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Value Sensitive Design of a Humanitarian Cargo Drone*

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Abstract— **Value Sensitive Design (VSD) is an interdisciplinary approach to technological development that systematically incorporates ethical considerations and social impacts as design inputs. Here, the VSD methodology is described, and elements of VSD are applied with a technological focus to analyze an existing prototype humanitarian cargo drone. Then, a new proposed drone design that better supports the values of human welfare (physical, psychological, and material welfare), and environmental sustainability is developed. The new drone is a high-speed fixed-wing drone which uses internal combustion engines and drops its payload via parachute to minimize transportation time and maximize patient physical welfare. It uses lower levels of automation such as manual flight monitoring to increase reliability and safety (physical welfare), and support the local workforce (material welfare). The drone uses much less energy than the technology it replaces, and is therefore much more environmentally friendly, supporting environmental sustainability. This work contributes by being the first to apply VSD methods to the technological development of a specific drone platform, and by demonstrating how drone engineers can use VSD to develop ”ethical” drones.**

I. INTRODUCTION

In this section, the VSD methodology is briefly described, foundational concepts that underlay the method are introduced, and prior research relevant to this work is discussed.

A. Background

Value Sensitive Design (VSD) was first introduced over 20 years ago, and ”is considered by many as the most comprehensive approach to account for human values in technology design” [1] (e.g. [2]; [3]). VSD is an interdisciplinary approach to technological development that accounts for human values in a principled and comprehensive manner throughout the design process [4]. It does so by way of an iterative analysis consisting of three main phases: a conceptual phase, an empirical phase, and a technological phase [5]. In the conceptual phase, relevant human values are identified. In the empirical phase, social impacts of the technology are taken into account. In the technological phase, technical capabilities are explored which best support the identified human values and positive social impacts. The technological phase of VSD is usually performed by engineers, the conceptual phase by ethicists, and the empirical phase by social scientists.

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B. Embodied values

Value Sensitive Design is grounded in an embodied values paradigm, a well-established approach within the field of philosophy of science. The embodied values approach states that technologies such as drones are not morally neutral, but enhance or limit the expression of certain human values. ”Technical artefacts (i.e. products) are not morally neutral because their functions and use plans pertain to the objectives of human actions, and those actions are always morally relevant” [6]. Technology increases the power to perform certain actions or reduce the power to perform others; thereby ”technologies can destroy certain values...and make others virtually certain to be realized” [7]. Therefore, VSD provides an opportunity to bring to the fore a proactive integration of ethics in the design of technology [8]. A consequence of the embodied values paradigm is that unique technologies are required to support different values for different stakeholders within different social contexts; a one-product-fits-all approach is not appropriate. For example, drones developed within a civilian context necessitate different features than those for military or policing [9]. The embodied values paradigm is in contrast to the neutrality thesis, which states that technology is neutral, and can be ”good” or ”bad” depending *only* on how it is used [10] (i.e. products design does not play a role).

C. Technology in a social context

The way in which technology is used - by people, within a social context - contributes to its ethical relevance. Technical products, and drones in particular, can be misused - used in ways which they were not intended by the designer [6]. According to leading VSD scholars, most misuses can be avoided by including ”good” values as design inputs [11]. That is, the incorporation of desirable values into the design will necessarily lead to ”ethical” technologies which prevent, or at least makes it more difficult, for them to be misused. Engineers have a responsibility to envision likely misuses of their designs, and mitigate these appropriately [12].

D. Non-epistemic values

In recent years, the importance of non-epistemic values (e.g. ethics, safety, sustainability, equality, reliability, wellbeing) has become evident in science and engineering [13]. The analysis presented here contributes to this as a practical example of the direct involvement of non-epistemic or ethical-social values in he technological design and scientific knowledge-production processes - specifically, to create an ”ethically” embodied, value sensitive drone.

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E. Prior Art

The application of the VSD methodology in practice is small but growing; a review [1] identified more than 219 VSD studies. However, only 17 papers describe using all of the three analysis phases, only four of those performed an iterative analysis, and none involve drone design [1]. This work contributes to the VSD literature by discussing all elements of the entire three-part methodology with a technological focus, and performing two iterations of analysis - a retrospective analysis and a prospective analysis.

