



WINGCOPTER



***Comprehensive Summary
Vaccine Delivery Service in Vanuatu***

14 May 2019

Preamble

This document presents a comprehensive summary of the Transportation of Vaccines and Medical Supplies using Unmanned Aircraft Vehicles (UAV) or Drones on Pentecost Island (Phase 2A) conducted by Wingcopter Holding GmbH & Co. KG (hereafter referred to as the company) in accordance with the contract with the Ministry of Health of Vanuatu (MOH S1721-1_PENTECOST Phase 2A).

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List of abbreviations

4WD	Four Wheel Drive
AROC	Airband Radio Operator Certificate
ATC	Air Traffic Control
ATS	Air Traffic Service
BVLOS	Beyond Vision Line of Sight
CAAV	Civil Aviation Authority of Vanuatu
CASA	Australian Civil Aviation Safety Authority
EPI	Extended Programm of Immunization
ICAO	International Civil Aviation Organization
MoH	Ministry of Health of Vanuatu
OED	Onsite Equipment Demonstration
PCS	Power and Communication Solutions
RePL	Remote Pilot Licenses
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft Systems
RTL	Return to Launch
TVL	Telecom Vanuatu Limited
UAV	Unmanned Aerial Vehicles
UNICEF	United Nations Children’s Fund
VTOL	Vertical Take-Off and Landing

1. Introduction

1.1. Information about project

1.1.1. Project background

There is increasing innovation occurring in the area of so-called “last-mile-logistics” within the development context. This is particularly true for the use of unmanned aerial vehicles (UAVs), commonly known as drones as a means of transportation for medicines and medical commodities. This application has been tested in challenging locations in sub-Saharan Africa, Southeast Asia and Oceania. Ways to improve upon the models of drones in operation, and to expand efforts and test the use of UAVs in other regions continue to be explored.

In 2018, the Ministry of Health (MoH) in Vanuatu with support from the United Nations Children’s Fund (UNICEF), initiated a pilot project to explore the use of Unmanned Aircraft Systems (UAS), as a quick, reliable and effective mode of transportation for the last-mile delivery of vaccines from distribution centres to their final destinations on remote islands while maintaining the cold chain vital for the integrity of a vaccines shipment. The project aim was to identify an alternative solution to the logistical challenges that come with the lack of an adequate road network, the unreliability of the existing boat fleet, the time required to reach rural health facilities, the costs associated with transportation, and the high travel risks. The primary objectives were to test if this new mode of transportation could be included into the existing Expanded Programme on Immunization (EPI) as a last-mile delivery resource, if it is technically feasible, and if it can be accepted by the local community. To achieve this, Wingcopter was selected by the MoH through a procurement process to deliver EPI vaccines to Pentecost Island in Vanuatu. UNICEF provided both financial and technical support for the pilot project.

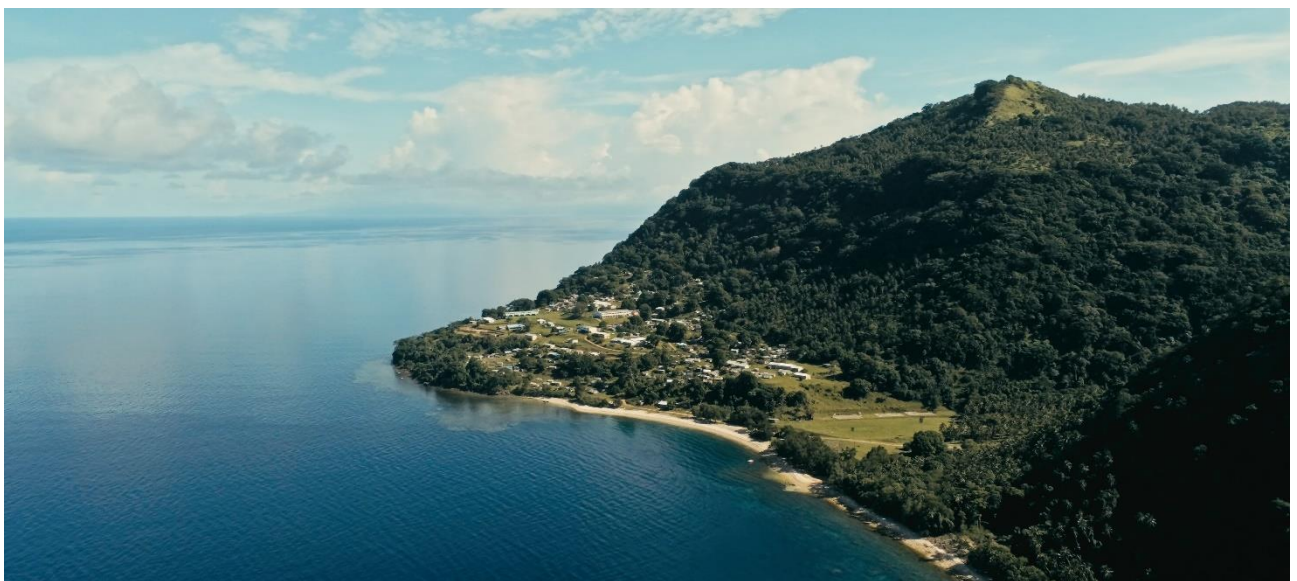


Figure 1 View of Melsisi and the hilly terrain of Pentecost Island

1.1.2. Local need in Pentecost

Pentecost is a very challenging island for medical supply in terms of topography, vegetation and remoteness. It has many mountains and hills that are covered in dense jungle. Most people living on the island do not have access to adequate roads, electricity or health facilities. The roads that do exist can only be driven by 4WD cars and become impassable following excessive rainfall. To provide access to vaccines in even the most remote areas, nurses must travel from a health centre taking vaccines with them to scattered communities, sometimes hiking for several hours or travelling by boat around the island. Seemingly short distances can take hours in which medical supplies are exposed to the tropical heat and the difficult travelling conditions. Such long exposure can spoil the heat-sensitive vaccines leading to waste and a lack of supply in geographically challenging areas.

