From HealthDrone to FrugalDrone: Value-Sensitive Design of a Blood Sample Transportation Drone

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Abstract - **In this work the preliminary design of HealthDrone, a cargo drone for blood sample transportation in Denmark, is performed using the value-sensitive design (VSD) methodology and an ethical framework. The ethical framework includes five ethical principles: beneficence, non-maleficence, human autonomy, justice, and explicability. First, a commercially available Wingcopter 178 drone is analyzed in the context of the blood sample transportation case; then, a redesigned drone is proposed. The redesigned drone is renamed FrugalDrone to signify its main beneficent characteristic: providing inexpensive transportation of blood samples. FrugalDrone's design addresses other relevant human values including health, safety, accountability, and environmental impacts. This work is aimed at the drone design community and interdisciplinary researchers. It contributes by evolving the VSD methodology via an ethical framework and applies it to the emerging domain of drones in public healthcare.**

Keywords—value-sensitive design (VSD); cargo drone design; ethical framework; values hierarchy; Danish public healthcare

I. INTRODUCTION

A. Background

Commercially-operated healthcare cargo drones are already being used in several locations around the world, including in Rwanda by Zipline and in Switzerland by Matternet. In the public health domain, drones could provide more efficient healthcare as financial concerns dominate the discussion. The current approach in Denmark, the context of this case study, is "centralization and specialization" - some smaller hospitals will be closed while new "superhospitals" are being built. The 10-year project is expected to cost 5.5 billion euros [1].

The case examined here, referred to as HealthDrone, entails the transportation of blood samples from Svendborg to Odense, Denmark. The project aims at improving public healthcare outcomes, reducing costs, and improving environmental sustainability. It has a total budget of 4 million euros and claims that "the use of health drones is expected to save the Danish hospital sector 27 million euros per year" [2].

B. Value-Sensitive Design and a Values Hierarchy

Value-sensitive design (VSD) is a pro-active design methodology which attempts to support human values via product design. VSD shows the connection between abstract philosophical values, social impacts, and tangible product features, and how design supports or diminishes certain values. It is an interdisciplinary approach taking inputs from philosophy, social science, and engineering. It can be used retrospectively to assess existing technology, prospectively to develop new technology, and iteratively to refine a product. Recently, VSD has been applied to drones [3] [4].

Van de Poel [5] introduced the idea of a values hierarchy to facilitate the translation of (abstract) values into design requirements (tangible product features) in VSD. In this work, the hierarchy contains four layers: ethical principles, human values, social norms, and design requirements.

II. ETHICAL FRAMEWORK

Recently, ethical frameworks intended to lead to the development of technologies for the "good of society" have been proposed within biotechnology [6] and artificial intelligence [7]. These ethical principals have been used to develop and evaluate emerging technologies by framing the activity as a socio-technical experiment conducted in the public space [8]. Here, five ethical principles are applied to the HealthDrone case: beneficence, non-maleficence, human autonomy, justice, and explicability.

A. Assessment of a Commercially Available Drone

The drone must be able to travel between Svendborg and Odense hospitals (46 km), have the payload to carry at least one blood sample, and be as light-weight as possible to maximize safety and minimize legal restrictions [9]. The HealthDrone project partners have not yet identified which drone they will use, but one possibility is the Wingcopter 178 shown in Fig. 1 [10]. The drone has a 1.78 meter wingspan, weighs 9.9 kg (the heaviest weight category allowed by current Danish legislation [9]) and can fly 45 km with a 6 kg payload

[10]. It can take off and land vertically, is electric powered, and built from carbon fiber and fiberglass materials [11].

B. Beneficence

The ethical principal of beneficence states that technology should be "beneficial to humanity" [7]. The HealthDrone project partners expect benefits to the values of human physical welfare (health), human material welfare (cost savings), and environmental sustainability [2]. They believe the drone could contribute to human physical welfare by reducing waiting time for blood sample analysis and thus the need to administer broad-spectrum antibiotics [12] or to implement quarantine if the patient may be contagious (i.e. with the flu) [2] benefiting public health. Testing is needed an average of 32 times per day [13] and samples are transported in batches by car (30-45 minutes with usual traffic); the Wingcopter drone could make the trip in around 30 minutes. Crucially, delivery currently takes place twice a day on weekdays and once a day on weekends, giving an average waiting time of 12 hours [2]. The Wingcopter drone could reduce this waiting time significantly if it is operated more often (as could more frequent driving). Material welfare could be improved through costs-savings if transport by drone is less expensive, benefitting Danish taxpayers (although one study shows large hybrid drones like the Wingcopter are more expensive than driving [14]). The Wingcopter drone is electric; 62% of electric power in Denmark comes from renewable sources [15] which could make it more sustainable than driving using fossil fuels. A life-cycle assessment would show the full environmental impact.

