



Innovative Health Service Delivery Systems in Rural Dominican Republic Cargo Drone Field Tests

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Contributors



Patrick Meier
Jurg Germann
Yoann Lapijover
Adam Klaptocz
Oriol Lopez



Orlando Perez
Joaquin Pulgar
Hamlet Vanderhorst

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Table of Contents

1 Executive Summary	3
2 Introduction	5
3 Healthcare Logistics in the Dominican Republic	7
3.1 Medical Supply lines	8
3.2 Untapped use cases - sample collection	9
4 Drone Delivery Field Tests	10
4.1 Delivery Routes	12
4.2 Communities and Permissions	13
4.3 Flight Descriptions, Lessons and Limitations	14
4.4 Flight Data and Results	16
5 Training and Local Capacity Building	18
6 Discussion and Remaining Challenges	21
6.1 Range	21
6.2 Payload	22
6.3 Usability	22
6.4 Software	23
6.5 Cost	23
7 Conclusion	25
8 Acknowledgements	26

1. Executive Summary

Transporting medicines and patient samples between hospitals and remote clinics in the mountains of the Dominican Republic (DR) can be slow and expensive. While roads to the remote villages - and thus clinics - do exist, they are not always paved and those that are paved are sometimes impassable due to the rivers that cross them, even during the dry season. Of course, this assumes one has access to ground transportation in the first place. Indeed, while the network of paved roads in the mountains of the DR is impressively widespread, local ownership of motorized vehicles is certainly not, nor is the availability of public transportation. This explains why doctors working at these hospitals and clinics are keen to explore other ways to expedite the collection and testing of patient samples and the distribution of essential medicines.

In December 2017, DR business incubator Emprende invited WeRobotics to evaluate the use of drones for the collection and delivery of patient samples and medicines and to build local capacity in their operation. This was preceded by an onsite scoping mission in October 2017 to select appropriate flight routes and takeoff/landing sites. Initial drone cargo tests took place in December over a 10-day period in two different mountainous regions of the DR. The field tests were carried out using 2 types of general-use drones that were adapted for cargo delivery: DJI's M600 multicopter drone and Vertical Technologies' DeltaQuad, a combined fixed-wing and multicopter, or hybrid, drone. Over 30 flights were logged in varying environmental conditions, with flight distances ranging between 5 kilometers and 12 kilometers, and altitude differences of up to 250 meters between takeoff and landing.



M600 (left) and DeltaQuad (right) drones in cargo configuration

The tests demonstrated the potential of drones to complement existing medical supply chains. The performance and limitations of each type of platform were evaluated, with multicopters well suited for deliveries up to 10-12km, and hybrids showing potential far beyond that distance.

Hybrid technology remains relatively new, however, with limitations in wind speed on takeoff and landing, and general flight robustness not yet achieving the same level as multicopters.

A subsequent hands-on training session with local drone pilots and government officials was organised in May 2018 in the outskirts of Santo Domingo. More than a dozen participants were trained on the operation of drones for cargo delivery, covering topics such as multi-operator flights, payload considerations and route planning. This training served to initiate the vital process of building local capacity, which is key to future deployment of drone cargo delivery in the country.



Dominican pilots being trained in cargo operations

Growing healthcare needs in the Dominican Republic, coupled with difficult and inefficient supply lines, make it clear that alternative solutions are needed. Our recent training and field tests confirm that cargo drones can be part of the solution. That said, more field research needs to be carried out to identify the most compelling supply lines and delivery routes in the country. On the technological side, drones show great promise, with multicopter, fixed-wing and hybrid drones all having a role to play, based on requirements of supply lines. The technology is at the brink of maturity, with remaining technical challenges being worked on by teams around the world. There is no doubt that we'll be seeing drones delivering essential cargo in outreach areas within a few short years.

Pictures and videos of the field tests are available at werobotics.org/blog.

2. Introduction

Drone delivery has been a hot topic in humanitarian, development and public health circles recently, with the promise of improving logistical challenges in outreach areas plagued with a limited or lack of ground infrastructure increasingly subject to disruptions in road access due to climate change. WeRobotics has been working for several years to better understand the promise but also the limitations of drone delivery technologies and to identify technological and operational gaps that need to be addressed in order for the technology to fulfill its promise. Our cargo drone work first began with our Peru Flying Labs in the [Amazon Rainforest](#) and has since expanded to other Flying Labs including the DR.



