D3.2 – Adaptation of workflows for drone deliveries to quarantines

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Executive Summary

The Coronavirus Disease (COVID-19) pandemic has affected and disrupted global health care supply chains including transportation. Several public health and social measures are put in place globally to break the chains of disease transmission. These measures also affect the delivery and distribution of medicines to hospitals and health care facilities. A key fear of transportation companies in the first wave of the COVID-19 pandemic was last mile distribution to quarantine zones as they would risk contagion to their people (drivers, assisting personnel), or that their vehicles and/or personnel would be quarantined. This calls for different approaches for medical deliveries to quarantine zones. One such approach is to use unmanned aerial vehicles (UAVs, drones) that do not expose any person to COVID-19.

The focus of D3.2 is on the use of UAVs in delivering medicines to quarantine zones. This deliverable develops the workflows of drone deliveries, which are simulated and demonstrated in the next deliverable (D3.3.).

UAVs as delivery systems during pandemics have significant benefits such as (a) timely deliveries of emergency medicines in quarantine zones, (b) reduction if not the elimination of potential contagion and (c) cost reductions. There are though also new challenges. The current regulations seem to limit the full potential of UAV applications. The lack of drone-specific frameworks results in time-consuming authorisation processes. Drone delivery systems also have limitations of payload, range, speed, safety, and security, as well as added specific requirements for a management and support infrastructure. Testing procedures and quality protocols should be in place before the delivery to ensure that the quality of the transported medicines is appropriate for the end patients.

In addition, the workflows of drone deliveries should adapt to the regulations that apply to the transportation of medicines, such as temperature, humidity, and vibration controls. The final recipient - the hospital or health care facility - must also ensure the availability of qualified and trained personnel to receive these kinds of items. Governments, the pharmaceutical sector as well as UAV service providers should all work together to ensure that the right medicines will arrive at the right quality at the right time at the right patients.

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List of Acronyms

Abbreviation / acronym	Description
COVID-19	Novel Coronavirus Disease
EU	European Union
HERoS	Health Emergency Response in Interconnected Systems
NGO	Non-Governmental Organisation
UAV	Unmanned aerial vehicle
VLOS	Visual line of sight
AGL	Above ground level
US	United States of America
EASA	European Aviation Safety Agency

1 Introduction

The Coronavirus Disease (COVID-19) pandemic has affected and disrupted global health care supply chains including transportation (Ivanov, 2020, Queiroz et al., 2020). Several public health and social measures are put in place globally to break the chains of disease transmission. These measures also affect the delivery and distribution of medicines to hospitals and health care facilities. A key fear of transportation companies including freight forwards and couriers in the first wave of the COVID-19 pandemic was last mile distribution to quarantine zones as they would risk contagion to their people (drivers, assisting personnel; Woo and Deng, 2020), or that their vehicles and/or personnel would be quarantined. Previous epidemics and pandemics, like the 2015 Ebola crisis, showed that people delivering aid risked being quarantined as well. This calls for different approaches for medical deliveries (Foks-Ryznar et al., 2019), especially when it comes to quarantine zones.

The last mile represents the final leg of product distribution, whereby the product is delivered to the end consumer (beneficiary, or patient). This is considered the most crucial step in the distribution process (Mangiaracina et al., 2019, Perboli and Rosano, 2019). The traditional method of last mile delivery uses plenty of human-operated vehicles such as trucks. This results in the last mile being the most expensive part of the delivery process (Chou and Lu, 2009, Macioszek, 2017, Schwerdfeger and Boysen, 2020), in extreme cases accounting for up to 75% of the total cost of the logistics process (Gevaers, 2011).

Several innovative solutions have been analysed to overcome the last mile challenges (cf. Mangiaracina et al., 2019). One of these is the use of unmanned aerial vehicles (UAVs). A crucial potential benefit of these is that they would not expose personnel to direct contagion in an epidemic or pandemic (Kunovjanek and Wankmüller, 2021).

The focus of D3.2 is on the use of UAVs in delivering medicines to quarantine zones. This deliverable develops the workflows of drone deliveries, which are simulated and demonstrated in the next deliverable (D3.3.). Thereby, HERoS develops guidelines and procedures for their use as well as tests them in a specifically built simulator, targeting their adaptation, validation, and testing (TRL 5-6).

The delivery of medical supplies via UAVs is still relatively new. Since 2016, Zipline has operated drones for the Government of Rwanda, delivering up to 3 litres of blood within 30 minutes to health facilities that request it on demand (Eichleay et al., 2019). Medical UAV deliveries in Rwanda are based on a complex hub and spoke system that facilitates the delivery of rare, critical items such as snake antivenom, vital blood supplies, and other medication. Since then, also other companies have received approval to deliver medicines in different countries (Matternet in Switzerland, Alphabet's Wing in Australia) (Eichleay et al., 2019). There is an increasing interest in using UAVs for delivering emergency blood supplies, vaccines, medicines, diagnostic samples, and even organs, particularly in the last mile (Wright et al., 2018). Overall, this new mode of last mile distribution aims to address some of the transportation challenges by ensuring the right infrastructure and delivery processes, and to enhance supply chain efficiencies (Weber, 2020).

