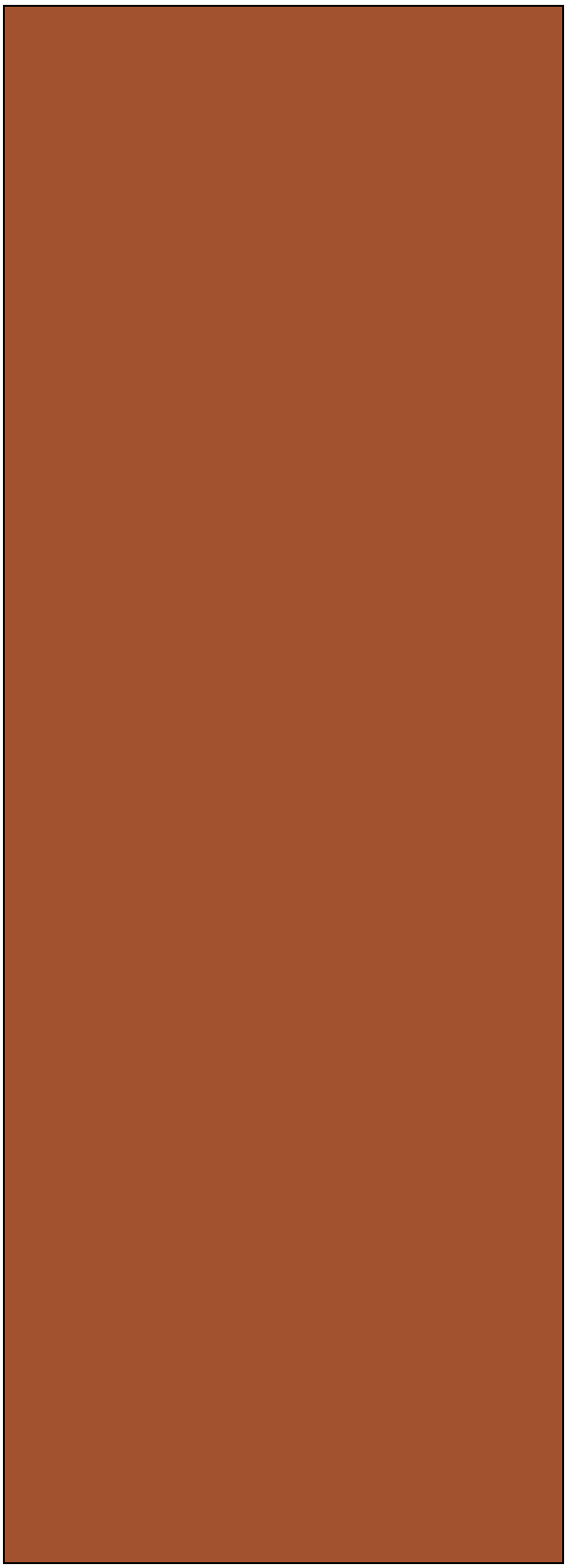
Assessing the Feasibility of Unmanned Aerial Vehicles (UAVs) for Medical Commodity Delivery in Obstetrical Emergencies:

Business Case Investigation Report

April 2019



VillageReach Starting at the Last Mile

VillageReach works with governments to solve health care delivery challenges in low-resource communities.

villagereach.org // info@villagereach.org

Table of Contents

Executive Summary

The use of unmanned aerial vehicles (UAVs, frequently called drones or remotely piloted aircraft/RPA) has the potential to address critical transportation barriers in global health. VillageReach, a nonprofit social innovator with a mission to increase access to quality healthcare at the last mile, has been supporting governments and collaborating with interested stakeholders to determine the feasibility and efficiency of using UAVs to augment existing transport systems to transport health products and services, including in Malawi. The Malawi Ministry of Health and Population (MOHP), in partnership with VillageReach, the Malawi Blood Transfusion Service (MBTS), the Malawi Pharmacy, Medicines, and Poisons Board (PMPB), and NextWing, a UAV manufacturer, conducted a proof of concept study in March 2019. Alongside this proof of concept study, VillageReach consulted with key stakeholders to develop an initial business case and identify next steps for further analyses needed to guide the longer-term use of UAVs to ensure that life-saving products and services are available to health workers and patients in hard-to-reach areas and in high volume facilities that deal with medical emergencies. Key recommendations focused on:

