example of this is Indonesia, where drone flight is prohibited within a 15-kilometre radius of any airport (Peraturan Menteri Perhubungan Republik Indonesia; uavcoach.com, 2021c). Of the 12 cities in Indonesia with a population of 1,000,000 million or more[2], all of them except Medan (the third largest) have a majority of the city within an airport's 15-kilometre bounds[3].

In India, no-fly zones include (but are not limited to) 25 kilometres from international borders, within 3 kilometres of military facilities, or close to certain government buildings (Office of the Director General of Civil Aviation, 2018).

2.2.1.5 Registration, insurance, licences

Some nations have established laws that require drones to be locally registered. The nuances of the registration, the lengths and the difficulty of receiving a registration likewise differ based on country. For USAR, this means that drones might not be operable shortly after arriving in a country. Since USAR is usually required during unexpected times, drones are likely not registered prior to arrival. And if the required drones are not registered when the drones are needed, they cannot be used. By the time the drone is registered, it will not contribute much more to the mission.

[2] Cities in Indonesia with a population of 1,000,000 or greater in order from most to least: Jakarta, Surabaya, Medan, Bandung, Bekasi, Palembang, Tangerang, Makassar, South Tangerang, Samarang, Depok, and Batam (worldpopulationreview.com, 2022).

[3] Distance calculated using Google Earth's distance measuring tool. Distance taken from airport perimeter.

The eligibility to register can come with prerequisites, further complicating the process. In Ghana, third party liability insurance is required to receive the registration (Ghana Civil Aviation Authority, 2018). For a USAR usage, it likely means that for the registration approval process, the Ghana Civil Aviation Authority will need to get into contact with the issuer of the insurance and confirm that the insurance works internationally. Other places require the operator to possess specific medical certifications (Agência Nacional de Aviação Civil, 2017; uavcoach.com, 2021a). Depending on the drone used and the country in which it is flown, under certain conditions, the pilot must have a (drone) pilot licence.

It is also possible that drone flights must be approved before the flight. In Cameroon, all drone flights must be approved at least 30 days before take-off (uavcoach.com, 2021b). In such cases where drone flight needs to be approved a significant time period before flight, most often the payoff will not be worth the investment needed for USAR purposes. In other situations, drone operators need to be in contact with air traffic control (Ghana Civil Aviation Authority, 2018), adding another hurdle to drone adaptation as the operator needs the additional skills and background.

2.2.1.6 Weight

In some states, weight is an essential element regarding drone usage. Drones will be sorted into categories based on weight and will have different regulations based on what category the drone is in. Often there exist upper limits on how much a drone may weigh, making the flying of drones that surpass that threshold illegal unless special permission is granted– adding further complications for USAR personnel. In cases where multiple drones are used, it is possible that different protocols to be learned. It is also possible that the drone falls within a qualification that adds extensive hurdles to its usage, causing at least one of the other complications laid out in this section to apply to using that specific drone as well.

2.2.1.7 Solutions to Legislative Issues

There is no simple solution to the legislation issue regarding drones. Legislation, rightfully so, is there to stay. While this thesis is not promoting a lawless adaptation of drones, it does propose a system in which USAR drones operate on a different basis than what gets laid out by civil law. The Humanitarian UAV Code of Conduct, for example, stipulates to adhere to local laws. When that is not possible (such as a lack of laws pertaining to drone usage), it recommends using the International Civil Aviation Organization (ICAO) framework as a guideline with the permission of the local government (International Civil Aviation Organization, 2012; UAViators, 2022). The limitation with ICAO as a framework is that it is too broad and generalized for drone usage, in general, to be effectively applied for USAR purposes. As such, if such a USAR drone framework gets created, it might be appropriate to defer to that instead.

This thesis proposes a framework be explicitly developed stipulating how USAR teams may use drones during deployment. Similarly to how emergency services in certain situations are allowed to work under a different set of guidelines than the public, this thesis proposes a likewise exception. Such a framework would need to address the constraints examined in this section, such as maximum flight altitude, no-fly zones, licenses, and proximity to flying to others and provide a baseline to international USAR teams to adhere to. This framework is further explored in section 4.1.

For local USAR teams getting an exception to operate using different guidelines is also a possibility. Since constraints are local and different per country, a locally based approach can be highly beneficial. Countries that deal with disasters tend to have a branch of their government and/or military dedicated to disaster response. USAR teams are often either a division within existing government infrastructure or closely work in tandem with the existing authorities. If the USAR team falls under the country's military/defence umbrella, it might not be beholden to civil aviation regulations but to military regulations instead.

In instances when the USAR team is a different organization, perhaps even a local NGO, the organization will be able to request clearance for its operations prior to a disaster so that in cases of emergency, it can provide the best services possible. Even when such permission is not granted, organisations within a country will be able to deduce how beneficial drones are when working according to the local legislation. If drones are judged to be an asset, it becomes possible to train to the legal guidelines and adhere to them when an emergency happens. Such a local team will have local expertise that international USAR teams would lack.

2.3 Privacy, GDPR, and Data Management

Another important aspect of drone usage has to do with data usage and privacy. Depending on how the drone gets used, specific data could be collected on individuals and/or the individual's property. On both legal and ethical grounds, there are various issues that come into play in such scenarios (Finn & Donovan, 2016; Madianou, 2019). While section 2.2 showcased the importance of having a framework that is dedicated to flying a drone, this section will showcase the importance of having a framework dedicated to data management, storage, sharing, and protection. The data drones are able to collect is extensive and results in a plethora of legal and ethical questions. Cameras being one of the most frequented sensors used with drones is a facet in this discussion, as in many situations, drones will use their camera to enable the operator to see what is happening but also record what is being shown.

2.3.1 Hypothetical Scenario to Demonstrate Data Collection Problems

The issue that arises is that collected data can have implications on the people whom it features, as well as others surrounding them. Even data that does not contain people can have implications for society. As such, steps must be taken that all data is handled responsibly and safely in the best interest of the local population (International Committee of the Red Cross, 2020). Take the following hypothetical scenario where drones were used during search and rescue missions. Extensive footage was collected, showcasing damage done to infrastructure and buildings. Further, there was some footage showing some of the people affected by the disaster, including footage recorded by drones during USAR missions showing the faces of those partially stuck under rubble, resulting in them being identifiable. If a family member or friend were to watch the video, the person could be identified.

If the footage is shared with other organizations and local or international governments, the organization is spreading another person's data (European Union, 2016; International Committee of the Red Cross, 2020). There are numerous ways in which these recordings can be used. An organization might want to do a donation drive and create a video of the disaster and its after-effects. Suppose that most of the footage in the developed video is what was gathered by the drone and includes the people affected who are personally identifiable. The video goes viral, and donations come pouring in. Meanwhile, another video was made from the drone footage for organizations to showcase how effective drones can be in USAR. This second video gets used to propose broader drone adoption in other organizations. The video is a hit, and other organizations start investing in drones.

In this hypothetical scenario, both videos did great but also came with complications. One of the videos went viral, and as a result, the faces used in the video ended up becoming closely associated with the disaster worldwide. How does that affect the people featured once life gets a semblance of normalcy again? Family, friends, and colleagues might have seen that. A state in which most people would not want others to see them can have an impact on them. Namely, how does this affect the person's dignity? To have their suffering being used as the face of a disaster. Did the people in the video consent to having their image be used for these purposes? To what extent do the people filmed need to give consent? What are the local laws pertaining to consent? Likewise, the question of where the data gets stored is also critical. Determining where the data is stored, often also has an impact on who has access to it. The recordings are likely stored on the drone and can be transferred to a computer. Who has access to that computer? Does the data get shared with other organizations? What method is used to share data safely? Is it saved on any online servers? If so, who controls the servers; is it a third party or the organization itself? Are there systems in place that ensure third parties do not have access to all this data? Is the data being sent to a country where the host country has regulations against storing (personally identifiable) data? Are there regulations pertaining to data storage in the country? Is it possible that local storage methods are seized by the local government, and/or is there a demand that the data be shared? Does the government have the people's interests at heart when the data is requested? How vulnerable are the servers to cyberattacks? Those are all questions that need to be taken into consideration when dealing with the storage of the collected data.

Once storage has been resolved, the question becomes, who owns the data? The various stakeholders involved in this make this more complicated. Do the people who are closely featured in it and have their personal data included own (part of) it? Does the USAR team who collected the data also own it? Does the government own the data? How long does the data remain stored? Do the USAR teams delete data after each rescue, after each mission, or is it stored for multiple years?

2.3.2 Solutions to the Data Management Issues

As can be seen, extremely many legal and ethical questions are raised, showcasing the importance of developing a framework that stipulates how data can and cannot be used, managed, stored, processed, and shared for USAR purposes. While being unable to answer all the above questions, two elements will be explored. First, the legal and ethical considerations regarding consent are explored. Secondly, an investigation of data minimization is taken and the role it could play for USAR.

When dealing with data, the legality and nuances of collecting, processing, storing, and sharing data of people differ per country. As such, the General Data Protection Regulation (GDPR) of the European Union will be used as a legal baseline. The GDPR is used as it is both strict and one of the most impactful privacy regulations to have come into play in recent years, often being more encompassing than other existing privacy regulations (Albrecht, 2016; Zaeem & Barber, 2020). As such, using the GDPR as a reference point seems appropriate.

2.3.2.1 Exploring the Legal and Ethical Considerations of Consent Regarding Data in USAR

One of the first issues that need to be addressed is consent. Can a USAR team collect data on people without their consent? To answer this, it must first be established why USAR teams collect the data. According to the GDPR, the reason why one collects and uses data is one of the determinants of when consent is needed. If a USAR team is conducting an operation, the data collected on the scene can be integral to the mission's success. Being able to provide teams with valuable information on possible dangers, aspects to consider, locations of debris, and potentially spotting people. In such situations, the data collected is needed to ensure the safety of the USAR team, as well as the people the team is helping.