Reference [9] utilized VSD methodology to perform retrospective and prospective analyses on four broad categories of drones - military, agriculture, rescue and disaster management, and policing. The work presented here contributes by applying VSD to the case of a specific humanitarian cargo drone, and performing detailed technical analysis.

The authors have utilized the humanitarian cargo drone case study presented here to make a contribution within ethics as well [14]; in it, they refine the conceptual phase of VSD by applying a procedural-deliberative capability approach to the conception of human welfare.

II. VALUE SENSITIVE DESIGN METHODOLOGY

In this section, the VSD methodology is described in more detail, as are the three main phases of VSD. Then, some features and limitations of the method are discussed.

A. The three phases of VSD

The VSD methodology utilized here is based on [4] [5]. It is an iterative process with three main components: *1) conceptual phase*, *2) empirical phase*, and *3) technological phase* as illustrated in Figure 1 and described below.

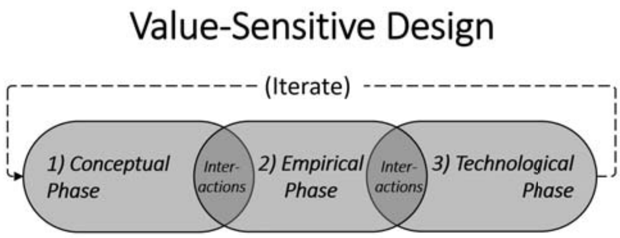

Fig. 1. Value Sensitive Design consists of three phases: a conceptual phase, an empirical phase, and a technological phase, with interactions occurring between the phases. VSD analysis can be repeated in an iterative fashion to continuously refine the design (graphic by the authors based on [4]).

1) Conceptual phase: In the conceptual phase, relevant human values are identified and an ethical analysis can take place. "The conceptual phase is dedicated to uncovering and understanding the values at stake from an ethical/philosophical stand point, as well as in the context of use." [9]. Reference [4] lists twelve human values that are relevant within technological development, and are summarized in Table 1.

The conceptual phase includes stakeholder analysis, where stakeholders are identified and their inputs on the proposed technology are considered. Stakeholders are individuals or groups which are impacted by the proposed technology, either directly or indirectly. They can include users, companies, governments, and the general public. Stakeholder inputs can be gathered in various ways, including focus groups and interviews, using qualitative and/or quantitative methods [15].

Human welfare	Includes physical, material, and psychological welfare Physical welfare deals with bodily well-being, such as physical health Psychological welfare concerns mental health, such as stress Material welfare refers to physical circumstances, and is related to economics and employment
Ownership and property	The right to possess an object (or information)
Privacy	The ability to determine what information about one's self can be communicated to others
Freedom from bias	Without systematic unfairness towards individuals or groups, including preexisting social bias, technical bias, and emergent social bias
Universal usability	Technology that can be successfully used by all people
Trust	The expectation to experience goodwill from others
Autonomy	The ability to decide, plan, and act in ways that allow one to achieve their goals
Informed consent	Garnering voluntary agreement, such as in the use of information systems
Accountability	Ensuring that actions may be traced uniquely to the person, people, or institution responsible
Calmness	A peaceful and composed psychological state
Identity	The understanding of who one is over time, embracing both continuity and discontinuity over time
Environmental sustainability	Sustaining ecosystems such that they meet the needs of the present without compromising future generations

TABLE I

HUMAN VALUES THAT ARE RELEVANT WITHIN TECHNOLOGICAL DESIGN (BASED ON TABLE 4.1 IN [4]).

2) Empirical phase: In the empirical phase, social impacts of the technology are taken into account. The empirical phase is where "human interaction with the technology" are analyzed [5], and "prescriptions for, and restrictions on, action" are defined [11] based on the context of use. Various social science methods can be utilized in this phase [16].

3) Technological phase: In the technological phase, technical capabilities are explored. Specifically, technologies which support the chosen human values/social impacts are identified and assessed. "The technical phase is dedicated to understanding the artifact (i.e. product) in context and how it manifests values or fails to do so" [9].