C. Non-maleficence

The ethical principal of non-maleficence means that the technology should "do-no-harm". Non-maleficence means avoiding the creation of technologies that make humanity worse off. Unfortunately, several harms are possible. These include safety and security, privacy, jobs, the environment, capability risks, and technological paternalism (the latter is discussed in section *D.* about human autonomy).

A goal of the project is that the drone has an equivalent level of safety (ELS) to commercial aviation: less than one fatality every-ten million flight hours [16]. The greatest risks occur in areas with high population density – here, near the hospitals in Svendborg and Odense. Flying in "safety corridors" which avoid roads and populated areas could reduce this risk [2]. The current method, transportation by car, is extremely safe with around 4 fatalities per billion km driven [17]. In this case, the probability of a fatality from driving is $1.8*10^{-7}$ while the probability of a fatality with a drone *operating at ELS* is $1.5*10^{-7}$. The drone would be slightly less dangerous than driving and therefore less maleficent – *provided the real drone can operate at ELS.* The Wingcopter has not yet logged enough flight hours to reliably determine its level of safety. In addition, there is an important difference between commercial aviation and drone flight – in the former, passengers actively accept the risk when they board the flight, while in the latter those on the ground typically do not have the opportunity to accept the risk of a drone operation. Therefore, ELS should only be used under the condition of informed consent (discussed in Section III.)

The drone will carry potentially infectious blood, another safety risk; the samples must be packaged in primary and secondary leak-proof receptacles with absorbent material in-between and a structural outer container [18]. Security risks include the possibility of hacking to hijack or intentionally crash the drone.

Fig. 1. The Wingcopter 178 drone [19].

Privacy violations are another well-documented potential risk of drones in Denmark [20] [21]. Most privacy issues are linked with the use of cameras. The project partners state that general photography cameras will not be installed [2]. Even so, it has been found that some members of the Danish public believe all drones carry a camera so the Wingcopter can still violate the *perception* of privacy [20]. Bodily privacy is relevant when transporting blood samples as they include a patient's DNA. The sample bottle can contain personal information such a civil registration (CPR) number. Currently, the courier is entrusted with the samples and ensures that they are transported in a way that maintains patient privacy. The Wingcopter drone would fly fully autonomously with a safety pilot overseeing the operation [2], but there would not be a person with direct control over the samples.

The drone may impact the quantity and nature of jobs available. It could eliminate courier jobs and create jobs such as drone safety pilot. The Danish unemployment rate is 5% and the population of Odense is 200,000 meaning 10,000 locals are currently seeking work. It is highly unlikely that the initial implementation will have any substantial impact on the (un)employment rate in the region. Still, these new jobs would not be equivalent in kind - many drone jobs would be "high-tech", benefitting those with higher-level education and computer skills.

Environmental risks exist as well; the drone could facilitate a "rebound effect" where its use is increased, increasing environmental impacts (as well as safety, privacy, etc. risks). The Wingcoper's impact on birds, bats, and other animals has not yet been documented. The drone is made from non-recyclable composite materials, limiting the end-of-life options.

Capability risks are also present. Capability caution refers to setting upper-limits to the capabilities of a technology so that it remains under human control and cannot (easily) be misused [7]. For example, manufacturers often produce dual-use drones that can be used for civil or military applications, or they build drones that can take any payload making misuse easy. There is nothing to prevent the Wingcopter drone from being used for military purposes, or any limits to its cargo.

Direct maleficent (harmful or evil) use of the drone must also be considered. It will be operated by healthcare professionals, who generally have a high degree of trustworthiness. Still, the Wingcopter drone has a payload capacity of six kilograms, giving the ability to carry an explosive the size of those detonated in Venezuela [22].

