DrOTS : Drone Optimized Therapy Systems

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EXECUTIVE SUMMARY

Almost half of the planet's human population lives in rural areas, with 90% of rural residents living in Asia and Africa. In Nepal, more than 80% of residents live in rural areas and 50% live in remote, mountainous regions with poor access to healthcare. There are substantial discrepancies in access to healthcare between urban and rural residents[1], particularly in low and middle income countries like Nepal with fragile infrastructure and limited skilled human resources for healthcare. To achieve the sustainable development goals, we must close this gap and improve access to primary healthcare in remote rural areas [2,3]. Around 70% of Nepalese are carriers of Mycobacterium tuberculosis and many of them are suffering from active tuberculosis disease. In fact, TB is the 4th leading cause of death in Nepal and countless rural cases of TB go undiagnosed because patients cannot access simple diagnostic tests and get free treatment provided by the government. The National TB Programme has set a target to diagnose an additional 20,000 cases of TB over the next 5 years to close this diagnostic gap, but systematically reaching those in remote areas is extremely resource intensive.

One of the greatest challenges for improving rural healthcare is transport of clinical samples, medical devices for diagnosis and delivery of medications. The majority of healthcare facilities in the country are not accessible by roads. On average, it takes six-to-eight hours to travel between a hospital and healthcare facility in rural Nepal. This leads to shortage of essential medicines and explains why it can take so long for patients to be diagnosed for diseases like tuberculosis (TB) as patient samples can only be tested at diagnostic labs in major cities. This is a challenge which can clearly be addressed by the use of drones. Drone technology is advancing rapidly opening the possibility of many potential applications to healthcare, the scope of which is only just becoming apparent.

The Drone Optimized Treatment System (DrOTS) project aims to improve the accessibility of TB diagnostic tests by linking community health workers (CHWs) with state-of-the-art diagnostic tools (GeneXpert) via drone. Drone-assisted sputum sample collection is now operational in eight of twelve health posts in Pyuthan and Swargadwari municipalities of Pyuthan district. Till date, over 106 drone flights have been carried out, delivering more than 742 sputum samples from eight remote health facilities, and delivered directly to two regional hospitals for rapid testing out of which 26 are positively diagnosed. Once diagnosed, patients are offered the option to receive their six-month TB therapy using an electronic treatment adherence device (e-DOTS), to remove the need for daily attendance at the health post- a further barrier to healthcare.

In Phase I of the DROTS project, we have:

- ❏ Obtained permission to fly beyond line of sight with medical cargo drones for the first time in Nepal from 12 government ministries and agencies.
- ❏ Networked 8 health posts to two GeneXpert laboratory hubs using two modified DJI Matrice 600 drones.
- ❏ Operated regular drone cargo flights between two central health centers and 8 of the 12 rural health posts since June 2019.

Birat Nepal Medical Trust (BNMT), WeRobotics, Nepal Flying Labs and DroNepal, therefore, teamed up with the Liverpool School of Tropical Medicine, the Ministry of Health and Population (MoHP Nepal), the National TB Center, the District Public Health Office (DPHO Pyuthan) and under the support of Stony Brook University, the Nick Simons Foundation, brought this interesting application of cargo drones in important public health work.

Nepal Flying Labs is one of 25+ Flying Labs in Asia, Latin America and Africa. Flying Labs are local knowledge hubs run entirely by local experts who are trained, equipped, and supported by WeRobotics as needed. Since 2016, WeRobotics and Flying Labs have set up multiple cargo drone projects in Peru, Dominican Republic Fiji, Papua New Guinea, Brazil, and Nepal with a range of public health partners. To learn from this direct, hands-on experience in cargo drones along with lessons learned from the broader cargo drone community, please see this peer-reviewed online training on medical cargo drones.

ACKNOWLEDGEMENTS

We would like to express our special thanks of gratitude to Mr. Mahendrabahadur Shrestha, Head of Planning Section, Ministry of Health and Population for strongly endorsing and supporting this project with the recommendation letter on behalf of the health ministry, which helped us to convince other agencies during the permission process and foster belief in the potential of drones for health care.

Similarly, we appreciate much help from Mr. Subash Jha and Mukesh Dahal from the Civil Aviation Authority of Nepal who believed in our proposal and the potential of drones in health care and helped us get the letter from the civil aviation in a very short time.

We sincerely thank Mr. Ramkrishna Subedi-Spokesperson, Ministry of Home Affairs; for having faith in this project and convincing his team at the home ministry to give us the required permission to begin the projects.

The project would have been impossible if we did not have the strong support letters from the Mayors of Swargadwari and Pyuthan Municipality, we thank you for providing the support letters with which we were able to convince the ministries at the central level about this project. A big thanks to Mr. Bishal Subedi, Head of District Public Health Office, Pyuthan for his leadership and constant support across all phases of the project implementation. We would like to extend our gratitude to Mr. Gangaram Subedi for visiting all major provincial ministries departments and securing the support letter to implement the project in Pyuthan district.

We feel to acknowledge our indebtedness and deep sense of gratitude to Mr. Rajesh Parajuli from BNMT Nepal for actively following up and facilitating the import of drones into the country for the first time in Nepal and getting them registered at the department of aviation safety. Lastly we would like to thank all the individuals who directly or indirectly contributed to successfully doing the field tests without which the project would have been incomplete.

CHAPTER 1: INTRODUCTION

1.1 Rural HealthCare in Nepal

Nepal boasts a distinctive and diverse natural and cultural climate with its ancient heritage and the Himalayan landscape as an awe-inspiring backdrop. The lack of proper accessibility to infrastructure that stems from harsh topographical conditions is the chief element why Nepal is one of the poorest countries in the world. 25% of 29.3 million population live below the national poverty line without access to basic necessities, one of which is healthcare. Over 80% of the total population lives in rural areas, the majority of which are compelled to seek health care through walking for several hours. Although the country is rich in cultural and scenic splendor, the adverse terrain poses an unrelenting hindrance to development, as a result of which several sectors of development are severely restricted.

The major obstacle to healthcare, as of any other sector in Nepal, is attributed by the topography of the country. Only few of healthcare facilities in Nepal are accessible by roads and, as a result, with advanced health centers concentrated only in urban areas and diagnostic laboratories not being present in most primary health facilities, the majority of people are forced to walk by foot to access the existing health infrastructures. Also, the means to deliver medicines which are usually stored at the nearest urban hospital is through unpaved earthen roads that are completely flooded during the monsoon season in lowland areas. Thus, traveling on foot makes the travel time long and hectic between a hospital and healthcare facility in rural Nepal, which also leads to shortages and stock outs of drugs. A 2013 Service Tracking Systems report cites drug stock out as one of the major challenges to rural healthcare access and delivery in Nepal, with more than 74 percent of health-posts and sub-health-posts reporting stock out of many of the 22 essential drugs in the 2012/13 fiscal year[4].

Primary health posts in rural areas are also not adequately staffed. The doctors to patient ratio of an extraordinarily high 1:18,400 clearly depicts how limited the accessibility to health services are in Nepal. With the majority of doctors residing in urban areas, poor inhabitants to rural Nepal have a very bleak opportunity to get even the most basic medical advice and treatment. As a result, 22% of the population does not have access to basic healthcare facilities (DFID, 2010), and there are frequent instances where people die with diseases as common as fever. Tuberculosis alone presents a daunting fact of dire need of upgrades in healthcare diagnostics in Nepal. According to the data of 2015, of more than 70,000 cases of tuberculosis reported in the National Tuberculosis Program (NTP), about 15% of the TB cases missed the chances of treatment due to lack of transportation of sputum samples for diagnosis. This is largely due to limited accessibility. Furthermore, the majority of rural-based pregnant women and infants face similar limited access to healthcare diagnostics.

The problems with connectivity: among health facilities, diagnostic laboratories and well-trained personnel, as well as with the access to basic medicines at the time of emergencies can be ameliorated efficiently and cost-effectively through Unmanned Aerial Vehicles (UAV), also known as drones, UAVs can be used as a crucial component to connect primary health facilities to hospitals by delivering patient information such as blood, urine and stool samples required for diagnosis from primary facilities to hospitals; and medicines from hospitals to patients in nearby rural locations for treatment. The DROTS project in Nepal is pioneering the application of this technology to strengthen a rural healthcare system in a model demonstration district.

1.2 Tuberculosis Problem in Nepal

Tuberculosis (TB) is the 4th leading cause of death in Nepal in 2015 [5] and the leading cause of death from an infectious disease. Nepal is typical of remote settings, many of which are only accessible by foot, with 50% of the population living in mountainous and hilly areas with extremely poor transport and access to a healthcare facility. This lack of infrastructure has a direct impact on health outcomes, especially when disasters strike. When inhabitants of such areas become ill they must run through a gauntlet of challenges on their pathway to healthcare. These include arduous walks to reach health clinics, health facilities staffed by poorly trained health workers equipped with limited diagnostic tests, and a need to return frequently to clinics for continued health monitoring.

As eloquently stated by Margaret Chan, the world has committed to universal tuberculosis (TB) care. To achieve this requires combating TB in all its myriad settings. While great progress has been made in urban areas, the unique health challenges faced by people living in harsh terrain or sparse population has not been addressed. The WHO's End TB strategy has set a target of zero TB affected families facing catastrophic costs by 2020 within the framework of the wider goal to reduce global TB incidence to less than 10 per million population by 2035 [6]. This target to eliminate catastrophic costs by 2020 is clearly unachievable with the current levels of investment in Universal Health Coverage and TB care. To develop effective strategies to reduce catastrophic costs, countries must understand how novel interventions in the TB care cascade influence both patient and health system costs.

Nepal has made little progress against TB in the last decade. The first ever Nepal TB prevalence survey conducted in 2018-2019 has shown that the true burden is 1.7 times higher than estimated by WHO in the past. This means that the scale of the challenge is much higher than previously thought. It is now clear that over 20,000TB cases are 'missing' in Nepal each year (8). Many of these cases occur in poor rural households unable to access a TB diagnosis.

1.3 About DrOTS

The fact that UAVs are far less time consuming than having to travel through foot, or through dangerous winding roads in mountains not only serve to reduce additional consequences, but have the added advantage of increasing resilience and preparedness in case of emergencies. To be truly sustainable and integrated, a drone network was operated and maintained by rural health staff who often have limited formal education and many competing demands on their time, which is a distinct proposition from a commercial drone network operating for profit. This included development of simplified protocols for flight operation, including fly/no-fly weather criteria, validated training modules, robust and durable hardware and customized software.

Drone Optimized Therapy System (DrOTS) links community health workers with high-end GeneXpert diagnostic tool via drones aiming to improve the accessibility of Tuberculosis diagnostic tests. Under this system, the drone flies from central district hospital to health care centers in the remote villages and brings back the sputum sample where the sputum sample is checked by the healthcare personnel using state-of-art diagnostic tool (GeneXpert Machine). The purpose of this project is to assist the Ministry of Health and Population (MoHP) and National Tuberculosis Center (NTC) by generating the data necessary to assess the suitability of the approach for nationwide expansion.

In Pyuthan district of Nepal, DrOTS uses a drone transport network to improve access to the most advanced diagnostic testing for tuberculosis (TB), and to remote treatment adherence monitoring (e-DOTS) using electronic pill boxes (Wisepill Technologies, South Africa). The major objectives of the project include the following:

- ❏ To Establish "On-Demand" Drone Service in the mountainous/hilly area that included an appropriately equipped and staffed base camp and a cadre of health workers who were able to request a drone when required with easy-to-use system for operating the drone flights.

- To Remotely Diagnose TB – This same cadre of health workers were trained to recognize a person likely to have TB according to the norms of the National TB Program, explained to them the need for testing and safely obtained quality sputum samples.
- To Remotely Observe TB Therapy – By combining conventional health provider interaction and innovative technologies,patients were monitored over the six-month treatment for adverse drug reactions, ensured medication adherence and assess trends in symptoms.

The secondary objectives include:

- To educate and empower local partners to assume full ownership of the DrOTS program, so as to ensure its sustainability after the project ends.
- To generate evidence regarding the feasibility, acceptance, and cost-effectiveness of the DrOTS program, with a focus on informing an eventual scale-up of its services nationwide.

CHAPTER 2: PROJECT METHODOLOGY

2.1 Preparatory Phase

The project was started by creating a project team with different individuals pertaining specific roles. The roles of different partners were set forming the final project team to lead DrOTS. Memorandum of Understanding were signed among different project partners. Finally project documents were prepared to communicate with different stakeholders. The project team includes

- ❏ Birat Nepal Medical Trust : Public health partner leading all health related activities
- ❏ DroNepal & Nepal Flying Labs : Technical team on ground, handling all flight permission & aerial flights related activities
- ❏ WeRobotics: Technical team leading the customization of drone and development of the necessary software modules for flight operations
- ❏ Stony Brook University : Team leading the Project Management
- ❏ Liverpool School of Tropical Medicine : Team providing mentorship and capacity building for research and laboratory strengthening

2.2 Legal Permissions

The implementation of the project initiated as the local stakeholders were introduced to the benefits of this project. It followed by receival of recommendation letters from different agencies which were used to get permission from the central level. The support letter from the Ministry of Health and Population Nepal helped extensively for these permissions. This was the first time the Government of Nepal officially gave permission to fly a DJI M600 for medical cargo purpose. This consumed a significant amount of time as we had to work together with all three levels (Local, Provincial, Federal) of the government and the permission were secured from everyone in 6 months. The required hardware were imported and the drones were registered under the department of aviation safety office. Finally a unique identification number for both of the drones were obtained and registered under the name of BNMT. To sum it up, approvals were received from 12 different agencies.