1. Next steps to **demonstrate the feasibility of UAVs** to transport health products and services in Malawi
2. **Description of the most promising scenarios for the use of UAVs in Malawi**, both in terms of geography and products.
3. **Technology improvements** needed to reliably and safely deliver health products and services in the recommended scenarios
4. **Information and coordination** needed to optimize the current transport system to introduce and scale-up the use of UAVs through the recommended scenarios
5. **Human, infrastructure and financial resources** needed to maintain the use of UAVs in the recommended scenarios
6. Identification of additional **government strategy, policy, regulation, and governance** needed to maintain the use of UAVs in these scenarios

The initial business case has been developed for and presented to the government of Malawi, and will be made available publicly, with appropriate permissions and support from the MOHP.

1. Background

Despite recent progress, Malawi has one of the highest maternal mortality ratios in sub-Saharan Africa, with 439 deaths per 100,000 live births[1]. Reproductive health challenges are even more pronounced in rural and hard-to-reach areas, where 84% of the country's population live. The Malawi Ministry of Health and Population (MOHP) has identified reducing maternal death as one of its key strategic priorities in its 2017-2022 Health Sector Strategic Plan II. Studies indicate that one of the most common causes of maternal death in Malawi is obstetric hemorrhaging[2], which can be treated through blood transfusion and administration of an uterotonic drug, oxytocin. However, these products are not always available in a timely manner due to road conditions, distance between health facilities, shortage of vehicles, financial constraints, lack of a dedicated system for blood, and difficulties maintaining the cold chain with limited electricity.

The use of unmanned aerial vehicles (UAVs, frequently called drones or remotely piloted aircrafts/RPAs) has the potential to address these critical transportation barriers. VillageReach, a nonprofit social innovator with a mission to increase access to quality healthcare at the last mile, has been supporting governments and collaborating with interested stakeholders to determine the feasibility and efficiency of using UAVs to augment existing transport systems to transport health products and services. VillageReach has been working with the government of Malawi, which has been at the forefront of using this new technology for medical transport. In 2016, UNICEF led a study to test the use of UAVs to transport dried blood spots for HIV diagnosis in Malawi, for which VillageReach provided a cost analysis. In 2017, the Malawi government launched a UAV corridor to further facilitate the testing of the UAV technology in local conditions. Additionally, the Department of Civil Aviation (DCA) drafted regulatory guidelines for the use of UAVs. In 2018, the DCA, with support from VillageReach, established a technical working group (called the RPA Steering Committee) to guide the introduction of UAVs in Malawi for a variety of humanitarian purposes, drawing on the combined input of public, private, donor, and non-governmental actors. VillageReach serves as the Secretariat for the RPA Steering Committee. To further build local capacity in the maintenance and operations of UAVs in Malawi, UNICEF will establish the African Drone and Data Academy in late 2019. To guide next steps, the government of Malawi needs evidence demonstrating the feasibility, cost implications, safety, and long-term business case associated with introducing UAVs.