B. Interactions

The conceptual, empirical, and technological analyses interact throughout the design process. In practice, the interactions between the phases can be quite dynamic since design changes made in one phase can impact the other two. For example, a change in the technical solution could lead to new social risks, or new empirical inputs from stakeholders could require a technological design change. Some changes will reinforce another phase, some will have no interaction, and others will be in conflict. This process is similar to other design methods where multiple, often conflicting, requirements must be weighed and balanced. This requires judgment and creativity on the part of the designer [11]. There are many strategies for dealing with value conflicts in design, including professional judgment, direct trade-off, design compromise, satisficing, and technological innovation [17]. The interactions between the VSD phases will be described in detail via the case study in Section IV.

C. Iteration

This process of conceptual, empirical, and technological analysis is iterated as the design matures and additional insights are gained. Value conflicts, social impacts, and technological capabilities will become more concrete, and can be refined to produce an optimized product.

D. Basis of analysis

The basis for VSD can start at any phase - it can be based on a specific human value (conceptual phase), a desired social impact (empirical phase), or a promising new technology (technological phase) [4], such as drone technology. The phases do not need to be performed in a specific sequence, and in practice they will often be developed in parallel. VSD can be used to perform a retrospective analysis of an existing technology, and/or a prospective analysis of a proposed technology. For example, in a retrospective analysis of a drone, the values identified (conceptual phase) can be used to assess how well an existing prototype drone's technological attributes (technological phase) supports these values, and what the social impacts will be within the specified context of use (empirical phase). In a prospective analysis, the design (technological phase) which best supports the identified values (conceptual phase) and desired social impacts (empirical phase) is developed. In this work, an iterative retrospective and then prospective analysis are performed (Sections III and IV, respectively).

E. Applications

VSD has the flexibility to be utilized in a variety of different circumstances. It can be applied to "hard" cases, as demonstrated via the development of a command and control system for the Tactical Tomahawk U.S. Navy cruise missile [5]. It can also be used in "softer" cases, such as humanitarian applications, as demonstrated here. Even in seemingly benign or beneficial "soft" cases, VSD helps to highlight the underlying value conflicts and take stock of the social impacts, including those people that benefit and those that are harmed.

III. RETROSPECTIVE ANALYSIS

In this section, a retrospective VSD analysis of the prototype cargo drone as used by the humanitarian organization in Peru is performed. In Section IV, a prospective VSD analysis is conducted and a new drone design is proposed to address some of the limitations of the prototype drone.

A. Introduction

It is widely believed that cargo drones could revolutionize the transportation of goods, and lead to a material internet where physical items can be transported easily, much the way data flows on the internet [18]. Cargo drones could bypass traditional infrastructure (roads, bridges), like mobile phones did with telecommunications infrastructure, making them especially promising in developing countries with challenging terrain [19] [20] and in emergent situations such as humanitarian crises [21]. In healthcare, cargo drones are expected to help in saving lives and improving quality of life, for example, by quickly and inexpensively transporting medicine and blood samples between local clinics and regional hospitals [22] .

WeRobotics is a non-profit humanitarian organization that aims to take advantage of the potential drones offer; they seek to use robots and drones to improve the lives of people in emerging economies [23]. In 2017, WeRobotics tested a prototype humanitarian cargo drone - a commercially available Event 38 E384 fixed-wing mapping drone that had been modified to carry cargo [24]. The drone was used to transport blood samples and medical supplies between Pucallpa and Masisea, Peru [20] shown in Figure 2.

Fig. 2. The Event 38 E384 fixed-wing drone, as operated by WeRobotics, being hand-launched in Pucallpa, Peru (image from [25]).

1) Conceptual phase: The conceptual phase of VSD requires identification of the relevant human values and the impacted stakeholders, and ethical analysis of these values. The WeRobotics report describes having identified and engaged with a variety of stakeholders. These included local communities, regional and local doctors and clinics, local authorities and government officials, the medical technology manufacturer and distributor Becton, Dickinson and Company, the Peruvian Ministry of Health, UAV del Peru, and Peru Flying Labs [20]. "Community outreach and raising of public awareness were carried out the weekend prior to the cargo delivery field tests. This was done in person with relevant government officials, doctors and community representatives" [20]. However, no documentation of the values of various stakeholders (which will undoubtedly be varying) was found. One common risk with stakeholder engagement is that those critical of a new technology are often excluded from the development process [26]. This analysis was restricted to the use of secondary data, so the values of WeRobotics we used as a proxy to represent those of all stakeholders. A future, full VSD analysis should investigate stakeholder values in depth.