D3.2 focuses on the adaptation of workflows for UAV deliveries to quarantine zones during the COVID-19 pandemic. As opposed to small-scale deliveries of individual items, the focus here is on larger, long-range UAVs that can deliver higher volumes of medical items over a longer distance. The workflows here focus on the particularities of medical deliveries to quarantine zones, and especially on particular requirements posed by the COVID-19 pandemic. The aim is to reduce the exposure of people working with transportation and logistics to any contagion.

The structure of this report is as follows: Section 2 introduces the different types of drones, their benefits and challenges as well as the stakeholders involved in these deliveries. The section concludes with the current status of the use of UAVs in medical last mile deliveries, and an overview of the regulations of the use of UAVs with a focus on the European Union (EU). Section 3 presents the workflows of the use of UAVs in delivering medicines in the last mile, while section 4 concludes the deliverable and provides an outlook to the next ones to come.

2 Overview of UAV deliveries in health care

This section introduces the different types of drones, their benefits and challenges as well as the stakeholders involved in these deliveries.

2.1 Types of UAVs and their characteristics

Although the definition of unmanned aerial vehicles (UAVs) aka drones is complex due to the diversity of their characteristics, it is generally agreed that drones are devices capable of sustained flight without any human onboard and that they are under sufficient control to perform useful functions (Rabta et al., 2018; Weber, 2020). The terms 'drone' and 'UAV' are used synonymously throughout this report.

People usually associate drones with vehicles that deliver small individual packages. Many of these are even used in medical deliveries (as Weber, 2020 summarises). For example, fixed-wing drones with a payload of 1.5-4.5 kg are the ones used by Zipline in Rwanda. They use catapults for take-off, have a relatively long service range (up to 150/160 km distance), use drop-off zones for deliveries while humming onboard and returning to their base without landing in between. Matternet in Switzerland uses rotary wing (or multirotor) drones with a payload of 5 kg but that can take off and land vertically. However, their range is limited to ca. 20 km. Wingcopter drones in Vanuatu are of a hybrid design with tilting wings, again with a payload of 5 kg. They cover a distance of 80-100 km. All of these types are especially useful for medical deliveries when the deliveries are urgent but small, such as anti-venoms, or even organs. Their main aim is to save an individual patient's life, and thereby, to deliver quickly and overcome for instance difficult terrains or avoid traffic jams.

Different types of drones are in use when looking at heavier payloads or longer distances (see Table 1).

Table 1:Mid- to long-range UAVs and their payloads

Characteristics	Types of Drones		
	Wingspan – 3000 mm 	Windracers ULTRA UAV 	FG-98 
Range	140 km	1000Km	1200Km
Length	1835 mm	3 m	12 m
MTOM	14Kg	350 kg	5500 kg
Cruising speed	85-90 km/h	100 km/h	190 km/h
Payload ability	3Kg	50 kg (confirmed) 150 kg (plan)	1.5t
Drive	5 electric motors	2 fuel motors	1 fuel motor
Flight time	1,5hour	N/A	4 h

Advantages	Power supply electric	The ULTRA platform uses an innovative high-reliability avionics system	• Biggest transport drone • Ability to land on flat and nearly-flat surfaces of a length of 150 metres • FG-98s can deliver bulk cargo to various regions, where individual packages would be loaded into smaller quadcopters for the final stage of delivery
Disadvantages	Small payload	Not tested with a full load	Complicated maintenance and logistical footprint

For more complex deliveries, entire delivery systems would need to be built up, however, including hubs for hub-and-spoke systems, and even recharging stations (Rabta et al., 2018).

Medical deliveries to quarantine zones, on the other hand, include deliveries of larger quantities and over larger distances. In these cases, drones are not used for the sake of individual patients but for the treatment of many while *avoiding potential contagion to delivery personnel*. Adapting drone deliveries to and from quarantine zones will enable better access to these zones, and thereby a more effective pandemic response.

2.2 Benefits and challenges of the use of UAVs

The use of UAVs in health care supply chains has the potential to improve logistics and contribute significantly to the timely delivery of medical items for emergency response (Scott and Scott, 2018). During an epidemic or pandemic where restrictions and quarantine zones are applied, UAVs help in reducing the contagion of the disease (Kunovjanek and Wankmüller, 2021). A good example during the COVID-19 outbreak is how China used drones to transport medical supplies and quarantine materials between Xinchang County hospitals and the disease control centre (Cozzens, 2020).

UAV delivery systems during pandemics have significant benefits as they:

- timely deliver emergency medicines in quarantine zones,
- reduce contagion of the epidemic and pandemic,
- (potentially) reduce delivery costs,
- relieve some of the personnel shortage during the pandemic,
- help organisations and governments leverage real-time data to increase supply chain efficiencies for vital, high-volume medicines, and
- reduce emissions.