The main hospital and main distribution centre for vaccines on Pentecost Island is located in the settlement of Melsisi, which provides a central location on the more accessible west coast of the island. Also, the hospital has the most reliable solar power-supply for its refrigerator compared to other facilities. Deliveries are made from Melsisi to 19 different locations across the island including other fixed clinics with permanent stationed medical staff and cooling capabilities, but also mobile clinics and outreach locations where the health facility is only temporarily visited by a nurse and does not have cooling capabilities.

From Melsisi, deliveries are made to the far north and the far south of the 60km-long island. However, most challenging are the vaccine deliveries to the mountainous east coast of the island. Although geographically near to Melsisi, destinations on the east coast are the hardest to reach, as there are not even dirt roads connecting these areas.

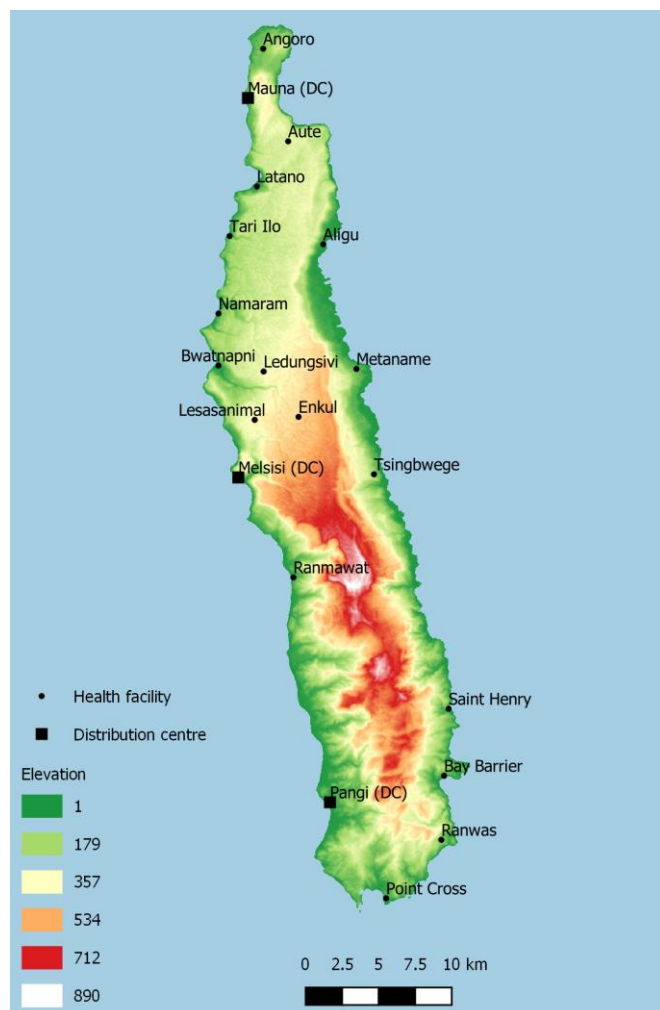


Figure 2 Map of Pentecost with all health facilities in the island

“After visiting the remote clinic in Tsingbwege on the east coast in site visit involving long hikes through slippery terrain and adventurous boat rides in rainy conditions, the necessity and benefit of a 20-minute drone flight for vaccine delivery becomes very clear”, says Lukas Martin, project manager of Wingcopter who spent three months on Pentecost Island.

1.2. Introduction to Wingcopter technology

1.2.1. Wingcopter 178 Heavy Lift and prior experiences

Wingcopter is a German drone manufacturer that has been developing drones since 2011. The core innovation of the Wingcopter drone is the ability to vertically take off and land and transition into an efficient forward flight once air-borne. The latest product, the Wingcopter 178 Heavy Lift, is a UAV that incorporates the unique Tiltrotor Technology. It can reach a top speed of 150km/h, cover distances of up to 100kms, carry a payload of up to 6kg and safely land, even in small areas. Specific advantages in the market of commercially available electric vertical take-off and landing (VTOL), fixed-wing drones are the great payload capacity and stable flight behaviour even in strong winds and other challenging weather conditions.

The Wingcopter technology was previously applied for delivery applications in the Deliver Future pilot project in Tanzania in 2018, where payloads were delivered over a distance of 60km. The concept of the Deliver Future project focussed on two-way delivery and local capacity building of pilots and health workers. Four local pilots were qualified to operate the Wingcopter drones and conduct flight operations between central stores and local health facilities.

1.2.2. Technical innovation throughout the Vanuatu project

The vaccine delivery in Vanuatu focussed on servicing multiple locations from one main facility and Wingcopter adapted its technical approach to implement and showcase a scalable solution with a focus on flight safety. The operational concept was the supply of vaccines to 19 remote facilities from the one central location in the settlement of Melsisi. The technological and operational challenge to conduct safe flight operations without a pilot at the delivery location was resolved by an innovative winch mechanism that allowed the drones to precisely and gently deliver the goods via cable without landing.

Wingcopter considers landing in remote locations without a fenced-off landing area or the ability to interfere with the drone's operations on the receiving end a safety concern. Critical concerns with landing beyond visual line of sight of the operator include potential interference of the landing area by humans or animals and missing a pre-take-off check.

In the operational concept for the service in Vanuatu, the Wingcopter 178 Heavy Lift delivers the vaccines by hovering at approximately 10 meters above the ground and lowering down the payload with a controlled speed via a cable attached to both the drone and payload. This procedure allowed the project team to remotely monitor the drop-off sites and deliver goods without landing or conducting a physical assessment.

Because the drone is capable of vertical take-off and landing in a quadcopter-style hover-mode, this makes selection of landing and launch locations very simple as only an open space of approximately 5x5m is required.

The drone completed all delivery flights fully automatically including take-off, lowering down and landing upon return with the missions being pre-programmed from a ground station computer that also monitored the flights. However, for safety reasons, a safety pilot was always present during take-off and landing in Melsisi that could have taken over manual control if needed during an emergency.

2. Project Scope



Figure 3 Children from the primary school in Enkul at the mobile clinic receiving vaccinations

2.1. Methodology

The solution to safely deliver a monthly supply of vaccines was achieved using two drones (one as a backup) based out of a single distribution centre in Melsisi on Pentecost Island. This main distribution centre also served as a place for storing, charging and launching the drones; it is the location from which all flights commenced.