While the GDPR has severely increased the right and control individuals have over their own data, it is not immutable. Paragraph 46 of the preface of the GDPR states: "The processing of personal data should also be regarded to be lawful where it is necessary to protect an interest which is essential for the life of the data subject or that of another natural person. […] Some types of processing may serve both important grounds of public interest and the vital interests of the data subject as for instance when processing is necessary for humanitarian purposes, […] particular in situations of natural and man-made disasters.”(European Union, 2016, pp. 8-9). From this, it can be taken that consent is not needed from a legal perspective for the USAR team to conduct their operations.

While something might be legal, that does not imply that it is ethical. UAViators (2022) refers to data collection in the Humanitarian UAV Code of Conduct. “When consent cannot be obtained, affected populations must be informed […] In such circumstances, data may be processed only if is it established that the data is necessary to protect the life, health, integrity, and security of the subject or other persons and where the benefits outweigh the risks.” (UAViators, 2022, p. 18) It also mentions the United Nations Office for the Coordination of Humanitarian Affairs and the International Committee of the Red Cross (ICRC) having data regulations that should be adhered to. The United Nations Office for the Coordination of Humanitarian Affairs (2021) does not provide extensive information on consent but does stipulate that it needs to adhere to local laws and that the default method of handling data should adhere to the required data and safety protocols of the country. Conversely, the International Committee of the Red Cross (2020) goes into extensive depth as to what is needed in order to get valid consent[4]. Further, Chapter 3.3 Vital Interest states, “When Consent cannot be validly obtained, Personal Data may still be processed if the Humanitarian Organization establishes that this is in the vital interest of the Data Subject or of another person, i.e. where data Processing is necessary in order to protect an interest which is essential for the Data Subject’s life, integrity, health, dignity, or security or that of another person.” (International Committee of the Red Cross, 2020, p. 66). It also provides other reasons such as important grounds of public interest, legitimate interest, performance of a contract, and compliance with a legal obligation.

[4] According to chapter ‘3.2 Consent’ there are certain elements that come into play when discussing consent, namely the topics of consent include: unambiguity, timing, validity, vulnerability, children, informed, documented, and withholding/withdrawing consent.

As such, it can be presumed that using the drone to locate people as well as help in USAR operations can be done without the consent of those involved. It could be argued that the earlier hypothetical example, which used peoples' data in videos without their consent, is justified as well. The resultant funding thereof could enable many other people to be saved. This could be an argument used to open the debate of whether consent would be needed for such usage. While an interesting discussion, it is outside the scope of this thesis.

2.3.2.2 The Importance of Data Minimization in USAR

One important consideration is the idea of data minimization. Only the minimum required data is collected, stored, and processed. There is both legal and ethical president for this. Article 25, paragraph 2 of the GDPR states: "The controller shall implement appropriate technical and organisational measures for ensuring that, by default, only personal data which are necessary for each specific purpose of the processing are processed. That obligation applies to the amount of personal data collected, the extent of their processing, the period of their storage and their accessibility. In particular, such measures shall ensure that by default personal data are not made accessible without the individual's intervention to an indefinite number of natural persons." (European Union, 2016, p. 48) A similar clause exists in the ICRC's handbook. "Data minimization seeks to ensure that only the minimum amount of Personal Data are processed to achieve the objective and purposes for which the data were collected. Data minimization requires limiting Personal Data Processing to the minimum amount and extent necessary. Personal Data should be deleted when they are no longer necessary for the purposes of the initial collection or for compatible Further Processing. Data must also be deleted when Data Subjects have withdrawn their Consent for Processing [...]" (International Committee of the Red Cross, 2020, p. 38).

It is shown that the default should thusly be only collect what is necessary. It would be beneficial to have standard procedures as to what drone footage can and cannot be used for, how it must be stored, sharing regulations and other complexities. This is addressed further in section 4.1.

2.4 Electrical Limitations

Electricity is one of the main issues when it comes to drone technology that needs to be considered. The issue electricity presents are two-fold, referring both to the power required to operate the drone and the electricity required to recharge them. The ramifications of electricity and drones are less integral regarding the development of a framework, which was more central in sections 2.2 and 2.3, but can play a crucial role in further understanding the lack of adoption of drones into the USAR sector. Additionally, showcasing how further developments in the technology can drastically alter the usability as well as the perception of usability of the technology.

2.4.1 Flight Time

Flight time is an issue that limits the use of drones significantly. The shorter the flight time, the shorter the drone can stay in the air, and the more limited the UAV becomes. The impact flight time can also be impacted by time lost because of factors such as battery switches, take off, and landing procedures. Presume the situation in which conducting a damage assessment of a building would take 100 minutes of inspecting with a drone. If take-off, landing, and battery switching each took 1 minute, a drone with a flight time of 7.5 minutes requires 157 minutes to complete the inspection. The drone would need to take off and land 19 times. A drone with a flight time of 60 minutes would finish the mission in 106 minutes, taking off and landing only twice. For a mission the same length, but take-off, landing, and battery switching take 2 minutes each, a drone with a maximum flight time of 7.5 minutes would take 274 minutes to complete the mission, having to take-off and land 29 times. A drone with a flight time of 60 minutes would take around 112 minutes, with 2 take-offs and landings.

The impacts of a drone’s maximum flight time (differentiated with colours) and the amount of time required to spend taking-off, landing, and changing batteries (differentiated between graphs) are illustrated in the below graphs in Figure 1. The x-axis showcases the amount of time spent operating the drone (input), and the y-axis indicates the amount of time spent on completing the mission correlating to the provided input. Several elements from this graph are noteworthy. Firstly, the most notable jump in performance is when the drone’s maximum flight time doubles from

7.5 minutes to 15 minutes. While subsequent doubling in maximum flight times does increase performance, it does so at a decreasing rate.

How often a drone has to take-off, land, and change batteries is essential because the simplicity regarding take-off and landing differs per drone, situation, and even country. Some drones have more accessible batteries than others. The more complicated, the more time is required to change them. Depending on the surroundings of the drone, to ensure safe landing and take-off, more time is needed to spend on that. In some countries, government clearance or communication with air traffic control is required for every take-off (discussed further in section 2.2.1.5)(Ghana Civil Aviation Authority, 2018). In such cases, the time taken to get the drone in the air combined with a drone’s maximum flight time can really hamper the efficacy of drone usage.

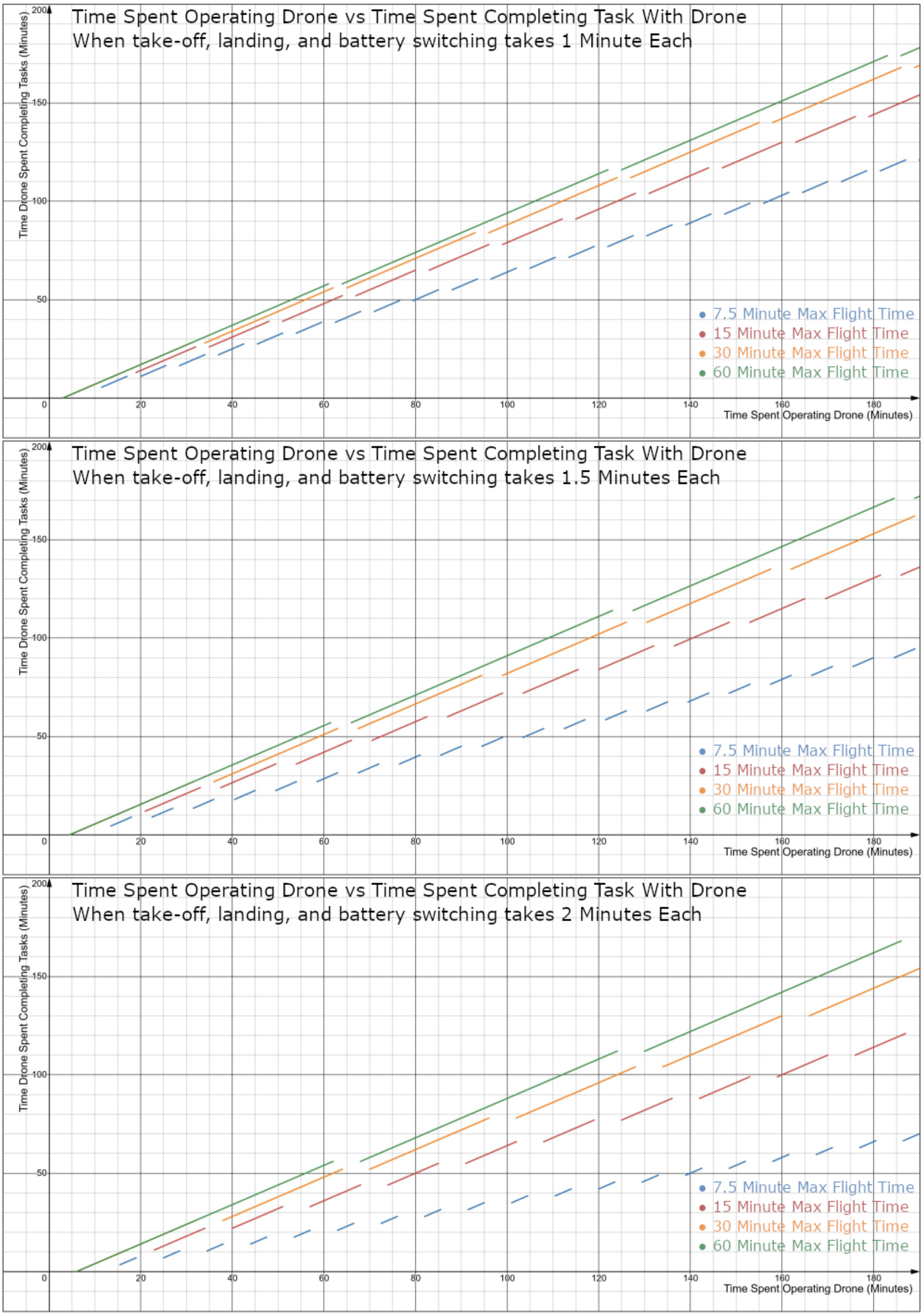

Figure 1: Graphs illustrating the amount of time input spent on operating a drone (x-axis) and the amount of time output spent on completing a task using the drone (y-axis). Output time depends on factors such as the amount of time taken to take-off, land, and change the batteries of the drone (first graph 1 minute each, second graph 1.5 minutes each, third graph 2 minutes each) while taking account of different max flight time of drones (7.5 minute max flight time in blue, 15 minute max flight time in red, 30 minute max flight time in orange, and 60 minute max flight time in green)