In addition to these benefits, the use of UAVs also imposes new challenges. The current global regulations on using drones in general and specifically in the health care sector constrain the full potential of UAV applications. There is a lack of drone-specific frameworks resulting in time-consuming authorisation processes as responsibilities and liabilities must be defined and project-specific risks must be assessed continuously (Weber, 2020). These constraints the full development and usage of drones (Balasingam, 2017). Also, the characteristics and capabilities of the drones such as battery efficiency and distance coverage delimit their usage, which is why Rabta et al. (2018) add "energy constraints" to their list of constraints delimiting the use of UAVs.

In addition, the delivery of medicines is a highly regulated sector and not all countries have specific regulations for using drones in health care yet. A lack of regulations does unfortunately not mean that anything is permitted, quite the contrary, it can also lead to confusion and thereby delimit the implementation of such types of deliveries.

In particular, the challenges of UAV delivery systems during pandemics are:

- lack of regulations in delivering medicines via UAVs,
- time-consuming authorisation processes,
- battery efficiency of UAVs and operating times,
- distance coverage and limited flight range,
- the payload capacity of UAVs,
- replacement and spare part of drones,
- trained staff to launch, monitor and maintain the UAVs,
- authorised personnel to receive specific medicines,
- cold chain specifications (for temperature control),
- other product specifications (e.g. with regards to vibration, noise, humidity),
- social-cultural acceptance in different countries.

In conclusion, UAVs seem to be a promising transportation mode during pandemics; however, their use brings along constraints that need to be considered before the implementation.

2.3 Stakeholders in medical deliveries via UAVs

Medical supply chains differ from country to country. Usually, a diverse arrange of stakeholders are involved in them who need to co-ordinate and collaborate to offer medicines to patients especially during pandemics and quarantines (Yadav, 2015). In particular, the main stakeholders in medical deliveries in the last mile (by UAVs) involve:

- regulatory agencies for medicines deliveries,
- regulatory agencies for airspace management,
- regulatory agencies for restriction due to epidemics/pandemics,
- national and international airspaces agencies and organisations,
- aircraft operators,
- hospitals and health facilities,
- logistics service providers,
- trained staff to launch, monitor and maintain the UAVs,
- authorised and trained personnel to receive specific medicines,
- spare parts delivery agencies,

- dangerous goods delivery agencies,
- safety stakeholders and local public areas management authority,
- UAVs hardware and software stakeholders,
- physical infrastructure and network design (operation centres, take-off and landing, recharging stations),
- national civil aviation authority and aircraft traffic management authorities,
- design on the unnamed aircraft traffic management, and
- insurance providers.

In other words, relevant stakeholders include not just the drone operators but a variety of regulatory agencies, links to other logistics service providers, and of course the health care sector itself.

2.4 The status of the use of UAVs in medical last mile deliveries

The first non-military deployments of drones occurred following major disasters, where they supported damage assessments in the affected areas (Balasingam,2017). Their ability to fly without crews made them ideal for deployments in emergencies. UAVs were used to deliver small aid packages to communities affected by major disasters, such as the 2010 Haiti earthquake, Hurricane Sandy response in 2012 in the United States, or the 2015 Nepal earthquake (Balasingam,2017).

Humanitarian organisations also use drones to transport medicines and vaccines in remote rural areas in developing countries. For example, in Papua New Guinea, Doctors Without Borders used drones to transport tuberculosis test samples from a remote village to a large coastal city (MSF, 2014). The United Nations Children's Fund (UNICEF) in Malawi delivered HIV testing kits using drones, thereby dramatically reducing the time required to test infants living in rural areas (UNICEF, 2019).In Rwanda, drones are used to transport blood products and medicines to critical access hospitals and remote regions. Their hub and spoke system of (small) drones for medical deliveries is often considered the prime benchmark for the use of UAVs in medicine (McCall, 2019). These drones are navigated using the Global Positioning System (GPS) and Rwanda's cellular network. Hospitals order blood and medicines via text message and received the supplies within 30 minutes (Balasignam, 2017).

In health care overall, drones have been used for delivering medical items from blood samples to automated external defibrillators, and more recently also COVID-19 test kits (Wankmüller et al., 2021). In mountainous areas but also e.g. in the humanitarian context, the use of drones is can provide a cost advantage in reaching difficult-to-reach, or remote locations, which often represent an expensive component of operations from mountain rescue to humanitarian logistics networks (Wankmüller et al., 2021). Drones can also provide access to conflict zones where deliveries pose a threat to aid workers (Van Wynsberghe and Comes, 2019, Haidari et al. 2016). That said, their use in conflict zones in particular is heavily disputed as drones are also used by military forces (Sandvik and Jumbert, 2016). Yet the overall tenet is that drones can provide access, and deliver to difficult-to-reach locations.

The use of drones has also been tested during the COVID-19 pandemic. In June 2021, the Italian Red Cross deployed a drone delivery of medicines and COVID-19 diagnostic tests on board of one of the ships used as quarantine zone for migrants in the Mediterranean Sea. Using drones increased the speed of transportation by more than 50% compared to road transportation – up to 700% to sea transportation (5.30 minutes by drone vs 35 minutes by boat).