The MoH-EPI staff were responsible for delivering the vaccines and other medical commodities to the main distribution centre, after which they were loaded into a cold chain-compliant box that was then attached to the drone. The drone was capable of carrying up to 4kg of cargo with each delivery flight. This high cargo capacity allowed for the project team to meet the total monthly demand of each health facility with a single delivery flight in most cases. In some cases other needed supplies, such as syringes, were delivered in a separate second shipment to the site if they exceeded the storage or weight capacity of the first delivery.

Following vertical take-off, the drone would transition to a forward, fixed-wing, energy-efficient flight mode, which allowed the aircraft to reach ranges of up to 83km in a single flight with 3.3kg of payload. With a cruising speed of approximately 90km/h it delivered to a location 40km away in less than 30 minutes. Delivery to these locations would have otherwise required a two-hour drive on a 4WD crossing rivers and then taking a several hour boat trip around the island.

After flying to each delivery site (a previously determined safe location) in fixed-wing flight mode, the drone transitioned back to vertical hover mode and descended to an exact height of 10.5 meters (measured by a laser altimeter on board or LIDAR¹ installed in the drone) above the delivery zone. Rather than landing, the drone could remain air-borne at a safe distance to watching bystanders. The trained local nurses informed the local inhabitants about the arriving drone delivery and the safety rules, which had to be followed (for example standing back from the delivery area during delivery, etc.; For more info see Annex Drone Vaccine Delivery Manual under 5 Section Safety Rules)

¹ LIDAR is a device that can accurately measure distance by illuminating a target with pulsed laser light and measure the reflected pulses using a sensor to calculate the differences in wavelength and their return time.



Once the payload was lowered down, the drone ascended slightly, releasing the cable attached to a speed-limited spool from the drone, which remained attached to the payload. Because the cable is only fixed to the payload and not to the drone itself meant that in the event of any tangling of the cable or other problems, the drone simply needs to ascend, and the cable would come free and the payload released. If someone were to pull on the cable during delivery, the drone would not be affected.

This lowering mechanism was specially designed for the project in Vanuatu. In order to cover the vaccine supply of the entire island would have required flights to many different locations and coordination of many different individuals at the receiving sites. Furthermore, we expected many people including young children would want to watch the drone arrive. Thus, choosing not to land but rather lower down provided both safety and simplicity.

After ascending again to a safe height, the drone transitioned back to fixed-wing flight mode and returned to the distribution centre where it then landed. Once the drone had left the receiving area, the box carrying the vaccines was picked up by the nurse and unloaded. The vaccines were checked and a vaccine arrival report was completed.

The drone completed all delivery flights fully automatically. The telemetry² from the drone was sent via radio to a ground station, which displayed the drone's location, speed, remaining battery power and altitude at all times. The ground station was also capable of sending overriding, high level commands to the drone in the event of an emergency or change in conditions, such as a loiter command to pause the mission or a return to land command.

Communication with the Remotely Piloted Aircraft system (RPA) was primarily maintained by sending it through a radio mesh network. The network consisted of several forwarding nodes, which were installed on strategically placed towers on the island. As a backup, a satellite telemetry module was fitted in the RPA that provided a second channel for communication in the case of a loss of connection over the radio network. The satellite connection works over the Iridium satellite network, which is accessible globally but provides a less frequent and more expensive way of forwarding messages between the RPA and the ground station.

2.2. *Preparations and Phase 1*

2.2.1. Remote Preparations

Before arriving in Vanuatu, technical preparations were made in Germany. These included ordering and locally testing the customized antenna solution, testing the project-specific winch mechanism, as well as logistics and contracting of the project staff. The shipment of batteries overseas proved to be a major challenge as routing of such hazardous goods to Vanuatu was postponed several times by subcontractors. The first set of batteries was transported by ship and experienced unexpected delays before arriving in Vanuatu on 16 December 2018.

² Telemetry refers to the flight information that is communicated from the drone to the ground station.

2.2.2. Onsite Equipment Demonstration (OED)

The project team and additional Wingcopter staff arrived in the beginning of December in the capital city, Port Vila, and had their first meetings with representatives of the Ministry of Health of Vanuatu (MoH), the Extended Program of Immunization (EPI), United Nations Children’s Fund (UNICEF), the Civil Aviation Authority of Vanuatu (CAAV), its technical advisors and also the local nurses who reside and work on Pentecost Island. The drone was presented to the visiting nurses and communities in North Efate, which kindly hosted the first phase of the project. The opportunity to meet the nurses was used to gather information, understanding daily challenges and to increase their understanding of the technology. A first training with the nurses was completed and a gradual delivery schedule was revised.

Afterwards it became clear that the delay in arrival of the drone batteries would delay the Onsite Equipment Demonstration (OED) past December 2018, Wingcopter therefore requested the rescheduling of the project timeline in the variation letter #1.

Phase 1 was successfully demonstrated to the representatives of the CAAV, the MoH and UNICEF on Efate Island in Vanuatu on 16 January 2019. Clearance was granted for the team to move forward to Phase 2 of the project on Pentecost Island.

2.2.3. In-country preparation

After the initial OED, the drone pilots of Wingcopter acquired additional Unmanned Aircraft Remote Pilot Licenses (REPL) under the Australian Civil Aviation Safety Authority (CASA) and Airband Radio Operator Certificates (AROCS) to comply with CAAV requirements. Also, the time was used to source the equipment for the Pentecost Island operation and to conduct a site visit to the island. On Pentecost Island, accommodation arrangements for project staff were made, and some health facilities and radio towers needed for the communication solution were visited.

The short time on Pentecost Island prior to commencing with test flights helped to gain a more accurate view of the challenges ahead. Relationship building with health workers onsite gave confidence in their support and increased the acceptance of citizens for the planned operation.

After the flights in north Efate were completed, the final equipment sourcing was made and the equipment was shipped to Melsisi. The cell-tower providers (TVL and Digicel) agreed to the planned antenna installation and a local company Power and Communication Solutions (PCS) was able to provide tower climbers, who travelled together with the project team at the end of January to the island.