The M600 cargo-modified drone in front of the hospital in Juan de Herrera

Since December 2017 WeRobotics has been working together with Dominican business incubator Emprende to better understand the potential of drones for medical cargo delivery in the Dominican Republic as part of a project funded by the Inter-American Development Bank.

The main goals of the project were:

- To better understand the medical logistics system in the Dominican Republic and the potential use-cases for drones in the country
- To test different Beyond Visual Line of Sight (BVLOS) drone technologies in the specific conditions of the Dominican Republic
- To better understand the failure points and failure rates of the technology and the limitations of affordable solutions in relevant social, geographical and environmental contexts
- To develop streamlined workflows to enable the safe and regular delivery of essential items in the Dominican Republic
- To contribute to local capacity through training of local drone pilots



*Removing the medical cargo from the M600 drone
after landing at a remote clinic in the mountains*

3. Healthcare Logistics in the Dominican Republic

The Dominican Republic has a robust healthcare infrastructure run by the Ministry of Health, comprising of three tiers of medical centres - large hospitals in urban centres, smaller hospitals in towns, and local clinics in villages.

The first two tiers of centres are typically easy to reach, as the road infrastructure between cities and large towns is well developed. Traffic is often the biggest hurdle for transport to these levels, especially in Santo Domingo and other bigger urban areas.

Delivery to the third-level clinics is often a much bigger challenge. These clinics serve small populations (hundreds or a few thousand people) in small villages. Roads leading to the villages are not always paved, and it is not uncommon to have bridges or roads washed out and unusable during heavy rain. Regular postal or transportation services between villages and their closest town often don't exist or only run every few days. Many villages are located within the mountainous interior of the island, making it difficult to access on foot.

Villagers in these remote regions earn very little income, and travelling to and from the nearest hospital to get their blood tested can take an entire day, or even several days. Some patients are in pain, and simply unable to “hop” on the back of a truck driving over washed out country roads.



Due to muddy roads and flooding, local transport is often done by horse, as seen here in front of the clinic in the small town of Ingenito

The above reasons led us to focus on logistics in the third-level clinics in the rural, mountainous regions of the country.

3.1 Medical Supply lines

There are three main levels of supply between these tiers of medical centres:

PROMESE: PROgrama Medicamentos ESEnciales (Program of Essential Medicines)

PROMESE is in charge of all the basic supplies and is managed by government vehicles and drivers with some warehouses distributed in key points. They distribute down to second level hospitals. The last leg of supply (from second-level hospitals to third-level clinics) is done from a storage warehouse in second level hospitals. This leg of supply is the least organised and is not working very efficiently. This is where we see a high potential for the use of cargo delivery drones, though further analysis of this part of the supply chain is needed to identify its weak points.

In particular, the delivery of emergency medicines and supplies presents a strong use-case at third-level clinics. During our scoping of third-level clinics we collected many anecdotes of cases when patients had to be sent to second-level hospitals, often in life-threatening condition, due to a lack of basic medicines or supplies on-site. In many of these cases it would have been safer for the patient to stay within the clinic if speedy access to the supplies or medicine could be enabled by drone.

PAI: Programa Ampliado de Inmunización (Expanded Immunization Program)

PAI is a supply line specifically used for the transport of vaccines and is completely independent of PROMESE. Vaccines are typically delivered down to second-level hospitals. There are occasional immunization campaigns that are organised in third-level clinics in small villages. As the third-level clinics often do not have refrigeration facilities, vaccines are delivered by motorbike in coolboxes and the immunization campaign must be performed on the spot. In this case we see a potential to support the motorbike delivery with drones in hard-to-reach villages.

PMAC: Programa Medico Alto Costo (Medical Program of High Cost)

PMAC is the special supply line for very expensive medicines like those for cancer. Due to the high value of these supplies, there is not enough trust in the capacity of hospitals to control them, and thus all of the supplies are centrally stocked and controlled in only 2 warehouses, in Santo Domingo and Santiago. Patients have to pick up their medicine personally at one of those two locations, often at a high personal cost. For such high-value supplies the issue is more related to trust and corruption than to actual logistics, and thus the use of drones in this supply line does not add much value compared to traditional ground transportation.