In mid-December 2020, PANSA (Polish Air Space Agency) launched special air corridors for drones, testing fast air connections between medical facilities and coronavirus testing laboratories. On December 14-21, several Polish records were broken in medical flights on routes between Warsaw and hospitals in Pułtusk, Sochaczew and Otwock. On these three routes (see *Figure 1*), about a dozen flights of an unmanned vertical take-off plane from the Polish film by Farada Sp. z o.o. were deployed. These used a drone weighing 14 kg, rising vertically to a height of 50 m, then, similar to a typical airplane, travelling a distance of 100 m to 120 m above the ground (AGL). Both drones and airspace management systems were tested.

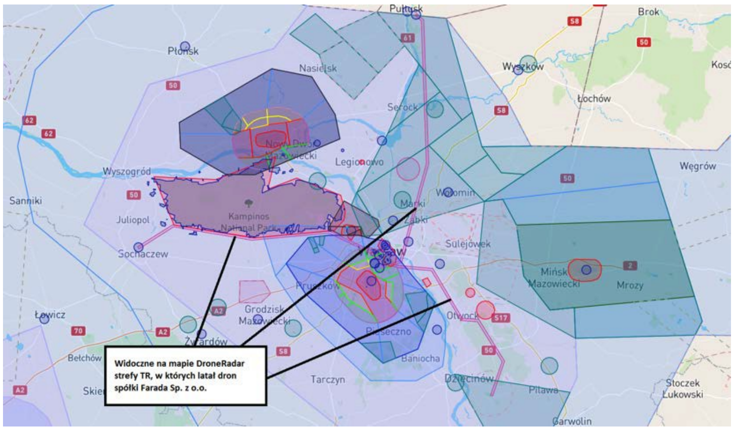

Figure 1 : Transport drone air corridors for medicine delivery from hospitals to Warsaw

The Unmanned Aerial Vehicle of the Farada company covered the routes to Pułtusk and Sochaczew with a length of about 60 km each, on average in 45 minutes. To Otwock, the flight from the centre of Warsaw takes less than 15 minutes. While flying through a dedicated air corridor and at a maximum speed of up to 90 km / h, it delivers medical parcels on average half as fast as by road transport. Importantly, the ship emits its own signal from the transponder, making it visible to other aircraft and air traffic services. Each drone is remotely controlled using 4G / 5G technology from the flight management centre in Warsaw.

2.5 Drone-related regulations

Drone regulations vary across countries and depending on the size of drones (Jones, 2017). Usually, there are four elements considered by regulators: (a) pilot license, (b) aircraft registration, (c) restricted zones, and (d) insurance. Authorities determine basic guidelines and measures for technological, safety and security, privacy as well as administrative issues, and closely monitor and support operations (Balasingam 2017). In addition, depending on drone mass, there are regulations about drone altitude, drone use, and pilot license level (Jones, 2017). For small drones, many of those requirements do not exist, but for commercial use drones, a pilot licence is a de facto standard for countries without drone-specific licensing procedures (Jones, 2017).

Airspace is typically restricted around airports and the use of drones in populated zones is often either forbidden or restricted. Visual line of sight (VLOS) is often required for all users, restricting the horizontal and vertical distance of a drone operation, as well as meteorological and lighting conditions. Liability insurance is required across much of the European Union (EU) but is not a requirement in the United States (US)(EU, 2019).

The European Aviation Safety Agency (EASA) presents the respective regulatory authority for Europe (EU + Switzerland, Norway, Iceland, Liechtenstein). More specifically, EU Regulations 2019/947 and 2019/945 set the framework for the safe operation of drones in European skies (EU and EASA Member States). They adopt a risk-based approach, and as such, do not distinguish between leisure or commercial activities. They consider the weight and specifications of the drone and the operation it is intended to undertake (EU,2019).

The recent EU Regulation 2019/947 (fully applicable since December 30, 2020) caters for most types of operation and their levels of risk. It defines three categories of operations: the 'open', 'specific' and 'certified' categories:

- The 'open' category addresses operations in the lower risk bracket, where safety is ensured provided the drone operator complies with the relevant requirements for its intended operation. This category is subdivided into three further subcategories called A1, A2 and A3. Operational risks in the 'open' category are considered low, and therefore no authorisation is required before starting a flight.
- The 'specific' category covers riskier operations, where safety is ensured by the drone operator obtaining an operational authorisation from the national competent authority before starting the operation. To obtain the authorisation, the drone operator is required to conduct a safety risk assessment, which will determine the requirements necessary for the safe operation of the drone(s).
- In the 'certified' category, the safety risk is so high that certification of the drone operator and the aircraft is required to ensure safety, as well as the licensing of the remote pilot(s).

In HERoS, drone traffic management is ensured through the U-space. The U-space is another arm of the drone regulatory framework. Its blueprint was published in 2017 and discussions and roll-outs have been ongoing since (EU, 2021). The U-space creates and harmonises the necessary conditions for manned and unmanned aircraft to operate safely in the U-space airspace, to prevent collisions between aircraft and to mitigate the air and ground risks. The U-space regulatory framework should permit safe aircraft operations in all areas and for all types of unmanned operations. This is the airspace architecture and services that will ensure the safe flight of drones once in flight.