2.4.1.1 *Solutions to Flight Time*

Ensuring the most suitable drone is used for the job is an integral part of countering flight time limitations. Fixed-wing drones tend to be more energy-efficient than multi-rotor drones. Fixed-wing drones do generally require more space (the exact amount varies wildly between different fixed-wing drones) than multi-rotor drones (types of drones discussed further in section 3.3). While more efficient, fixed-wing drones lack the vertical take-off and landing[5] (VTOL), hovering, and precision control to navigate complex spaces that multi-rotor drones have. If these are not essential and there is space to take off with a fixed-wing drone, a fixed-wing drone might provide to be more beneficial. When mapping more extensive areas, fixed-wing drones provide longer flight times. In situations where VTOL, hovering, and/precision control are necessary, hybrid or multi-rotor drones will be required. It is possible to exchange batteries, but that also has limitations.

While not an immediate solution nor particularly useful to a USAR team that is deployed, drone technology does keep evolving, including flight times. It should be noted, however, that in recent years flight times have significantly increased. Currently, drones tend to lean closer to the 30 minutes and 60 minutes of the graph (DJI, n.d.-a, n.d.-b, n.d.-c; Swiss Foundation of Mine Action & CartONG, 2016a). This indicates that even if the current max flight time is doubled, it will result in marginal improvements. This indicates that one of the potential reasons drones were not more commonly adopted is due to flight time, until recently, being a significant bottleneck. Current improvements would thus indicate that in the coming years' drone adoption might look more appealing. This is especially true because other factors also improve over time. With the improvement of sensor qualities and drone speed, missions might be completed quicker, even if the drone's maximum flight time does not improve.

2.4.2 Rechargeability

When drones run out of electricity, the drone's battery will need to be recharged. Recharging a battery requires access to electricity which can be difficult after a disaster, significantly if the infrastructure that generates and/or delivers electricity around the

[5] VTOL, or Vertical take-off and landing is when an aircraft can take-off and land like a helicopter or a rocket; directly up and down.

country gets damaged. The impact that any disaster will have on a country's power grid is highly variable. Depending on the type, location, and severity of the disaster and the resilience of established infrastructure, the severity of the impact of the disaster can be great or minor.

According to Gargani (2022), when two major hurricanes hit the Caribbean islands of Saint-Martin, Saint-Barthelemy, and Puerto Rico in 2017, their energy production was significantly affected. Comparing the energy production pre-hurricanes and approximately three weeks post-hurricanes, electricity production had only recovered to about 33% of its original. Meanwhile, Araneda, Rudnick, Mocarquer, and Miquel (2010) examined Chile in 2010 after the country experienced an earthquake (8.8 on the scale of Richter) and tsunamis. Before the disaster, the country supplied around 120,000MWh of electricity, which was reduced to around 40,000MWh when the disaster struck. Despite the brutal hit, 4 days later Chile was supplying 60,000MWh of electricity and within the end of the week, reaching 100,000MWh. It did have issues in distribution, with some areas being without power for several days or weeks.

For USAR, further complications can arrive depending on what neighbourhood the team is operating in. While electricity is more widespread in urban areas than in rural regions, in urban settings, slums and poorer neighbourhoods often will not have the same level of access to electricity (Singh, Wang, Mendoza, & Ackom, 2015).

For drone usage in USAR, access to electricity the first couple of days after a disaster is the most important, as the first couple of days are most vital during rescue operations. It is also the time in which electricity is the most scarce. If the USAR team does not have access to electricity, drones cannot be recharged. While the USAR team would have brought charged drones, being unable to recharge them would prevent them from being used extensively.

2.4.2.1 Solutions to Rechargability

The rechargeability of drones is only a problem when the local power grid is damaged and/or unreliable. As such, a solution only needs to be found in cases where this happens. The most straightforward would be to bring a generator, either fuel-powered or otherwise (such as solar). These could be provided by local sources or be brought in from abroad. Regardless, it is possible to presume that search and rescue teams will have access to electricity (via a generator or otherwise). According to INSARAG, when a USAR team gets deployed, the team should be able to set up a base of operations (International Search and Rescue Advisory Group, 2020b, p. 50). A base of operations requires to have electricity (International Search and Rescue Advisory Group, 2020e)[6]. As such, access to electricity can be presumed to be present.

2.5 Conclusion to Understanding the Complexities of Drones in the USAR Sector

This section has showcased the importance of paradigm when examining what a drone is. The analysis of the concept of what constitutes a drone using various perspectives resulted in a diverse set of interpretations and considerations regarding the technology. Drone technology in the context of USAR was first placed in the broader context of technology in the humanitarian sector. A social constructionist analysis was done to explore the relationship between various stakeholders and technology. Examining these relationships showcased that the interpretation of a social group and their disposition towards technology is of utmost importance. This was linked back to the SCOT model first introduced in the 1980s as explored by Bijker (2015). Using the updated model by Humphreys (2005) enabled the departure of the initial concept of ‘closure’. The updated model provided the framework of ‘temporary closure’ enabling the artefact and its ‘interpretive flexibilities’ to be applied to various settings in which USAR teams operate. The section further explores how different forms of stabilization pertaining to the use, language, and structure of drones can likewise reinvigorate ‘interpretive flexibility’.

The concept of a humanitarian technologist, as proposed by Oerther (2021), was examined. Who described those with the required skillsets as ‘V’ shaped professionals, building on the earlier work of Oerther and Glasgow (2021). Said earlier work introduced the concept of ‘V’ shape professionals as those who are trained in two separate disciplines and work towards the convergence and intersectionality of these two fields. This outlook towards professionals, while useful for specific fields, was identified to lack the ability to cover enough nuance in many situations. The thesis proposed a different system, a method of dual grading using the ‘I’ and ‘T’ shaped

[6] Found in Annex B14: Base of Operations Requirements

professionals. This was done by introducing the term techno-social scientist, someone trained in both the technology sector and the social sciences. Based on one's expertise in both sectors, one is determined to be either an 'II', 'TI', 'IT, or 'TT' professional, with the first letter referring to the technological background and the second letter to the social scientist background. An important distinction as this allowed for further framing of the integration of drones into USAR as an 'IT' problem, focused on the technology but broad regarding various social sciences fields.

The 'IT' distinction is showcased further by an analysis of the legal constraints drones operate under. Numerous states have legislation limiting what is legal regarding drone operations. The specificities are different per state but often include aspects such as maximum flight height, maximum distance from which the operator may control the drone, different weight categorizations that further implicate the limitations on drones, and other legal constraints that must be upheld. It showcased an element that USAR teams must constantly be wary and considerate of, as it is a factor that could, at times, prevent drone usage. Such hurdles must be considered by a USAR team both when attempting to use drones as well considering the integration of drones into the team to begin with. Having to further navigate legal obstacles in an attempt to do their job could dissuade teams entirely from drones. This identified the importance of establishing an international framework or standardization which stipulates how drones can be used for the purposes of USAR, noting how existing frameworks are often too broad and not specific enough for proper application in the required contexts.

This was followed by an ethical and legal analysis that arose due to the use of various sensors on drones. Showcasing that the use of various sensors, especially cameras, creates a new set of problems that a USAR team needs to deal with. Ethical and legal questions arise as the data collected can be personally identifiable, and different states have different regulations regarding the processing, storing, and potential sharing of such data. While any USAR team (and other organizations) has to deal with legal challenges that arise from collected data, drones can further complicate any such processes. The paper deemed it vital that in order to ensure the safety and wellbeing of all stakeholders and the ethical and safe use of data collected from drones, the framework explicitly catering to USAR drones and their operations also includes data management/processing practices.

This section was rounded off by exploring various electrical considerations relevant to drone technology. The battery life limitations of drones have various implications on their usage. USAR teams can expect to have the facilities to charge drones, as USAR teams have access to electricity. Further, while battery life developments of drones in recent years have been noteworthy, due to diminishing returns of investment, even if battery life were to double, the practical impact it would have on USAR teams is surprisingly minor. Other improvements in drones, such as decreased price and increased lift capacity, will likely be more beneficial.

3 Investigating Drones

This section builds a foundation for both the role of international USAR teams and the framework those teams work within. Providing insight into how USAR operates and how drones can potentially be integrated. This is followed up by examining drone technology in depth. First, looking at what drones are from a more technical perspective and investigating the types and classification for drones. This is followed up by looking at various sensors that can be attached to drones. Cameras enable pictures and videos to be taken. Infrared cameras allow the sensing of heat and, when combined with other sensors, enable multispectral imaging. Lidar units provide the ability to recreate accurate 3D models of the surrounding environment.