3.2 Untapped Use Cases - Sample Collection

One of the big potential uses of drones for medical logistics is for the transportation of patient samples for testing. Machines and techniques for testing blood, sputum, stool or other samples are usually expensive and run in specialised laboratories often placed near first- or second-tier hospitals. These samples can often be collected quite easily at third-tier clinics, but there is no existing supply line to transport them safely to the laboratories. Patients are currently told to go down to the local town to perform their tests, requiring them to take one or two days off from work, pay for transportation, and travel while they are sick; it is no wonder that many patients simply do not perform these tests. Creating a new supply line between third-level clinics and testing laboratories could significantly alleviate the population, enable better follow-up of pregnancies and chronic disease in villages and may ultimately reduce healthcare costs by diagnosing and treating disease earlier. Having drones available at testing clinics and able to collect samples from villages is one potential solution.



Medicine vials being loaded into a cargo box before drone delivery

4. Drone Delivery Field Tests

We can classify delivery drones into three major categories: Fixed-wing, rotary wing and hybrid. As there are already many comparisons of these drones in other reports, we'll simply include a small summary below:

	Multicopter	Fixed-wing	Hybrid
Range	Low	High	Medium
Landing area	Small - 5-10 m ²	Large - 1,000+ m ²	Small - 10-20 m ²
Payload	High	Medium	Low
Advantages	• Vertical takeoff/landing • Robustness to wind • Simple to operate	• Maximum range	• Vertical takeoff while retaining range • Backup safety mechanisms - use of vertical motors in fixed-wing mode
Drawbacks	• Limited range	• Requires large landing area	• Increased complexity - two powertrains • Sensitive to wind on takeoff/landing

During our previous [cargo drone field tests in Peru](#) we tested the performance and limitations of various fixed-wing aircraft, ranging from small electric drones with a payload of 500g to larger gas-powered airplanes that could carry several kilograms. Fixed-wing drones, however, require hand or catapult launch and a large landing area (a football field or even a small airstrip), and thus their use is limited for certain applications. In our next series of trials, we wanted to test both multicopter and hybrid drones to test the limitations of Vertical Takeoff and Landing (VTOL) drones and complete our evaluation. This allows streamlining of operations from an area closer to or even on the roof of hospitals and clinics.

For this series of trials we used the DJI M600 multicopter and the Vertical Technologies DeltaQuad hybrid drone. The M600 is a very robust, well tested and professional off-the-shelf platform with 6 propellers (Hexacopter). Though marketed as a customizable platform, it is originally designed for carrying large cameras for imagery. Access to the flight controller is quite limited, so we had to modify it significantly using a second on-board computer, additional radio and a custom flight-planning application in order to perform cargo operations. The DeltaQuad is a relatively new platform based on the open-source autopilot PX4. Modifications for cargo

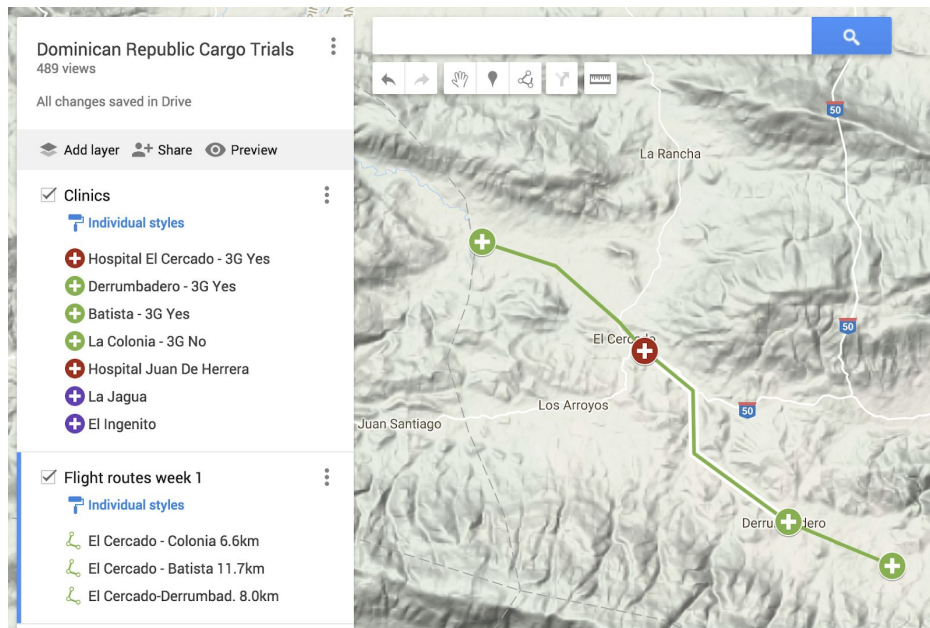
operations were more easily implemented, with only an additional radio that needed to be added. Details of the technology that was used are available in the table below.