2.3 Sensitization Workshops

Different level of sensitization was required and it was the crucial initial need before the inauguration of the Project. Community consultancy and sensitization workshops were organized at district level as well as municipal level to educate local people and officials about the benefits of this technology .

Figure 2.1 : Municipal level orientation program about DrOTS

The following were accomplished during these stakeholder engagement workshops:

- Interaction programs were organised inviting the head of the district, CDO, mayors from both Pyuthan and Swargadwari municipality and chairperson from all wards-
- Local People and ward officials from all wards of both municipalities were acquainted with this technology and how it is being used for the improvement of healthcare in Pyuthan.
- The flight paths and detailed procedures of each planned flights were shared and their queries regarding drones were answered.
- **Children/Students from local schools** from the local communities being influencers to disseminate messages over different sections of the society, interaction and demonstration sessions were organised in several local schools to educate and engage them with this novel technology.

2.4 Aerial Mapping of all health posts and Hospitals

Most of the rural areas in Nepal lack accurate updated maps. The pilot team required high resolution maps of health facilities to plan tentative takeoff and landing sites prior to beginning of the actual flights; 12 health post sites and the 2 central health centers were mapped by the technical team from Nepal Flying Labs and Dronepal.

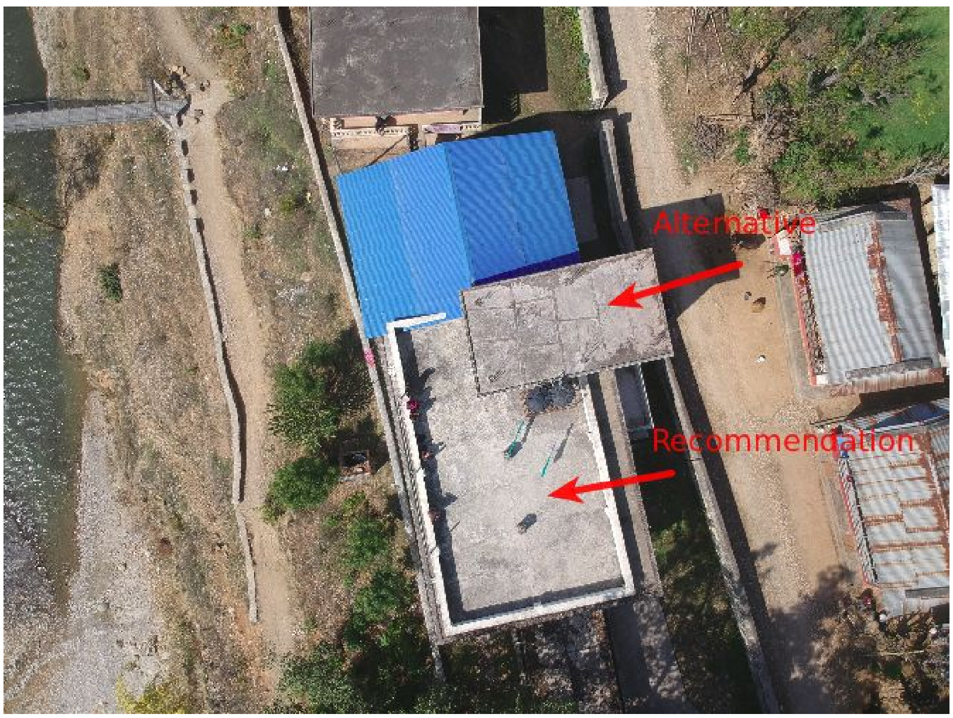

Figure 2.4: Aerial mapping and recommended possible landing sites

2.5 Flight Planning and Testing

Using the drone maps Flight routes were carefully created using QGround control software, for each path. Intermediate stations were also planned at certain locations for emergency landing.

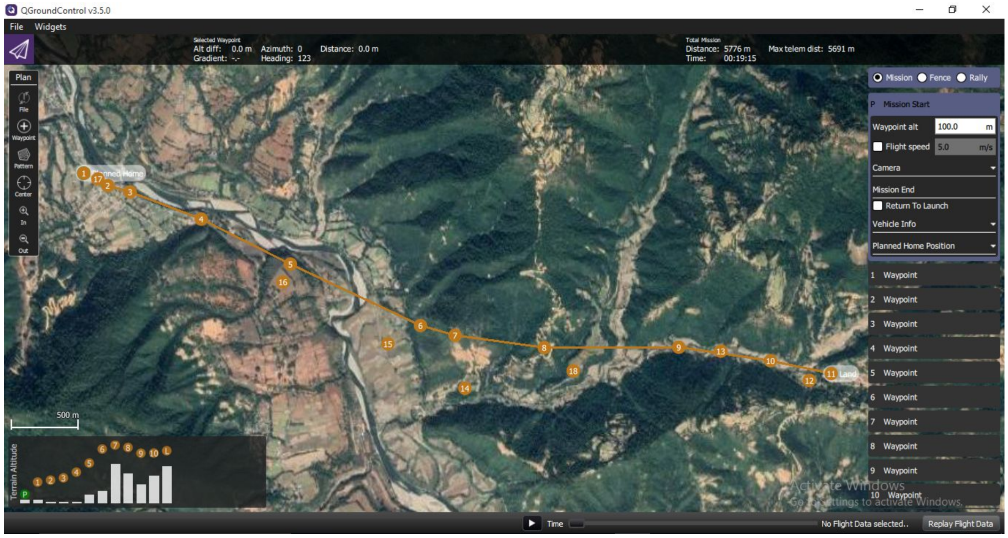

Figure 2.5: Qground control software showing the flight plans

The following considerations were taken into account while planning the flight routes.

1. Avoid settlements as much as possible
2. Maintain gentle slope ascend
3. Establish intermediate points for emergency landing
4. Maintain at least 90m ground height clearance across all paths

A series of field activities were carried out by the Engineering team from WeRobotics that stayed in Nepal from 22nd May to 2nd June and 15th July to 27th July. A number of test flights were performed between central hospital and health posts in the rural areas.

2.6 Official Inaugural/Kick Off

After a series of test flights and detailed field mapping, the technical team were ready for beginning the operations. An event was organized at Bijuwar, Pyuthan to formally kick of the flights. On 2nd June 2019, (DrOTS project was successfully inaugurated in Pyuthan district with the objective of sharing the details of the project with concerned stakeholders. The program was an extravagant affair, having active participation of government from Ministry of Health and Population, National TB Center, Health Office Pyuthan, mayors and elected representatives from local governments and other stakeholders & partners.

Figure 2.6: Inauguration ceremony of DrOTS Project

During the official inauguration of DrOTS Project, the program was chaired by Bishal Subedi, *Chief of Health office, Pyuthan*; followed by Chief Guest Mahendra Shrestha, *Chief, Department of Health Coordination, MoHP*; Special Guest, Dr. Bhim Singh Tinkari , *Director, NTC*; and guests, Peter Small, *Principal Investigator, Stony Brook University*; Badri Nath Gaire, *CDO, Pyuthan*; Ghamsyam Pokharel, *Chief of NTD and Vector Borne Disease Control Section*, *EDCD*; Netra Bahadur Roka, *Mayor, Swargadwari Municipality* and Arjun Kumar Kakshyapati, *Mayor, Pyuthan Municipality.* The program was formally inaugurated by Chief Guest Mr. Mahendra Shrestha, *Chief, Department of Health Coordination, MoHP*, with presence of BNMT team, the stakeholders including partners.

2.7 Medical Cargo Operations

The medical cargo drone operation officially began right after the inaugural. The first official flight took off from Pyuthan hospital to Dharmawati health center on June 16. Flights were operational on 8 health centers out of 12 health posts, and drone flights were carried out from Pyuthan hospital and Bhingri primary health center. Every week, 10 flights were conducted from central hospitals to health post. In average weekly 80 sputum samples were transported. All the flights are fully automated and precision landing improved landing accuracy. The Longest route was recorded to be 6.7km.

Figure 2.5: Medical Cargo Drone Operation

Flights were conducted 5 days a week to 8 of the health-posts from two different health care center. Friday was allocated maintenance. Two flights were carried out a day. The belows shows the schedule of the flights however these routines were changed according to the health-post demand.

S.N.	Site	Day
1.	Pyuthan to Dharmawati	Monday
2.	Pyuthan to Maranthana	
3.	Pyuthan to Majhkot	Wednesday
4.	Pyuthan to Addapata	
5.	Bhingri to Shotre	Tuesday
6.	Bhingri to Barjiwang	

7.	Bhingri to Gothiwang	Sunday
8.	Bhingri to Saari	
9.	Bhingri to Gothiwang	Thursday
10.	Bhingri to Saari	

2.8 Training and capacity building

We have conducted a number of trainings and workshops from the initial phase of the project. Orientation about the project have been conducted at different levels and agencies. Along with that, Standard Operating Procedure Workshops have also been organized to different Health Workers and Volunteers. Hands-on flight training to health facility staff have been organized aiming for the sustainability of the project.

S.N	Event	Month	Participant	Venue
1	Orientation to district Stakeholders about DrOTS	May	55	Ayushma Hotel,Pyuthan
2	Orientation to elected bodies about DrOTS	May	40	Pyuthan NP Swargadwari NP
3	SOP Workshop about about DrOTS	June	51	Ayushma Hotel,Pyuthan
4	Orientation and training to the volunteer about DrOTS	June	34	Ayushma Hotel,Pyuthan
5	2 Day Training to the Lab Personal about DrOTS	June	23	Heath Office Pyuthan
6	Orientation to Health Facility staff and FCHV = 10	July to Oct	150	All Health facility
7	Orientation and training about Smart Pillbox to Health facility = 2	Aug	35	Pyuthan Hospital and Bhingri PHC
8	Orientation to local level school about DrOTS Project = 16	Oct	More than 3000 school student	16 local school
9	Drone flight Training to Health Facility Staff = 2	Dec	45	Heath Office Pyuthan
10.	OSM Training to School Students and Teachers	Dec	25	Janata Secondary School Bagdula

CHAPTER 3: DROTS-PROJECT DETAILS

3.1 Working Procedure:

A system has been built that is centered around drones as a service for sputum sample collection which can be implemented to other medical services. The primary objective of this intervention was to enhance connectivity between hospitals and rural healthcare centers, and to improve the accessibility of the rural population to basic healthcare facilities.

The system consisted of the following:

- ❏ A drone lab at the hospital from where the drone took off
- ❏ A second lab at the rural health post where in-house personnel observed the precision landing
- ❏ The in-house personnel took manual control and landed the drone when needed, received reports and medicines, loaded test samples for diagnosis into the drone and sent it back to the hospital
- ❏ The hospital then received test samples to perform diagnostic tests and the process was repeated.
- ❏ Sample was received and taken to genexpert machine for the diagnostic.
- ❏ The above process was repeated.

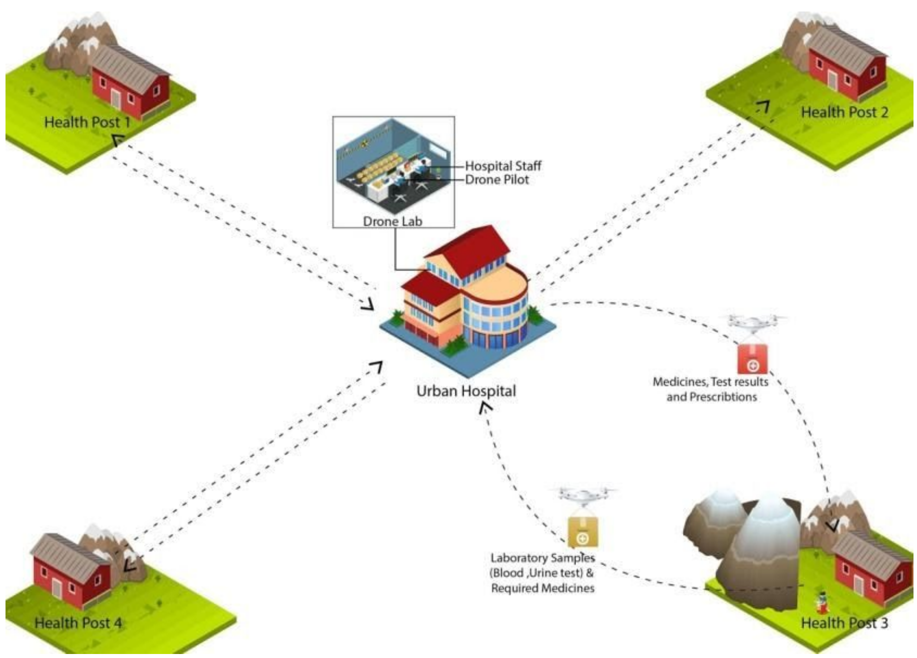

Figure 3.1: Schematic diagram showing all process included in DrOTS

3.2 Medical Cargo Drone Technology

The project primarily consisted of an integrated system with distinct components that worked in synergy to optimally utilize cutting-edge technology while providing easy-to-use interfaces and automation. This enabled swift adoption of the technology by unskilled users to apply the system sustainable within a healthsystem. In order to simplify the whole process from sample loading to the delivery to the destination and return flight, an intuitive android application had been developed for the project. Also, in order to assist with safe and precise landing, need for any manual intervention had been removed by the use of precision landing system assisted by camera and other sensors. The whole system can be divided into four distinct components which are described in detail below:

1. Medical Cargo Drone
2. Medical Cargo Box
3. Application Software
4. Expanded Telemetry System
5. Precision Landing System

3.2.1 Drone Delivery hardware :

The technical team at WeRobotics had customized the industrial Drone DJI Matrice 600 and repurposed it into a medical cargo drone for the DROTS project (Figure 3.2). Two of these drones had been purchased and used in the DROTS project. The technical specifications of the drone are given below (Table 1).