D. Human Autonomy

This principal relates to freedom and is associated with the values of human agency and responsibility [7]. Agency includes decision-making and control, and includes control over autonomous systems like drones. The practice of blood sample transportation between hospitals can be conceptualized as goal-directed activity within the care practice [23]: there is no direct interaction with the patient and the transportation meets an instrumental need for the healthcare practitioners. Therefore, it seems that the Wingcopter drone will not detract from patient care or autonomy. Further research can study how the drone impacts the autonomy of the healthcare practitioners, their workflows etc.

Initial investigations indicate that the Danish public is more accepting of drones that are implemented by trusted entities for "good" uses: "There is…a higher level of tolerance when it comes to the use of drones by 'public service' organizations or drones that perform 'clear and valuable tasks'" [21]. HealthDrone arguably falls into this category, although it does not perform direct life-saving operations. Critics point to the initial introduction of "good drones" as a gateway to public acceptance - once the public associates positively with drones, other, less responsible designs and uses will emerge.

HealthDrone would be publicly operated; studies have found that some Danish citizens do not trust the local government and find drones an additional intrusion: "what about the municipality? they are already snooping around" [21]. However, in general, there is a high level of trust of the government in Denmark and the HealthDrone is well positioned to be considered trustworthy. Ironically this can lead to a risk of citizens being taken advantage of by having the drone pushed upon them by the Danish government and technology developers – a form of technological paternalism. A way to avoid this risk is inclusion of impacted stakeholders and even critics during the design and implementation process [24] as in the VSD methodology.

E. Justice

The ethical principal of justice relates to legality as well as the values of fairness, such as the (equitable) distribution of benefits and harms [7]. Cost savings and better health outcomes would be beneficial to Danish taxpayers and the general public. Risks to safety, privacy, and jobs would also be placed upon the public. In the driving scenario, pedestrians, bicyclists, and motorcyclists are most vulnerable, followed by motorists (i.e. the driver) [17]. For the drone case, people living near the hospitals and safety corridors are most at risk. Residents over the age of 65 benefit the most from increased blood sample testing - they are most at risk of diseases such as the flu that can be identified in blood tests [25].

Couriers currently transporting the samples risk unemployment. Initially this impact appears minimal since only two trips are performed per day and the Danish government ensures good unemployment benefits. Still, widespread implementation of drones as an integral part of healthcare logistics would be one more step in the "transformative" sweep of automaton [26] and could end in widespread unemployment. This risk may be at least partially mitigated with government-sponsored re-training.

Fairness is critical when deciding how technology is implemented. Is the default that citizens are assumed to "opt-in" i.e. accept the technology, or "opt-out"? And if they are assumed to opt-in, do they still have the choice to opt-out later? Typically, after testing, such projects proceed assuming citizens have opted-in, with lawmakers and technology developers having, by proxy, given consent on behalf of the public.

F. Explicability

Explicability deals with the ease at which systems (especially complex or "opaque" systems) can be understood [7]. This principal is linked with the idea of "transparency", in contrast with a system that operates as a "black box". Two related values are that of intelligibility - what is happening inside the "black box" - and accountability - who or what is responsible (blame-worthy, praise-worthy [27]) for the system's behaviors.

Bajde et al. [20] studied elements of explicability via the public's level of "disturbance and uncertainty" when exposed to a drone operation. It was found that three factors play an important role: perceived height and distance to the drone, unclear purpose, and uncertain legitimacy. Participants in the experiment reported being "comfortable" when the drone was over 50 meters away. The Wingcopter drone will cruise at up to 100-meters altitude, meaning it will be at a comfortable distance from the public (outside take-off/landing). It will predominantly fly direct routes, indicating by its behavior that it has a clear purpose. And the drone will be operated by a public entity which adds to its legitimacy.

Still, even if citizens are comfortable with the technology it is preferable to create an easily understood system that actively affirms its legitimacy. The restriction that the drone be operated at a comfortable distance conflicts with visual means of explicability - seeing the Wingcopter drone from the ground will be challenging due to its size and white color (which will be difficult to detect in flight especially on a cloudy day). Silhouette is critical to visibility, and here the drone performs well - it has a unique shape. However, it is commercially available and could be used outside of public healthcare, so the silhouette does not ensure legitimacy. It lacks any markings that indicate its purpose, or that it does not carry a general photography camera.

Accountability could also be a challenge in the project. Experiments in Denmark have shown that people expect every drone has (one) human operator, and that the operator is nearby - if they see a drone they look around for the pilot [20] [21]. The Wingcopter drone would be operated from beyond view of the public (currently requiring special permission from the

Danish traffic authority for flights "beyond visual line of sight of the operator" [9]). And eventually it would not be controlled directly; its flight would be autonomous and only be overseen by a safety pilot [2]; both factors reduce accountability.