Apart from regulations for the operation of drones, medical deliveries by drones are even more complex since they need to observe any regulations with respect to their medical cargo. These are taken into account when adapting workflows for medical deliveries.

3 Workflows for delivering medicine by UAVs to quarantine zones

This section presents the workflows of the use of UAVs in delivering medicines in the last mile.

3.1 Last mile deliveries in health care

A supply chain can be defined as the physical and informational resources required to deliver a good or service to the final consumer (Stock and Boyer, 2009). The objective of health care supply chains is to provide the right materials and services, at the right quantity to the right patients in need. Health care includes five main categories of medical products: pharmaceuticals, personal protective equipment (PPE), medical devices, medical supplies, and blood (Mirchandani, 2020). The focus of this report is on the last mile deliveries of pharmaceuticals that include medicines and vaccines.

The last mile represents the final leg of distributing a product, whereby the product is delivered to the end consumer (beneficiary, or patient). Medical supply chains include a complex combination of institutions and organisations that provide regulations, funds, producing, importing, wholesaling, and retailing that have to co-ordinate and collaborate to make health care available to the end patient (Mirchandani, 2020, Attridge and Preker, 2000). Thus, in health care, the last mile can encompass the distribution of items to patients, or from suppliers to health care facilities.

What is more, medical distribution differs from country to country. Some countries follow a more decentralised approach, where hospitals order their medicines directly from pharmaceutical companies and receive them through transportation providers. Others follow a more centralised approach, where hospitals place their orders with regional or national agencies responsible for the procurement and distribution of medicines. By focusing on the last mile, D3.2 focuses on the workflows that support deliveries from the (central/regional) warehouse of e.g. a procurement agency to health care facilities in a quarantine zone. Crucially, this follows the very last movement from any sending facility outside a quarantine zone to a receiving facility within it (see Figure 2).

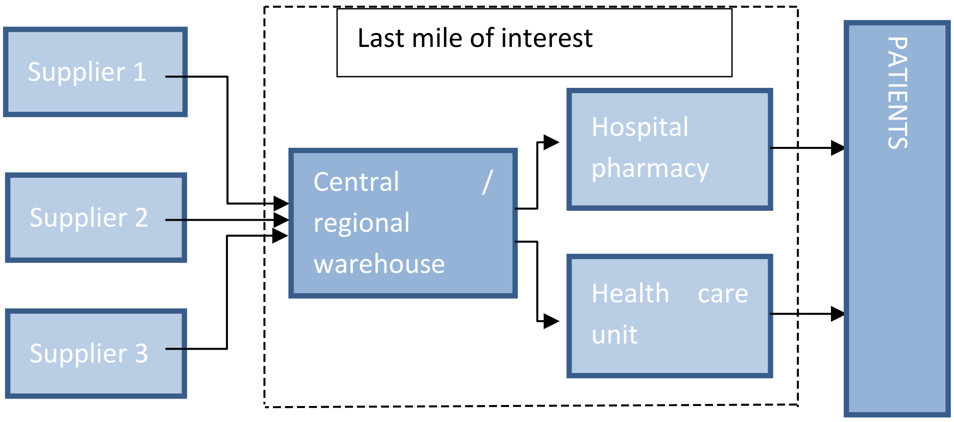

Figure 2 : The last mile in the health care supply chain

 [PU]

A simplified health supply process and last miles of interest are described in Figure 2. Hospitals, health care units as well as pharmacies are intermediate facilities that receive medicines from a point of access, the central or regional warehouse. Medicines are then directly distributed to patients. In some cases, medicines could be transported between different branches of hospital groups. The delivery could be done with the transportation means of the agency or by a logistics provider. These subtle differences will to some degree alter the workflows of medical drone deliveries.

3.2 Workflow of medical drone deliveries to quarantine zones

To determine the workflow of medical drone deliveries to quarantine zones, both the aspects of the cargo (pharmaceuticals such as medicine or vaccines) and the vehicle (drones) and its operations need to be considered. Drone-related regulations have been previously introduced in section 2.5. In addition to these, the following considerations come from medical deliveries:

a. The need for **attended deliveries** that identify the recipient person and their role in the health care system.
b. The need for **vehicle- and operating system-specific handling capacities for various types of medicine**.

Point (a) ensures that the recipient is authorised to handle the type of medicine. Importantly, who is authorised to handle what differs across countries: in some countries pharma technicians would be authorised for specific types of drugs, in others, nurses need to be present. Yet other e.g. classified drugs have even more specific requirements on who can handle and thereby also receive them. Only if no restrictions on the licences of recipients are present and if the items themselves are not restricted can unattended drop-offs be used (as in e.g. Wankmüller et al., 2021).

Point (b) encompasses requirements that stem from the cargo, such as temperature, humidity, and vibration control. Some of these requirements will constrain vehicle selection, others the selection of operating systems (e.g. stability requirements).Both impact on both the testing procedures and the resulting workflows for such deliveries.