	
DJI M600 - A heavy-lift multicopter that can carry up to 5kg of payload. The drone has been modified to deliver cargo, and can be connected to using two separate remote control radios - on sending and receiving sides. It's range is around 10-15 km, depending on payload.	Vertical Technologies DeltaQuad - A long-range hybrid VTOL drone that can carry 1kg a distance of over around 70 km. It can take off vertically (like a helicopter) from near a clinic, transition to plane mode and land again like a helicopter at destination
	
DJI Mavic Pro - A small quad-copter drone that was used for pilot training and scoping before handling the M600.	Tablets used for drone control and monitoring, including a specially-designed Android app for cargo operations of the DJI M600.

Drones and interface used for the cargo delivery field trials

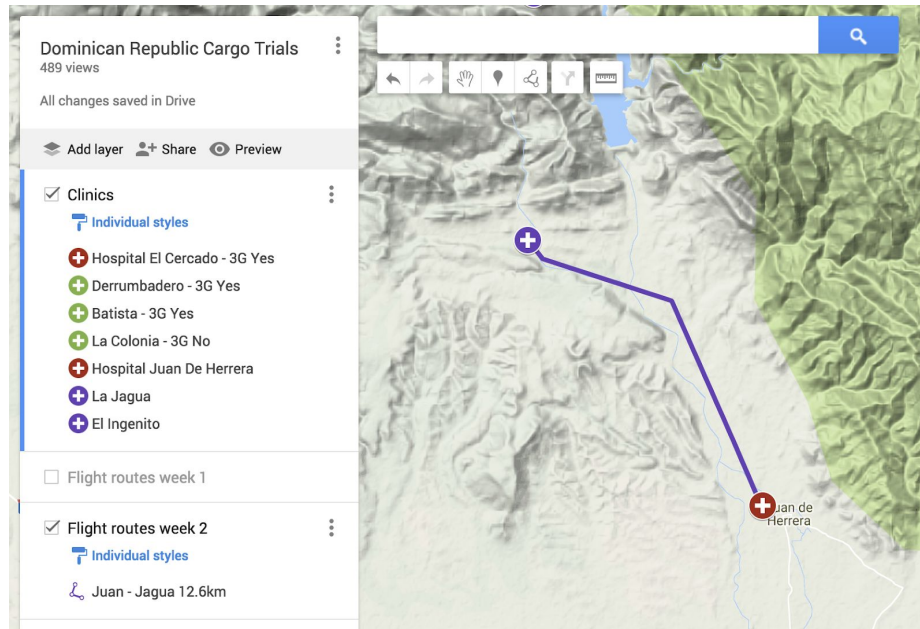
4.1 Delivery Routes

In order to test the drones through a variety of environments, we selected several clinics in the west of the Dominican Republic, within the district of San Juan de la Maguana. For a first week of trials we operated between the reference hospital “Hospital Municipal El Cercado” and clinics in La Colonia (6.6 km away) and Derrumbadero (8 km away) that do the referrals to this hospital. Both clinics might experience problems of supply in case of heavy rains.



El Cercado Hospital (Red dot) with La Colonia in the north-west and Derrumbadero in the south-east

During a second week, we delivered packages between the Hospital Municipal Juan Herrera in the village of Juan Herrera and a remote clinic in La Jagua, situated on the top of a hill 12.6 km from the hospital. When choosing locations we had to compromise between very challenging locations that are difficult to reach, where cargo drones have a very high potential impact and locations that were practical for the purpose of testing the platforms and evaluate the technology in an environment close to the challenges we want to face, but easy enough to access from a logistical point of view.



Juan De Herrera Hospital (Red dot) with La Jagua in the north-west

The objective of this campaign was to evaluate 2 platforms, the workflows of cargo and understand the challenges of getting medical care in Dominican Republic, but not yet to have a direct impact on the patients.