WeRobotics' values can be extracted from their mission statement and development goals. They aim to develop "robotics for the benefit of all", and "to sustainably localize appropriate robotics solutions in low-income countries to accelerate the positive impact of aid, health, development and environmental efforts" [23]. In addition, they strive to contribute to several of the United Nations Sustainable Development Goals (UN SDGs). These statements are mapped to the list of twelve human values in Table 1:

- "The benefit of all" = Human welfare; Universal usability
- "Sustainably" = Environmental sustainability; Material welfare
- "Aid" = Human welfare (Physical, Psychological, and Material welfare)
- "Development" = Material welfare
- "Environmental efforts" = Environmental Sustainability

WeRobotics' aims implicitly suggest additional values about the enhancement of human welfare via technological innovation, specifically, the positive development of disadvantaged/vulnerable ("low-income") local communities ("localize"). This development could lead to local communities that are more autonomous and able to develop their identity. These elements correspond to the values of human welfare, autonomy, and identity in Table 1.

Another aim of WeRobotics is to contribute to the United Nations Sustainable Development Goals (UN SDGs) [23]. The health sector programs are designed to contribute to the following SDGs, which are again mapped to the values identified in Table 1:

- Goal 3: Good health and well-being for people = Physical, Psychological welfare
- Goal 9: Industry, innovation, and infrastructure = Material welfare
- Goal 10: Reducing inequalities = Material welfare, Psychological welfare
- Goal 11: Sustainable cities and communities = Environmental sustainability
- Goal 13: Climate action = Environmental sustainability
- Goal 14: Life below water = Environmental sustainability
- Goal 15: Life on land = Environmental sustainability

There is no documented ranking or prioritization of these values, so the following assumptions will be made for the purposes of these analyses: the drone's primary function is to transport blood samples which contributes to the physical welfare (health) of the patient. Therefore, the physical and psychological welfare of patients will be taken as the highest priority. Material welfare of the "low income" local community will be ranked second, and environmental sustainability third.

The stated values are well aligned with the human values identified in Table 1 [4], giving them ethical validity. A more thorough ethical analysis would examine ethical issues in more detail. For example, the approach to the ranking of values can be framed. If unethical stakeholder desires are identified, these can be addressed. Differing conceptions of wellbeing with regards to isolation or connection could be assessed: small villages could remain isolated, and perhaps peaceful, or be connected to larger cities, which might offer more healthcare and economic opportunities. The adoption of cargo drones would offer a much different type of connection to larger cities than traditional infrastructure such as bridges and roads. The concept of technological paternalism - when more powerful stakeholders such as developed countries or humanitarian organizations may risk to impose their values upon less powerful parties such as developing countries - could be relevant here. Most likely, no technology can satisfy every person's values at the same time, so a transparent and fair process should be followed.

In summary, the result of the conceptual analysis is that physical welfare, psychological welfare, material welfare, and environmental sustainability - in this order - are the values that should be supported.

2) Empirical phase: In the empirical phase, the context of use, current practices, and social norms should be understood. This analysis is limited to the use of secondary data, and while the technological aspects of the project are well documented, elements of an empirical investigation are less well known. Still, relevant considerations can be discussed.

The drone was operated in the Amazon of Peru, flying between the village of Masisea (population 12,000) and the city of Pucallpa (population 200,000). According to [20], the existing healthcare practice involves transporting patients from Masisea to the hospital in Pucallpa, typically by charter boat on the Ucayali River, where they are treated in-person. The boat trip takes between two and four hours, and boat services run once or twice per day leading to wait times up to twenty-four hours [20].

A detailed understanding of the current process is required as adoption of the drone could lead to significant changes in healthcare practice. It could be possible that, despite being logistically challenging, in-person care is better for the patient, and that a better diagnosis is possible. Unemployment rates in Peru are low (3.7%) [27], but local employment rates, conditions, and skills should be investigated - what skills exist, and what skills would the residents wish to develop. The current practice involves hiring a charter boat, which adds to the material welfare of the boat operator in the form of income. An assessment of the financial impacts to the local economy would be beneficial. The intensification of cargo drone services could have far-reaching implications regarding infrastructure investments in the area. It is possible that traditional infrastructure such as roads and bridges will not be built if cargo drones are commonplace. This has significant implications for the physical, psychological, and material welfare of stakeholders. In addition, cultural norms and values should be understood and fed into the analysis.