2.3. Phase 2

2.3.1. Set up of flight operations on Pentecost Island

During the initial weeks on Pentecost Island, the communication system was installed strategically on five towers on the island with two towers in the south, two towers in the north and one tower close to the central operational hub in Melsisi. The system was tested with modems on the ground before testing with the drone.



After the completion of Phase 1, the MoH requested a detailed temperature logging of the first 5 delivery flights on Pentecost Island to investigate the cooling capabilities of the Wingcopter delivery box and the implemented cold chain procedures. At the same time, CAAV requested to scrutinize all Beyond Vision Line of Sight (BVLOS) flights until the first five successful deliveries were carried out.

The installed communication system was tested with BVLOS flights as planned in the week prior to the official start of deliveries from 4 to 8 February; all BVLOS flight operations were reviewed by a technical advisor of the CAAV. Problems with the radio system that were not identified during previous checks were identified in these test flights and resolved. Therefore, the test week of BVLOS flights on Pentecost Island prior to attempting the first deliveries were necessary and should always be conducted when flying in a new environment.

Unfortunately, the wind gusts and flight delays of Air Vanuatu flights for CAAV and EPI representatives caused by cyclone "Oma" prohibited commercial flights until 20 February 2019. On this date, representatives of UNICEF and CAAV arrived to Pentecost Island for monitoring checks of the first five deliveries starting with the first scheduled delivery to the nearby health facility in Ranmawat on 22 February.

2.3.2. Flight operations Phase 2

In the seven and a half weeks starting from 20 February to 12 April, the team in Melsisi performed scouting flights to 18 different delivery destinations and completed 27 deliveries to 15 of those locations. In total, the Wingcopter drones completed 91 BVLOS flights covering a distance of over 3664km during that time span.

The monitoring information for each individual BVLOS flight and each delivery is provided in the accompanying excel sheets:

"Final-FlightData_Delivery-Flights_Wingcopter" and ***"All_BVLOS flight logs_Wingcopter"***

A visualization of the flights can be found here: <https://ayvri.com/explore?q=wingcopter>

The operation centre in Melsisi performed up to three deliveries per day, however, the actual frequency of delivery was dependent on the coordination with the nurses at the delivery locations.

There were also two further deliveries performed at the request of the CAAV in addition to the 27 deliveries for MoH. The average weight of the payloads delivered was 3,3kg and the average energy cost of a delivery in the local currency Vatu was approx. was VT343 VUV (approx. \$3 USD).

The total BVLOS flight capacity including scouting flights demonstrated in this project was about 11 BVLOS flights per week with up to 4-5 BVLOS flights on a single day.

In order to choose safe delivery sites or to optimize the approach of the arriving drone, the team performed scouting flights at a higher altitude over the delivery areas. During these flights the drone also flew with a dummy payload over these sites to simulate the weight and drag of the real deliveries. Additionally, the drone was outfitted with a camera and video footage was used to assess any unforeseen obstacles, such as large trees or challenging terrain before attempting a delivery. The first scouting flight was set at a higher altitude, which then was reduced in the following scouting flights until the optimal and safe approach height was determined.

Terrain data gathered by the exact measurements of the laser altimeter on board (LIDAR), as well as information extracted through the video footage were analysed by the flight crew after each scouting flight and the optimal approach path and height were identified.



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Experience showed that the available data on the island's terrain was not always accurate, therefore, the scouting flights were invaluable. An optimal approach height also ensured that the drone did not have to hover down for too long to release the delivery payload, making the overall flight more efficient and reducing the chance of the motor overheating.

Lowering down the boxes instead of landing the drone allowed for delivery to locations that were never physically visited by the team. Instead the scouting flights over the drop area and communication with the trained nurses on site provided enough data for a delivery to those areas.

In order to support the nurse and check on their training to receive their first payload, a team member would visit the nurse at a drop area for their first received delivery. However, later deliveries to places like Saint Henry or Bay Barrier where a then fully trained nurse was present were done only with scouting flights over those places. Visiting Saint Henry or Bay Barrier beforehand would have costed at least two days of travel. The risks that come with large crowds of people, poor mobile phone reception, less optimal landing areas and quickly changing weather conditions, would have made it unacceptable to land there without a pilot on site, but the lowering-mechanism enabled the project team to conduct safe flight operations.

By the end of the project 18 of the 19 delivery destinations were scouted. The exception being the delivery site of Angoro as both CAAV and Wingcopter had safety concerns to conduct safe flight operations there because of the proximity to the airport Sara. The vaccines of Angoro were delivered to an alternative site outside the 4km radius of the airport. Deliveries to Latano, Tari Ilo and Aligu were scheduled and scouted but did not occurred in the operation time span due to events outside of the control of Wingcopter (loss of mobile phone of the receiving nurse and cancellations after multiple attempts to reschedule deliveries).

The flight routes for all deliveries were pre-planned and provided to CAAV before each flight. To reduce any possible safety risk to citizens the flights were routed over water as much as possible and avoided inhabited areas when flying over land was necessary.

The vaccines were delivered with standard 0,5L ice packs used by MoH staff on Pentecost Island. Deliveries included a monthly stock to those health facilities with a working fridge but most deliveries contained the amount of vaccines needed for the nurses to conduct mobile clinics or