The two Matrice 600 pros were both identically modified to work independently, which allowed for simultaneous testing of newer upgrades while still having a functional system for flight tests.

Figure 3.2: The DJI Matrice 600 drone customized as a medical cargo delivery drone for DrOTS.

Some of the key technical specifications of the drone, as provided by the manufacturer, are shown in table 1 below.

Table 1: Key specifications of the DJI Matrice 600 drone used in DROTS.

Feature	**Specification**
Diagonal Wheelbase	**1133 mm**

Dimensions	**1668 mm × 1518 mm × 727 mm** with propellers, frame arms and GPS mount unfolded (including landing gear) **437 mm × 402 mm × 553 mm** with propellers, frame arms and GPS mount folded (excluding landing gear)
Package dimensions	**525 mm × 480 mm × 640 mm**
Weight (with batteries)	9.5 Kg
Max Takeoff Weight	15.5 Kg
Max Flight Time	35 mins
Maximum Speed (no wind)	40 mph / 65 kph
Wind Resistance (Max)	8 m/s
Ascent Speed (Max)	5 m/s
Descent Speed (Max)	3 m/s

3.2.2. Medical Cargo Box

The DJI drone had to be modified for the purpose of transporting sputum samples contained in clinical sample tubes. This required a custom designed cargo box that could safely transport the sample tubes, while at the same time allowing easy and fast loading-unloading of the samples. Hence, the Engineering team at WeRobotics designed and 3D printed customized Cargo box for the purpose, with a capacity of carrying 16 sample tubes in a single flight.

Table 2: Specifications of the custom designed cargo box.

Dimensions	Length: 22 cm Breadth: 14 cm Height: 16 cm
Total capacity	16 sputum samples (up to 1kg)
Weight of box	250g
Manufacturing type	3D Printed PLA

3.2.3 Application software for the drone flights

One of the most significant objectives of the DROTS project was to create an easy-to-use system for operating the drone flights which were used by healthcare workers in remote areas with limited formal education. To facilitate this, an application was developed with a simple user interface in both Nepali and English, alongside simple Standard Operating Procedures (SOPs) and protocols. The major components of the software and application aspect of the DrOTS project for the planning, monitoring and controlling of the system are described below.

- ***Route planning***:

Prior to conducting any test flights, the optimal flight paths were determined between any two locations (health post and laboratory hub) by evaluating and comparing alternative flight routes. Hence, the route planning was performed by the expert team using open source mission planning software, and the confirmed routes were made available to the end user through importing it in the user application. Predetermined flight path programmes were then followed during test flights. This minimized the user intervention for any flight by providing predetermined route options without having to manoeuver the drone manually.

- **Autopilot System**:

In order to automatically perform the planned flight missions, an autopilot system was developed for the drone, converting the Matrice 600 into a cargo drone. With separate onboard computer setup for handling the flight missions, the system is capable of accepting routes planned in the mission planning software and converting it to flight mission for the drone to follow.

- **User application for monitoring and controlling the drone:**

An android based tablet application was developed which has been carefully designed to make it appealing while at the same time reducing complex operations, keeping the application minimal and user friendly.

The user application has two principal functions

Firstly, monitoring of the drone vitals and status of the in-flight missions. The user application presented the drone vitals including the remaining battery percentage, altitude of the drones, distance from the ground, the location of the drone, the number of connected GPS satellites, identification of connected controllers.

And secondly, controlling the flight operations. The user, prior to any flight, was provided with a drop-down list from which the desired mission could be selected. The list consists of the flight routes heading from the current location of the user, and hence the user was able to easily choose between available routes. Moreover, during the flights, in case of any unexpected event, the user could switch the drone from automatic mode to manual mode and handover the control to a remote control operator, who should be an experienced pilot.

- **Remote control for manual operations and emergency takeover:**

The remote control of the drone is normally unused in the system during normal delivery flights, and is available to expert drone pilots only, who could intervene in case of emergencies. As the drone flights were all automatic, the manual intervention was not required for any deliveries, from takeoff to landing, however, during emergencies it was used.

Table 3: Specifications of the Remote Controller

Operating frequency	920.6 MHz to 928 MHz (Japan); 5.725 GHz to 5.825 GHz; 2.400 GHz to 2.483 GHz

Maximum Transmission distance	FCC Compliant: 3.1 mi (5 km), CE Compliant: 2.2 mi (3.5 km) (Unobstructed, free of interference)
Battery	6000 mAh LiPo 2S

3.2.4 Expanded telemetry system

The drone and the tablet based user application used communication radios in the DROTS system to directly communicate with each other. However, the range of communication was limited, and with the flight operations occurring across multiple hills, and distances stretching several kilometers, the telemetry system was not capable of communicating over the entire flight. For the drone to complete the mission automatically without requiring any human intervention, it was important to have a connection with the ground station at all times in order to monitor the status of the mission as well as the drone, therefore allowing manual intervention when necessary. Hence, a telemetry extending system had also been designed and implemented for the DROTS project with multiple ground stations capable of repeating communication between the drone and the user. These ground stations were small repeaters fixed at predetermined locations in posts or similar structures to ensure uninterrupted communication between the drone and the users. The drone was capable of communicating with more than one user application at a time, hence allowing the user on the district hospital as well as the user on the healthcare center to simultaneously monitor the flight operations, though kilometers apart.

3.2.5 Precision landing system

One of the major technical hurdles for operating a drone was associated with safe landing and takeoff, and even more so in areas with rough topography. Most of the health facilities in the rural locations did not have a proper sized open space. Also they were surrounded by trees making it very difficult for proper landing. With significantly large errors in GPS locational and altitudinal accuracy (the accuracy was up to 5m horizontally and up to 20 m vertically), relying on GPS alone for automatic landing was not practical. Landing required expertise, good reflexes and ample experience to safely land a drone with precision at a designated spot.

Figure 3.3: Drone landing precisely on landing tag

In order to simplify the process of takeoff and landing, a separate precision landing system had been developed and integrated with the Matrice DJI drone. Utilizing distance sensors and a camera sensor along with a powerful processing unit, a precision landing system had been developed for the project that allowed the drone to detect markers on a landing mat (shown in figure 3.2.5) from up to tens of meters of height above the ground, and safely land the drone over the marker without requiring any human intervention. As the drone reached its destination, it automatically started searching for the landing marker, detected the marker, and oriented itself to land above the marker. Three different size markers were used to allow the drone to precisely orient from different heights as it descended towards the landing site. Takeoff did not require a precision system, as the drone takes off and flied to the first designated waypoint, and then followed the predetermined path for the flight.

CHAPTER 4 : DRONE OPERATION

Two drone labs (virtual) with GeneXpert testing centres had been established at the Pyuthan District Hospital and Bhingri Primary Health Centre (PHC) from where the drone was dispatched. Firstly the drones were flown to a peripheral drone port at the rural health post where the drone was landed by in-house personnel/ precision landing system. Based on the lab reports which were received by the in-house personnel, the clinical samples were loaded for diagnosis into the drone cargo holder. Finally, it was dispatched back to the GeneXpert laboratory hub and the clinical samples were then received by the GeneXpert laboratory where diagnostic tests were performed and processed for testing. The drone performed multiple flights when necessary with each flight taking approximately 5 minutes to complete (average flight speed 1km/minute). Eight health posts out of twelve were networked to two GeneXpert testing centres.

4.1 List of health center and health post

There are 12 health posts, 6 in each municipality and two health centers one in each municipality. The list of all health centers with their topography properties are given below.

Pyuthan Municipality

S.N.	Route	Distance	X(deg)	Y(deg)	Z(m)	Dev_elevation (m)	Topography Type
1	Pyuthan Hospital	-	82.85	28.10	807.8	-	Valley Floor
2	Dharmawati	5.22	82.9	28.13	882.18	-74.38	Valley floor
3	Maranthana	6.48	82.91	28.12	922.09	-114.29	Valley floor
4	Addapata	4.63	82.82	28.11	970.95	-163.15	Valley floor
5	Majhkot	7.57	82.85	28.15	1703.99	-896.19	Hill Top
6	Jhumrikanda	8.25	82.82	28.17	1711.91	-904.11	Hill Top
7	Dhakkanwadi	8.7	82.78	28.1	617.77	190.03	Valley Floor

Swargadwari Municipality

S.N.	Route	Distance	X(deg)	Y(deg)	Z(m)	Dev_elevation (m)	Topography Type
1	Bhingri PHC	-	82.71	28.14	675.42	-	Valley Floor
2	Shotre	0.9	82.72	28.14	641.36	34.06	Valley Floor
3	Saari	3.89	82.7	28.18	782.44	-107.02	Valley Floor
4	Gothiwang	5.78	82.75	28.11	697.64	-22.22	Valley Floor
5	Barjiwang	5.72	82.77	28.13	851.09	-175.67	Valley Floor
6	Kochiwang	8.1	82.66	28.09	1263.63	-588.21	Hill top

7	Sorgadwari	8.14	82.63	28.14	1753.63	-1078.21	Hill top

Out of the above health centers the drone operation is only operational at 8 health centers.

4.2 Existing Flight Network

Figure 4.2 shows the network around the Pyuthan District Hospital in Bijuwar and Bhingri Primary Health Centre (PHC). Regular flights were operated from eight health posts to the two laboratory hubs, with a total of twelve mapped and ready to operate.

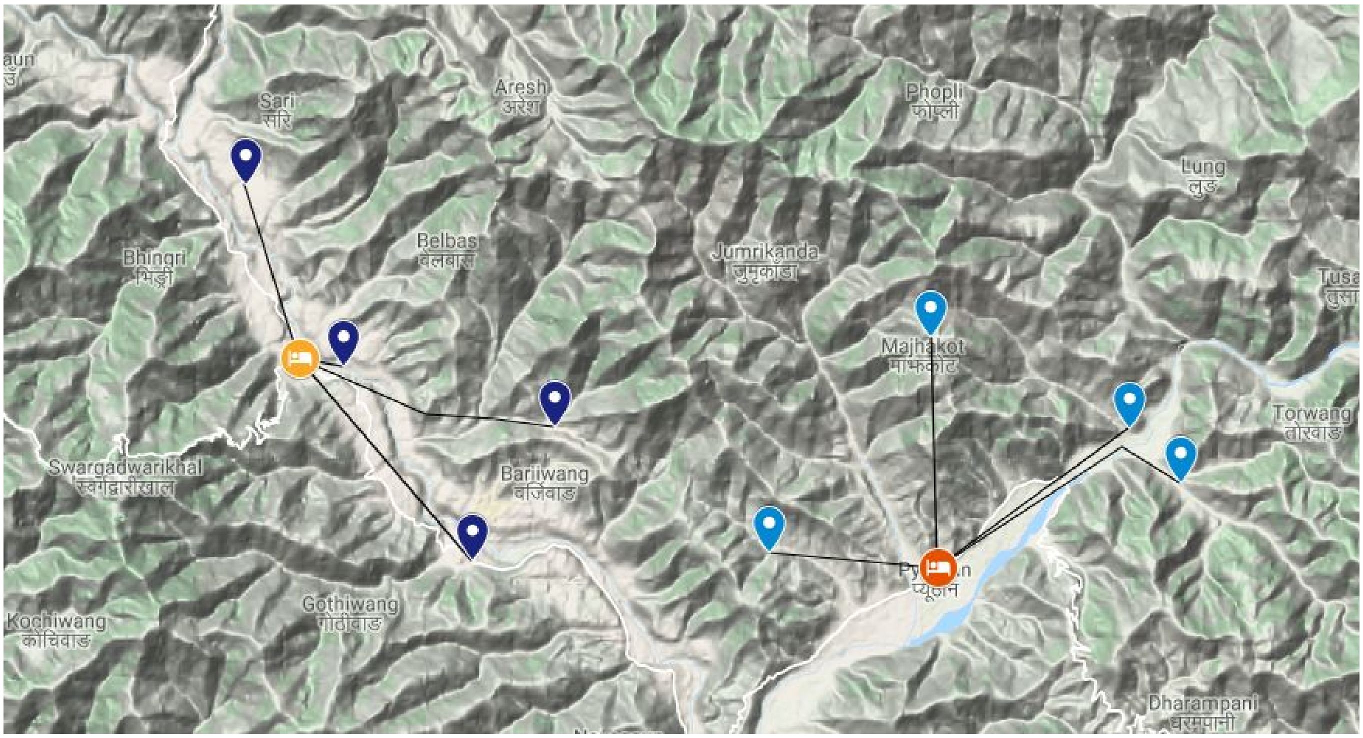

Figure 4.2: Drone network in Pyuthan district. Eight health posts operated regular flights from two different Health Care Centre.