3) Technological phase: In the technological phase the technology is described and assessed for how well it supports the human values and desirable social impacts identified earlier.

The prototype drone is pictured in Figure 2. It is a model E384 fixed-wing, electric powered mapping drone produced by Event 38 in Akron, Ohio U.S.A [28] that was modified to carry medical samples instead of a camera. It has a wingspan of 190 cm, a maximum take-off weight of 3.5 kg, and a maximum payload capacity of 800 grams [20]. It has a flight range of up to 70 km, a cruise speed of 47 km/hr, and a cost of 3,000 USD [29].

Physical welfare: The drone is expected to reduce diagnostic time from between two and twenty-four hours to around one hour in total; thus, the use of the drone is expected to increase patient's physical welfare. When the drone is used, patients have their blood sample taken at the local clinic in Masisea. The patient remains in Masisea, while their blood sample is transported by drone to Pucallpa where it is analyzed at the hospital. The drone flies a direct route over the river and jungle to the edge of the no-fly zone of the Pucallpa airport where it lands [25]. The drone flies a distance of forty kilometers and completes the flight in just under one hour [20].

Safety risks exist as well, which could negatively impact physical welfare. These risks include the possibility of the drone striking an aircraft, hitting someone on the ground, injuring the operator, or spilling the blood sample. Drone flights are customarily designed to be at least as safe as manned aviation, with maximum one fatality per million flight hours [30].

This flight operation is classified as Air Risk Class Two (four is the maximum) - the risk of collision between the drone and a manned aircraft is very low [30]. The drone's take-off and landing zones are the required five kilometers outside the airport, but a system failure could allow the drone to enter the airport's airspace. The drone failed in one out of five flights [20], which is fairly unreliable, but not uncommon for small drones [31]. This was preliminary testing, so it is possible future operations will be more reliable.

The risk of hitting someone on the ground is also low. The population density in Peru is half the world average (twenty-five versus fifty-one people per square kilometer [32]), and the drone is flying over sparsely populated jungle for the majority of the flight. The drone has around three hundred joules of kinetic energy at cruise speed, which places it in Risk Class two out of eleven [30]. Still, the drone could cause serious injury or even a fatality under some circumstances such as an impact to the head when in a high-speed dive [33].

Risks of operator injury are relatively minor; these include the drone's battery catching fire (which usually occurs during charging or in a crash), and an operator getting cut by the spinning propeller. The drone's configuration, with the motor somewhat protected behind the main wing, makes it safer than a drone with a front-mounted motor.

The blood sample payload is a category B, class 6.2 infectious or potentially infectious substance, and must be packaged in double-layer containers with an absorbent material between the layers [34]. These containers are made of impact-resistant plastic, and it is likely they are able to withstand a crash without spilling, but this could be verified experimentally.

Psychological welfare: Empirical studies in other contexts of use identify the value of psychological welfare via privacy being impinged upon by drones [35], and although the prototype no longer carries a camera, research shows that people may assume all drones carry cameras [36]. The drone used by WeRobotics is difficult to see when it is at cruise altitude (it is mostly white and relatively small), and almost silent (due to the electric power system) [25] making it quite stealthy. This could lead to a so-called "chilling effect", where people modify their behavior because they feel they are (or could be) being observed at all times [37].

Material welfare: The material welfare (i.e. jobs, the economy) in the region will be impacted by introduction of the humanitarian drone. The flight path of the prototype drone is programmed by a drone operator via the ground station laptop using custom 'Mission Planner' software [38]. The drone flies autonomously, but is monitored by the pilot from the ground station. The drone and its medical payload are retrieved at the landing site in Pucallpa and launched again to return to Masisea. Operators need the skills to program the drone's flight path and monitor the flights. Staff must also maintain the drone and repair it when it is damaged, as well as performing more routine activities such as changing batteries, loading the medical samples, and hand-launching [20]. These jobs will provide material welfare (i.e. income) to those that are part of the operation. The level and type of automation the drone possesses has a direct impact on the staff via the types of job skills and activities required for its operation. A widespread adoption of drones could create a shift in the type of work available in the region that requires different skills and different competences.