III. REDESIGNED DRONE - FRUGALDRONE

When designing new technology, innovation can create new solutions to ethical problems. "Technical innovation can entail moral progress...(because) it enlarges the opportunity set by changing the world in such a way that we can live by all our values" [28]. However "new options also bring new side-effects and risks" [28] which must be managed. An innovation approach will be used here to manage these opportunities and risks while redesigning HealthDrone [29].

The redesigned drone's design requirements should support the five ethical principles and their corresponding values and relevant norms. Ideally, the drone will (among other factors discussed earlier): be beneficial (cost, health, jobs, environmental sustainability), do no harm (safety and security, privacy, jobs), enhance human autonomy (trust), be just (fairly distribute benefits and risks), and be easily understandable (explicable). If this can be accomplished, the HealthDrone socio-technical experiment can proceed.

A. Results

The proposed drone is shown in Fig 2. and is renamed FrugalDrone to reflect its purpose and primary design goal: to reduce transportation costs. It is a small fixed-wing drone which maximizes beneficence as shown in Table I – small fixed-wing drones have the lowest fixed and recurring costs [14]. It has a 1-meter wingspan, a range of 60 km, a 250-gram payload to carry at most a few blood samples at a time, and weighs around one kilogram (its specifications are similar to the Drone Volt DV Wing [30]). The drone is catapult launched from the hospital roof and recovered by flying into a net; this reduces the weight compared to a vertical take-off drone (but increases infrastructure costs [14]). Solar and wind energy are collected from the hospital roof to recharge the drone's batteries, ensuring it operates on 100% renewable energy.

FrugalDrone flies between Svendborg and Odense in one hour. Critically, waiting time is reduced to minutes as a drone can be launched each time a blood sample needs testing. More frequent transportation will be required to reduce waiting time under 12 hours irrespective of the method of transport. This increases the risks associated with driving, the Wingcopter drone, or by FrugalDrone; the strategy with FrugalDrone is to minimize the severity of harm should a failure take place.

Fig. 2. Preliminary design of FrugalDrone (rendering via [31]).

TABLE I: VALUES HIERARCHY FOR BENEFICENCE VIA COST SAVINGS

Ethical Principal	Beneficence
Value	Cost savings
Norm	Reduced cost vs driving (110 Euro/trip)
Design Requirement	Small fixed wing configuration [14]

TABLE II: VALUES HIERARCHY FOR NON-MALEFICENCE VIA SAFETY

Ethical Principal	Non-Maleficence			
Value	Safety			
Norm	Safer than driving (1.5*10^-7 fatalities per round-trip)			
Design Requirement	Minimize weight <1.5 kg	Minimize impact speed <60 km/hr	Maximize "bluntness" >10 cm	Components < 300 grams

Reducing maleficence via safety risks is shown in Table II. FrugalDrone is slow and light-weight to minimize injury. The nose is large (maximizing "bluntness") and the motor is in the back to reduce damage from forward impacts. The drone's battery weighs under 300 grams so as not to damage an aircraft engine if ingested [32]. It is in the lightest weight category under Danish legislation [9], and the lowest risk category [16]. The cruise speed is low at 12 m/s (43 km/hr) to increase inherent safety; therefore, a failsafe system such as a parachute is not required [16].

Reliability will be critical in building trust in the technology. FrugalDrone has positive aerodynamic stability and split, redundant elevator and rudder controls and individual actuators to increase reliability [33]. Its actual level of safety will need to be tested to see if it can achieve ELS. If implemented, it can first be used to deliver urgent/acute samples. Vehicle transport should remain possible as a back-up if the drone fails or if the weather prevents flying [34].

Potential misuse of the drone is reduced as the payload capacity is not over-specified. A uniquely-shaped blood sample container must be inserted into the cargo bay before the motor will operate. The cargo bay is locked so it can only be accessed by the hospital should the drone crash or be intercepted during flight. The blood sample is anonymized and does not include personal information such as the patient's CPR number, protecting privacy. "Geo-fencing" is used to prevent the drone from flying into unauthorized locations such as within 5 km of

a public airport or 8 km of a military airport [9] via DroneID [35]. Security is ensured by using encrypted communication links.