3.2.1 Testing procedures

In the healthcare context and especially in times of pandemics, the timely delivery of medicines is crucial. UAVs can potentially overcome logistical challenges that come from the restriction imposed to control the spread of an epidemic and they are also able to reach regions that lack adequate infrastructure (Rabta et al., 2018; Weber, 2020). For the delivery of medicines, the UAVs are recommended only if the quality of transported products is not affected. Thus, UAVs must first be tested to determine their impact on medicine quality and the technical procedures and protocols to fly the UAVs (Hii et al.2019). See also the testing procedures for the deliveries of e.g. COVID-19 self-test kits in Wankmüller et al. (2021).

The following testing procedures should apply before the delivery of medicines:

- testing with respect to the safe flight time and the risk of failure either because of environmental conditions or the type of drones used,
- testing the pilot to ensure full flight readiness according to standard flight operations in the airspace (ie. alcohol, drugs, etc.),
- testing of the UAV in terms of airworthiness and weight balance,
- testing the quality of the medicines transported. The quality should adhere to pharmaceutical regulations on the quality of the medicines to be delivered to the patient,
- on-board monitoring of the medicine's environment during drone flight: Parameters such as temperature, pressure, vibration frequency and g-force should be monitored and adhere to the manufacturer's guidelines for the medicines,
- testing the security of the medicines throughout the drone delivery, such as anti-tamper monitoring and recipient authentication,
- testing loading compartment in terms of illegal goods,
- understanding the effects of any type of failure during the flight, and developing contingency plans.

More generally, live-savings medicines need special transportation controls with respect the temperature, humidity, and vibration.

3.2.2 The resultant workflow

The resultant workflow follows Figure 2, i.e. deliveries from a (final central/regional) warehouse to a hospital or health care facility. The workflow of the drone delivery operationalises the request for any medical delivery that the recipient files with the sender, and that the sender has authorised to be sent. It does not replace nor override any referral system nor the supplier-customer relationship between the pharmaceutical company or agent with the hospital or health care facility. Also, any advance notifications to customs clearance agents, and any other documentation accompanying the cargo takes place as with any other type of delivery.

There are three main stakeholders involved in the delivery itself, and hence the workflow, namely, the warehouse (sender), the UAV mission system, and the hospital / health care facility (recipient). Figure 3 shows the resultant workflow of the medical drone delivery.