Widespread adoption of cargo drones could have a substantial impact on the local and national economy. It is likely that local charter boat operators will be harmed financially by the implementation of the drone service due to the reduced number of patients they will transport. However, patients and their families will benefit since they will no longer have to pay for the transportation. Overall health care costs could be substantially reduced by faster transportation and diagnosis, benefiting the Peruvian Ministry of Health and Peruvian taxpayers.

Environmental sustainability: The drone operation will also have an impact on the environment. The value of environmental sustainability requires both the preservation of nature and minimizing pollution. The E384 drone will impact the environment during its entire life-cycle, via extraction of the materials it is constructed from, manufacturing of the drone in the U.S.A., its transportation to WeRobotics, its use in the Amazon of Peru, and its disposal or end-of-life. The manufacturing process includes building the airframe and the power and control electronics. Producing the printed circuit boards in a drone and its ground-control station has been shown to have the most significant impact on toxicity and the climate [39]. The use-phase has a much greater impact than that of manufacturing though; in one case, the use-phase constituted 95% of the impact compared with 5% for manufacturing [39]. The prototype drone has an electric motor and lithium-polymer batteries and uses at most 0.48 kWh of energy per round-trip flight [20]. For comparison, the river boat uses fossil-fuels and consumes on the order of one-hundred times more energy [40] per round-trip (40-80 kWh, assuming a 10 kW motor). The drone only needs to carry a payload of 800 grams, while the river boat must transport hundreds of kilograms. The river boat will produce between 16 and 32 kg of carbon-dioxide per round-trip while the drone will produce only 0.6 [40]. Twenty-five percent of the Peruvian energy grid is produced from renewable sources [27] which makes the electric powered drone even more environmentally friendly than the technology it replaces. Thus, the drone is significantly more environmentally sustainable than the conventional transportation method it aims to replace by virtue of the very small payload and the cleaner energy source.

In summary, WeRobotics' main foundational values - physical welfare, psychological welfare, material welfare, and environmental sustainability are embodied and supported by the Event 38 drone. In particular, the physical welfare (i.e health) of patients is expected to be positively increased by the reduced transportation time. The physical welfare (i.e. safety) of those exposed to the drone operation will not be substantially reduced since the safety risks are low. The very small payload and cleaner electrical power system make the drone more environmentally sustainable than the current transportation method. The main risk the drone poses is to the material welfare (i.e. jobs, economics) of some of the local population, in particular the river boat operators. The drone will initiate changes in the workforce which could require retraining. In addition, the positive impact of reduced healthcare costs could be annulled by the negative implications with respect to infrastructures investments such as the building of roads and bridges.

IV. PROSPECTIVE ANALYSIS

VSD methods are now used to carry out a prospective analysis, where a new drone design is developed via a second iteration of the conceptual, empirical, and technological VSD cycle. The aim is to develop a drone that better supports the human values of physical welfare, psychological welfare, material welfare, and environmental sustainability.

Physical welfare: The value of physical welfare in this context can be understood in terms of maximizing the healthcare service ability and the safety of the drone. This means that the drone should provide rapid and reliable transportation of blood samples from Masisea to Pucallpa while being as safe as possible. The faster the blood samples are analyzed, the better the patient's health outcome; quarantine of potentially sick people could be eliminated or reduced in duration, and the unnecessary use of broad-spectrum antibiotics could be reduced. Therefore, a high-speed drone will be desirable. A fixed-wing drone is faster than other drone configurations such as multirotors and hybrid vertical take-off and landing (VTOL) aircraft due to its lower drag. A fixed wing drone with internal combustion engines (two, for redundancy) could easily attain a cruise speed of 100 km/hr. Small internal-combustion, model aircraft-style engines have significantly more power and range than equivalent electric motors - the fuel has a specific energy one-hundred times greater than batteries [40]. This would cut the transportation time down to 30 minutes. However, fixed-wing drones lack vertical landing capability, meaning it could take longer to retrieve the samples if the drone lands far from the hospital [20]. Instead, it could drop the payload directly at the hospital via parachute to avoid needing to land, and it would have enough range to return to the village without stopping. Only one landing site at Masisea would then be necessary. Fuel has more energy than batteries, but it also has a greater environmental impact [40] - this is a value conflict, as discussed in Section II. *B. Interactions*. The value of physical welfare and the value of environmental sustainability are in opposition. The value of physical welfare was ranked as most important during the conceptual analysis, so a design compromise would be to value physical welfare over environmental impacts and select the internal combustion engines as power sources. This conflict identifies an opportunity for technological innovation, specifically, the need to develop high energy-density power sources that are environmentally friendly, so that design compromise is not necessary.