To help provide the required evidence, the Malawi Ministry of Health and Population (MOHP), in partnership with VillageReach, the Malawi Blood Transfusion Service (MBTS), and the Malawi Pharmacy, Medicines, and Poisons Board (PMPB), has been working on a proof of concept since 2017, and enlisted a UAV manufacturer, NextWing[3], in 2019. The study objectives were to investigate safety concerns and perceptions of the community and stakeholders, the costs and potential benefits of using UAVs (including potential time saved and the ability to deliver commodities that would otherwise be unavailable), the feasibility of UAV use in country, and the quality of blood and oxytocin samples flown by UAV. VillageReach conducted an analysis of community and stakeholder perceptions in 2018, which informed a community outreach strategy. In March 2019, VillageReach conducted the costs and benefits analysis, alongside initial test flights conducted by NextWing in Malawi. Additionally, this report serves as an initial business case and next steps for further analyses needed to guide the longer-term use of UAVs to ensure that life-saving

[1] National Statistical Office (NSO) Zomba, Malawi and ICF, Rockville, USA, 2017. *Malawi Demographic and Health Survey 2015-2016*. Accessed at: https://dhsprogram.com/pubs/pdf/FR319/FR319.pdf

[2] Mataya R et al. *Report on the confidential enquiry into maternal deaths in Malawi (2008-2012)*. Republic of Malawi, Ministry of Health and Population.

[3] VillageReach first contracted Vayu to conduct test flights as part of the feasibility study in April 2018, but they were unsuccessful due to technical challenges. VillageReach replaced Vayu, with NextWing because Vayu was unable to return to Malawi in the timeframe needed. VillageReach chose NextWing through an extensive interview process and based on performance at the Lake Victoria Challenge, an event that brought together UAV providers from around the world.

products and services are available to health workers and patients in hard-to-reach areas and in high volume facilities that deal with medical emergencies.

2. Literature Review

Although governments in sub-Saharan Africa are increasingly interested in the use of UAVs to enhance existing public health transport networks, there are limited models of how the use of UAVs can be sustained at the national level or across multiple use cases. Rwanda has been working with Zipline since 2016 to provide a service delivery system (including inventory management, order management, transport management and operations) for emergency blood transfusion, but no other national-scale examples of UAV-enhanced public health transport systems exist. Several governments, including Malawi, Tanzania, Ghana, Mozambique, Madagascar, and the Democratic Republic of the Congo are considering the integration of drones into the medical transport system.

Although a full national-level business case for the use of UAS has not been developed in sub-Saharan Africa, modeling studies have suggested key factors for consideration in elaborating the business case. In 2016 in Malawi, VillageReach conducted a cost analysis comparing multiple options to transport dried blood spot specimens between health facilities and laboratories, including introducing UAVs to augment, not replace, ground transport, optimizing the transport network using only ground-based transport, and maintaining the status quo. The study concluded that the costs of the UAV-enhanced transport system become more cost-effective as the number of facilities served increases and the number of products delivered increases[4]. JSI Research & Training Institute, Inc. (JSI) conducted further analysis of potential transport systems for laboratory specimens in Malawi, and stakeholders expressed a preference for transport systems that integrate the use of UAVs over those that relied on traditional modes of transport. Participants suggested demonstrating success with a single use case first before expanding to multiple uses, using a phased approach to ensure strong performance before adding complexity.[5]

JSI, along with LLamasoft and the Nichols Group, compared traditional modes of public health product delivery (such as motorcycles) with transport systems enhanced with the use of UAVs. The study examined data across multiple uses of UAVs, including blood for transfusion. The analysis concluded that introducing UAVs for a single use case is not cost-effective in the long-term; though introducing a single use case initially can provide valuable information on feasibility and safety and help to identify cost drivers. The analysis also suggests that the highest potential for uses of UAVs are likely in areas with a high density of health facilities, that are difficult to access by road and in which products have a high financial value, have high life-saving potential, have unpredictable demand, and are expensive or difficult to store at the health facility level.[6]

3. Objectives

The overall objective of the business case is to provide the Malawi government with evidence on the feasibility of using UAVs to enhance the existing health product supply chain, to ensure that life-saving products are available to health workers and patients when needed. This report contains recommendations for the next steps the government and key stakeholders should take to further demonstrate the feasibility of this new technology and to develop the business case for its use.