4.2 Communities and Permissions

Community engagement is a key component of understand the underlying need for improved medical logistics and for getting buy-in for our tests. The trials were well supported by the Ministry of Public Health and Social Assistance (Dominican Republic), with particular support from the hospitals in both El Cercado and Juan De Herrera. Hospital staff kindly offered us dedicated rooms within the hospitals as a staging point, access to the roof as a takeoff/landing area, and sample medical cargo for us to carry. On the aviation side, permissions were sought and granted from the Civil Aviation Authority for all drone flights. All flight routes were first scoped using the small DJI Mavic drone and a pilot following by car, in order to ensure there were no unforeseen obstacles along the route.



Hospital staff at Juan De Herrera Hospital, together with the M600 and DeltaQuad drones

4.3 Flight Descriptions, Lessons and Limitations

The goal of the flight tests was to gain experience with both multicopter and hybrid platforms for cargo delivery, to see their advantages and limitations, to refine and improve our Standard Operating Procedures (SOPs) for cargo delivery by drone, and to build local capacity in cargo operations. During 7 days of flight trials we performed over 30 test flights with the M600 and DeltaQuad platforms over distances between 5 kilometers and 12 kilometers, and altitude differences of up to 250 meters between takeoff and landing. The types of cargo transported included items of up to 2kg including water, sample tubes, some medicines and even avocados and energy bars for testing purposes.

The following are some of the lessons learned during these trials:

Range

- The M600 is one of the most mature and robust multicopters on the market, and is thus a good representation of the performance of multicopter drones in this range (~10kg total weight, payload of 2-5kg).

- The practical range of the M600 (and drones in this range) for **1-2 kg of cargo is of around 10-12 km**. Beyond this distance, safety margins become too slim to ensure safe delivery.
- Hybrid drones use **10-20 times more power** when hovering than when in fixed-wing flight. This means that the speed in which a hybrid transitions to fixed-wing flight after takeoff, and inversely from fixed-wing to landing, can have a large impact on its power consumption and thus its practical range.
- The DeltaQuad has a specified range of 100 km with 1 kg of payload. From our field tests, however, a more reasonable range would be around 50-70 km if you want to keep safety margins.

Robustness to Wind

- Multicopters such as the M600 use a lot of power to stay in the air. They are less affected by wind speeds and directions. Hybrid drones, when in fixed-wing flight, can see a 2 or 3 times increase in energy consumption when flying against the wind than with it. This has a great influence on their range.
- The DeltaQuad is quite sensitive to wind during takeoff and landing, potentially due to its large wing surface, light weight and lack of tail. From a practical point of view, flying when the wind was above 5 m/s was not safe. This was ultimately a great limitation, especially in an island nation like the Dominican Republic where higher winds are common. The manufacturer has promised a firmware update that should make the drone more robust to winds - further tests will be required.
- The DeltaQuad does not have a pitot tube, which makes its estimate of the wind speed and direction less accurate, and thus its ability to regulate speed in different altitudes and environmental conditions is more limited. We experienced several stall events during the trials due to its inability to compensate for the wind.

Failsafes

- The DeltaQuad runs an open-source autopilot that has a safety feature called "QuadChute" - if the drone has problems during fixed-wing flight, such as a stall, it will turn on its vertical motors in order to save the drone rather than have it fall. We experienced several flights in which high winds caused a stall of the drone, and the QuadChute feature saved the drone from a crash, so it definitely has value.
- However - the downside with QuadChute is that it can occur at any time during the flight, and the drone uses up to 20 times more power when hovering than when in fixed-wing flight. If it occurs in the middle of a flight, for example, the drone will not have enough

power to fly back to home in multicopter mode. Though QuadChute may save the drone from a stall, it's ultimate results may still be a crash.

Communication

- A big challenge in BVLOS drone operations is to keep communications with the drone during a long route, beyond the range of a standard radio. This problem is compounded in mountainous areas such as the Dominican Republic where line-of-sight is quickly lost. Mobile data communications is still not available throughout the country, so we had to rely on a combination of local telemetry radio, Remote-control (RC) radio, 3G/4G modems and satellite modems to keep track of the drones. In addition, we had two teams for each flight, one at takeoff and one at landing, that needed to communicate with the drone simultaneously.
- DJI's radio system, called Lightbridge, is a proprietary and closed system. Being able to interface two separate Lightbridge radios in order to have control at both takeoff and landing sites required significant engineering and the addition of an on-board computer to handle. The solution is not ideal.
- The DeltaQuad is based on an open-source autopilot so it was easier to interface multiple RC and telemetry radios. On the software side, however, there is still a lack of proper handling of multiple radio signals, and thus we experienced several undesired behaviours during autonomous missions when signals from different radios were received.