Attempting to maximize the safety of the drone leads to other value conflicts. A high-speed drone increases safety risks - a faster drone has more kinetic energy and can cause more serious injury. This is a conflict between the positive value of physical welfare the drone supplies by transporting blood samples, and the negative physical welfare via safety risks caused by the drone's operation. As noted, the safety risks are low, so one solution is a high-speed drone with additional passive safety features. A large, rounded frangible nose would reduce injury in case the drone hit someone on the ground. A pusher-propeller configuration with the engines in the back of the aircraft, and shrouds around the propellers, would increase operator safety. The drone must be reliable to provide a valuable healthcare service but also to ensure safety. As suggested in [41], both tasks can be achieved by using redundant actuators and flaps on the primary control surfaces. The high-speed drone would be more tolerant of wind, so it would be able to operate in adverse weather conditions and provide more reliable service. The drone should be programmed to stay out of the airspace around the airport, reducing the chance of hitting an aircraft. In order to increase safety and make the payload drop more accurate, the flight speed should be reduced around Pucallpa.

Psychological welfare: To counteract the potential risks to psychological welfare identified in the retrospective analysis such as privacy and the "chilling effect", it would be beneficial to make the drone highly visible with lights and painting it in bright colors [9]. Its twin internal combustion engines will give it a distinctive sound profile during its operation, meaning that, by design, it could not act or be perceived as an effective spy drone, supporting the value of privacy. The aircraft could be marked with a logo that indicates it does not carry a camera on board, and this fact could be explained to the medical staff and local communities to reduce any chilling effect. The safety of the physical system plays a part on psychological welfare - if the drone is either unsafe, or perceived to be unsafe, it could create fear in the local population.

Material welfare: The value of material welfare in this context can be understood as maximizing financial benefits, economic opportunities, and high-quality employment. Jobs provide money for meeting physical needs (the values of physical and material welfare), but they also play an important part in a person's mental well-being (the values of psychological welfare), as well as their dignity and self-respect (the value of identify) as shown in Table 1. Local design, manufacturing, and maintenance of the drone could create technical jobs for people living in Peru. Local design could potentially produce better products since the designers would have more intimate knowledge of the drone's operational environment and its possible social impacts on local communities. The choice of drone power source could ease the transition for the local workforce - internal combustion engines, as used in river boats, are familiar power sources. But developing the skills and infrastructure required to produce drones in Peru would be a significant undertaking, and impact jobs outside of Peru (in the U.S.A., in the case of the Event 38 drone).

At a smaller scale, employment possibilities and material welfare can be modulated based on the drone's type and level of automation. High-levels of autonomy can mean fewer jobs (or at least different types of jobs); the type of autonomy dictates what tasks humans must perform and what tasks the drone must perform. Readily available technology allows drones to fly autonomously without operator input after being programmed. Humans need to fuel the engine or charge the batteries, load the payload into the drone, launch, and recover the drone and payload at the landing site. If an automatic system for loading of the payload were added, this would displace the human labor. In this operation, reliability and safety are important as the drone must dependably transport the medical cargo, and adding human labor could be beneficial. For example, an extended visual line of sight (EVLOS) operation could be utilized [30]. The drone pilot could oversee the flight at the ground station while spotters on the ground could monitor the drone at critical locations, such as during payload drop, flying near the airport, and flying over highly populated areas. The spotters could report any problems back to the safety pilot who could immediately take over manual control of the drone and mitigate the risks of the situation. Such an operation requires well-trained personnel and well established operating procedures to be effective.