4.3 Flight Descriptions

In total eight health care centers were connected with flight. Precision landing had helped to make the landing automatic and accurate. There was a drone station in health centers of each municipality. Necessary controls were made by the pilots who were standby with ground station at both ends

FLIGHT SUMMARY TILL DECEMBER 31st

S.N	DETAILS	TOTAL NUMBER
1	Sputum Samples Collected	744
2	1 Way Flights with sputum (From Hospital to Health posts)	107

3	2 way Flights with sputum (From Hosp. to Health Post & Back)	**214**
4	Tests Flights	**80**
5	Total flights (2 way flight with sputum + Test flights)	**294**
6	Technical Failures	**1 (at the time of swiss eng. visit)**
7	Precision Landing	**163**
8	Manual Landing	**51**

A detailed flight log is in **Annex 3**

Following were the drone delivery routes

From Bhingri PHC

S.N.	Route Name	Flight Time(Approx)	Route Distance(km)
1	27_2_Bhingri-Barjiwang	8 min	5.7
2	21_0_Bhingri-Shotre	4 min	1.1
3	23_1_Bhingri-saari	5 min	4.2
4	25_0_Bhingri-Gothibang	8 min	6.3

From Pyuthan Hospital

S.N.	Route Name	Flight Time(Approx)	Route Distance(km)
1	5_0_Pyuthan-Addapata	4 min	4.5
2	3_2_Pyuthan-Dharmawati	6 min	6.2
3	9_1_Pyuthan-Majhkot	6 min	6.1\
4	7_1_Pyuthan-Maranthana	7 min	6.5

***Note for the convention used:**

e.g. 9_1_Pyuthan-Majhkot
9 = Number of flight route
1 = Number of updates on route
Pyuthan = Drone Station
Majhkot = Health post

4.4 Standard Operating Procedures

Operating an automated system might seem easy but specific steps are needed to be followed by health personnel and the pilot at both ends of the flight route to ensure safe, secure and smooth operations. Thus, WeRobotics drafted this standard operating procedure (**Annex 5**) and all the flights are carried out accordingly.

4.5 Emergency Procedures

Care must be taken at all cost while flying a technically sophisticated system like drone. The drone should always be fully charged and the hardware has to be checked before running the flights. However, few preflight and on-flight problems could still come up which should be systematically troubleshooted. There could be different kinds of emergency situations during a drone operation such as critical battery during flight, bad weather, drone going off route etc. There are standard procedures that need to be followed during such emergencies. A list of standard procedures is in **Annex 6.**

CHAPTER 5: ACCOMPLISHMENTS

A drone transport system in Pyuthan district of Nepal has successfully been established and over 106 flights from June-December 2019 have been operated. This successful pilot took place including the most challenging weather season for flight operations in Nepal - the monsoon season.

5.1 Local district outputs

A fleet of two drones have been successfully established and it had been operated regularly for 6 months along the mapped routes and a network of drone docking stations for precision landing. Twelve health posts have been mapped for networking to two laboratory hubs with precision landing sites. Flight routes were operational for eight health posts networked to two GeneXpert testing hubs. This had led to the expansion of comprehensive TB active case finding using GeneXpert testing to remote areas with addition installment of a second GeneXpert machine for TB diagnosis at Bhingri Health Post and identification of third GeneXpert site at Okharkot health post. The District laboratory had been strengthened in collaboration with Nepal Tuberculosis Center(NTC) and the project has enhanced training of healthcare workers in TB awareness, diagnosis and treatment. One hundred additional TB cases have been diagnosed since the expanded access to GeneXpert testing for the district has been established. Over 742 clinical samples have been transported for rapid diagnostic testing and 26 positive cases have been identified.. The local healthcare workers have been trained to operate drones, along with local residents who had been identified and trained for drone flight and maintenance. This had improved technical skills of the local manpower of Pyuthan district leading to a successful career in the near future. A detailed aerial mapping of the healthposts had been carried out and the datasets had been digitized and uploaded on openstreetmap. A complete GIS mapping of district health system network had been recorded with prioritization roadmap for expansion of drone service for healthcare in the district.

5.2 National capacity building

DrOTS project has established a model demonstration district for medical drone transport network obtaining permission to fly beyond line of sight with medical cargo for the first time in Nepal from 12 government ministries and agencies at federal, provincial, district and municipal level. This has increased technical skills of early career professionals in geomatics, drone technology, health economics, infectious disease epidemiology, health system strengthening and data analysis. An extensive community engagement for partnership, cultural integration and inclusion has been conducted .This has also established an effective transdisciplinary team of engineers, public health specialists, community volunteers, researchers and government stakeholders. An easy to use mobile app has been developed in both English and Nepali which can manage flight operations. The strengths and limitations of the system and priorities has been identified for future development of the technology. An appropriate model district (Pyuthan) has been selected to demonstrate the technology considering health needs, geographic, demographic, political, social aspects. The review of the available technology has been conducted along with the assessment to determine optimal drone payload size to implement.

5.3 International knowledge contribution

A pioneer in cargo drone delivery system for healthcare has been established. The review of the available technology has been conducted with a needs assessment to determine optimal drone payload size to implement. This is the first time where the health economic evaluation of drone implementation for healthcare has been successfully done.

Dissemination of findings, knowledge and experience through the WeRobotics Flying Labs international network.

Media Coverage

A number of national and international agencies have shared the Project. Some of them are given below:

1) Nepal Times writes "Nepal tests and treats TB with a flying pharmacy" on June 7 2019
2) Kantipur Media covered a news story at the end of the project.
3) AbouT DrOTS Project by SBU , HERE and Several media coverage are in Nepali .

CHAPTER 6: FAILURES AND LESSONS LEARNED

6.1. Technical Shortcomings

Details of technical challenges encountered and addressed till date are given in the DROTS progress report (appendix A).

A summary table follows:

Technical aspect	Challenge	Solution	Further development required
Permission to fly	No clear process existing for obtaining permission to fly/beyond line of sight permission never before granted for cargo drones	Engaged with and obtained beyond line of sight permission from 12 government ministries and agencies and national, provincial and district level	Renewal of flight permission currently required every three months-advocating for longer timeframes
Communications	GSM network suffer from high latency and availability.	A custom low power network on the 2.4GHz bands was adopted. The range of the radios is limited to 2-3km line of sight. In order to keep constant contact with the drone on each route multiples relay stations have had to be installed	Yes. Explore optimal solution for topography in Nepal.
Weather	Unreliable and rapidly changeable weather	Protocol to verify weather at dispatch and landing sites before each flight. Limitations on flight operations during uncertain weather.	Yes- field test alternative drones with high weather resilience. Eg: DJI M200 is a waterproof drone but higher cost.
Operation by nontechnical staff	Staff with limited literacy and technical knowledge needed to operate the drones for sustainability/expansion of the network	Development of a simple step by-step user interface translated in Nepali	Yes-translation and validation to be finalized
Autonomous landing of drones	Accuracy of the positioning system (satellite based) used by the drone was not optimal for autonomous landing.	Additional module has been developed and added to the drone, using a ground based QR code at landing site in order to enhance its positioning capability during the landing process.	Yes-precision landing to be developed for remaining health posts

Cargo box	A simple, robust and easy to load cargo box was needed to accommodate clinic samples and devices	Box developed and field tested with appropriate labeling	Yes- alternative boxes needed for biohazard materials and cold chain shipment.
Maintenance and R&D of drones	Local staff need to be trained in minor repairs to drones to minimize maintenance costs.	Local capacity development and skills transfer commenced to enable local residents to carry out basic maintenance and simple repairs	Yes, ongoing process- development of training modules and HR capacity needed for sustainability

6.2 Strategies applied to mitigate the losses

Different challenges were encountered and the team applied different techniques to solve those challenges.Following were some of the strategies applied to mitigate possible damage and loss.

(A)Healthcare worker Ms. Sita G.C loading sputum samples into the custom made cargo box.
(B) QR code mat to enable precision landing. The three QR sizes enable the drone to locate and lock the landing area at different elevations as it descends to land
(C) Simple software interface developed for non-technical staff to operate drone flights
(D) Permission letters obtained from 12 ministries and government agencies at National, provincial and district level.

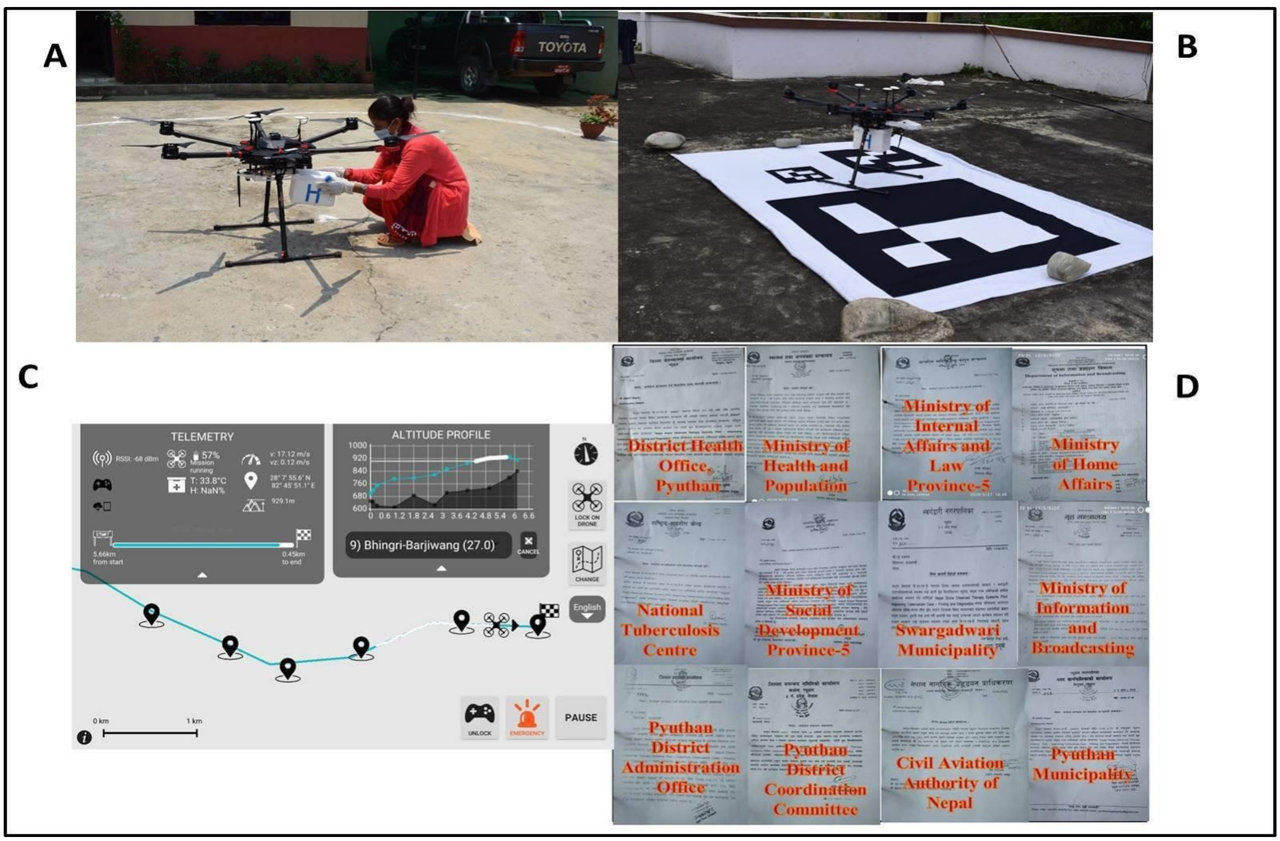

Figure 6.1: Addressing technical challenges encountered in the development of the drone transport system for Pyuthan district.

6.3 Lessons learnt

For a cargo system to be widely used, it has to be simple, reliable and as autonomous as possible. During the first phase of the project some issues were encountered regarding the following points.

I. Reliability:

Communication : The topography in Pyuthan and generally in Nepal is a challenge for communications. GSM network suffers from high latency and congestion. Therefore a custom low-powered network operating on the 2.4GHz bands has been used. The range of the radios is limited to 5km line of sight. In order to keep constant contact with the drone on each route multiple relay stations have to be installed. This adds to a big overhead on the workflow.