3.1 Placing Drones in the Context of Urban Search and Rescue

To understand the role drones can have in USAR, it is essential to know what USAR entails. According to the International Search and Rescue Advisory Group (2020a, p. 22), "USAR involves the location, extrication, and initial stabilisation of people trapped in a confined space or under debris due to a sudden-onset large-scale structural collapse such as an earthquake, in a coordinated and standardised fashion. This can occur due to disasters, landslides, accidents, and deliberate actions. The goal of search and rescue operations is to rescue the greatest number of trapped people in the shortest amount of time while minimising the risk to rescuers."

In order to investigate how drones can best be integrated into the USAR framework, the framework needs to be analysed. The first element to understand about USAR is that it consists of several stages and is known as the International USAR Response Cycle. The stages are Preparedness, Mobilisation, Operations, Demobilisation, and Post-Mission[7]. The response cycle is seen in Figure 2.

Preparedness consists of training, research and updating procedures. Mobilisation starts when a country requests aid. It consists of learning about the local context and making sure that the USAR team is permitted to work in the destination country. The operations phase starts on arrival and consists of working with local authorities to

[7] Different countries will have different nuances regarding the procedures of USAR teams, structure, and deployment; for that reason, the international recommended guidelines as proposed by INSARAG will be referenced.

conduct search and rescue operations. Demobilization starts upon request of the local authorities to stop working and involves departure and handing over tasks to local bodies. Post-mission happens after the mission and includes analysing lessons learned and restocking of resources (International Search and Rescue Advisory Group, 2020a, 2020c).

The second aspect to explore are the various tasks and divisions of USAR teams. According to the International Search and Rescue Advisory Group (2020c, p. 14), a USAR team consist of several sub-teams. USAR Team Management is responsible for the entire USAT team guides the various activities through the USAR cycle. USAR Team Search conducts searching operations to find people using various tools and/or canines. USAR Team Rescue conducts the actual rescue operations, such as cutting away debris and extracting victims. USAR Team Medical is responsible for the health of the USAR team, canines, and found victims. Lastly, USAR Team Logistics handles logistics, including the "Base of Operations, communications, border-crossing and transportation." (International Search and Rescue Advisory Group, 2020c, p. 14).

Figure 2: The INSARAG International USAR Response Cycle. Retrieved from (International Search and Rescue Advisory Group, 2020a, p. 23)

Drones are most applicable for usage during the Operations phase when teams are deployed abroad and conducting search and rescue operations. Mapping, damage assessments, and 3D modelling of environments are activities the USAR team can only do when deployed. Albeit, it is also crucial that USAR Teams train with drones during the Preparedness phase. It is likewise essential that drones are maintained and registered. When a USAR team starts the Mobilization phase, it is vital to ensure that drones are permitted in the destination country and that all licenses are recognized by the host government.

As for what USAR Team is best suited for using drones, according to International Search and Rescue Advisory Group (2020e, p. 18), during the operations phase, USAR Team Search is responsible for "[determining] search strategy and reconnaissance." This entails: "[determining] whether the search will be conducted using personnel or listening equipment or other methods such as thermal imaging cameras or drones. […]" This is the only time in which the word 'drone' is mentioned in all the INSARAG guidelines and its annexes at the time of writing. As such, it can be deduced that drones fall under the purview of USAR Team Search. USAR Team Search also does the risk assessments before searching commences, another task drones can assist in. Enabling USAR Team Search to gather data concerning search efforts, such as mapping of sites or recreating 3D digital reconstructions of buildings to help in locating dangers and people.

UASR Team Rescue is responsible for confirming rescue tactics with structural engineers and identifying potential sewer spillages and leaks. For such situations when drones are needed, USAR Team Rescue can work in tandem with USAR Team Search. The two teams already share several responsibilities and work closely together (International Search and Rescue Advisory Group, 2020e).

3.2 What is a Drone?

As discussed in section 2.1.1, using Humphreys (2005) updated SCOT model, various forms of stabilization can be reached. The three forms mentioned are language, structure, and use-cases. Drones will be examined from these perspectives, in that order. Language and structure can be discussed briefly. The use cases and potential use drones provide to USAR are examined by investigating the various sensors that can be added to drones.

The first stabilization to be addressed is language. The term drone is somewhat ambiguous. While section 1.1 provides a brief explanation of what a drone is, this section aims to explore it in more depth. The inherent vagueness of the word ‘drone’ stems from it meaning different things in different contexts. The interpretative flexibility of a drone has an impact on how it is defined by a group. Showcased in section 2.1, in a setting such as Afghanistan, the term drone would have a different connotation than when used by an amateur aerial photographer.

Broadly speaking, the term drone is used to refer to a type of aircraft that is controlled remotely. Miguel Molina and Santamarina Campos (2018, p. 8) note that drones are also referred to by different names, such as “unmanned aerial vehicles (UAV), unmanned aerial system (UAS), unmanned combat aerial vehicle, remotely piloted aircraft (RPA), and remotely piloted aircraft system”. In specific settings, nuances between these synonyms are vital. Well noted by ICAO, the International Civil Aviation Organization (2012). According to the ICAO, a UAS is an aircraft controlled without a pilot on board, and an RPA is an aircraft that is piloted remotely. The distinction is that the former holds true for AI-controlled systems, whilst the latter does not.

It should also be noted that while the term drone is used chiefly for flying vehicles, not all drones possess the ability to fly. Meng, Hirayama, and Oyanagi (2018) conducted a study on an underwater drone, a remote-controlled submarine. While it is essential to note the nuance, this paper will continue to use drone, UAS, UAV, and RPA interchangeably. Further, drones will refer to flying variants of the technology. In situations where more nuance is required, it shall be explicitly stated.

A significant hurdle for humanitarian drones is the ties the term drone has to military contexts. This dissonance is noted by Emery (2016) and showcases that military drones have an impact on the legal and ethical considerations of humanitarian drones. N. Wang (2020) illustrates that such associations between drones and the military (such associations are also interpretive flexibility of drones) can result in humanitarian organizations using drones being less trusted by various stakeholders. Hence it is essential to proliferate the discussion of drones for humanitarian contexts; as Emery (2016) explores, the impact of drones on the humanitarian sector is heavily dependent on who is using the drone and for what purpose. The importance of disposition towards drones and why it must be changed is further analysed in section 2.1

3.3 Different Types of Drones

The second stabilization that gets analysed is the ‘structure’ of the artefact, analysing how the shape of the drone impacts how people understand the technology. In the instance of drones, ‘structure’ is also heavily related to language. Since a drone is an aircraft without a pilot, the range of aircraft that the word drone encompasses is tremendous. Some of the smallest drones are known as Smart Dust and are smaller than the human hair is thick (Robbins, 1988; Warneke, Last, Liebowitz, & Pister, 2001); meanwhile, the largest drones “may have a wing span as broad as a Boeing 737” (Hassanalian & Abdelkefi, 2017, p. 2). In essence, the broadness this includes is somewhat akin to a ‘manned driving vehicle’- this could refer to a scooter or a tank. As such, it is vital to classify different types of drones; and that is where Humphreys (2005) stabilization of ‘structure’ comes in.

Often drone classification is done based on metrics such as weight, wingspan, and/or flight range. This is seen in the work of Hassanalian and Abdelkefi (2017), referring to various taxonomies to differentiate between drones based on the above characteristics. Weight is the most frequented metric, either as a standalone metric or in combination with others. While various taxonomies are presented, they largely remain arbitrary decisions made by the various creators of the presented taxonomies. The benefit is that distinctions can often be calibrated to fit specific contexts better. While a taxonomy might work well for drone usage in USAR, it does not mean it is appropriate for military drone use.

Another important distinction that can be made is based on the mechanism the UAV uses to fly. This distinction is both an essential element used in classifying drones generally, as well as for USAR specific purposes. There are three archetypes, as pictured in Figure 3. Fixed-wing drones, multi-rotor drones, and hybrid drones (Swiss Foundation of Mine Action & CartONG, 2016a; Vergouw et al., 2016). For more specificity and nuances, these archetypes can be divided into other types and subtypes. Hassanalian and Abdelkefi (2017) mention approximately 30 different ways to classify drones, many of which end up being a subtype of multi-rotor or fixed-wing drones. While the various subtypes each offer their own advantages and disadvantages, the most critical differences lay between fixed-wing, multi-rotor, and hybrid drones.

Figure 3: The three types of drones, from left to right, fixed-wing, multi-rotor, and hybrid. Picture(s) retrieved from Swiss Foundation of Mine Action and CartONG (2016a, p. 17)

Fixed-wing Drone:

Fixed-wing drones work similarly to aeroplanes. While carrying heavier loads or travelling over long distances, fixed-wing drones are the most ideal, being the most energy-efficient type of drone. Due to their extended flight time, if mapping large areas using drones, fixed-wing drones can be advantageous. Likewise, similarly to aeroplanes, fixed-wing drones require more space for take-off and landing (Swiss Foundation of Mine Action & CartONG, 2016a) than multi-rotor drones. The amount of space is highly dependent on the drone; some are only required to be thrown by a person.

Multi-Rotor Drone:

Multirotor drones are drones that contain propellors similar to that of a helicopter but instead laid out on various points around the drone. The most common configurations either have 4, 6, or 8 propellors. Having vertical take-off and landing (VTOL) and hovering in place capabilities, these drones are easily deployed in areas with little space. The ability to stay in one spot in the air is invaluable for tasks such as damage assessments. A trade-off for these features is shorter flight times and the ability to carry less cargo than fixed-wing drones (Swiss Foundation of Mine Action & CartONG, 2016a).

Hybrid Drone:

Hybrid drones attempt to combine the best of both fixed-wing and multi-rotor drones. Having VTOL capabilities as well as the ability to fly longer distances with heavier payloads. A payoff is that these types of drones are more complex, more expensive, and difficult to develop (Saeed, Bani Younes, Cai, & Cai, 2018; Swiss Foundation of Mine Action & CartONG, 2016a). It is highly possible that with further research and development, these types of drones will become more prominent.