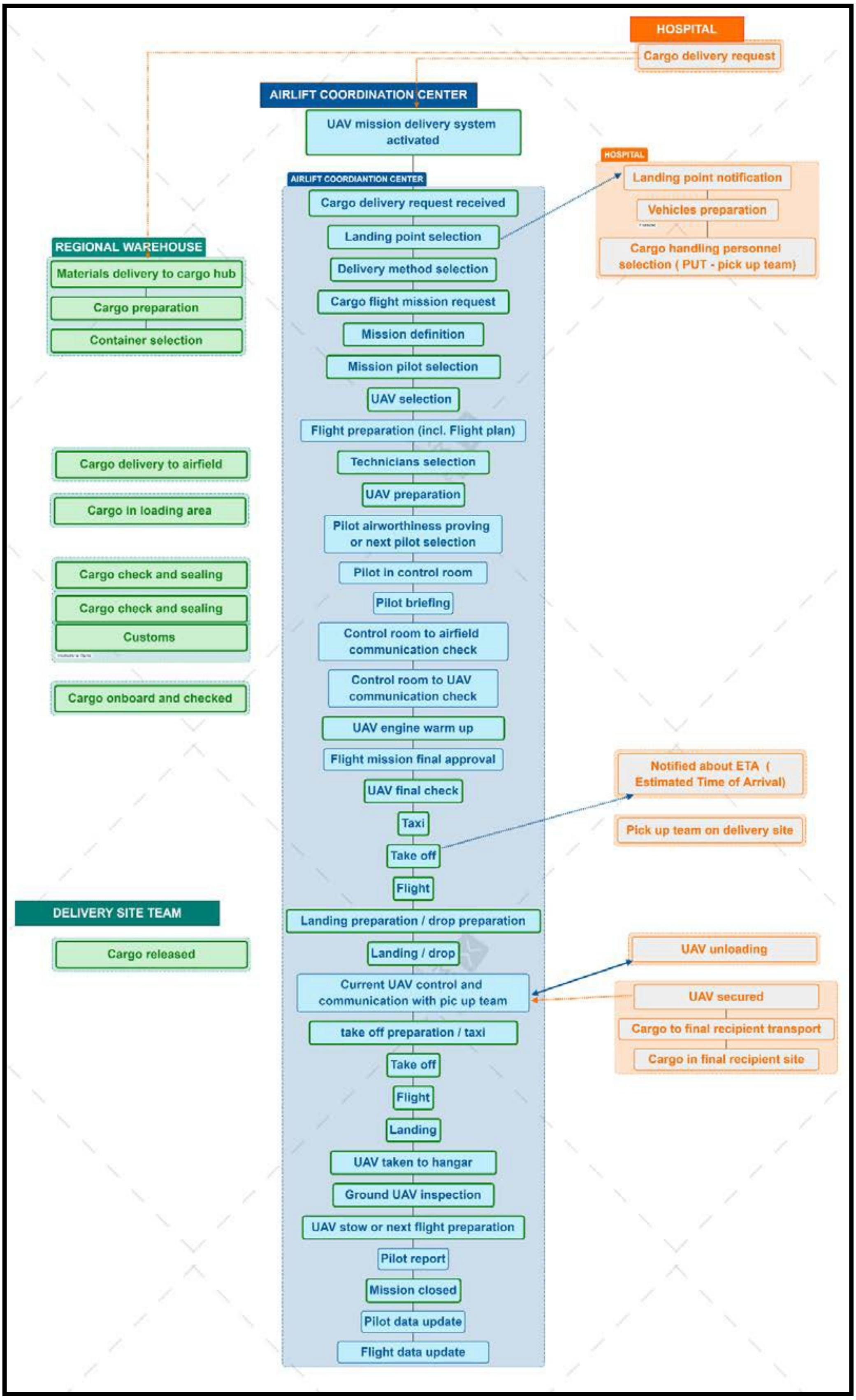

Figure 3 : Workflow of drones deliveries to quarantine zones

Typically, the sender would take care of the activities on the left (in green), and the recipient of those on the right (in red). Special attention is to be paid to any potential alterations, or to verifications in these steps:

- Once the sender and receiver have agreed on a delivery, either of them can place the cargo delivery request to the UAV mission. This is done either based on a specific order from the hospital / health care facility, or a push delivery from the warehouse. Regardless of the type of push or pull system in place in the specific health care system, both of these need to have agreed prior to an actual delivery taking place.
- The cargo delivery request needs to specify the type of cargo in light of its handling requirements during loading, unloading, and during flight. Specific attention needs to be paid to any characteristics that will impact on vehicle selection (e.g. temperature / noise / humidity / vibration control) or on the selection of the operation system (esp. vibration control) that could not be taken care of by the packaging of the cargo. For example, in the case of COVID-19 vaccines, three main temperature ranges exist in last mile deliveries, either requiring an "ultra-cold" chain (-80 – -60˚C), a "frozen" chain (-25 – -15˚C) or a "refrigerated" cold chain (+2 – +8˚C). Of these, ultra-cold chains require active plus passive cooling, i.e. a combination of dry ice and containers that are being cooled also under transportation. UAVs selected for their delivery would need to be equipped for the possibility of active cooling of their cargo.
- Quarantine zones usually restrict movement of people, but not of UAVs. No-fly zones are to be observed as in any other restrictions to UAV movements.
- Any documentation accompanying the cargo (including customs clearance) needs to be verified in accordance with the agreed INCOTERMS. Customs clearance needs to follow the official drug lists and any other medical regulations of the exporting and importing countries.
- All the involved parties need to ensure their personnel is authorised to handle the cargo in question. This needs to be verified prior to loading or unloading.

4 Conclusions and next steps

Drones seem to be a promising technology with increasing applications. Common drone applications in medicine include "providing disaster assessments when other means of access are severely restricted; delivering aid packages, medicines, vaccines, blood and other medical supplies to remote areas; providing safe transport of disease test samples and test kits in areas with high contagion" (Balasingam, 2017, p.3). Global Market Insights Inc. (2019) estimates the annual growth rate of the medical drone market to 25% within a time frame of five years, exceeding USD 399 million by 2025.

Using drones for last mile deliveries in the COVID-19 pandemic is an answer to the concerns of many transportation companies for their personnel being exposed to contagion. Thereby, the use of drones would contribute to better access to quarantine zones as well as a more effective delivery overall.

Drone delivery systems have limitations such as payload, range, speed, safety, and security, as well as requirements for a management and support infrastructure that impacts total costs and operational effectiveness (Sanchez et al., 2014, Samsioe et al., 2017). The also comes with various challenges both at the regulation and the operational level. Testing procedures and quality protocols should be in place before the delivery to ensure that the quality of the transported medicines is appropriate for patients.

In addition, workflows need to adapt to the regulations of transporting medicines including temperature, humidity, and vibration controls. This was the focus of this deliverable. On top of this, the final recipient - namely the hospital or health care facility - must also ensure the availability of qualified personnel as well as to train them to receive these kinds of items. Governments, the pharmaceutical sector as well as drone services providers should all work together to ensure that the right medicines will arrive at the right quality at the right time for the patients.

Next, HERoS WP3 will use these workflows to simulate the delivery of medicines in two main cases: the delivery of items on the refugee camp in Uganda getting data from our project partner PCPM, and the delivery of medicines from a central warehouse in Finland to a district hospital. For this purpose, the milestone M7 was reached in May 2021, namely to acquire and implement the depicted simulation platform.

Figure 4 : Simulation platform

The next milestone of defining the long-range flight crew is to be reached by Nov 30, 2021. D3.3 (due Sep 30, 2022) will then implement the workflows for drone deliveries from this deliverable, and demonstrate the use of drones for medical deliveries to and from quarantine zones. Further technical details about the design of the special cargo drones for HERoS can be found in Appendix 1.