Weather conditions: The weather in Nepal can drastically change all of a sudden. The drone used until now is not waterproof. In order to realize longer mission and to fly whenever a flight is needed other drones solutions would need to be evaluated including better weather resistance.

II. **Simplicity:** The health workers demonstrate a lot of attention to the project and were present for each flight. They have no technical background, therefore it is imperative to have a simple interface translated the local language. The User Interface we are using is simplified to the minimum and guides the user over each step one by one. A partial translation to Nepalese has been performed and is a work in progress.

III. **Autonomous:** As outlined above, a drone cargo system will only have impact if it can be used by local with limited technical knowledge. This means most of the operations and the safety procedures have to be autonomous. During the first tests, the accuracy of the positioning system (GPS satellite based) used by the drone was found to be not-optimal for autonomous landing. Therefore an additional module has been developed and added to the drone in order to enhance its positioning capability during the landing process. This should reduce drastically the need for any manual landings carried by a drone operator.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

Conclusion

One of the greatest challenges faced by the rural health systems in countries such as Nepal is with transport systems; both transporting samples to laboratories for testing and delivering medicines or devices to patients. In rural areas, the lack of roads means patients and healthcare workers often have to walk for several hours along steep winding goat trails and through the hills to reach health posts or home - ever harder challenge for elderly and ill people - and even essential drug supplies face frequent stock outs.

The pilot phase of DrOTS has successfully demonstrated that Drones, or unmanned aerial vehicles (UAVs) hold great potential to address these challenges. However, the technology is not yet at a level where it can simply be implemented within a fragile health system. 'Real world' experience is required to inform development and optimization of appropriate and robust implementation models. The technology is advancing rapidly due to sustained investment, but with a focus on the development of commercial applications.

To be truly sustainable and integrated, a drone network needs to be operated and maintained by local health staff who often have limited formal education and many competing demands on their time, which is a distinct proposition from a commercial drone network operating for profit. This includes development of simplified protocols for flight operation, including fly/no-fly weather criteria, validated training modules, robust and durable hardware and customized software.

- ❏ The DROTS project in Nepal is pioneering the application of Drones in improving rural health.
- ❏ This district needs to be set up as a model district.

7.1 Recommendations

- ❏ Drones based Medical cargo delivery in rural areas of Nepal truly has a potential to reach and benefit the most vulnerable living at remote places and thus needs to be further developed and optimised for application in Nepal in collaborative partnership with government and community stakeholders.
- ❏ DrOTS is the first pilot carried out which have helped us to develop a process for drone implementation in rural Nepali healthcare services. Steps include the pathway to legal documentation and approval, successful engagement of local communities and understanding the performance of a multicopter hardware in the undulating topography of Nepal in comparison with 'idealised performance specifications reported by the manufacturer. Operational comparison of different model and specifications of drone needs to be tested for detailed data on which hardware performs optimally in the various Nepali contexts (eg. terai vs. himalya).
- ❏ A health economic evaluation of operations should also be a priority. Currently obtained data include substantial costs of troubleshooting, development and optimisation. Therefore, Cost per delivery or Cost of protect operations will be expected to fall as the operational delivery is streamlined and the technology is optimised.
- ❏ Flight planning of cargo drone operations in the hilly area always needs to consider the abrupt change in the topography event within a short distance and hence always a tricky process.
- ❏ Technical training modules for the non-technical personnel i.e the health care workers need to be designed, validated and refined for clarity and effectiveness.
- ❏ .Precision landing system developed during the DroTS project allows unskilled staff to operate flights without the need for manual control of drones during landing and should be applied during scale-up to new sites.
- ❏ Resource allocation needs to include backup hardware to avoid service interruption during technical faults with hardware.
- ❏ The variable and unpredictable nature of mountain weather necessitates the use of robust, weather resistant hardware.
- ❏ Status(on/off) of relay station should be displayed in application.

- ❏ Improved battery life/power will increase the flight distance and reliability of drones in coming years as new developments in battery technology become available.
- ❏ An exploratory consultation with healthcare workers and stakeholders should be conducted to prioritise service delivery areas for drones in Nepal in coming years. Maximising service delivery provided by the network will increase cost efficiency and feasibility for scale.

After the health economic evaluation this could be successfully scaled-up to newer districts in the near future for which a policy dialogue for evidence dissemination, recommendations and advocacy for proper clauses in national drone policies mainly for medical drone application and its expansion can be put forward to the government.

7.2 Broader Policy Considerations

WeRobotics and Flying Labs are developing a conceptual framework for complementary drone delivery models: the state model and the community model. There is increasing concern that drone companies have to follow the "state model" to make a profit, i.e., they need to focus on high-frequency deliveries to areas with relatively large populations. In other words, their business models are not viable for the "community model" since smaller and more dispersed communities don't require high-frequency deliveries. As such, WeRobotics and Flying Labs are concerned that these smaller communities like those in Nepal are being overlooked even though they typically face the greatest health risks.

The state and community models are necessarily complementary, however, and should be combined into one holistic approach. This can be compared to "highways" versus "country roads," for example. Leading drone companies are busy building "national highways" with their state-based delivery model, while others like WeRobotics are more interested in developing the "back roads" to serve the community model. Combining both models can provide the speed and geographical coverage necessary to ensure equal access, a duty of care, patient impact, cost-savings, resource optimization, and to improve healthcare outcomes at a truly national scale without discriminating against smaller and more dispersed populations. The business models for the state and community models have to be different. This project in Nepal represents one step forward in developing and testing the business model for the community delivery model.

In sum, WeRobotics and Flying Labs recommend that more operational data be generated to validate the community model and the corresponding business model fully. They also recommend testing the use of both the state and community models in one country to evaluate overall impact since the implications of drone delivery should not be focused narrowly on specific technical models but broadly on the transformation of health care logistics. This requires a commitment of time, attention, and resources to see through.

CHAPTER 8: KEY MEMBERS INVOLVED IN THE PROJECT

8.1 Human Resource

The project consortium contains a dedicated team locally that continues both healthcare and drones related ground operation. This ground team is supported by international partners LSMT, and WeRobotics.

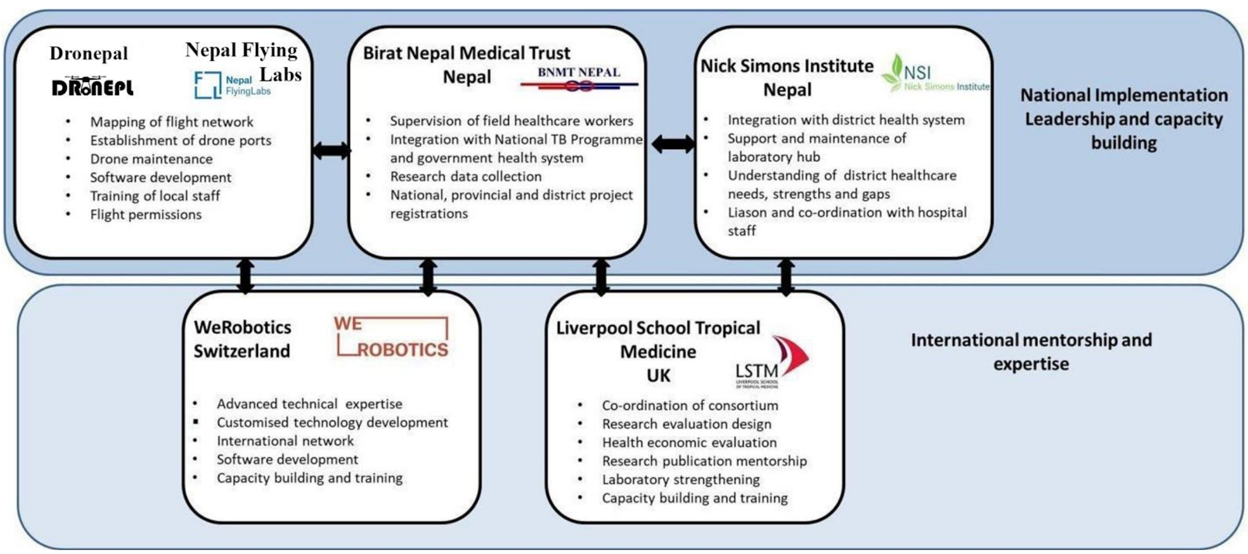

Figure 6.2: Qground control software showing the flight plans

8.2 Organizations

The project consortium contains both local and international experts with different designated roles.

BNMT:

- ❏ Oversee the hiring and training of a cadre of CHWs as well as community mobilisers for the period of July - December 2018.
- ❏ Oversee the procurement of non-UAV materials.
- ❏ Oversee and manage all issues related to laboratory testing and diagnostics.
- ❏ Coordinate with the NTC and MoHP on all medical and clinical issues.

- ❏ Liaise with relevant stakeholders to ensure coordination with global fund related case finding and ensure no duplication of activities.
- ❏ Carry out active case-finding under the BNMT model in the pilot district.
- ❏ Integrate drones into the transportation chain in the pilot district.
- ❏ Engage with SBU on matters of research and evaluation.
- ❏ Submit quarterly progress reports to SBU on budgetary and implementation matters.
- ❏ Submit the audit report to MoHP after the completion of the project.
- ❏ Make all data regarding diagnostics available in anonymized form to project partners in this MoU
- ❏ Adhere to the general principles, policies and best practices for TB case finding and holding, as per the BNMT's MOU with the MoHP in regards to IMPACT TB and TB REACH.
- ❏ Generate quarterly progress reports for the MoHP and NTC.

WeRobotics

- ❏ Drone development and customization.
- ❏ Train local pilots from NFL and Dronepal all flight operations related activities.
- ❏ Lead the development of technology as per local context.

NFL

- ❏ Procure all local and national permissions required for autonomous flight (outside of line-of-sight) including, but not limited to, the importation and purchase of vehicles, Ministry (Home, Defense, etc.) approvals, etc.
- ❏ Establish an "on-demand" drone service in Pyuthan district, which includes an appropriately equipped and staffed base camp and a cadre of health workers who are able to request a drone when appropriate, manage the drone and related technology upon arrival, and launch the drone for its return flight.
- ❏ Train the healthcare personals by jointly working with BNMT: The same cadre of health workers will be trained to recognize TB symptoms in people, explain to them the need for testing, and safely obtain quality sputum samples to be flown via drones for TB diagnosis with rapid molecular diagnostics.
- ❏ Make all data from all flights available to the project partners.

NSI

- ❏ Review and provide feedback on project operating procedures.
- ❏ Monitor and provide feedback on the progress of the project
- ❏ Coordinate with relevant government authorities to facilitate the procedure for bringing in required materials and logistics for project work.
- ❏ Provide technical guidance and suggestions when required.

SBU

- ❏ Provide the role of "project manager" and take overall responsibility for the project.
- ❏ Fund all necessary and agreed upon activities outside of partners' normal scope of funded activities
- ❏ Manage and oversee regular coordination meetings between project partners.
- ❏ Enact all services and materials procurement contracts with BNMT and NFL.

- ❏ Oversee research and evaluation of all project activities.
- ❏ Generate knowledge dissemination products for the international research community.

Details about all these institutions is mentioned in **Annex 2**

ANNEXES

Annex 1 : LIST OF HUMAN RESOURCES

Professor Buddha Bassnyat (co-PI) (Consultant Infectious Diseases Clinician) is a consultant at Patan Hospital and a Fellow of the American College of Physicians and a Fellow of the Royal College of Physicians, Edinburgh. He is a board member of BNMT, Director of the Oxford University Clinical Research Unit Nepal which is housed at Patan Academy of Health Sciences.He is a member of the steering committee for the BNMT implemented IMPACT TB and TB REACH projects for active TB case finding in Nepal. Professor Basnyat is also a previous vice chair of the Nepali National Health Research Council, a department of the Ministry of Health and will ensure engagement with policy makers throughout the project.

Dr Maxine Caws (co-PI) (Senior TB Researcher LSTM/BNMT) has over fifteen years of experience working on TB in the region, as head of TB research at the Oxford University Clinical Research Unit (OUCRU)-Vietnam from 2003-2014. She has been based in Kathmandu with BNMT for the last three years leading a TB research programme with funding as PI from the European Union, STOP TB/TB REACH, TB modeling Analysis Consortium (TB MAC) and the Wellcome Trust. She holds an appointment as Senior TB Researcher at Liverpool School of Tropical Medicine and will facilitate the links between consortium partners to ensure successful design, coordination and delivery of research goals.