It is not uncommon for drones to be able to automatically fly according to a preprogrammed flight path, requiring little interference from the remote pilot. Other features that drones can have, often found on multi-rotor variants, are enabled due to various embedded sensors in the system. The sensors and related features permit some drones to automatically detect and avoid obstacles making flying safer. It is also possible to keep the drone at a certain altitude relative to the ground, automatically adjusting to always stay a certain altitude above the ground even when the terrain becomes complex and intricate. When adding a sensor, such as a camera, features such as object tracking enable the drone to follow and remain focused on a particular object, such as a driving car or designated location. When enabled, the drone automatically faces the desired direction without the operator having to adjust for it (DJI, n.d.-a, n.d.-b, n.d.-c; Green, Hagon, Gómez, & Gregory, 2019). Sensors such as cameras, infrared cameras, or lidar units enable extensive data collection for various use cases.

3.4 Drones, Sensors, and Payloads

Drones are highly usable and flexible tools to be utilized for various tasks. In the case of USAR, drones have mapping capabilities and can be used for damage assessments. In order to explore this in further depth, several vital tools will be explored, namely the use of cameras, infrared cameras, and lidar. Each will be explored first by explaining what the technology is and followed up with examples of how that technology can be used in USAR specifically. In doing so, providing insight into reasons why USAR teams would want to utilize drones and showcasing why the creation of a framework enabling drone usage in USAR is beneficial.

3.4.1 Cameras and General Functionality

Cameras are the most common sensors to be added to drones. In most instances, camera footage gets transmitted to the drone operator, who can see it live on a display. Not only is there a live stream of the footage, but the camera is also able to take high-quality pictures and videos (higher quality than can be streamed) that can be reviewed later. Cameras tend to be mounted below the drone and often can be controlled independently and separately from the drone itself- the extent to which depends on the drone and camera. Possible adjustments include but are not limited to adjusting the tilt (upwards or downwards rotation as if nodding one's head), as well as the angle of azimuth (left/right rotation as if turning one's head) of the camera. Camera settings such as zoom, aperture size, shutter speed, colour balances, and other various options can be altered remotely by the operator as well (DJI, n.d.-a, n.d.-b, n.d.-c; Swiss Foundation of Mine Action & CartONG, 2016a).

There are various versatile methods in which a drone with a camera can be utilized for USAR purposes. The first is to provide real-time information to a team working on the ground. By flying a drone around the area, the team can see what the mission site looks like at that moment. By manoeuvring the drone to the desired location, various perspectives become possible, such as top-down. This enables the drone to reach and investigate areas that are otherwise dangerous, complicated, or outright impossible to access. This is a great tool to conduct damage assessments in a way that could not be done before (Greenwood et al., 2020; Półka et al., 2017; Restas, 2015; Swiss Foundation of Mine Action & CartONG, 2016f, 2016h, 2016j, 2016k; Vergouw et al., 2016).

Other than live footage, the drone can also take videos and pictures of the environment it finds itself in. This is likewise a highly beneficial ability for USAR Team Search during the Operations phase. USAR teams can get up to date maps to use for rescue operations. This is done by making ortho-mosaic maps (OMM). OMMs are created by flying a drone over a region and taking a large number of top-down pictures, with slightly overlaps towards the ends of the pictures. What is at the periphery of one image is also at the periphery of the subsequent image. Pictures are processed in specialized software that fuses the images together to generate one larger image. This generated image becomes a map of the environment the drone took pictures of (Greenwood et al., 2020; Surmann et al., 2019; Swiss Foundation of Mine Action & CartONG, 2016a, 2016e, 2016g, 2016k). An example of an OMM is pictured in Figure 4.

Figure 4: An ortho mosaic map of Jama Canton in the Manabí province of Ecuador. Made by Aerovision in May 2016. Image retrieved from Swiss Foundation of Mine Action and CartONG (2016k)

Ortho-mosaic maps have been used more often in humanitarian settings. This is seen in Tanzania, Nepal, Bosnia and Herzegovina, Vanuatu, and Ecuador, where OMMs were used for various purposes such as determining flood risks, updating local maps, helping to locate landmines, conducting damage assessments, and to provide search and rescue teams with up to date information in a simulation training exercise (Swiss Foundation of Mine Action & CartONG, 2016a, 2016b, 2016c, 2016d, 2016h, 2016i, 2016j, 2016k).

During the Operations phase, USAR Team Search can use drones for photogrammetry. It consists of taking multiple photos of an object, such as a building, from various angles and perspectives. By processing the data and taking into account the various angles at which the photos were taken, it becomes possible to use the images to generate a 3D model of the subject of the image, as can be seen in Figure 5 (Colomina & Molina, 2014; Surmann et al., 2019). In the United States of America, in the state of Florida, the Florida Urban Search and Rescue Task Force requested help from the Florida State University Centre for Disaster Risk Reduction Policy for drone support after a building collapsed. “In less than 30 minutes, the team can fly, process and upload the latest information from a disaster scene. This improves responder effectiveness and increases responder safety."(Florida State University, 2021).

Figure 5: An example of a 3D model of a warehouse and surrounding buildings made using photogrammetry. Image retrieved from Jobsite Editorial Staff (2018)

The use of photogrammetry can help provide USAR teams with further up to date information regarding the worksite, as well as provide a 3D model of the environment (Caroti, Piemonte, & Pieracci, 2017). Getting high-quality 3D models using photogrammetry can be an extensive process, however, but it will likely keep developing (Colomina & Molina, 2014).

A camera drone is most beneficial in Phase 3 Operations by providing the USAR Teams with up to date information. Providing up to date maps is something drones can help facilitate during other phases as well; such as giving the updated map to local authorities during the Demobilization phase. Additionally, if there are up-to-date maps before a disaster, it enables USAR teams to make a comparison to new maps made using drones. During the Preparedness phase, local USAR teams can create up-to-date maps of local areas prone to disaster as a method to practice drone usage. Such maps are highly beneficial and can map out areas that are otherwise poorly mapped, as seen in Dar es Salaam in Tanzania (Swiss Foundation of Mine Action & CartONG, 2016b).

The mapping and 3D modelling provided by camera drones are not the only way these drones can be effective. Drones have some potential in being able to deliver supplies or medicine/automated external defibrillators to areas in need quickly or areas that are hard to reach. This is discussed in its own section 3.4.5. Further footage from drones can be used to tangentially help humanitarian efforts. The data collected could help other humanitarian organizations on the ground. It could provide information that other organizations might lack. The footage could also be used for donation campaigns, showcasing how an area was struck by a disaster and using the footage to help with fund appeals; this is likewise discussed in its own section, section 2.3. Lastly, drone footage, photos, videos, ortho mosaic maps, and photogrammetry can be used in phase 5 post mission to help teams reflect on what could have gone better.

3.4.2 Infrared Camera

Visible light, the type of light that humans perceive is electromagnetic radiation (EMR) in the 'visible light' spectrum. There are seven spectra of EMR, radio waves, microwaves, infrared, visible light, ultraviolet, x-rays, and gamma rays. Using specialized equipment allows for the generation and/or perception of various spectra of EMR. Hospitals use x-ray machines to look within humans; microwaves (the kitchen appliance) can generate microwaves (the EMR) to heat up food. Most cameras capture EMR waves on the visible light spectrum; however, infrared cameras allow the capture of EMR waves on the infrared spectrum. Given that objects at room temperature emit EMR on the infrared spectrum, with the exact wavelength emitted on the infrared spectrum being dependent on temperature, it becomes possible to differentiate between objects, people, and matter based on temperature and not on colour as would be the case with a typical image (National Aeronautics and Space Administration, 2004; Trigg, 2010). A drone with an infrared camera provides the drone operator with night vision or thermal vision. This is done by mapping certain temperatures to specific colours and works for both full colour and black and white, as seen in Figure 6.

Figure 6: Sets of pictures of regular pictures and corresponding thermal images beneath. Image retrieved from Rudol and Doherty (2008) © 2008 IEEE

Infrared cameras open numerous possibilities in the context of USAR. Survivors can be challenging to spot in debris with a regular camera. It is possible only part of them is visible and the victim is covered with dust, grime, and dirt, creating a form of camouflage with the person easily blending into the background. Further, shadows and poor lighting conditions can make spotting people more complicated. An infrared camera can bypass this hurdle because it does not look for colour but rather for heat. Usually, a body will be warmer than the surrounding debris and will stand out in the resulting image, as seen in Figure 6. Combining thermal sensors with other sensors such as standard cameras and lidar enables multispectral imaging, such as by highlighting elements on a picture above a specific temperature (Lee et al., 2016; Rasmussen, Morse, Goodrich, & Eggett, 2009; Vergouw et al., 2016).

Infrared goes further to provide extra clarity in some situations than standard cameras, being able to capture scenes that regular cameras simply cannot. Thermal imaging can be used to spot invisible gas leaks due to differences in the temperature of the air and gas (J. Wang et al., 2020). This can be used by USAR Team Rescue while working with USAR Team Search in the Operations phase to ensure the surroundings are safe (International Search and Rescue Advisory Group, 2020e).

3.4.3 Lidar

Lidar (Light Detection and Ranging) is a technology that has seen significant improvements in recent years. Lidar enables photogrammetry as cameras do, albeit using a significantly different method. Where cameras use pictures from various angles to extrapolate a 3D model, lidar collects a 3D point cloud. A 3D point cloud is a collection of data with locations in a 3D space. By collecting thousands of individuals points, it becomes possible to recreate environments (National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, 2012), as seen in Figure 7.