[4] Phillips, N., Blauvelt, C., Ziba, M., Sherman, J., Saka, E., Bancroft, E., and Wilcox, A. (2016). "Costs Associated with the Use of Unmanned Aerial Vehicles for Transportation of Laboratory Samples in Malawi." VillageReach.

[5] JSI Research & Training Institute, Inc. "Network assessment and system design for transport of EID samples and test results." Project report submitted to UNICEF Malawi. June 5, 2018.

[6] Wright, C.; Rupani, S.; Nichols, K.; Chandani, Y.; Machagge, M. (2018). "What should you deliver by unmanned aerial systems? The role of geography, product, and UAS type in prioritizing deliveries by UAS." JSI Research & Training Institute, Inc.

4. Methodology

The proof of concept study first assessed health worker and stakeholder knowledge and attitudes towards UAVs for the transport of blood and oxytocin, then aimed to demonstrate the safety and potential costs and benefits of the use of UAVs to transport blood and oxytocin.

To assess health worker and stakeholder knowledge and attitudes, VillageReach conducted 10 focus group discussions (FGDs) in spring 2018 with a total of 130 participants, from the national, city, and district levels, as well as with health workers, community leaders, and women. We asked FGD participants about their awareness and opinions of the use of UAVs to transport blood and oxytocin, as well as their recommendations for the use of UAVs in the long-term. Please see Annex A for the Community Sensitization Strategy and Final Results.

In March 2019, VillageReach conducted a costing analysis to explore the implications of introducing UAVs into the blood and oxytocin supply chains. The analysis included a desk review of existing literature, comparison of transport scenarios using an Excel-based model, and qualitative interviews with the UAV manufacturer and MBTS representatives. The costing model compared the transportation costs of using UAVs to transport blood to eight health facilities to the transportation costs of using UAVs to transport blood to only the four health facilities located more than 35 km from the take-off site. In both scenarios, the use of UAVs was 51 less costly than using four-wheel drive vehicles in instances of maternal hemorrhage in Lilongwe and Dowa District. See Annex B for the final cost analysis report describing the methods used and results generated in this cost analysis.

VillageReach, through its UAV partner, NextWing, intended to demonstrate safety and feasibility through repeated transport of a 1 kg payload between blood distribution centers and hard-to-reach facilities. Additionally, we planned to conduct, quality testing and temperature monitoring of the blood and oxytocin to document any safety concerns and conduct a comparative time test to measure whether additional benefits existed. However, due to an issue with GPS interference, NextWing was unable to complete the planned flights as of April 2019.[7] Please see Annex C for the flight report.

Alongside this study, we conducted 19 individual interviews with key stakeholders, including:

- A total of eight government representatives, including representatives from the MOHP, including the Reproductive Health Directorate; Human Resource Department; Diagnostics; Senior Management at the MOHP, including the Chief of Health Services; Department of HIV and AIDS; and the Department of TB, as well as representatives of the DCA and the MBTS.
- Six organizations testing the use of UAVs, including UNICEF, DFID, USAID, Global Health Supply Chain Program-Procurement Supplies Management (GHSC-PSM), John Snow International (JSI), and Riders for Health.
- Five UAV companies, including the UAV supplier for the proof of concept study (NextWing) as well as four other companies who have tested the use of UAVs in resource-constrained environments (Wingcopter, RigiTech, Latitude, and Precision Air).

A full list of respondents and their titles is included in Appendix A and a full list of questions used to guide the interviews is included in Appendix B.

[7] Although the NextWing test flights were not completed, their software was able to definitively identify the barrier to flight as GPS interference. This issue has been an ongoing problem for UAV providers when flying in Malawi. UAVs used for surveillance have been able to adjust their software to account for interference. NextWing and DCA have been working together to document their experience and brainstorm software and hardware upgrades to mitigate interference to enable UAVs with vertical take-off and landing to carry commodities.