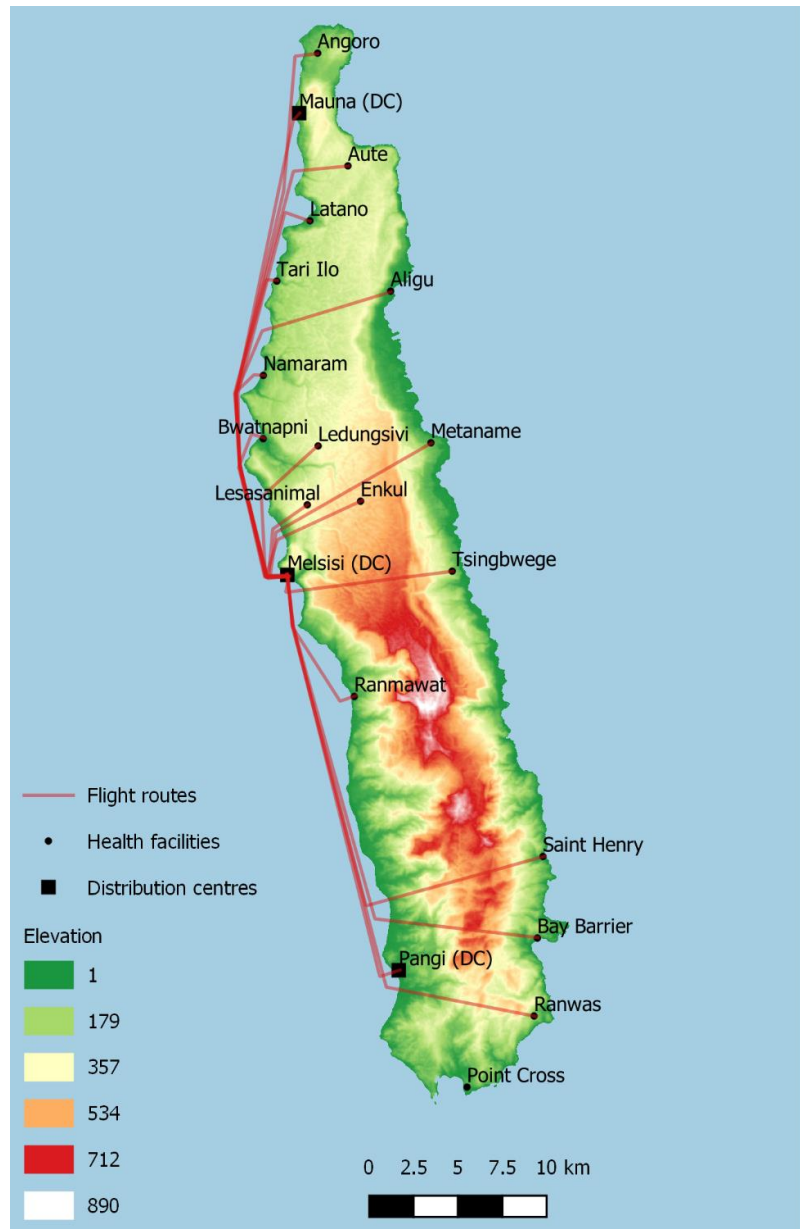


Figure 4 Flight routes from Melsisi to 19 destination across the island



outreach in remote areas. In many cases the vaccines were used straight away by the receiving nurse.

These on-demand deliveries ensured to minimize the risk of waste and exposure of the vaccines to high temperatures during transport. It also minimized the risk of storing too many vaccines in unreliable cooling facilities.

In addition to vaccines, Wingcopter also delivered syringes and droplets when needed. In one instance, Wingcopter also included tablets to treat epilepsy (phenobarbital) at the request of the nurse who visited the southern mobile clinic in Ranwas. In another instance, 1,1kg of medical paperwork together with needed syringes were delivered to the northern fixed clinic in Mauna.

2.3.3. Challenges in flight deliveries

Temperature effects on winch mechanism material

The Wingcopter payload delivery mechanism is simple. The cable which lowers down the box is fixed to the payload box and wrapped around a speed limited spool connected to the drone, which limits the speed of descent. The spool was tested several times in Germany and revised accordingly. Due to different weather conditions in Vanuatu, especially high humidity, the spool material was compromised. After some design changes to the spool there were no further issues with it in both phases. Testing equipment in the operational environment is key to the successful implementation of the project. Wingcopter proposes for future projects to schedule time for equipment testing and localization.

Communication with nurses, cancelations and rescheduling

Providing an on-demand delivery service with a drone was very welcomed on the island. The drone deliveries were most welcomed by the nurses who now had an easier and more reliable system than before. Nevertheless, delivering vaccines required repeated communication with the nurses to understand their demand and schedule for vaccinations at the community level. The delivery dates were chosen by their availability for a planned outreach. However, the dates were always kept flexible should the nurses have to reschedule.

The team experienced several times that the drone was ready for a planned delivery, but the receiving nurse had to suddenly cancel because they had patient consultations. In one case a nurse was unable to arrange a mobile clinic because of problems organizing a vehicle to get there. Each nurse was contacted in the week before the delivery and again on the day before the delivery to reduce the chance of unavailability of the nurse.

A confirmation of the nurse on the day of the delivery was always necessary to ensure there would be someone to receive the payload at the drop site. However, reaching nurses was in itself another challenge. In one instance, the nurse had no mobile phone reception unless she went to a specific area (tree) near a cliff. To resolve this problem, the team arranged set times to discuss deliveries, though this arrangement did not come without challenges, as in some instances the nurse was did not contact the team in Melsisi and deliveries were not able to be completed.



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In another circumstance, the same nurse had lost her mobile phone and was not able to make contact at all. She chose to conduct two mobile clinics (Latano and Tari Ilo) with vaccines from her fixed clinic knowing that if she does not contact the team in Melsisi the drone will not arrive. The nurse informed Wingcopter the day after the vaccination program had finished. This resulted in the missed opportunity to deliver to those two mobile clinics directly with the drone.

Apart from cancellations, the project team received on several occasions unexpected orders from local health officials without a prior notice and were at times asked for a same-day delivery. The team was mostly able to fulfil the demand by delaying flexible deliveries to fixed clinics by a couple of hours to fit in the unexpected but urgent deliveries to facilities without cooling capabilities.

Heavier payloads and long flights

The heaviest delivery was made to Ledungsivi (flight No.10, picture at chapter 3.1.1 figure 10) and had a payload of over 1kg of vaccines, 587g of syringes and 1.9kg of icepacks totalling 4.15kg. Runner up was the much longer flight to Mauna (flight no. 11; 53.7km) with a total weight of 3.75kg again including over 1kg of vaccines.

Previously, the nurses received one delivery every three months that included the vaccines for all the areas that they were responsible for. The new drone delivery system however, was intended to bring the monthly supply of one area in order to minimize overstocking in unreliable cooling facilities. A misunderstanding of this aim led in some cases to large orders of vaccines and heavier than expected cargo weights.