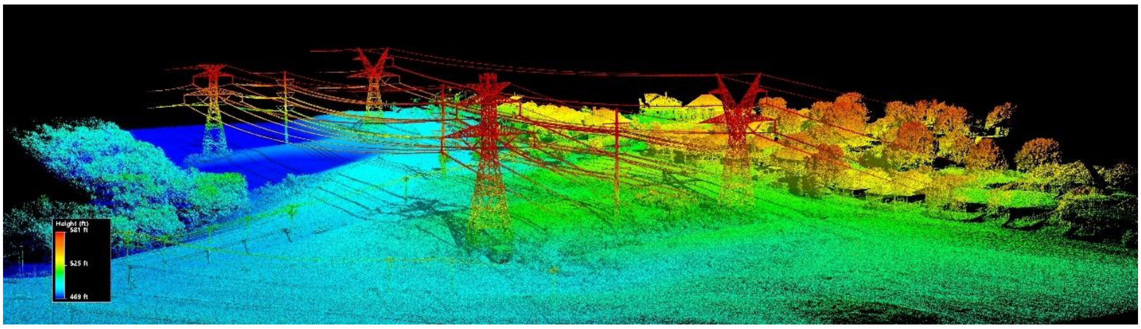

Figure 7: An example of lidar point data. Colour represents alleviation. Image retrieved from McCord Geospatial Services (n.d.)

Lidar functions by generating thousands of pulses of laser (at times over 100,000 pulses per second) that bounce off objects and are reflected back at the lidar unit. The waves that get bounced back get processed by the lidar unit and can be used to produce the location of a point in the 3D point cloud. This is done by calculating the distance the laser travelled to high accuracies.

This form of data collection enables the bypassing of certain amounts of foliage, allowing the data, once processed, to show the underlying earth without trees or shrubberies (National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, 2012). Further, lidar can be combined with infrared sensors (Lee et al., 2016) or with optical sensors to likewise record colour. The presented data comes out looking significantly more realistically (Simmers & Wagg, 2013), as shown in Figure 8.

In order to make the most out of a drone with lidar, however, some additional procedures need to be followed. Often a base station is required, another device placed on a tripod that handles various communications with the drone and lidar unit to increase accuracy. The data is not streamed to the operator, instead needs to be retrieved from the drone and processed. Depending on how the data was collected and how it needs to be filtered, this process can take some time (National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, 2012). Lidar units tend to be heavier than (thermal) cameras as well, often several kilograms, thus requiring a larger drone to operate (Green et al., 2019).

Similarly to camera drones, the photogrammetry produced by lidar can be especially useful in the Operations phase. It can help with damage assessments as well as provide highly accurate 3D models of infrastructure to plan missions around. It should be noted that while lidar can be used for 2D mapping like cameras, OMMs are still likely the best choice for that purpose as they can be produced cheaper. Lidar is highly efficient for making 3D maps and can be used for purposes such as simulating how floods would affect an area.

In the Operations Phase, lidar can be used for damage assessments and to provide teams with more up to date information. 3D reconstructions of the mission site can help spot dangers and enable more accurate and safer planning for both USAR Team Search and USAR Team Rescue. In the Demobilisation phase, the data could potentially be given to governments (depending on data sharing regulation), and in the Post-Mission phase, it can be used to reflect and learn from the mission, as well as investigate what can be done better next time.

Figure 8: Colorized point cloud collected using lidar. Black spots are missing data. Image retrieved from Simmers and Wagg (2013, p. 4)

3.4.4 Other Sensors

There are various other sensors that can be used for USAR purposes. Due to a combination of the stage of development these sensors are in, the lack of literature on these sensors and their usage in USAR situations, and the scope of this thesis, these sensors cannot be analysed in further depth. Regardless, it should be noted that microphones can be used to localize people based on sound (Deleforge et al., 2019; Go & Choi, 2021; Yamada, Itoyama, Nishida, & Nakadai, 2020). Chemical sensors can be used to help detect leaks and dangerous chemicals/gasses around USAR sites (Burgués & Marco, 2020). Cellular sensors can be used to pick up and track cellular signals from cell phones to potentially find the locations of people (Grogan, Pellerin, & Gamache, 2018).

3.4.5 Payload Delivery

Another expected benefit of drones is the ability to aid in the logistics of all USAR Teams during the Operations phase. Their ability to reach locations quickly and not having to rely on local infrastructure such as roads or bridges can potentially be beneficial.

Cargo delivery has been identified as one of the more notable logistic benefits a drone can provide (Swiss Foundation of Mine Action & CartONG, 2016a). The question arises of how beneficial payload delivery is for USAR Teams during the various phases, however. Cargo delivery is most needed during the Mobilization and Demobilization phases to get cargo to and from the host country. This would require drones the size of planes and helicopters, however, and the benefit a drone would give in these situations is more limited, as USAR personnel need to reach the destination as well.

There are various reasons causing the use of drone cargo delivery to be of limited use for USAR purposes. The legislative issues laid out in Section 2.2.1 stipulate that in many states, a drone has to remain in the line of sight of the operator. It is possible that governments partially waive line of sight regulation for USAR. Such exceptions would likely only enable the operator to break line of sight within a certain radius around them, permitting the drone to fly around a building or mission site but not to a destination several kilometres away.

Further, during the Operations phase, USAR Teams get deployed and assigned locations based on the capabilities of the team. In principle, the team should have the required equipment to handle the situation (International Search and Rescue Advisory Group, 2020c, 2020e) and should not be heavily relying on additional supplies. There are situations in which the payload delivery could still be helpful, such as for resupplying. USAR Team Medical could run out of bandages or need a particular medicine.

A limitation for payload delivery is weight. Strapping a significant weight on the drone limits its flying capabilities. Further, weight is something that governments are wary of. If something goes wrong, a drone carrying 10 kilograms of weight falling out of the sky can be dangerous. This is likely one of the reasons why many states do not permit drones above a certain weight.

For cargo delivery, VTOL and hovering capabilities are beneficial. This means that either multi-rotor or hybrid drones should be used. Fixed-wing drones are more energy-efficient and thus better for carrying cargo. The amount of space needed to launch and land a fixed-wing drone with cargo depends on the drone but would likely cause complications. Research and development is being conducted on using hybrid drones for cargo deliveries (Swiss Foundation of Mine Action & CartONG, 2016a).

The most plausible method of drone cargo delivery in USAR is by using a multi-rotor drone to deliver food, water, medical supplies, and potentially equipment to trapped victims or USAR personnel within a USAR site. An example is a team working several stories up requiring equipment that could be difficult to bring up due to the stairs in the building being destroyed. In such cases, drones could be used instead of alternatives such as pulley systems.

As the technology is now, however, payload delivery, while potentially being able to provide some assistance in niche situations, does not provide USAR teams with the most benefits overall. As such, it shall not be included as one of the recommended tasks for USAR teams in the proposed framework.

3.5 Conclusion to Investigating Drones

Regarding the 'IT' model, this section covers the 'I' section and explores what exactly drones entail. Since the goal is to place the drone into the USAR ecosystem, said ecosystem was analysed first. The investigation into the existing USAR framework provided insight into how USAR is organized. Comprising of 5 main phases, it was identified that drones would be most impactful in Phase 3 Operations. The phase in which USAR teams conduct search and rescue operations. However, to properly integrate drones, they must be considered at every phase of the USAR cycle. Failing to do so will result in drones being improperly used, being incorrectly registered and imported, or being used in an illegal manner. To avoid these transgressions, it is vital that the team knows how to operate the device and is familiar with the required paperwork and bureaucracy involved.

Further, USAR consists of five different teams. It was identified that USAR Team Search would be the most appropriate USAR Team to integrate drones too. This is for various reasons; the only reference to drones in the INSARAG guides is linked to USAR Team Search. Their experience with the logistics and handling of canines for search operations and the various legal hurdles that entail, and lastly, drones fit well with the various tasks USAR Team Search must undergo throughout the various stages of the international USAR cycle.

With the USAR framework established and having identified where USAR drones fit best, enables further exploration into the drones themselves. This is initiated by exploring the nuances of the term drone. First, illustrating the inherent vagueness of the term drone and how other frameworks such as ICAO draw distinctions between UAV and RPA. While such nuances are necessary for specific contexts, for the scope and depth of this paper, the various terms are used interchangeably.

When exploring the intricacies of drones, various forms of classifications exist, noting a lack of standardized internationally used divisions. Namely, categorization gets done on the basis of the drone's weight. This is further complicated by another element that does get classified and is regularly used in various settings, the configuration or form of the drone. Is it a fixed-wing, multi-rotor, or hybrid drone? These various configurations have various advantages and disadvantages, which are explored.

Additionally, there are various sensors that can be added to a drone. The first discussed is the camera. By adding a camera, the drone can be used to take pictures and videos. As a result, USAR Teams can use the drone to get an ‘eye in the sky’, allowing for the creation of up-to-date maps, photogrammetry to get a 3D model of the environment and conduct live damage assessments on locations that would otherwise be difficult, dangerous, or impossible to reach. The additional perspectives the drone can give are highly beneficial and open new doors.

In situations where coloured vision is not enough, it is possible to add an infrared camera. In doing so, it enables night vision and the sensing of heat, making distinctions that a regular camera cannot. This enables the operator to find people in tricky lighting conditions or camouflaged due to dust and grime. It is possible that these cameras detect gas leaks that are invisible to the naked eye. When used in unison with a standard camera, it is possible to take a camera output and highlight areas on the live feed that are at a specific temperature, such as highlighting a human’s body heat.

Another sensor that can be added to the drone is a lidar sensor, which by producing thousands of lasers and capturing those lasers as they reflect off surfaces, allows for highly accurate 3D recreations of the environment. These recreations could help USAR Team Search in planning searching methodology as well as spot possible dangers. While more post-processing is needed than for infrared and cameras, the resultant model can help in situations where finesse and accuracy are vital. These sensors can likewise be combined with a regular camera and used in tandem to recreate correctly coloured 3D photogrammetric models of the environment.