Combined, these results were analyzed to inform recommendations to develop an initial business case for the use of UAVs in Malawi, focused on:

1. Next steps to **demonstrate the feasibility of UAVs** to transport health products and services in Malawi
2. **Description of the most promising scenarios for the use of UAVs in Malawi**, both in terms of geography and products.
3. **Technology improvements** needed to reliably and safely deliver health products and services in the recommended scenarios
4. **Information and coordination** needed to optimize the current transport system to introduce and scale-up the use of UAVs through the recommended scenarios
5. **Human, infrastructure and financial resources** needed to maintain the use of UAVs in the recommended scenarios
6. Identification of additional **government strategy, policy, regulation, and governance** needed to maintain the use of UAVs in these scenarios

5. Results

Results are presented below by theme, and a full summary of key next steps are included in Appendix C.

5.1 Demonstrate the feasibility of transporting health products by UAV in Malawi

Recommendation 1: UAV manufacturers and implementers should conduct community awareness and perceptions assessments to inform outreach strategies for all UAV test flights outside the Kasungu corridor.

In order to demonstrate feasibility within the local context, the DCA and the relevant government ministry, in this case the MOHP, should require that UAV manufacturers and implementers assess community perceptions of the use of UAVs to transport public health products and services in any new area where they will introduce the use of UAVs. Different districts and regions of Malawi have different cultural perceptions and it is therefore necessary to do an assessment in each new area. The results of these assessments should be used to design outreach strategies that address any misconceptions or negative traditional beliefs, orient community leaders and members on the purpose and scope of all UAV flights, and provide instructions on the appropriate safety measures to be taken in case of adverse events. The community outreach based on these assessments should be interactive, including seeing and touching the UAV to build familiarity with the new technology.

Key next steps:

1.1. The MOHP, VillageReach and other implementers who have already conducted community perception assessments should share data collection methods, tools, and resulting outreach strategies.
1.2. DCA and the MOHP should require that community awareness strategies be based on a perceptions assessment for any future implementers.

Recommendation 2: Continue to provide UAV manufacturers updated information on the local context to enable the development and testing of UAVs that are reliable in Malawi.

The RPA Steering Committee should continue to facilitate information sharing between UAV manufacturers and Malawi government stakeholders. For example, during the NextWing study flights, GPS interference from cell phone towers prevented the UAV from flying along its planned route. As a follow up to the study, the members of the RPA Steering Committee are connecting with the Malawi Communications Regulatory

Authority (MACRA) to identify frequencies in use and assess the extent to which cell phone tower operators may operate outside existing regulations. In addition, UAV operators such as UAVAid that require quality fuel should be connected with the Malawi Energy Regulatory Authority (MERA) to ensure access to a reliable source of fuel. This information will enable NextWing and other UAV manufacturers to equip their UAVs with the hardware and software necessary to mitigate this challenge. The RPA Steering Committee should continue to facilitate this type of sharing of information and provide transparent information to all interested UAV manufacturers. Further, the RPA Steering Committee should share its lessons learned beyond Malawi, as other countries that are considering introducing UAVs into their public health supply chains may experience similar challenges.

Key next steps:

2.1. To address the current issue of GPS interference, the RPA Steering Committee should consult MACRA for full details of frequencies in use in targeted test flight areas and to compile the GPS locations for all cellular phone towers throughout the country. The RPA Steering Committee has already taken this step and is working with MACRA on the list of frequencies and tower locations.
2.2. The RPA Steering Committee should develop a toolkit and checklist for UAV implementers and UAV operators with key information from lessons learned, key contacts, challenges that they may face (including but not limited to GPS interference), and possible solutions to overcome those challenges.[8]
2.3. The RPA Steering Committee should share information with any incoming UAV providers and facilitate any further information gathering needed to adapt their technology to local conditions, including both software and hardware changes.
2.4. The RPA Steering Committee should support NextWing and other providers to test their updated technology in Malawi.
2.5. The RPA Steering Committee should share technical lessons learned beyond UAV implementers and operators within Malawi to include the global community through the UAV for Payload Delivery Working Group (UPDWG) as many of the challenges and lessons learned may be applicable throughout the region.