The vaccines delivered to Mauna included the vaccines needed for the mobile clinics Tari Ilo, Latano and Aligu, locations covered by the same nurse. The misunderstanding was cleared up afterwards.

The longest flight was to Bay Barrier on the remote east coast with 83.5km total flight distance. However, the drone returned with 39% of battery power remaining, which would be considered well above the safe tolerance range.

Challenging topography

The project team faced challenges regarding the terrain of delivery sites, for example at Tsingbwege. This clinic is located at the bottom of a hill, surrounded by tall trees and has no flat surface area in the immediate surrounding area. While conducting scouting flights to gather data on the drop sites' area terrain, surrounding structures, trees, possible cell towers and so on, a suitable small field (5x5m) was found. This field was within walking distance of the clinic, still surrounded by tall trees, but flat and with a safer approach route. While doing the risk assessment the decision for a drop site was always focussed on making the deliveries as safe as possible. If there was a safer field farther away but still within walking distance from the clinic this option was chosen.

At some difficult drop sites with no flat terrain the drone transitioned from fixed-wing to hover mode at 70m above the drop site to provide some clearance between the drone and the terrain in all directions in order to not be susceptible to any sudden and severe gusts of wind.



Communication

The advantage of the hovering-and-lowering-down method was that communication with the drone was improved. By staying above the trees, there was more secure connection to the telemetry network; the connection was likely to be weaker at ground level. However, the condition and position of some mobile phone towers proved to be not sufficient for reaching every drop destination with ideal communication. The additional installed satellite system provided a sufficient remedy to this challenge. However, even a satellite system can be vulnerable to unexpected delays when forwarding commands. These circumstances further supported the decision to not land at delivery areas. Where there is no trained pilot that could intercept the drone in the case of any sudden obstruction at the landing area, the drone remains at a safe vertical distance.

Special occurrences

On a mission to deliver vaccines to the mobile clinic in Enkul the RPA decided to abort the mission before the delivery took part and triggered a Return to Launch (RTL) command. The return to launch (RTL) command is an intended safety feature. However, due to an unexpected error in software, the RPA did not follow the correct return path, which resulted in a crash into a tree on an uninhabited mountain.

The location and altitude was broadcast immediately over radio, phone calls to Air Traffic Control (ATC) and the Air Traffic Service (ATS) at the airports in Port Vila (Efate) and Luganville (Santo), were made and CAAV was informed immediately. The RPA was located promptly at the expected coordinates, and Santo and Vila informed. There were no injuries or property damage.

The RPA was damaged beyond repair. All parts were recovered, collected and removed from the crash site. The payload of vaccines and icepacks was recovered completely with the exception of one broken vial of Tetanus-Diphtheria (Td). The vaccines in the payload were exposed to suboptimal temperatures but none of them expired. A report on the vaccines can be found in the vaccine transferal document in the attachment (Enkul_26_03_Vaccine transferal document).

The recovery in the dense jungle on the mountain during rainfall was only made possible by the support of the local communities. Wingcopter staff personally thanked their chiefs and explained the situation to them.

The accident was treated openly with the affected communities and health facility nurses, who were all very understanding. The software problem was conclusively identified, reproduced in a simulation, resolved, removed and an updated firmware was uploaded to the backup RPA on the following day. After the issue was resolved, further test flights in Melsisi were made until CAAV granted permission to fly BVLOS again within three days of the accident.

As a result of this event, deliveries had to be rescheduled but the flight team of Wingcopter quickly continued deliveries with the first flight to the nurse in Enkul to restock vaccines in her clinic in Ledungsivi.

As a request by CAAV at the end of the project, Wingcopter also recreated the flight operation with a dummy-delivery to Enkul. The drone followed the identical flight path with the same settings that led to the accident but with the updated firmware. The RTL-command was triggered and the drone followed the correct flight path home thus proving that the issue was adequately resolved.

2.4. Social impact



Figure 5 The project team presenting to the secondary school in Melsisi on the topic of drones

The success of the project would have not been possible without the incredible hospitality and help of the people on Pentecost Island. Throughout the project, the team had many people providing valuable assistance to aid the project. The community in Melsisi was very welcoming to the project team, who hosted them for three months.

The people were open and welcoming to the change the project brought about. It was mentioned that only a few people had initial doubts but these were put aside after seeing the cooperation of the project team with the nurses and the flight operations in action. The project team was met with gratitude. People were very thankful for the opportunity to see this technology being used to improve their community's access to vaccines.

They understood how a drone could be used to help others. One nurse even suspected that there were now more mothers coming with their children to the mobile clinics to receive vaccinations because they want to see the drone. This hypothesis would be interesting to validate with data in a prolonged time span.

Drone take-offs were often watched by larger audiences from surrounding areas. Many Children in Melsisi gathered daily to witness the drone in action.

On two occasions, the project team on Pentecost Island performed a presentation about drones and Wingcopters operations to students of the Melsisi primary and secondary schools. The opportunity was used to answer questions and to inspire the younger audience to become interested in the technology. As a thank you of for the presentation a teacher wrote a song for the project team, which the children then performed for the project team.

When it was time to say goodbye at the end of the project, speeches were given by nurses and the hospital. They expressed their gratitude and hoped that the project would continue soon. Although the delivery system would go back to the way it was before the trial, the people of Pentecost Island were proud to be one of the first to showcase to the world that drone technology can solve real world problems in challenging environments.



A chief (representative of the community) in Ranmawat who saw the drone deliver vaccines and heard a lot about the reactions in the community described in an interview the reaction of the drone arriving as following:

"The island of Pentecost is a traditional island and the people on Pentecost keep their Kastoms and live their Kastom. But they still need medicine. Our roads are very bad, in bad condition and the drone is very helpful to us. And the reaction of the people and the communities around Pentecost, they acknowledge the work the drone is doing now on Pentecost"

2.5. Visitors during phase 2



Figure 6 Project team and MoH-EPI staff meeting Prime Minister Hon. Charlot Salwai - photo provided by UNICEF

During operations on Pentecost Island, EPI-MoH staff, UNICEF and CAAV staff visited the project in the initial weeks of the operation.