4.4 Flight Data and Results

Drone	Routes	Distance with vehicle (KM)	Travel time in auto (MIN)	Average Speed Car (KM/h)	Distance with Drone (KM)	Travel time with Drone (MIN)	Average Speed Drone (KM/h)	Variation in Time (MIN)	Difference (%)
DQ	Hospital El Cercado-Colonia	8	18	26,6	6,97	11	38,00	-7	-39%
DQ	Hospital El Cercado-Derrumbadero	10,3	20,3	30,4	7,98	12,3	39	-8	-39%
DQ	Hospital Juan de Herrera-La Jagua	19,5	38	30,8	12,5	13,2	57	-24,8	-65%
M600	Hospital El Cercado-Colonia	8	18	26,6	6,97	11,77	36,00	-6,23	-35%
M600	Hospital Juan de Herrera-La Jagua	19,5	38	30,8	12,5	20,1	37,31	-17,9	-47%

The table above summarizes the main routes served by the two drones and compares their travel times with ground transportation. Take the case of the route between Juan de Herrera Hospital to the clinic in La Jagua, for example. It takes a car approximately 38 minutes (assuming there is no traffic and that the roads are usable) to travel between these the hospital and the clinic. In contrast, the drone can fly this route within 13 minutes, or 65% faster than a car. Naturally, these time savings clearly grow the longer the distance between a given hospital and clinic, particularly if there roads connecting these two points are not paved and subject to flooding during the rainy season.



DeltaQuad drone landing vertically at a remote clinic in the mountains

5. Training and Local Capacity Building

Following the cargo drone trials in December, we returned to the Dominican Republic in May 2018 for a week-long intensive training focused on cargo drone operations. Both M600 and Deltaquad platforms were used for the training, with flights being performed daily by participants.



Training in Parque Cibernético Santo Domingo

The training included several modules:

- Workshops about the specific challenges of cargo operations
- BVLOS operations requirements and regulation, with the support of IDAC (Instituto Dominicano de Aviación Civil), obtaining special permission to safely operate at low altitude at less than 5km from the International airport in Santo Domingo
- Evaluation of different type platforms: fixed wings, multicopters and hybrid VTOL platforms
- Drone parts, sensors, reliability, redundancy, dissimilar redundancy
- Standard Operating Procedures (SOPs), checklists, flight assessment, drone maintenance
- Route planning for cargo operations (safety, terrain, property, roads, electric lines...)
- Integration of operations into health centers
- Risk mitigation procedures
- Code of conduct and local sensitization campaigns
- Automatic cargo operations with a DJI M600 (WeRobotics cargo hardware modification and custom ground station) and Vertical Technologies Delta Quad Hybrid (PX4 and QGroundControl)
- Autopilot setup and configuration (PX4 and QGroundControl) with Caipirinha small fixed wing platform: from integration to manual, assisted and full automatic flight (include auto takeoff and autoland fixed wing op's)



Local capacity building is a key priority for WeRobotics

Part of the training was linked to the evaluation of operations between the main hospital at the location of Hato Mayor and the clinic at Morquecho. After the assessment we decided that conducting those operations with around 20 km BVLOS operations during the training would be too risky and it was better to moderate the objectives and maximize hands-on training.

Training flights were thus performed between the baseball field of Morquecho and a field near another small clinic 5 km north of Morquecho on the first day. On the second day of flights, due to unforecasted rainy weather, training was moved to Hobbyland, an RC flight field with ideal installations for the training that also enabled BVLOS operations in a safe manner. Coordination with local authorities were performed in both cases.

We had the pleasure of having team of highly skilled participants composed of:

- 5 members of the 911 emergency rescue team including pilots of manned cargo airplanes, all of them drone users for search and rescue operations
- 2 drone mapping pilots from the ministry of agriculture
- 2 drone racers with years of experience in RC flight and strong vehicle build and maintenance skills
- A pilot and local reseller of DJI aircraft
- 2 freelance drone pilots in mapping and videography



Local pilots learning to operate the cargo-enabled M600

This amazing and diverse team provided interesting perspective during the workshop sessions and discussion, different use cases, applications, points of view and understanding of the local drone ecosystem.