FrugalDrone is a fixed-wing configuration with a familiar aircraft shape, aiding explicability. It is easy to see which direction it is flying (compared with a symmetrical multirotor drone), again aiding explicability. It is painted bright yellow like the Danish medical helicopter. It does not carry a camera to support privacy, and is marked with a "no camera" icon. A biohazard marking signals its (potentially) harmful payload. The drone is intentionally non-anthropomorphic and non-zoomorphic; although giving the drone human or animal features (such as eyes and a smiley face) can illicit positive feelings and increase acceptance [36], it is positioned as a mechanism rather than a social robot, and its functionality does not depend on social interactions.

Fig. 3. Preliminary design of the proposed informed consent and explicability-enhancing smartphone app. It is presented in English, but the default language will be Danish (graphic by the authors).

FrugalDrone supports fairness by utilizing the approach of informed consent (traditionally applied in web applications) in its design and implementation [37]. First, the public is informed that a drone operation is taking place. Second, they must accept the risks of the flight (while also being informed of the benefits). If more than 10% of the population strongly disapproval of the project (identified as a heuristic for a "value dam" in the literature [38]), the operation is halted.

Informed consent and explicability are operationalized in the form of a smartphone app presented in Fig. 3. The app can use push or pull notifications to inform citizens when the drone is near their GPS location. The app allows users to opt-out of being overflown and provides a form for comments on the flight. The app introduces an additional risk to cyber security, so frequent penetration testing is performed.

The app shows a photo and the location of the drone's safety pilot, supporting accountability and reducing power asymmetry compared to an anonymous operator. This approach prioritizes transparency to the public over privacy of the drone operator which may be acceptable in a public healthcare context (but not necessarily other contexts). General data protection rules (GDPR) should be followed [39] and informed consent given by the drone operators such that their data can be shared. FrugalDrone maintains a one-to-one relation between operator and drone - each drone has one individual that is ultimately responsible for its safe operation.

Drone operators only oversee one drone at a time to prevent task overload.

Value-sensitive design is used to address a final form of explicability - it promotes transparency by naming the drone appropriately and by explicitly stating the ethical principles and human values that the design supports. The ethical framework, underlying assumptions, trade-offs, stakeholders, and so-on, are made available publicly available via the app and the project website.

Sale of the FrugalDrone platform is restricted to use in public healthcare, so the silhouette will be easily recognized as legitimate (at least as long as similar drones are not produced). Restricted distribution will also avoid the risks associated with dual-use.

Some design aspects of FrugalDrone could be applied to a modified off-the-shelf drone. For example, coloring and markings, the use of the app etc. could easily be applied. However, features such as low cost, capability caution via payload limitation, and inherent safety cannot be applied to an off-the-shelf drone.

IV. DISCUSSION

This work is a preliminary analysis; much data is not yet available such as the exact health benefits due to increased blood sample testing, drone reliability, relevant costs, impacts on jobs, the environment etc. Available data have been included to provide context; future work will define these in detail.

A key benefit of VSD is that it encourages consideration of "big" ethical questions and a long-term perspective on technology development. Perhaps, at least initially, drones should be utilized only in cases with clear beneficence or extremely low risk – for example, by public entities for direct life-saving operations such as delivery of defibrillators to heart attack victims [40].

Van de Poel [8] characterizes new technology as a "kind of social experiment"; this stresses the untried character of new technology, the role of uncertainty and ignorance, and the need for learning. This seems like an apt way to describe the HealthDrone project: there are potential benefits as well as significant risks. Alternative, low-risk approaches for inexpensive transportation of blood samples exist, such as courier motorcycle (32 Euros per round-trip [14]) are ride-share (estimated at 10 euros per one-way trip). And although the redesigned drone attempts to improve upon the currently available technology, it is still difficult to determine if implementing a blood sample transportation drone in Denmark is worth the risks.

V. FUTURE WORK

The preliminary analysis presented here will be enhanced by building a prototype drone and testing its technical, social, and ethical performance. Additional data will be collected to give a more complete health, financial, and environmental impact analysis, and a thorough stakeholder analysis will be performed. The ethical framework will be developed into a

general framework for the design and implementation of drones in public healthcare (forthcoming by the authors). Ultimately, the aim is to make it easier for drone designers and engineers to create responsible cargo drones for public healthcare - in Denmark, and abroad.

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