Other sensors such as microphones, chemical sensors, and cellular sensors can likewise be utilized for attempts to help find people or locate hazards. While in niche situations, these sensors can be effective, limited research is available on these for the context of USAR, and further developments need to take place before widespread adoption is possible.

4 Towards Developing a Framework

The first section of the thesis framed technology in a humanitarian context and analysed it from various perspectives. In doing so, discovering issues that arose as well as investigating some solutions to the limitations identified. The second section of the thesis explored USAR and further analysed drones showcasing the technology's capabilities. This section will combine both sections and provide recommendations for the usage of drones in USAR. This is done by the proposition to create an Urban Search and Rescue Drone Framework (USAR Drone framework or UDF), a framework catered explicitly to enabling ethical and safe usage of drones in USAR settings.

4.1 Developing a Framework

Various issues are raised with ethics and legislation pertaining to drones in USAR. These were discussed in sections 2.2 and 2.3. The legal bottlenecks on drone usage vary extensively between countries and add uncertainty regarding the adoption of drones for USAR teams. Then there are various ethical questions pertaining to when and how drones can be used as well as how to handle the data the drones collect. While these challenges are going to always be present with drones and other technology, it is possible to establish procedures to mitigate the risks as much as possible. The following recommendation is provided.

The creation of an Urban Search and Rescue Drone Framework, a framework and methodology tailored explicitly to the use of drones in the context of USAR. There exists a gap in existing frameworks that are caused due to the broadness of what constitutes a drone. This causes initiatives such as the Humanitarian UAV Code of Conduct to be too broad and general to properly be applied for drone usage in USAR. The USAR Drone Framework needs to be specific enough that it covers the nuances particular to drone usage in USAR. It needs to enable USAR teams to use drones safely, legally, and ethically whilst still ensuring that they can be effectively used. It needs to be designed such that governments accept it and that it aids the people whom the USAR team is there to help.

4.1.1 The Six Main Sections of the USAR Drone Framework

Six sections have been identified that should be covered by the UDF. While more is possible, the six provided are seen as the integral basis. Drone Classification, Requirements for Drone Operation, Flight Constraints, Drone Tasks, Data Management Practices, and When Not to Use Drones. Each of these sections shall be further investigated. The thesis will provide information on what content should be covered in each section of the UDF but does not specify what the content should contain. For example, it will stipulate that an agreement needs to be made on how close USAR teams may fly drones to buildings. It needs to be close enough to enable the team to do their work but also far enough such that governments accept it. The recommendations do not provide insight as to what that distance should be, simply that it needs to be stipulated in the UDF. This is mainly done for the reason that more research needs to be done into each of the propositions, to come up with an ethical and safe framework; research that is more extensive and nuanced than the scope of this thesis.

4.1.1.1 Drone Classification

It is crucial for the UDF to create a classification for drones– to place a constraint on what drones can and cannot be used. This is vital for practical and bureaucratic purposes. It is essential that the UDF framework recognizes that drone is a term that encompasses a wide range of different aircraft. The UDF should include Drone Classification such that this framework cannot be applied to a retrofitted Boeing 747, nor is it applicable to drones small enough to be breathed in like Smart Dust.

As such, this classification system would need to set upper and lower limits on what kind of drones can be used for USAR. This can be done based on metrics like weight or other metrics explored in section 3.3. It could also be helpful in classifying the configuration of the drone; is it fixed-wing, multi-rotor, or hybrid.

Having such a classification will also make countries more likely to accept this framework. As discussed in section 2.2.1.6, many states have regulations pertaining to a drone's maximum weight. This showcases that larger drones are viewed with some concern by states. Even if the classifications provided by the UDF do not align with a state's own classification, local authorities are more likely to agree to let the UDF be used as a framework if they know what they agree to. Having different classifications also enables local authorities to permit specific categories of drones as identified by the UDF, whilst not others.

4.1.1.2 Requirements for Drone Operation

The UDF requires a section that lays out the requirements needed for a USAR team to operate drones in a USAR context. It includes the required staff needed, such as a remote pilot and potentially a remote co-pilot. Section 2.2.1.5 of the thesis highlights that various countries have stipulations on licences and certificates that drone operators are required to have. Enforcing pilots to have undergone specific training to use drones. The UDF could potentially include requirements to be proficient in communication with Air Traffic Control, a requirement that some states have for drone operation. Another requirement could be expertise in USAR and drone operation, that the drone operator is a specific kind of professional as proposed in section 2.1.4.

The UDF should provide USAR Teams with the list and types of certificates and licences that must be gathered for the drones. Examples such as the drones must be registered in a specific database and must be insured. The drone might have to adhere to specific standards and be regularly maintained and inspected for safety. This could also include other safety measures such as lights akin to that of an aeroplane.

The UDF could also lay out the minimum requirements for the various sensors the drone uses. Section 3.4 discusses various sensors, and the UDF could stipulate that cameras must be able to produce pictures of at least a certain quality. Lidar units need to have a minimum accuracy. And thermal cameras must be able to differentiate between certain heat levels accurately.

As explored in section 2.4.2, a minimum level of self-sufficiency of the USAR team could be required. Expectations that a USAR team is able to operate, maintain, and fix minor damage to a drone while deployed. This includes having the means to charge the drone’s batteries.

4.1.1.3 Flight Constraints

The next aspect that the UDF needs to cover is creating a paradigm in which the drones can operate. This part of the UDF aims to provide a methodology to solve the issues laid out in section 2.2. Different states have different regulations drones must adhere to. Examples are, max flight altitudes, the ability to fly close to buildings and people, and the ability to fly close to airports. The UDF should develop constraints specifically for USAR personnel to adhere to while on a mission. These constraints, such as maximum flight height, should be strict enough that governments are willing to accept them but also be lax enough to enable USAR teams to fly drones effectively for their missions.

Strictness should be perfectly balanced. If the flight constraints set out by the UDF are too strict, USAR teams will not be able to use drones effectively. Potentially making it unfeasible to use drones altogether. Conversely, if the restrictions are too lax and encroach excessively, countries will not permit the USAR team to fly under UDF guidelines, then drones can likewise not be used.

This is one of the most significant limitations to the broadness of the Humanitarian UAV Code of Conduct. It does not cover these nuances, such as how far a drone may or may not fly to a building, and it leaves too much interpretation of how drones can be used. As discussed in section 2.1, technology can be used maliciously or with unintended consequences. The UDF should attempt to mitigate such consequences or misuses as much as possible.

4.1.1.4 Drone Tasks

This section of the UDF would stipulate for what tasks a drone can be used. It should include the tasks that the USAR team would use a drone for as well as potential requirements for such tasks. This section of the UDF should provide a clear precedent for how drones may or may not be used.

Section 3.4.1 discusses the role that cameras can play in USAR. The UDF should provide insight into how cameras can be best used for USAR purposes. For example, giving an indication that adding a camera to a drone enables it to conduct damage assessments. By using ortho-mosaic maps, it becomes possible to create an updated map of the rescue site. Further showcasing that cameras can be used to make photogrammetric models of the area.

The UDF could further make stipulations that at certain light levels cameras are too inaccurate to provide enough detail. In such situations, infrared cameras should be used, as explored in Section 3.4.2. Or make recommendations on how infrared cameras can be best combined with regular cameras for multispectral imaging purposes.

Other recommendations include stipulations on how lidar units explored in section 3.4.3 may be utilized for creating 3D point clouds to provide USAR Teams with the required information to conduct missions.

This section of the UDF should also include information on how drones may not be used. As explored in section 3.4.5, payload delivery comes with many complications. It causes legal issues due to line of sight, as investigated in section 2.2.1.1 and can be dangerous to people in case something goes wrong. As drones are versatile and can be used for non-USAR purposes, the UDF should also stipulate that the drones cannot be used for non-USAR related tasks, such as recording videos for donations drives (as seen in section 2.3).

Lastly, this section needs to leave some space that enables USAR teams to adapt on the fly to their surroundings and situation in an ethical and safe way. Just as the Humanitarian UAV Code of Conduct cannot cover the nuances needed for USAR, the UDF cannot predict and layout all the situations a USAR team end up in.

4.1.1.5 Data management constraints

Another essential element is how the data collected by the drones is managed and stored. Similarly, as with drone legislation, each country has different regulations pertaining to how and when data may be collected, how it needs to be stored, how it can be processed, and what it can be used for.

This is explored in section 2.3 of the thesis, in which a plethora of questions are asked. The UDF should, likewise, answer these questions. The concerns regarding data management are not unique to drones, however, and as such, the UDF can take extensive inspiration from frameworks such as the Handbook on Data Protection in Humanitarian Action (International Committee of the Red Cross, 2020). The UDF should encourage the adoption of principles such as data minimization discussed in section 2.3.2.2, as well as provide extensive insight into how consent is obtained and/or justified for the collected data, as seen in section 2.3.2.1. The UDF can further encourage data principles to abide by the GDPR.

It is also vital that this section extensively explains why data management is a crucial topic. Critiques provided by authors such as Madianou (2019), Jacobsen (2015), and Jacobsen and Fast (2019) are invaluable. Ensuring there is an understanding of the potential negative impact technology can have, especially when people's data is concerned, needs to be emphasized by the UDF.

4.1.1.6 When Not to Use Drones

The UDF needs to have the fundamental understanding that drones are not always the solution. Section 2.1 explores the different interpretive flexibilities that are associated with drones. With it arise situations in which using drones is irresponsible, dangerous, and unethical. The example given in that section is Afghanistan, where using drones can induce PTDS (Hijazi et al., 2019). It could result in USAR teams being associated with the military or becoming untrustworthy in the eyes of locals, causing them to refuse aid. In such situations, drones should be avoided.