Lessons learned during the training include:

- The DeltaQuad, when hovering during takeoff and landing, is highly sensitive to gusts of wind. This is a strong factor to take into account in the Dominican Republic, where wind can go from light to strong in minutes.
- Rain showed off for a full afternoon while not being forecasted; in the Caribbean, rainy clouds can be formed in a very short time
- Local capacity is key to future cargo operations. There is a robust base of drone pilots already existing in the Dominican Republic with diverse and complementary skills and experience.

Strong connection between regulators, government service providers, pilots and suppliers is key to cover all the requirements of these challenging operations. We envision that this good coordination will enable self-sustainable local capacity, opportunities for business incubation and attract external investment with the final aim of providing better health care and other services to the local population.

6. Discussion and Remaining Challenges

Cargo transportation by autonomous drone is a relatively new possibility being explored by different organizations but several key challenges remain. Some good examples of companies working on cargo drones that have operated in challenging environments are Matternet, Zipline, DHL and Amazon and Wingcopter, for example. In addition, a growing number of universities, hobbyists and small businesses that are experimenting with various technologies, use-cases and business models.

As drone delivery matures and different use cases are identified we can begin to categorize mission requirements of use-cases through a few key criteria.

6.1 Range

One of the first factors stated by any drone manufacturer is the range or distance that the drone can fly. It is important to understand this factor correctly, as it is one of the most important factors when selecting a platform for a use-case. At the same time, in our experience, we have found that range is also the factor that is most mis-represented by drone manufacturers. For example, manufacturers often quote the total flight time rather than a distance, as this is the more important factor for aerial imagery drones. However, neither flight time, distance or payload weight take into account environmental or topographical factors, for example. As such, specifications are often optimistic and in best-case scenarios.

Flight distance can also be reduced due to several other factors, including but not limited to:

- **Wind:** High wind strength can significantly reduce range, particularly for fixed-wing platforms that can see a doubling or even a tripling of energy use in high-wind conditions.
- **Payload weight and position:** The more payload, the more energy required to fly. Powertrains can become much less efficient when too much payload is being carried. For some drones with bad payload placement with respect to the Centre of Gravity (COG) of the drone, adding even a small payload can greatly destabilise the performance of the drone and reduce flight time.
- **Age of battery:** Batteries lose capacity as they age. Badly-designed powertrains can see range degradation already after the first 5 flights. Smart-batteries and well-designed powertrains are key to long-term robustness of range.
- **Temperature:** Low temperatures affect battery capacity - especially an issue for lithium-based powertrains.

- **Altitude:** Flying at high altitude can take more energy (especially for rotary-wing drones). Climbing from the source to a destination that is at a higher altitude also takes additional energy.
- **Safety reserve:** It's typically good practice to leave at least 20%, preferably 30% of energy reserves remaining after a drone has landed. Most manufacturers state their range assuming a 0% safety reserve.

From a use-case perspective, the most important factor to confirm is the guaranteed distance that the drone can attain, independent of the factors mentioned above. As opposed to imagery drones that takeoff and land in the same place, cargo drones often do not have the option to land half-way through a flight if the wind is too strong.

6.2 Payload

In our experience, the second most often quoted specification of cargo drones is their payload capacity. This is often stated as simply a maximum weight that the drone can carry before becoming unstable in flight. Additional weight will invariably reduce flight time and range, so should always be considered when evaluating a platform. Besides weight, however, there are several other factors that are equally important:

- **Volume:** Many drones currently used for cargo delivery are modified imagery drones, which typically have small or oddly-shaped payload bays designed specifically for dense, heavy, small cameras. Increased payload bay size means increased drag for the body of the drone, and thus cameras have traditionally been squeezed into oddly-shaped places within the drone's body. As drone cargo can have vastly different sizes, shapes and densities, having a large and regularly-sized payload bay (a rectangular box is easier to fill than an egg-shaped one) is important.
- **Adaptability:** Payload can change between every flight, both in size and in weight. The payload bay should be as close as possible to the drone's COG to ensure it's flight stability. The drone should also have some robustness to shifting weight if it's transporting liquids or loose packages.