UNICEF and MoH-EPI staff visited a second time at the beginning of March 2019 for the visit of the Prime Minister Hon. Charlot Salwai to Pentecost Island. Wingcopter met the Prime Minister on his arrival in Melsisi. The team demonstrated a delivery flight taking off in Melsisi, flying out over the Ocean, lowering down a box at a different location in Melsisi and then landing the aircraft automatically upon return. The team had used the opportunity to answer the Prime Minister's questions and to explain details of the project.

Furthermore, Leslie Cary, Chief, Remotely Piloted Aircraft Systems (RPAS) Section of the International Civil Aviation Organization (ICAO) also visited the project team on the island and was able to see an actual vaccine delivery to Ranmawat at the drop-off site.

2.6. Female empowerment



Figure 7 Nurse Nicole preparing the vaccination for a child from the primary school near the mobile clinic in Enkul

The majority of trained nurses were women (7 out of 12) and most (23 out of 27) of the deliveries were made to female nurses at drop off points. One nurse, Nicole, single handily received 9 out of 27 deliveries, and also helped the Wingcopter team reach other nurses to coordinate deliveries. The female nurses were therefore essential to the success of the project.

On the other hand, the Wingcopter team on site consisted of four male engineers. However, Wingcopter had one female applicant from Vanuatu to take up a role as a drone pilot but unfortunately, she decided to finish her studies in Fiji first as the job was on too short a notice.

3. Outlook

3.1. *Short term opportunities for improvement*

3.1.1. 100% biodegradable payload box and string

The delivery boxes used were prototypes and not the intended final 100% biodegradable version. The boxes consisted of cardboard and wood, but also included some non-biodegradable materials, such as the cable (fishing-line) and the Styrofoam insides that facilitated cold chain maintenance. Therefore, nurses were instructed to keep the delivery boxes. The boxes were then collected later by Wingcopter staff and were reused when possible or stored for proper disposal. Non-biodegradable materials were collected and shipped off the island.

In the future, Wingcopter aims to use a 100% biodegradable single-use delivery box. The supplier Intelsius, which supplied the boxes, has already designed improved versions. Unfortunately, it was not possible to supply these improved versions in the given timespan.

3.1.2. A prolonged operation time

In spite of operations of only seven and half weeks, the project team managed to scout all destination sites and deliver to nearly all of them. The amount of conducted BVLOS flights gives an indication of the capabilities of an operation with one active drone. Any further operations would have not needed further scouting flights.

A gradual approach in the delivery capacity is advised as most testing had to be done in the initial stage of the service. However, the longer the operation time is scheduled the greater ease of the deliveries. The increase in delivery flights without requiring any further scouting flights also has a substantial impact on the cost per delivery.

Furthermore, even in the rather short flight time of seven and a half weeks, the project team was able to meet the demand for vaccines of the entire island. Thus, in a prolonged operation time there is also capacity for deliveries of other commodities.

3.1.3. The delivery of other commodities

In one case, a delivery of paperwork envelopes that needed to arrive at the Mauna hospital was made. The envelopes had a weight of 1105g and possessed a larger volume compared to the vaccine vials. An empty payload box without the materials needed to maintain the cold chain allowed for more space. This delivery also included 200 syringes and some droplets for the clinic (897g) (see picture below, figure 8 “Envelopes and syringes being delivered to Mauna”).

In a delivery to Ranwas, phenobarbital tablets were also added. They only had a weight of 3g and were no additional effort for the scheduled delivery to be included.

Both of these cases show the capabilities to deliver other important goods quickly and reliably via drone. The payload box has enough volume to provide nurses with additional supplies if they need



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them. During the project, the empty tail and nose of the payload box was sometimes used to for commodities that did not require cooling (syringes for example)

Deliveries of other goods can be bundled with scheduled vaccine deliveries or can be quickly performed in separate deliveries offering the opportunity to deliver vital medicines quickly to remote areas.



Figure 8 Envelopes and syringes being delivered to Mauna



Figure 9 Delivery to Tsingbwege: two safety boxes and 200 syringes



Figure 10 Delivery to Ledungsivi: vaccine vials, droplets and syringes



3.2. Long-term sustainability

For Wingcopter, the key for project sustainability is the employment of local staff in the medium and long-term, as well as the national scale up of the technology to allow for cost-effective, in-country operation and maintenance of the drones. Both measures allow for a cost reduction on the one side and the maximization of value generation on the other side, as sustainability can only be achieved with a profitable business case.

Within the trial project, the Wingcopter project team validated assumptions made around the training requirements, flight frequency and applicability of the technology in the given environment in addition to the project aim to deliver vaccines to remote villages.

3.2.1. Localization of services

Flying drones beyond visual line of sight is a complex flight operation procedure that needs adequate training and safety measures. The personnel required to conduct these flight operations are a significant cost driver for the service. Wingcopter envisions localizing this part of the value creation by incubating or fostering a local business to run the flight operations with educated and certified drone pilots of local origin.

Wingcopter proposes taking the following action points into consideration before a third phase of the vaccine delivery:

- Schedule the third phase over a period of at least 12 months and include extensive training, certification and developing operational experience of local trainee pilots in support Wingcopter staff to qualify them to conduct drone operations independently from external operators.
- Create intern positions at the CAAV to familiarize citizens of Vanuatu with aviation. Comparable activity is already being undertaken by the UNICEF office and the Department of Civil Aviation in Malawi from which to learn from
- Award scholarships for drone related studies like aviation management and aerospace engineering in universities

3.2.2. A national-scale business model

The Wingcopter project team established drone delivery operations on Pentecost Island over the course of eight weeks. Ninetytwo BVLOS flights were conducted during the operating project period. Because of the necessity to run test flights before the first approach of a new drop-off site to allow for safe flight operations, not all of the flights were deliveries. However, once flight operations are established usage can be easily scaled up and less flights would be required to serve the islands in shorter time.