Recommendation 3: Support UAV technology which interoperates with existing health information and logistics management information systems as well as other UAV operators

To create an integrated system for transport, UAV software must be able to interoperate with or be built into existing supply chain, health information management, or other systems. In Malawi, the existing supply chain information system is OpenLMIS and the existing health information management system is DHIS2. Additional systems that track laboratory samples, vaccines, units of blood, and other health commodities exist. UAV software must interoperate within these existing systems as well as with other UAV models.

Key next steps:

3.1. UAV providers to work with supply chain and other key stakeholders to develop software that interoperates with existing systems.

[8] In light of these recommendations, the members of the RPA Steering Committee are developing a toolkit for UAV implementers and operators to prepare them for what to expect. See Annex D for the UAV toolkit outline developed at the March 2019 RPA Steering Committee Meeting.

3.2. The government, including the MOHP, and DCA should ensure cross-departmental integration through existing technical logistics working groups.

Recommendation 4: Demonstrate feasibility first of limited payload capacity (1 kg) and maximum distance (40 km) before increasing to desired payload capacity (at least 2 kg, up to 10 kg) and maximum distance (at least 75 km)

The RPA Steering Committee should continue to support UAV tests that carry approximately 1 kg, with the ability to carry at least two bags of blood, a distance of up to 45 km in order to demonstrate the feasibility and safety of the technology. Once proven effective, UAVs should increase these limits to between 2-10 kg and at least 75 km at full payload in order to promote cost-efficiency and utility to reach hard-to-reach areas. (See Recommendations 5 and 6 for more detail on prioritized payloads and geographies.)

Key next steps:

4.1. UAV providers should continue to work towards improving technology to demonstrate that they can safely and repeatedly fly the minimum 1 kg of payload a distance of 45 km in the local environment.
4.2. While addressing the technology issues with the existing technology, UAV providers should also explore the possibility of expanding to larger payloads and longer distances.

5.2 Most promising UAVs scenarios

Recommendation 5: Prioritize the use of UAVs to deliver products which have the potential to be lifesaving if available urgently, cost-efficient, or require cold chain or other special handling

Respondents in the business case interviews agreed that not all health products or services are appropriate for delivery by UAV, and that UAVs should only be used to address existing transport issues. They should be used as a way to augment, not replace, the existing system. It is not cost-efficient to use UAVs to transport medical cargo to sites that can be accessed reliably through existing methods of transport, which are not frequently stocked-out, or which are not in high enough demand to justify the cost. The use of UAVs to transport products and services that require cold chain or other special handling (and therefore are vulnerable to contamination during long, unstable transit by ground) has the potential to have a significant impact on the potency or quality of health products, for example, blood and laboratory samples such as tuberculosis samples. Determining the highest priority uses of UAVs would require establishing a baseline for demand. This would require a long-term study to analyze potential health impact, including lives saved, and supply chain impact, which may include costs saved, in comparison to the current transportation system. Such a long-term study would enable analysis based on real-world data, rather than assumptions.

Key next steps:

5.1. Conduct a larger-scale study that analyzes the most promising use cases for lives saved, health impact, and costs in comparison to the current transportation system.
5.2. Researchers should share and validate results with the RPA Steering Committee and then disseminate results widely through peer-reviewed publications.

Recommendation 6: Prioritize geographic locations for delivery of health products and services by UAV which are hard-to-reach or not reached by other services

Interviewees indicated that the critical geographic use cases for UAVs include areas that are hard-to-reach, whether seasonally or due to their proximity to lakes, plateaus, or forests. Even if not geographically distant from the site where a health product or service is available, some urban areas may be hard to reach due to traffic. This becomes a particularly critical issue when the product or service is lifesaving and urgently

needed, as in the case of blood for maternal hemorrhage. For example, locations such as Nkhatabay, Nkhotakota, and other island and shore areas far from health facilities should be prioritized based on their geography. Additional geographies might include those that are hard to reach from the designated district hospital or laboratory but are faster to reach by air from a different district. Any system that incorporated these optimizations would require further policy and financing discussions.