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Appendix 1

The cargo drone designed for HERoS is prepared to be checked in virtual simulation in terms of project scope and objectives. Its general characteristics are:

- Fixed wing plane with two fuel engines
- 150 – 200 kg payload
- Automatic landing mode
- Waypoints flight mode
- Back load with small ramp (to ensure easy load and unload)
- Drop capability
- Fixed landing gear
- V-shape tail
- > 500 km range
- Cruise speed 150 – 170 km/h

Sketches to designs are to be found in Figures 5-7 below.

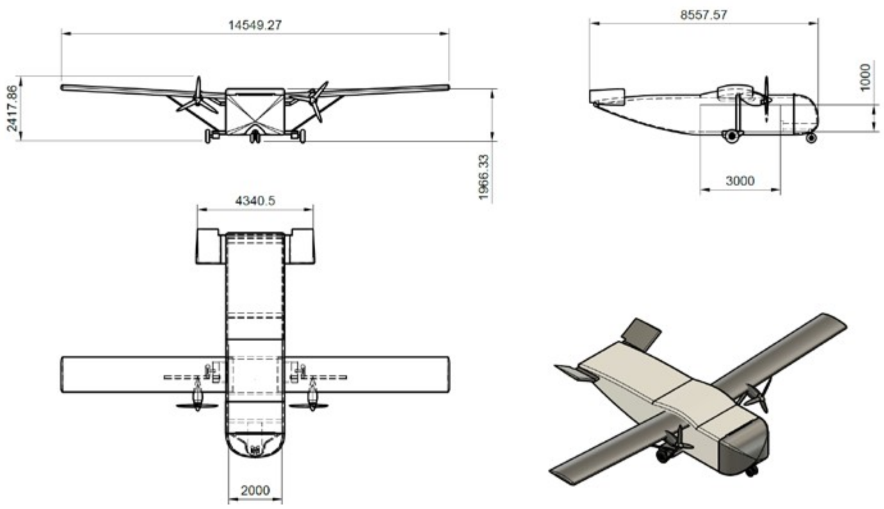

Figure 5 : Initial sketch

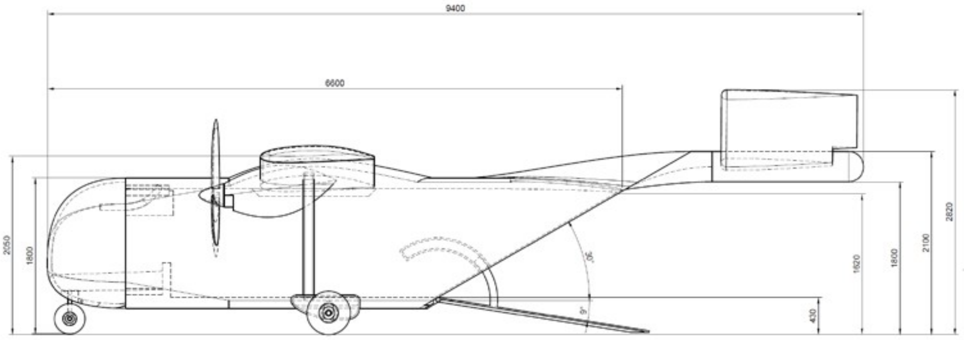

Figure 6 : Final concept sketch

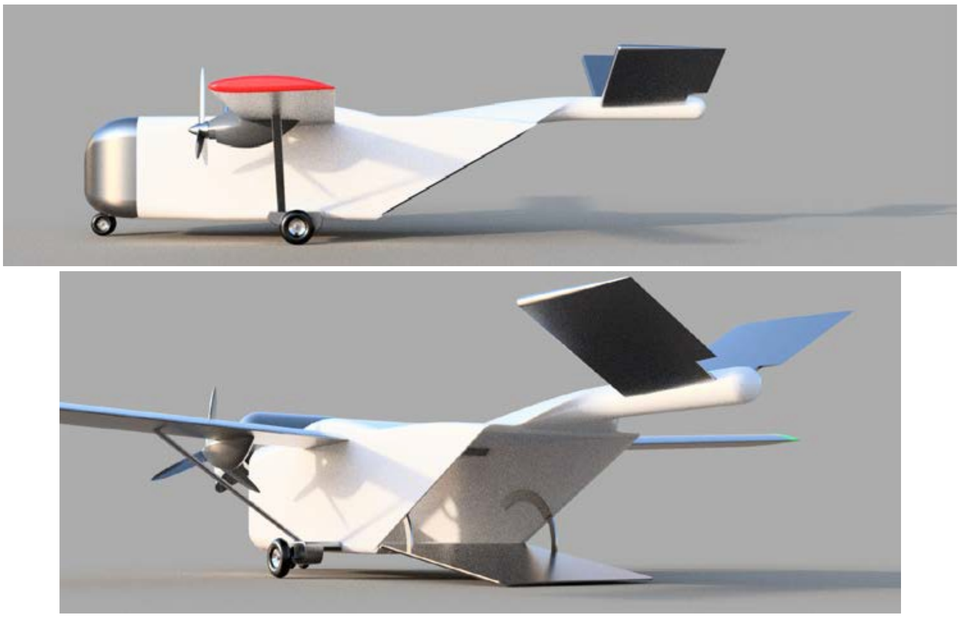

Figure 7: Final concept - 3D model