Environmental sustainability: The new drone's design will influence its environmental sustainability. A discussed in Section III, the drone's use-phase is the most significant environmental challenge, which is tied to its power source. The chosen internal combustion engine prioritizes the physical welfare of the patients over environmental sustainability, but is still much more environmentally friendly than river boats. Alternatively, electric power in conjunction with solar panels could be used, but the drone's speed and range would suffer, leading to a prioritization of sustainability over physical welfare. The drone could be designed in a modular fashion, so that components can easily be exchanged, and so that it can be disassembled to recover usable components and materials. Sustainable and recyclable materials should be chosen, especially as alternatives to commonly used non-recyclable carbon fiber reinforced plastic structures. There should be a safe method for disposal or recycling of the batteries, and dealing with hazardous electronic waste. Design for end of life (EOL) and circular economy principals could help mitigate these risks [42].

In summary, the proposed new drone design - representing a second iteration of the VSD process - should better support the values of physical welfare, psychological welfare, material welfare, and environmental sustainability. The new drone differs from the prototype in subtle but critical ways, demonstrating the far-reaching ramifications of simple technological choices as well as the embodied values paradigm. The new drone is twice as fast as the prototype. It is powered by internal combustion engines instead of electric motors which gives it a longer flight range. It utilizes redundant actuators and more passive safety features. The new drone utilizes modular components which are easily replaced, exchanged, and recovered when the drone reaches its end-of-life. The level and type of automation is carefully designed to maximize high-quality employment and reliability. A safety pilot monitors the flight at all times, and spotters report the drone's progress at safety-critical locations. In the future, the new drone could potentially be locally designed and manufactured, supporting the local economy.

V. DISCUSSION

In this section the VSD methodology is assessed and placed into context, and limitations of the case study are presented.

A. Benefits and drawbacks of Value Sensitive Design

VSD has benefits and drawbacks. It adds more requirements to the design process, including the consideration of human values, social impacts, and multiple stakeholders, making the process more complex. It is an interdisciplinary approach, which means it requires a diverse team of engineers, social scientists, and ethicists. VSD takes the technology as a given and then tries to optimize it, but there are situations where *not* developing a technology may be the most appropriate solution (the value sensitive alternative approach, as described in [15]). *Not* developing a technology should always be a consideration for engineers and designers; Aristotle was skeptical of innovation and considered it disruptive to the social order [43].

Yet VSD has key benefits which make it appealing. It directly supports human values, which is arguably the purpose of technological development. It can lead to technologies that are more readily accepted by the public and other stakeholders. By including multiple stakeholders, VSD reduces the risks associated with over-emphasis of a single viewpoint. For example, it addresses the risk of technological paternalism where engineers, companies, governments, or even humanitarian organizations risk to impose technologies upon less powerful groups. And it addresses a limitation of user-centered design where users could desire unethical products or those with adverse social or environmental impacts. Inclusion of multiple stakeholders makes VSD a more democratic design practice.

B. Limitations of the case-study

The case-study analysis was confined to the use of secondary data, leading to a number of limitations. The values of most of the stakeholders that would be impacted by the technology were not documented; instead, WeRobotics' values were used as a proxy. In addition, only the most-mentioned values were analyzed. Very little empirical evidence was available, meaning the interactions of the technology with the local community was in short supply.

Other values could also be relevant - for example, the values of trust and accountability. These could be supported by including design feature (e.g. painting it in a similar way to an ambulance) or markings (in the local language) which identify the origin, purpose, and authority of those operating the drone, and including a digital license plate [44]. The value of calmness may be relevant, especially in the case of the louder, internal combustion engine-powered drone. A better understanding of human-drone interaction at large distances would inform many of these concerns.

These issues impose limitations to the direct applicability of the resulting drone's specifications. However, the main contribution - demonstrating the VSD methodology and highlighting relevant considerations within the context of humanitarian drone development - is maintained.

VI. CONCLUSION

This iterative analysis demonstrates that VSD may be used to develop "ethical technology" - a drone that better supports the values of human welfare (physical, psychological, and material welfare), and environmental sustainability. The retrospective and prospective analyses highlight the intimate relationship between the conceptual, empirical, and technological phases of VSD, and how technologies embody non-epistemic values.

A. Future work

Despite over twenty years of development, the application of VSD methods is still limited, and the use of VSD to create "ethical drones" is at its infancy. In the future, VSD methods should continue to be refined and applied to existing and proposed drone technologies. The case study explicated here could be developed further, a complete VSD analysis performed, and a value sensitive design "ethical drone" built.

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