Perspectives with a more critical disposition, such as Madianou (2019), Jacobsen (2015), Jacobsen and Fast (2019), Emery (2016), and Sandvik et al. (2014), are crucial when it comes to creating the UDF. These authors can function as a reminder to not too hastily use drones and to remind USAR Teams what is at stake. To prevent technology from being seen as the solution to all problems, it is vital that critique and issues with existing methodology and frameworks are identified.

The UDF should provide sources and methodologies that can be utilized in order to investigate if it is appropriate to use drones in a specific setting and context. This can be done by analysing legal constraints within a country, as shown in section 2.2, and if it deviates extensively from the UDF, refuse to use drones. Another reason to not use drones is that the local government requires data collected to be shared with local authorities, especially if this is against the data protection principles laid out in the UDF.

4.1.2 Creation of the UDF

The creation of the UDF will not be a small undertaking and will require extensive research, investigation, and development. As such, it is essential to include various stakeholders in the process. It is recommended that the creation would be spearheaded by INSARAG, given their importance and role within USAR. Likewise, collaborating with

UAViators (the Humanitarian UAV network and the creators of the Humanitarian UAV Code of Conduct) would be beneficial. It is critical that there are both drone and USAR experts involved, preferably those with a background in both. INSARAG is chosen given its essential role as being the advisory group for international USAR teams. INSARAG, also being a body belonging to the United Nations, when combined with its influence and prominence, can help alleviate drone status and military ties, as explored in section 2.1.1. INSARAG can also ensure that the UDF is of appropriate quality and that the guidelines laid down are adhered to.

Notably, the UDF will need to be reviewed every couple of years. This is to ensure it stays up to date, vital given the development technology undergoes. By regularly updating the framework, the UDF likewise ensures that any shortcomings identified can be addressed. Regular updates will also prevent the UDF from becoming static; instead, it becomes a dynamic and changing piece of work. If possible, the UDF can become proactive and include sections to address issues that are expected in the future but are not present yet.

5 Conclusion

This thesis has shown that the integration of drones into USAR can be very advantageous but comes with many obstacles. It is these obstacles that answer the question of *'How can the lack of UAV integration into USAR be understood?'* The legal challenges that complicate the use of drones tend to be worst in urban environments. Restrictions to flight height and distance to the operator get expounded upon in some states with not being legally allowed to fly close to buildings and people. The legality of drones comes further into question with the addition of cameras and other sensors that could collect data of pictured individuals. This likewise raises ethical questions about data use policies.

The lack of adoption is further catalysed by the lack of expertise in drones within the USAR sphere. A lack of professionals with experience with both drones and the USAR response cycle results in little chance to execute drone usage even in situations where it would be applicable. Figuring out what situation is applicable for drone usage is a complex endeavour, often requiring the analysis of social relations between drones and various stakeholders. This has likewise been identified as a tumultuous element of the integration of drones. There is a criticalness with which technology is scrutinized, which makes people more adverse to the adoption. Such scrutiny is warranted, however, as the concerns raised often showcase problematic elements concerning drones- such as the ones mentioned earlier. That said, there likewise exists scrutiny that is overbearing in the sense that it stems from a place of lack of understanding. The critique in such instances is faulty and based on a misunderstanding of reality.

Further, this thesis investigated the USAR response cycle, analysing the various phases that make up USAR. Phase 3 Operations was identified as the phase most suited for drone integration. This was combined with an analysis of the various USAR Teams that could potentially be best suited to have such responsibility. USAR Team Search has been identified as the best candidate due to the Teams' experience with search dogs, requiring special training and licences to operate, as well as INSARAG making mention of USAR Teams Search's ability to utilize drones for searching purposes.

Cameras, infrared cameras, and lidar units have been identified to be able to provide invaluable information to USAR Teams. Not only providing up to date information that otherwise would not be able to be gathered (i.e. updated maps) but also providing new information that was not possible to be gathered otherwise (i.e. damage assessments of locations that otherwise could not be reached). For the purposes of damage assessment and mapping, drones can provide a quick, cheap, and efficient method of gathering the required intel. Using infrared cameras, especially in conjunction with regular cameras, allows the identification of not only victims in ways that would be complicated prior but can likewise discover potential gas leaks and dangers on the worksite. Lidar and the ability to collect 3D photogrammetric models, as well as mapping abilities provided by the various sensors, allow for better planning on the most efficient approaches to tackle missions.

While the ability to deliver payloads is a benefit of drones and is likewise being investigated for various purposes, for USAR, it has been identified as being of use only in niche situations. Namely, if something that is not too heavy needs to be delivered within the team to a location that is hard to reach (i.e. over rubble or to the top of a structure).

There are two concepts that the paper proposed and were created by the author of the paper. These propositions are paramount to answering '*Taking account of the complexities regarding drone usage in USAR, how can drones be constructively integrated into the USAR ecosystem for the benefit of both USAR teams and the victims the team is trying to aid?'* First and foremost is the concept of techno-social scientists. A term for a professional with a background in both the technology sector as well as the social sciences sector. With it comes a classification system based on the concept of 'I' and 'T' professionals; where 'I' shaped professions are trained in one specific discipline, and a 'T' shaped professional has experience in multiple disciplines but focuses on one (i.e. knowing about elements of psychology, anthropology, governance, and law whilst focusing on sociology). The proposed classification systems identify each techno-social scientist as either 'II', 'TI', 'IT', or 'TT'. The first letter refers to the shape of the professional in the technology field and the second in the social sciences. This system can be used to address the lack of technological integration in the humanitarian sector as a whole but also wider from a technological-social science perspective. For the humanitarian side, it would be a techno-humanitarian (TT), where it is likewise possible to further specify subcategories such as drone-humanitarian (IT), blockchain-psychological first aid (II), and techno-case worker (TI).

The second concept the thesis proposes is the creation of the USAR Drone Framework. A framework created explicitly for the usage of drones in the context of USAR. This was identified as a need because the closest exiting contemporary to such a framework, the Humanitarian UAV Code of Conduct, was identified to be too broad to be applied adequately to USAR. While it could work as an initial steppingstone, where the UDF uses the Humanitarian UAV Code of Conduct as a basis, it needs to cover various competencies and expectations specific to USAR such that users of the framework can clearly understand the expectations and requirements that are necessary for drone usage in this context.

Six topics were identified as vital. First is a method of classifying drones for USAR purposes. Due to the broad nature of what constitutes a drone, it must be clear what drones can and cannot be used. While such a section does not necessarily need to include specific models, it should specify elements such as maximum size or weight. This framework should not permit a USAR team to fly a passenger plane sized drone through a city.

Second is the concept of requirements for drone operation. This section of the UDF stipulated requirements for drones, such as insurance and registration. For the operators, possibilities include having undergone training, being familiar with USAR and drones, and being able to communicate with air traffic control.

Third, the constraints of drone operation. The UDF should provide an alternative to the existing legal framework of a country to which the drone operator can adhere if permission from the local government has been granted. This would enable the team to fly close to buildings and potentially in no-fly zones that otherwise would be illegal.

Fourth are the tasks that USAR teams can use drones for. The UDF should stipulate for what purposes drones can and cannot be used. Leaving some flexibility for adapting and improvisation but also providing a clear understanding of expectations that arise with drone usage.

Fifth, a strict explanation of how data must be stored and processed and how and if the data can be shared. This is to ensure ethical and safe usage of any potential data collected and to protect the victims the USAR team is trying to help.

And lastly, the sixth element of the UDF recognises that drones are not always the best tool for the job, and there exist situations in which those should be avoided. In such situations, drones should not be used. For this section of the UDF, critique of drone usage in USAR is seen as vital, a counterbalancing force that prevents potential abuse and unethical drone usage.

The recommendation was ended with identifying INSARAG and UAViatiors as bodies that would be the best candidates to develop the UDF. Further noting that it is vital that the UDF gets regularly reviewed and updated to account for changes in technology and fix any issues found within the framework.

6 Limitations:

One major shortcoming is that this thesis did not have the opportunity to discuss the role of drone producers. Drone producers have high stakes and interests in drone adoption in more sectors of society. In that vein, the commentary given by Madianou (2019) and Jacobsen (2015) regarding techno-colonialism should be strongly regarded. Drone producers are very much interested in shifting the perception of drones and them becoming more adopted. Emery (2016) and Custers (2016) do talk about this in more depth.

Another limitation to the research is that the collected data is secondary data with no primary data being collected. The thesis would have significantly benefited from conducting interviews with various professionals in the field. Especially someone who has experience with both drone operation and the USAR response cycle. On the topic of data, on several occasions, references to foreign laws were made. In cases where laws were in another language, the author had to result to other papers or websites that had been translated, which got corroborated with Google Translate. This method is more prone to errors and, as such, might be reflected in the thesis.

As mentioned in section 1.4, references to individual drones have been avoided as much as possible. While the author believes this to be beneficial, it should be noted as a potential shortcoming of the paper as well. In a similar vein, the costs of drones and peripheral technology have been avoided for likewise reasons. Due to regular developments being made, the author believed that adding such a section would be outdated relatively quickly.

7 Further Research

Regarding further research, the development of the UDF is identified: including explicit content in the six identified elements that the UDF should contain. Such research should be done from the perspective of someone with experience in both the technology and social sciences fields to ensure the needed expertise and nuances can be addressed. Additionally, this thesis would like to stipulate once more that further research itself is not enough. Instead, this thesis calls upon humanitarian organisations to start taking a proactive approach toward technology. A proactive approach is needed to create the paradigm shift recognizing that technology is going to become more embedded in the humanitarian system. The best way to protect against while also gaining the benefits of technology is to actively invest in it. To investigate the risks, identify the hurdles, and address the issues before they become problematic.

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