Uttam Pudasaini (Geomatics Engineer, Nepal Flying Labs co-ordinator) led the technical team at Nepal Flying Labs implementing the DrOTS project and worked closely with all stakeholders of the project coordinating project activities and operations.He has six years of experience working as a project lead on a wImmediately after completing Bachelor of Engineering in Geomatics Engineering in 2014. He is also a cofounder of a GIS and digital mapping service provider company- NAXA, based in Kathmandu. NAXA has been working on the fusion of mapping and IT, to develop application programs that can help in taking decisions more data driven, scientific and contextual. His journey as a young entrepreneur in Nepal has not only given him a corporate success but also an international platform to showcase what he has been doing in Nepal in the global arena. His contribution in the design and development of dozens of technological solutions to contemporary problems in Nepal has been appreciated in national and international forums. He and his team has received both national and international awards for their work including AUVSI XCELLENCE Humanitarian Operations Award 2018 for the important disaster risk reduction work that their team carried out with international partners Medair and Terrasense after Nepal earthquake

Dr. Patrick Meier (WeRobotics Executive Director) has over fifteen years of experience working on a wide range of humanitarian technology projects in the Sudan, Kenya, Ethiopia, Uganda, Somalia, Liberia, Congo-Brazzaville, Malawi, Tanzania, The Gambia, India, Nepal, Philippines, Timor-Leste, Kyrgyzstan, Turkey, Morocco, Western Sahara, Haiti, Fiji, Tonga, Vanuatu, Papua New Guinea, Peru and Northern Ireland with multiple international organizations including several UN agencies, the Red Cross and World Bank. His book, *Digital Humanitarians*, has been praised by experts at the UN, Red Cross, World Bank, USAID, Harvard, MIT, Stanford, Oxford and others.Patrick serves as Executive Director of WeRobotics where he coordinates the organization's HealthRobotics Program, focused on the use of cargo drones in public health. In 2010, he was publicly recognized by Clinton for his pioneering work in humanitarian technology, which he continues to this day. Patrick has served as a Fellow at MIT Solve, Stanford, Harvard, Rockefeller Foundation, UBS Global Visionaries, UNICEF Innovations and National Geographic. He holds a PhD from the Fletcher School of Law and Diplomacy, Pre-Doc from Stanford, an MA from Columbia University, and holds a CASA certified drone pilot license and was born & raised in Africa.

Mr Raghu Dhital (BNMT TB Programme Manager and Deputy Director) is a public health professional with over twenty years experience in Nepal. He has successfully led the implementation of BNMT TB REACH wave 2 and wave 5 projects, Global Fund sub-recipient programmes and the BNMT component of the

IMPACT TB consortium. His extensive network of collaborative contacts at both government and grassroots community level ensure he is able to navigate challenges in project implementation and adapt to evolving political structures. He will supervise the BNMT field staff implementing the project and ensure effective liaison with technical and government partners.

Biplav Pageni (Nepal Flying Labs, Program Manager) leads the team at DrOTS as Project coordinator implementing the project working closely with project lead, field coordinator and BNMT on overall project management and collaboration as well as with the federal government securing necessary permissions to keep all the legal activities uptodate. He is a mechanical engineering professional from Jawaharlal Nehru Technological University College of Engineering Hyderabad India. He has experience of working in an intensive Research, Design and Development of electric vehicles in Nepal as well as other mechanical fields including production industries and airlines where he worked in different aspects of procurement, supply chain management as well as continuous airworthiness management and aircraft maintenance program.

Darpan Pudasaini (Founder, Dronepal) is an electronics and communications engineer by education, and an innovator who has worked in the field of embedded system designs, IoT, Robotics, Sensors design, 3D printing, Drones and Augmented and Virtual Reality primarily. Some significant projects include: design and prototyping of anti-drone high energy radio frequency system with Nepal Army in 2014, a portable smart water testing device with UNICEF NEPAL in 2015, a virtual sensor framework for early warning of elephant intrusion in Chitwan and Bardiya districts of Nepal with WWF Nepal (2015 - 2017). He started working in innovation technological solutions through his first startup EANepal (Engineering ADDA Nepal) since 2013, then later on formed DroNepal, the first Drones as a Service and Drone R&D company in Nepal, in 2016 where he currently works as the CEO. He also designed and conducted UAV training of trainers for Nepal Police for the first time in Nepal, and has continued to provide trainings to multiple national and international organisations, government authorities and professionals since then.

Pravin Lamsal (Senior Drone Pilot, Nepal Flying Labs) senior Drone Pilot at DrOTS with three years of flying experience of different models of multicopters for various social good project applications and as a team lead for surveying and mapping projects at NFL. He has led the field operations as head drone pilot for DrOTS phase I. Pravin has a Bachelor in Geomatic Engineering from the Himalayan College of Geomatics Engineering(Purbanchal University), Kathmandu, Nepal.

Hem Bahadur Tamang (Junior Drone Pilot, Nepal Flying Labs) is a junior drone pilot at DrOTS with 6 months of flying experience of different models of DJI drones. He has been a keen drone enthusiast and have been building DIY drones since 5 years.. He has been flying drones as assistant drone pilot for DrOTS Phase I. Currently, he is studying Bachelor in Education(B.Ed) in Pyuthan District.

Jürg Germann (WeRobotics Head of Engineering) provides technical expertise, mentorship, troubleshooting and technical development to the DrOTS project with his team at WeRobotics. He visits the project site in Pyuthan to provide on-site support every six months and ad-hoc as required, in addition to e-meetings. Jurg serves as Head of Engineering at WeRobotics where he spearheads the engineering side of all cargo drone projects across the global Flying Labs network. This has included cargo drone projects in the Dominican Republic, Nepal and Fiji. Jurg holds a PhD in Robotics from EPFL and an MSc in Electrical Engineering from ETHZ.

Dr Kashim Shah (Senior Programme Manager, NSI) is a consultant medical doctor and has been Senior Programme Manager at Nick Simons Institute for the District Hospital Support Programme for 6 years. He qualified at the Institute of Medicine Kathmandu in 2004 and worked as MDGP doctor at Gulmi district hospital for three years. He therefore has a deep understanding of the spectrum of disease in rural populations and the barriers to care, coupled with a knowledge of the government health system and ministry personnel. Dr

Shah has collaborated with BNMT on the TB REACH wave 5 and IMPACT 2 projects for active TB case finding. Through his work managing the NSI programme he is ideally placed to understand how the drone transport system can integrate into the existing health infrastructure and identify priority health gaps for expansion of the drone services in the district.

Mr Gokul Mishra (National TB Programme Liaison Officer, LSTM) is the National TB programme liaison officer for IMPACT TB and will continue in this role on IMPACT 2 TB and DROTS. He is based at the National TB Centre in Kathmandu and works closely with the NTC staff to ensure alignment of project goals and activities with National Strategic Plan objectives. He has ten years experience of TB epidemiology in Nepal and has collaborated with the NTC on development of the national strategic plan, global fund applications, prevalence survey and national epidemiology review He will facilitate organization of the policy dialogue, key informant interviews and dissemination of research findings. His role will ensure integration of the research goals with evolving political structures and strategic plans of the NTC.

Ms Kritika Dixit (PhD candidate) is a young Nepali researcher with an Msc in Public Health with a specialization in Global Health from Thammasat University, Thailand. She has six years experience in project implementation, monitoring and evaluation with BNMT. She is currently a Project Manager for BNMT developing a locally appropriate socio-economic support package for TB affected households funded by a Wellcome Trust SEED award under the IMPACT TB project umbrella. She will register for a PhD at Karolinska Institute in early 2020, while still based in Nepal and supervised by Dr Caws and supported by IMPACT 2 TB. This will consolidate her skills in research design, analysis and interpretation to allow her to realize her ambition of becoming an independent infectious disease research leader while building local research capacity with international standard training. Ms Dixit will conduct qualitative research on the drone implementation, exploring feasibility, acceptability and utility among healthcare workers and community stakeholders.

Dr Noemia Taxiera Filha (Postdoctoral Health Economist, LSTM) is the health economic lead on IMPACT TB. She completed her PhD at the London School of Hygiene and Tropical Medicine on health economic evaluations of TB interventions in low and middle income countries. She has adapted and validated the WHO costing tool for application in Nepal and developed the data collection tools for the health system costing of ACF interventions in Nepal in collaboration with BNMT staff. She is familiar with the data availability and health system components in Nepal and will apply this knowledge to the health economic evaluations of DROTS. She has trained local field and research staff in applying and interpreting the costing questionnaire and will continue to build local research capacity for health economic evaluations in Nepal.

Annex 2 : About the Organizations

8.1.1 Birat Nepal Medical Trust (BNMT)

Birat Nepal Medical Trust will co-ordinate the field activities in Pyuthan district, supervising the cadre of healthcare workers engaged in active TB case finding and ensuring integration with the National TB Programme and government health system. BNMT staff liaise daily with Nepal Flying Labs staff in Pyuthan district to coordinate drone flights with sample collection and testing activities. A phased transition of drone operations to local field staff, with support from NFL staff, will take place during DROTS phase II. BNMT will also conduct the research data collection and analysis, with mentorship from LSTM.

BNMT is a Nepalese non-governmental organisation dedicated towards the improved health and well-being of the Nepalese people since 1967. BNMT envisions a new Nepal where all Nepalese are aware of their basic rights and are able to live healthy and productive lives, in a safe environment without having to worry about food, income or security regardless of their gender, ethnicity, disability or HIV status. BNMT Nepal is governed by a board of Nepalese nationals with diverse experience in health, livelihoods, climate change, and social and community development. The four pillars of BNMT Nepal are Promoting Quality Health Care and Ensuring Health Rights, Building Resilience to Climate Change, Policy and Advocacy Support. Since its inception, BNMT has supported the National TB Centre (NTC), playing a vital role in establishing the National TB Programme (NTP). Under the TB Programme, BNMT has served as sub-recipient of Global Fund, led two TB REACH grants (Wave 2 and 5) and a European Union Horizon2020 grant (www.impacttbproject.org). BNMT has extensive experience of implementing TB projects in Nepal in collaboration with the National TB programme to enhance government activities and pioneer novel approaches.

8.1.2 WeRobotics

WeRobotics provides technical expertise and mentorship to the DROTS project with both remote and in-person technical support on-site in Nepal. The goal of WeRobotics is to perform all training and operational activities related to the deployment of drones in the development and humanitarian sectors. WeRobotics is led by Patrick Meier, Andrew Schroeder, Sonja Betschart and Adam Klaptocz in order to keep up with the rapid pace of global, social and technological change. WeRobotics is fully dedicated to accelerating and scaling humanitarian, development and environmental projects through appropriate robotics solutions. WeRobotics represents an effort to apply the lessons learned so far from the use of drones for humanitarian aid, global development and environment protection to the fields of robotics and automation. WeRobotics has over 3 years of cargo drone testing experience in Peru, Fiji, Brazil, Dominican Republic and Nepal.

8.1.3 Nepal Flying Labs (NFL)

Nepal Flying Labs is one of a locally led international network of Flying Labs established to build local capacity for drones for social good in partner countries. A WeRobotics flying lab is a local innovation lab which works to accelerate and scale the impact of humanitarian, development, health and environmental efforts through the use of appropriate robotics solutions. NFL has all the required resources to quickly deploy aerial, maritime and terrestrial robotics for a range of local applications such as surveying and mapping, data collection and cargo transportation. NFL facilitates and strengthens the local robotics ecosystem through organizing local “Drones as a Service” Business Incubation Programs, implementing projects addressing the humanitarian, agriculture, conservation, development and health sectors, organizing and providing hands-on Drone hardware and software trainings for various drone platforms and Social Good use cases. Once trained, we support the participants of our courses with advice for their projects.

8.1.4 Nick Simons Institute (NSI)

The DROTS project central hub is based in the NSI supported government district hospital in Bhingri, Pyuthan district. Implementation of the project has been conducted in collaboration with NSI from the outset. NSI has supported the installation and operation of the GeneXpert machine and facilitated referral of samples for testing for the hospital OPD. NSI expertise will be central to understanding the health landscape of Pyuthan district and prioritizing needs for expansion of health services facilitated by the drone transport network.

The Nick Simons Institute is a non-governmental philanthropic organization whose aim is to enhance rural healthcare services. The mission of the organization is to innovate solutions in rural healthcare - through training and hospital support - and to advocate for their scale up with the government of Nepal. Founded in 2006, the Institute has established a programme of support to enhance rural healthcare in partnership with the government. Supporting the development and retention of strong highly skilled human resources for health is at the core of the NSI mission through the District Hospital Support Programme.

The Nick Simons Institute has partnered with BNMT Nepal on the TB REACH wave 5 active TB case finding project which demonstrated that many symptomatic cases of TB present to rural district hospitals but are not being diagnosed effectively. Through scaling up access to the advanced molecular diagnostic GeneXpert for TB at NSI-supported hospitals and initiating simple symptom screening the project was able to substantially increase the number of TB cases detected and effectively treated in four districts. Continued and strengthened linkage with NSI infrastructure and healthcare worker expertise will ensure the success of the IMPACT 2 TB project in integrated partnership with government health services.

8.1.5 The Liverpool School of Tropical Medicine (LSTM)

Liverpool School of Tropical Medicine will provide mentorship and capacity building for research and laboratory strengthening. LSTM will conduct the health economic evaluation, while training Nepali early career researchers in design and analysis of health economic evaluations. The PI, Dr Max Caws is employed by LSTM but based full time in Kathmandu at BNMT and will be responsible for overall coordination and delivery of the project.