6.3 Usability

It's easy to get caught up in comparing numbers and technical specifications between various platforms as they're what's most concrete. The best platform for a use-case, however, is the one that can be the most reliable platform that can be the most easily used by the greatest number of users. Numbers will not describe the ease of use of a platform; in-person testing and demonstrations should always be done to better understand the true performance of a drone-delivery system. The following factors should be considered:

- **Takeoff/landing:** Some drones, such as multicopters or hybrid drones, can takeoff and land vertically and require relatively little space to operate in. Fixed-wing drones, depending on their size, may need a small football field or even an airstrip.
- **Training requirements:** Ideally, delivery drone operation should require the same skill level as riding a motorcycle - the technology it is trying to replace. Automation of the flight is critical to achieving this.
- **Environmental robustness:** Wind and rain should not have to ground operation of the drone, particularly in emergency medical use-cases.
- **Maintenance and repairability:** As opposed to imagery drones that may fly only a few times a month, cargo drones may operate daily, or even several times a day. They need to be robust and easy to repair locally, with parts that are easily attainable.

6.4 Software

The major applications of small drones in today's market are video, mapping and other aerial imagery, and existing control software reflects that. A cargo drone should have a dedicated software stack that's adapted to the application.

- **Flight planning:** Cargo delivery flights are often flown in straight lines, though they do need to account for terrain variability, no-fly zones and altitude differences between takeoff and landing. In most existing flight planning software the user is obliged to manually create waypoints for each delivery route. Automation of flight trajectories for cargo delivery is a significant challenge compared to simple drone mapping flights. Planning should also take into consideration weather conditions and mission feasibility.
- **Source and Destination handling:** Most software currently assumes a drone will takeoff and land in the same place, usually called the Home point. Cargo drones need a way to define a second location as a destination, and a second operator or mechanism at the destination to receive the drone on landing. In addition, the destination may be at a different altitude than the source - this requires intelligent climb and descend planning.
- **Recovery and safety:** An imagery drone that stays within line-of-sight often triggers a return-to-home action whenever it has a serious problem. A cargo drone may fly tens or hundreds of kilometers during a delivery - returning to home after a fault is not always the best option. Intelligent fault recovery, rally points and additional safety mechanisms need to be integrated to compensate.
- **Long-range communication:** Deliveries beyond a few kilometers in distance usually end up BVLOS at which point local communication is usually lost. Cargo drones should have a solution to allow the operator to communicate with the drone during the entire

flight. This can be done through a combination of local radio, mobile phone networks, satellite radio and cloud-based solutions. This is both a software and a hardware problem.

- **User interface:** Cargo drones bring new users, including drone operators at both source and destination, logisticians that handle packages and flight planners that create the flight plans and orders. Cargo drone software should enable these different actors to interact with the drone system in different ways. Tracking of the payload that is being delivered should be integrated within the software.

6.5 Cost

Unlike mapping, video or hobby drones, cargo drones are not yet available as reliable, mass-produced, affordable off-the-shelf solutions. The commercial case for cargo drones for many use-cases in emerging economies and rural environments begins when costs for drones drops below \$10,000 USD, or even down to \$3,000 USD - the cost of a motorcycle. The commercial solutions mentioned above are either demonstration projects not for sale (Amazon, DHL), full-stack solutions available only as a service to large clients like national governments (Zipline, Matternet) or expensive, specialised platforms with unit costs in the tens or hundreds of thousands of dollars (Vayu, Wingcopter).

The main limiting factor for drone prices is scale - it is difficult for drone companies that produce a few drones each month to significantly drop their prices. As the technology matures, use-cases emerge that require hundreds or thousands of drones, the price should reach the required levels. As an example, the DJI M600 drone, designed for carrying large cinematic cameras (and modified for cargo in our field trials), is already produced in a sufficient quantity to be sold for around \$4,000 USD.

7. Conclusion

The potential of drones to revolutionize logistics of small packages, in particular for outreach communities and those most affected by climate change, is real. Through our latest series of live, in-country field-tests, we've been able to add multicopter and hybrid drones to our comparison of cargo-capable drone technologies. These tests reveal several limitations to existing technologies, including range, communication and cost. These limitations, however, are not insurmountable; they are simply indications of an industry that is not yet mature, but holds great promise. Technical solutions to these challenges are already being worked on by companies throughout the globe, some based in the very same communities where the technology would have the most impact. Once developed, there's already a strong local capacity available to deploy it, especially now in the Dominican Republic. We're excited to see what they will create over the next few years.



New cargo drone pilots being trained in Santo Domingo

8. Acknowledgements

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Dominican Republic training team



Innovative Health Service Delivery Systems in Rural Dominican Republic Cargo Drone Field Tests