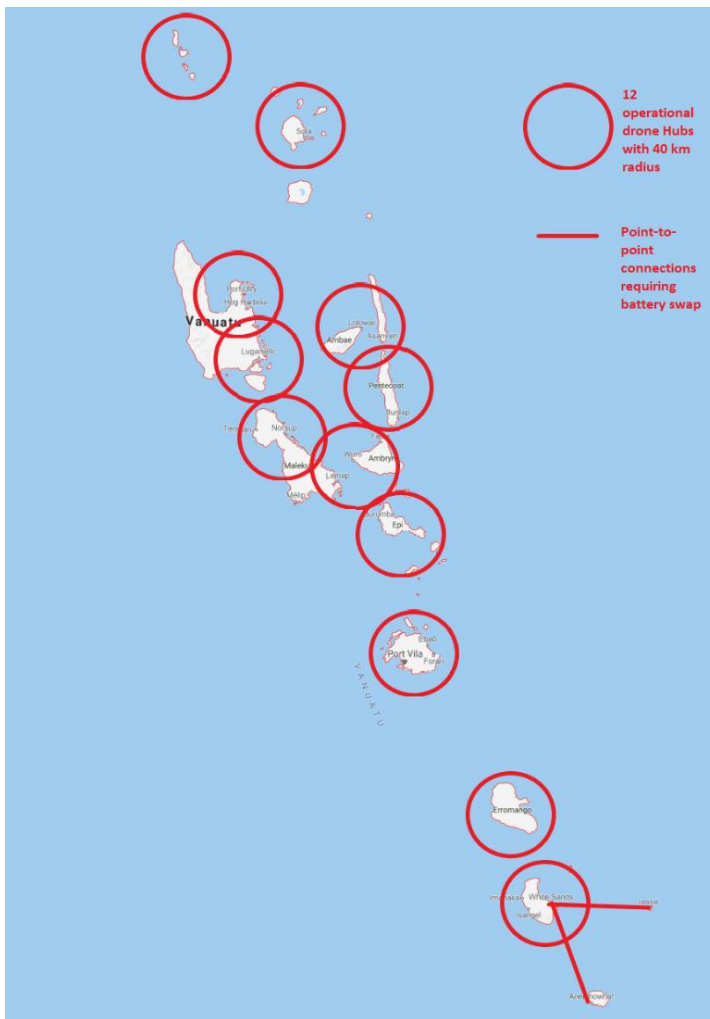


Figure 11 Rough estimates on servicing multiple islands with a 40Km radius around the drone hub

With the average flight frequency demonstrated in this project, around 11 flights per week, one can estimate the following key metrics for an optimal, fully-operational delivery system once preparation and scouting is complete:

- Servicability of an area like Pentecost Island within two weeks of monthly flight operations
- Capacity for servicing two districts comparable to Pentecost Island by potentially one operational team

The following details the requirements for a fully-operational team:

- A maximum of three drone operators assigned to each operational team
- One to two drone in each operational team
- Six operational teams to service potentially up to 85% of the area of Vanuatu
- Central pool of spare parts and three UAS as quick replacement stock in Port Vila

This leads to a total staff of around 18 local drone operators and a fleet of nine Wingcopter 178 Heavy Lift to service Vanuatu on a national scale with the existing technology.



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The developed capacity of drone pilots and technical equipment available would allow for a variety of business opportunities for the local drone operator.

Additional business opportunities can be based around delivery and pick-up of other cargo, one-way deliveries as well as the utilization of the drones as platforms for data collection. Concrete examples include:

- Delivery of emergency medication
- Pick-up of lab samples
- Postal services, E-commerce or cash deliveries
- Landscape surveying
- Disaster assessment and response and vulcano monitoring



Figure 12 The Wingcopter 178HL flying over an active volcano - Mount Etna in Italy



4. Evaluation

When arriving in Vanuatu the expected challenges were acceptance of the project by the community, interaction with the health workers and technological challenges for safe deliveries. After successful completion of the project the former two challenges turned out to be less difficult than expected. The people of Vanuatu were very welcoming to the changes that such a new technology could bring. Rather than being afraid or sceptical they appreciated the potential of the project and watched with curiosity. Also, working closely with the nurses and understanding their challenges enabled the team to perform to the level as they did. The nurses understood the safety aspects of an arriving UAV, did an excellent job of raising awareness of their communities and successfully implemented the safety rules as trained.

The topography of the remote island of Pentecost did not make it easy for the flight team nevertheless the challenges were overcome. The drone provided a reliable but flexible system for delivering the vaccines safely in spite of the harsh environment of Pentecost Island. The project, therefore, demonstrated that the use of drones can be technically feasible, accepted by the community and be embedded within the existing infrastructure to provide a solution for last mile deliveries of medical goods to hard-to-reach areas.

The operational time compared to the time spent establishing and disassembling the operational hub was rather short. In a prolonged project, the capacity of deliveries can be further scaled up and the cost effectiveness increased. Many of the BVLOS flights conducted were done to gather important terrain data for safe flight deliveries. However, these flights are only needed in the initial operation time and did not hinder the project team to meet the demand of the needed vaccines in its gradual approach. Each destination that received one successful delivery was then on-boarded and able to receive further delivery payloads much easier due to the simplicity of repeating programmed flight routes. This indicates that there are capacities for delivering additional goods over a prolonged time span following an initial set-up phase.

Delivering heat-sensitive vaccines via drone proved to be a viable alternative solution to the logistical challenges that come with the lack of an adequate road network, the unreliability of the existing boat fleet, the time required to reach rural health facilities, the costs associated with transportation, and the associated high travel risks. The same delivery system can also be used to deliver a variety of other medical goods.

Besides extending the cargo portfolio, Wingcopter also identifies an opportunity in training local drone pilots to become part in the drone delivery service in the future.

Wingcopter is grateful to have had the opportunity to work together with the people of Vanuatu towards this successful implementation. The company had many learnings throughout the project and continues to strive for improvement on every level. Wingcopter hopes to advance the work in Vanuatu in a further Phase 3 using the lessons from Pentecost to offer a service at a greater scale and cost effectiveness.

With this project, Wingcopter got one step closer to its vision of saving and improving lives by building a fast and safe drone delivery infrastructure for medicines and medical products.



| *Figure 13 Wingcopter staff receiving a traditional Pentecost Island satchel during a farewell ceremony at the health centre in Ledungsivi*