LSTM is an international postgraduate centre of excellence in the UK, devoted to research, education and training, and consultancy. LSTM conducts world-leading and high impact research on infectious diseases and diseases of poverty and supports research capacity development in low and middle income countries. It has extensive links with United Nations organisations, health ministries, universities, NGOs and research institutions worldwide and is an integral partner in numerous programmes that contribute to controlling diseases of poverty, and the development of more effective systems for health care. A fundamental aim of DROTS phase II is to generate evidence to inform health policy, and LSTM has a strong track record of high impact translation of research findings particularly in TB. LSTM has led and contributed to extensive innovative research on TB.

8.1.5 Dronepal

Dronepal is the first dedicated Drone as a Service (DaaS) and Drone as a Technology (DaaT) company of Nepal, pioneering the field of drone usage in Nepal as well as constantly pushing drone sensitization, education and advocacy. Having worked with and alongside diverse stakeholders, partners and collaborators, we are doing our level best in pushing the drone industry in Nepal in multiple various application areas including surveying and mapping, project monitoring, research and analysis, planning and design, skills & knowledge transfer, and much more. Their major areas of expertise spread across a multitude of applications could be shortlisted as:

Drone as a Service (DaaS) -Through which they provide drones based quality survey data and analytics along with all kinds of survey, planning and design services to aid government and all stakeholders in achieving Sustainable Development Goals enabling quality-data driven decisions, planning and designs. They also provide technological tools that enable all stakeholders to collaborate and contribute on development projects by adding layers of interactions, visualizations, metrics and analytics through the use of latest technologies in remote sensing, 3d printing, Augmented/Virtual Reality and much more.

Drone School (Drone Education, Advocacy and Capacity Building) -Through which they provide customized and practical drone training on the use of drones in surveying, humanitarian responses, cargo deliveries, security & surveillance and photo/videography, and also provide technical training to enable drone enthusiasts and technical professionals in drone customization, assemblies and maintenance through our modular drone syllabus and a strong network of national and international technology experts and industry leaders.

Drone as a Technology (DaaT) -Through which they keep innovating frontier technologies through research, development and customization, and also provide application-specifically customized or fabricated drones for use in diverse application areas.

Annex 3: Flight Details

Flight no.	Date	Flight Route	Take off time	Average Speed	Landing Time	No. of Sample
PH1	17/06/2019	3_0_Pyuthan_Dharmawati	10:40	17	10:46	12
		4_1_Dharmawati_Pyuthan	10:55	17	11:01	
BH1	19/07/2019	21_0_Bhingri_Shotre	11:25	17	11:29	7
		22_1_Shotre_Bhingri	11:34	17	11:38	
PH2	01/07/0219	3_0_Pyuthan_Dharmawati	10:26	18	10:32	4
		4_1_Dharmawati_Pyuthan	10:38	18	10:45	
PH3	21/07/2019	3_0_Pyuthan_Dharmawati	10:50	18	10:57	6
		4_1_Dharmawati_Pyuthan	11:06	18	11:13	
PH4	22/07/2019	7_1_Pyuthan_Maranthana	11:08	18	11:15	10
		8_1_Maranthan_Pyuthan	11:22	18	11:.30	
BH2	02/07/2019	23_1_Bhingri_Saari	11:46	18	11:52	7
		24_2_Saari_Bhingri	11:59	18	12:06	
BH3	17/07/2019	27_0_Bhingri_Barjiwang	11:33	17	11:41	9
		28_0_Barjiwang_Bhingri	11:50	17	11:59	
PH5	14/08/2019	9_1_Pyuthan_Majhkot	11:05	16	11:16	7
		10_1_Majhkot_Pyuthan	11:27	16	11:38	
PH6	15/08/2019	7_1_Pyuthan_Maranthana	10:38	18	10:45	4
		8_1_Maranthana_Pyuthan	10:57	18	11:05	
BH4	12/08/2019	27_0_Bhingri_Barjiwang	11:30	17	11:39	10

		28_0_Barjiwang_Bhingri	11:22	17	11:30	
BH5	13/08/2019	23_1_Bhingri_Saari	11:34	18	11:41	10
		24_2_Saari_Bhingri	11:54	18	12:01	
BH6	15/08/2019	21_1_Bhingri_Shotre	11:48	18	11:52	4
		22_1_Shotre_Bhingri	11:59	18	12:04	
BH7	18/08/2019	25_0_Bhingri_Gothiwang	11:41	16.5	11:51	6
		26_0_Gothiwang_Bhingri	11:58	16.5	12:09	
BH8	18/08/2019	23_1_Bhingir_Saari	11:49	18	11:58	11
		24_2_Saari_Bhingri	12:05	18	12:16	
PH7	19/08/2019	3_0_Pyuthan_Dharmawati	10:58	17.69	11:09	7
		4_1_Dharmawati_Pyuthan	11:16	17.69	11:23	
PH8	19/08/2019	7_1_Pyutha_Maranthana	10:50	17.4	11:02	13
		8_1_Maranthana_Pyuthan	11:10	17.4	11:18	
BH9	20/08/2019	27_0_Bhingr_Barjiwang	11:49	17.03	11:57	7
		28_0_Barjiwang_Bhingri	12:15	17.03	12:23	
PH9	21/08/2019	9_1_Pyuthan_Majhkot	11:36	16.07	11:45	4
		10_1_Majhkot_Pyuthan	11:50	16.07	11:58	
BH10	22/08/2019	25_0_Bhingri_Gothiwang	11:05	16.7	11:37	8
		26_0_Gothiwang_Bhingri	11:28	16.7	12:08	
BH11	22/08/2019	21_1_Bhingri_Shotre	12:05	17.8	12:08	0
		22_1_Shotre_Bhingri	12:14	17.8	12:20	
BH12	25/08/2019	23_1_Bhingri_Saari	12:23	18	12:28	8

		24_2_Saari_Bhingri	12:31	18	12:37	
PH10	25/08/2019	3_0_Pyuthan_Dharmawati	10:46	17.9	10:53	3
		4_1_Dharmawati_Pyuthan	11:02	17.9	11:09	
PH11	28/08/2019	9_1_Pyuthan_Majhkot	11:10	17.9	11:23	6
		10_1_Majhko_-Pyuthan	11:38	18	11:49	
BH13	05/09/2019	25_0_Bhingri_Gothibang	11:28	17.6	11:37	5
		26_0_Gothibang_Bhingri	11:40	17.6	11:41	
BH14	05/09/2019	21_1_Bhingr_Shotre	12:5	17.8	12:15	4
		22_1_Shotre_Bhingri	12:20	17.8	12:29	
BH15	09/09/2019	25_0_Bhingri_Gothiwang	11:20	17.6	11:29	7
		26_0_Gothiwang-Bhingri	11:35	17.6	11:44	
BH16	09/09/2019	23_1_Bhingri_Saari	12:10	17.9	12:22	7
		24_2_Saari_Bhingri	12:10	17.9	12:37	
PH12	09/09/2019	3_0_Pyuthan_Dharmawati	11:28	18	11:35	4
		4_1_Dharmawati_Pyuthan	11:37	18	11:42	
PH13	09/09/2019	7_1_Pyuthan_Maranthana	12:01	18	12:08	13
		8_1_Maranthana_Pyuthan	12:14	18	12:24	
BH17	10/09/0209	21_1_Bhingri_Shotre	12:50	15.13	12:53	6
		22_1_Shotre_Bhingri	12:55	15	12:59	
BH18	10/09/2019	27_1_Bhingri_Barjiwang	01:32	15.10	01:41	11
		28_1_Barjiwang_Bhingri	02:00	17.30	02:09	
PH14	11/09/2019	9_1_Pyuthan_Majhkot	11:20	15	11:26	7

		10_1_Majhkot_Pyuthan	11:31	15	11:39	
BH19	12/09/2019	21_1_Bhingri_Shotre	12:18	15	12:21	8
		22_1_Shotre_Bhingri	12:24	16	12:28	
BH20	12/09/2019	25_0_Bhingri_Gothiwang	01:07	16.72	01:15	2
		26_0_Gothiwang_Bhingri	01:24	18	01:32	
BH21	15/09/2019	25_0_Bhingri_Gothiwang	12:11	18	12:19	7
		26_0_Gothiwang_Bhingri	12:20	17	12:28	
BH22	15/09/2019	23_2_Bhingri_Saari	01:05	17	01:12	6
		24_2_Saari_Bhingri	01:14	17	01:22	
PH15	18/09/2019	9_1_Pyuthan_Majhkot	11:20	15	11:32	4
		10_1_Majhko_Pyuthan	11:48	16	11:36	
BH23	22/09/2019	25_0_Bhingri_Gothiwang	11:23	17	11:33	5
		26_0_Gothiwang_Bhingri	11:40	17	11:49	
BH24	22/09/2019	23_0_Bhingri_Saari	11:55	17	12:04	6
		24_0_Saar_Bhingri	12:10	17	12:17	
PH16	23/09/2019	3_0_Pyuthan_Dharmawati	11:56	17	12:04	3
		4_1_Dharmawati_Pyuthan	12:06	17	12:13	
PH17	23/09/2019	7_1_Pyuthan_Maranthana	12:44	17	12:51	15
		8_1_Maranthana_Pyuthan	12:55	17	1:04	
BH25	24/09/219	21_1_Bhingri_Shotre	12:29	17	12:32	5
		22_1_Shotre_Bhingri	12:40	17	12:44	
BH26	24/09/2019	27_1_Bhingri_Barjiwang	01:36	17	01:45	6

		28_1_Barjiwang_Bhingri	01:47	17	01:55	
PH18	25/09/2019	9_2_Pyuthan_Majhkot	12:24	15	12:32	16
		10_2_Majhkot_Pyuthan	12:47	17	12:56	
BH27	26/09/2019	25_1_Bhingri_Gothiwang	12:07	17	12:15	5
		26_1_Gothiwang_Bhingri	12:18	17	12:27	
PH19	30/09/2019	3_2_Pyuthan_Dharmawati	10:33	17	10:40	5
		4_2_Dharmawati_Pyuthan	10:42	14	10:49	
BH28	2019/10/15	27_1_Bhingr_Barjiwang	12:01	16	12:09	5
		28_1_Barjiwang_Bhingri	01:17	17	01:25	
PH20	2019/10/16	9_2_Pyuthan_Majhkot	12:20	14	12:31	6
		10_2_Majhkot_Pyuthan	02:30	13	02:37	
BH29	2019/10/17	25_1_Bhingri_Gothiwang	12:56	16	01:04	5
		26_1_Gothiwang_Bhingri	01:08	15	01:16	
BH30	2019/10/20	25_1_Bhingri_Gothiwang	12:07	17	12:14	5
		26_1_Gothiwang_Bhingri	12:17	16	12:25	
PH21	2019/10/21	7_1_Pyuthan_Maranthana	11:40	16	11:47	6
		8_1_Maranthana_Pyuthan	11:49	16	11:57	
PH22	2019/10/21	3_2_Pyuthan_Dharmawati	12:23	17	12:30	5
		4_2_Dharmawati_Pyuthan	:12:32	17	12:39	
BH31	2019/10/22	27_1_Bhingri_Barjiwang	12:11	16	12:19	4
		28_1_Barjiwang_Bhingri	12:22	17	12:32	
PH23	2019/10/23	9_2_Pyuthan_Majhkot	12:20	15	12:28	5

		10_2_Majhkot_Pyuthan	12:30	16	12:37	
BH32	2019/11/05	27_1_Bhingri_Barjiwang	12:30	16	12:38	5
		28_1_Barjiwang_Bhingri	12:42	17	12:50	
BH33	2019/11/05	21_1_Bhingri_Shotre	01:15	17	01:19	5
		22_1_Shotre_Bhingri	01:20	17	01:24	
PH24	2019/11/06	9_2_Pyuthan_Majhkot	11:45	14	11:53	4
		10_2_Majhkot_Pyuthan	11:54	14	12:02	
PH25	2019/11/06	5_0_Pyuthan_Addapata	01:26	17	01:34	6
		6_0_Addapata_Pyuthan	01:37	17	01:42	
BH34	2019/11/10	23_0_Bhingri_Saari	12:26	17	12:32	14
		24_0_Saari_Bhingri	12:40	17	12:47	
PH26	2019/11/11	3_2_Pyuthan_Dharmawati	11:51	17	11:58	3
		4_2_Dharmawati_Pyuthan	12:00	17	12:8	
PH27	2019/11/11	7_1_Pyuthan_Maranthana	12:55	17	01:3	6
		8_1_Maranthana_Pyuthan	01:6	17	01:14	
PH28	2019/11/13	9_2_Pyuthan_Majhkot	12:15	14	12:21	4
		10_2_Majhkot_Pyuthan	12:23	14	12:33	
BH35	2019/11/14	21_0_Bhingri_Shotre	11:31	17	11:35	4
		21_1_Shotre_Bhingri	11:56	17	12:03	
BH36	2019/11/14	25_0_Bhingri_Gothiwang	12:46	16	12:53	6
		26_0_Gothiwang_Bhingri	12:58	16	01:05	
BH37	2019/11/17	23_0_Bhingri_Saari	11:47	16	11:53	17

		24_0_Saari_Bhingri	12:00	17	12:08	
PH29	2019/11/18	3_2_Pyuthan_Dharmawati	12:18	17	12:25	
		4_2_Dharmawati_Pyuthan	12:27	17	12:35	5
PH30	2019/11/19	5_0_Pyuthan_Addapata	10:59	16	11:06	
		6_0_Addapata_Pyuthan	11:08	16	11:14	5
BH38	2019/11/19	21_0_Bhingri_Shotre	12:53	17	12:57	
		22_0_Shotre_Bhingri	01:01	17	01:05	5

Detailed Flight plan after November 19

PH31	2019/11/20	9_2_Pyuthan_Majhkot	12:35	15	12:43	
		10_2_Majhkot_Pyuthan	12:46	14	12:54	3
BH39	2019/11/21	25_0_Bhingri_Gothibang	12:44	16	12:52	
		26_0_Gothibang_Bhingri	12:56	16	1:4	6
BH40	2019/11/24	23_0_Bhingri_Saari	1:20	16	1:27	
		24_0_Saari_Bhingri	1:30	16	1:36	8
PH32	2019/11/25	3_2_Pyuthan_Dharmawati	11:45	16	11:52	
		4_2_Dharmawati_Pyuthan	11:56	17	12:4	11
BH41	2019/11/26	27_1_Bhingri_Barjibang	11:59	17	12:7	
		28_1_Barjibang_Bhingri	12:12	17	12:20	4
PH33	2019/11/27	9_2_Pyuthan_Majhkot	12:45	16	12:53	
		10_2_Majhkot_Pyuthan	12:55	16	1:8	10
BH42	2019/11/28	25_0_Bhingri_Gothibang	11:55	17	12:4	5

		26_0_Gothibang_Bhingri	12:14	16	12:21	
BH43	2019/11/28	21_0_Bhingri_Shotre	1:22	17	1:25	
		22_0_Shotre_Bhingri	1:28	17	1:32	4
PH34	2019/11/29	7_1_Pyuthan_Maranthana	12:26	17	12:32	
		8_1_Maranthana_Pyuthan	1:52	17	1:59	7
BH44	2019/12/01	21_0_Bhingri_Shotre	11:30	17	11:33	
		22_0_Shotre_Bhingri	11:38	17	11:41	10
BH45	2019/12/01	25_0_Bhingri_Gothibang	12:31	16	12:40	
		26_0_Gothibang_Bhingri	1:27	16	1:36	11
BH46	2019/12/01	23_0_Bhingri_Saari	2:5	17	2:12	
		24_0_Saari_Bhingri	2:15	17	2:23	5
BH47	2019/12/03	27_1_Bhingri_Barjibang	11:22	17	11:31	
		28_1_Barjibang_Bhingri	12:10	17	12:19	9
BH48	2019/12/03	21_0_Bhingri_Shotre	1:15	17	1:19	
		22_0_Shotre_Bhingri	1:22	17	1:26	11
PH35	2019/12/4	7_1_Pyuthan_Maranthana	11:15	17	11:23	
		8_1_Maranthana_Pyuthan	11:26	17	11:34	7
PH36	2019/12/4	5_0_Pyuthan_Addapata	12:7	17	12:14	
		6_0_Addapata_Pyuthan	12:17	17	12:22	5
PH37	2019/12/6	9_0_Pyuthan_Majhkot	11:52	15	12:2	
		10_0-Majhkot_Pyuthan	12:6	16	12:15	6
BH49	2019/12/8	25_0_Bhingri_Gothibang	12:26	17	12:33	4

		26_0_Gothibang_Bhingri	12:36	17	12:42	
BH50	2019/12/8	23_0_Bhingri_Saari	1:24	17	1:32	
		24_0_Saari_Bhingri	1:52	17	2:00	14
PH38	2019/12/9	3_2_Pyuthan_Dharmawati	12:10	17	12:17	
		4_2_Dharmawati_Pyuthan	11:59	17	12:29	7
PH39	2019/12/9	5_0_Pyuthan_Addapata	1:8	17	1:15	
		6_0_Addapata_Pyuthan	1:20	17	1:29	17
PH40	2019/12/9	7_1_Pyuthan_Maranthana	1:40	17	1:48	
		8_1_Maranthana_Pyuthan	1:51	17	2:5	6
BH51	2019/12/10	27_2_Bhingri_Barjibang	11:29	17	11:38	
		28_2_Barjibang_Bhingri	12:11	17	12:19	6
PH41	2019/12/11	9_0_Pyuthan_Majhkot	12:42	17	12:49	
		10_0_Majhkot_Pyuthan	12:55	17	1:4	9
BH52	2019/12/15	25_0_Bhingri_Gothibang	11:38	17	11;45	
		26_0-Gothibang_Bhingri	11:48	17	11:56	2
BH53	2019/12/15	23_0_Bhingri_Saari	12:53	16	1:00	
		24_0_Saari_Bhingri	1:3	17	1:9	15
PH42	2019/12/16	3_2_Pyuthan_Dharmawati	12:40	17	12:48	
		4_2_Dharmawati_Pyuthan	12:47	17	12:55	4
PH43	2019/12/16	7_1_Pyuthan_Maranthana	2:00	17	2:10	
		8_1_Maranthana_Pyuthan	2:14	17	2:22	10
BH54	2019/12/17	27_0_Bhingri_Barjibang	12:22	16	12:30	5

		28_0_Barjibang_Bhingri	12:33	17	12:42	
PH44	2019/12/18	9-0_Pyuthan_Majhkot	12:50	14	12:58	
		10_0_Majhkot_Pyuthan	1:3	14	1:11	3
BH55	2019/12/22	25_0_Bhingri_Gothibang	11:44	16	11:53	
		26_0_Gothibang_Bhingri	12:35	17	12:44	9
BH56	2019/12/22	23_0_Bhingri_Saari	1:48	16	1:54	
		24_0_Saari_Bhingri	1:56	17	2:4	15
PH45	2019/12/23	3_2_Pyuthan_Dharmawati	12:21	17	12:30	
		4_2_Dharmawati_Pyuthan	12:35	17	12:43	5
PH46	2019/12/23	7_1_Pyuthan_Maranthana	1:50	17	1:58	
		8_1_Maranthan_Pyuthan	2:5	17	2:13	10
BH57	2019/12/24	27_2_Bhingri_Barjibang	12:25	17	12:33	
		28_2_Barjibang_Bhingri	12:58	17	1:7	10
BH58	2019/12/24	21-0_Bhingri_Shotre	1:15	17	1:21	
		22-0_Shotre_Bhingri	1:25	17	1:32	5
PH47	2019/12/25	9_0_Pyuthan_Majhkot	11:56	16	12:8	
		10-0_Majhkot_Pyuthan	12:14	16	12:22	6
PH48	2019/12/25	5_0_Pyuthan_Addapata	1:40	17	1:46	
		6_0_Addapata-Pyuthan	1:50	17	1:57	7

Annex 4 : Location of all 12 health posts and 2 central health units with topographical details

S.N.	Name	x_deg_	Y_deg_	Elevation(m)	Topography Type
1	Bhingri_PHC	82.71	28.14	675.42	Valley Floor
2	Barjiwang	82.77	28.13	851.09	Valley Floor
3	Shotre	82.72	28.14	641.36	Valley Floor
4	Saari	82.70	28.18	782.44	Valley Floor
5	Kochiwang	82.66	28.09	1263.63	Hill Top
6	Sorgadwari	82.63	28.14	1753.63	Hill Top
7	Gothiwang	82.75	28.11	697.64	Valley Floor
8	Pyuthan_Hospital	82.85	28.10	807.8	Valley Floor
9	Dakhawadi	82.78	28.10	617.77	Valley Floor
10	Addapata	82.82	28.11	970.95	Valley Floor
11	Dharmawati	82.90	28.13	882.18	Valley Floor
12	Majhkot	82.85	28.15	1703.99	Hill Top
13	Jhumrikanda	82.82	28.17	1711.91	Hill Top
14	Maranthana	82.91	28.12	922.09	Valley Floor

Annex 5 : Standard Operating Procedure

Execute a cargo mission

STEPS	SENDER (Pilot)	RECEIVER (Health care worker)
1	Cargo delivery request via call.	
2	Open the Drone log book and fill in data.	
3	Give flight number to health worker.	Fill paper form including flight number.
4	Enable location on tablet, open Google Maps to check it.	Enable location on tablet, open Google Maps to check it.
5	Connect radio to tablet, which opens the cargo_GS app.	Connect radio to tablet, which opens the cargo_GS app.
6	Place drone on take-off location, insert batteries, unfold arms, props and antennas.	Clear landing site and wait for launch call.
7	Turn on drone and remote control.	
8	Select route and press go in the cargo_GS app.	
9	Wait for drone connection to tablet. Mission is sent to drone.	
10	Check weather forecast and press "continue".	
11	Log pilot name.	
12	Execute safety checks as instructed by app: 1. Secure cargo box under drone, label both. 2. Check drone, tablet battery, authorizations, flight plan. 3. Clear take-off site.	
13	Wait for drone ready.	
14	Call health care worker and ask for launch confirmation: - Ask for tablet battery level. - Ask if landing site is clear. - Ask if radio connection is successful. - Ask if weather conditions are good.	
15	Start mission.	
16	Observe and monitor drone.	Observe and monitor drone.
17		Receive drone and load samples.
18		Select route and press go.

19	-	Check weather forecast and press "continue".
20		Log health care worker name.
21		Execute safety checks as instructed by app: 4. Secure cargo box under drone, label both. 5. Check drone, tablet battery, authorizations, flight plan. 6. Clear take-off site.
22		Wait for drone ready.
23		Call pilot to confirm launch.
24		Start mission.
25	Observe and monitor drone.	Observe and monitor drone.
26	Receive drone and unload cargo box.	
27	Stop onboard app by pressing black button on the cargo system for 5 seconds.	
28	Turn off drone.	
29	Fold antennas, props and arms, put socks on.	
30	Remove drone batteries	
31	Stop ground station app, disable location.	Stop ground station app, disable location.
32	Disconnect radio from tablet.	Disconnect radio from tablet.
33	Charge tablet, drone batteries, remote control.	Charge tablet.

Annex 5: Standard Emergency Procedures

PROBLEM		SOLUTION
Before flight	Restart procedure	1. Stop the onboard application (press the yellow button for 2 seconds) 2. Wait 10s 3. Turn off the drone. 4. Check the wiring of all the system. 5. Turn the drone on.
	Drone is in landed error	(This is caused by a missing component at start) 1. Check the error message on the tablet. 2. Do a restart procedure.
	Ground station app crashes at launch	1. Check logs. 2. Check and correct config file.
	Weather query fails due location data	1. Check that localisation service is turned on. 2. Open Google Maps app and wait until tablet location is found. 3. Go back to Cargo GS app and try again.
	Mission not accepted by drone	1. Try to start the mission again. 2. Check error message on tablet (bottom left), check the battery level, check mission file.
	Message not sent successfully (popup on tablet)	Sometimes command is executed anyway. In this case do nothing (press no). 1. Try to resend (click “yes” on popup message). 2. If it reappears, check tablet connection to ground station box (“Connect” button). 3. Check drone connection (white color). 4. If it reappears, restart the ground station app and try again.
During flight	Critical battery (<20%)	1.The drone will trigger a rally point landing autonomously. 2. The pilot can take over if in range but this is not recommended.
	Emergency battery (<15%)	❏ The drone will trigger an emergency landing autonomously and land where it is. - The pilot can take over if in range but this is not recommended.
	Battery < 10%	❏ The DJI autopilot will trigger an emergency landing at current location. ❏ The pilot cannot take over.
	Bad weather (wind, rain, ...)	*The weather condition should be checked prior to each flight. In case the weather is likely to turn bad the mission should not be started* ❏ If the destination is not reachable the drone will trigger a rally point. ❏ The pilot can trigger a rally point or an emergency landing at any moment.
	Ground station app crash	❏ Close the application and re-open it.

		❏ The drone will reconnect and send information about the current mission. ❏ The drone is not affected by a crash of the ground station.
	The drone does not follow the route anymore (something went wrong...)	The telemetry is not updating anymore but the radio link looks stable (location and speed don't change but the temperature and time of mission change). - This is due to a failure in communication between the onboard computer and the DJI autopilot. The onboard computer will detect this situation after 10s and reboot immediately. - If this happens more than 5 times it is unlikely that the drone will be able to finish the mission. Get it back with a car or motorbike using the DJI radio control.

Annex 6: PhotoGallery

Group photo with BNMT team after successful import of drones into the country

Drone Based Topographical Survey for planning take off and landing sites

Community level Orientation program

WeRobotics Engineering team at Drone lab/workshop at the hospital before the field operations

A Group photo with province 5 health officials, team from NSI and country representative of Nick Simons Foundation

Field testing

Signal Testing

Drone Flight Demonstration

Drone Flight Training to Health Care Worker

Project Location(Beautiful Pyuthan)

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