Results of the cost analysis indicate that cost efficiencies can be gained when UAVs are introduced to deliver blood to sites which are a certain distance from the distribution center; in VillageReach's analysis, data was analyzed for sites more than 35 km from the distribution center, but it is expected that cost efficiency would increase with further distances as the UAV technology allows. The key cost driver identified was the purchase of the vehicle, both the four-wheel drive for the ground-based transport system and the UAV. Additional cost efficiency could be gained in either method of transport as opportunities for resource-sharing are identified, but it would be necessary to design a system in which the vehicle (either four-wheel drive vehicle or UAV) are available at all times for rapid emergency response.

Distribution sites should also be selected from amongst those with the capacity to administer the targeted product. For example, blood should only be distributed to district hospitals or high-volume health centers that have an operating theater.

Key next steps:

6.1. Analyze existing maps of hard-to-reach areas and cross-reference existing data on burden of maternal hemorrhage and flight radius of a blood distribution center to identify priority geographies
6.2. Compare map of hard-to-reach areas which have a high burden of maternal hemorrhage to existing data on burden of other health conditions prioritized for service by UAV to identify potential for layering use cases

5.3 Technology improvements needed

Recommendation 7: UAV manufacturers need to improve their software and hardware to safely enable achievement of the most promising scenarios identified

A main priority for all stakeholders was to demonstrate the safety and feasibility of transporting payloads by UAV. UAV companies need to progressively build the capacity to reach the payload required by the prioritized scenarios at the full distance required by the prioritized geographies. In order to achieve this, several technical improvements to the UAVs are needed, including hardware and software adjustments to mitigate the GPS interference experienced by NextWing and other UAV providers and the ability to extend dead reckoning time before fail-safe mechanisms are engaged (without compromising safety). UAVs should be able to withstand a minimum level of wind and rain to enable flight in typical real-world conditions.

Improvements are also needed to battery systems, including longer available charge time, shorter re-charging time, ability to charge at mid-point stations, and ability to charge with solar power. UAV manufacturers should also either design their UAVs to use batteries available in country or build a local market for the batteries used in their UAV to ensure that batteries can be consistently available for repair and maintenance.

Key next steps:

7.1 UAV manufacturers need to upgrade their hardware, including battery systems to reach the desired distances and ability to withstand a reasonable level of rain and wind
7.2 UAV manufacturers need to improve software to ensure that they can mitigate challenges experienced in the local contexts

5.4 Information and coordination to optimize and scale-up the use of UAVs

Recommendation 8: Compile and collect the data needed to optimize the transport system with UAVs

Because cost-efficiency is greatest when UAVs are used to serve hard-to-reach areas, which also have a high demand for the targeted products, it is necessary to ensure the availability of accurate and updated health burden data as well as GPS locations for all health centers, MBTS centers, district hospitals, other health facilities, cellular phone towers, and satellites. Where this data is not available, the MOHP should mobilize partners to collect this data. Demand data should be overlaid on maps of prioritized geographies, as well as complementary use cases.

Cost-efficiency should be estimated in the beginning and monitored during implementation based on a comparison of a well-managed ground-based transportation system and a UAV-enhanced transportation system. Cost monitoring should include an analysis of hidden costs such as costs personally borne by the health worker in procuring products from distribution centers. This is particularly important in cases in which the current ground-based transportation system does not reach or does not adequately serve the targeted areas.

Accurate demand data and location data can be used to advocate for efficient UAV flight plans, based on proximity rather than political district and enabling optimization of transport systems that serve people as close to where they live as possible. This would require extensive political and financial advocacy due to Malawi's de-centralized health system.

Key next steps:

8.1. Identify and compile existing demand data or collect necessary new data for prioritized use cases
8.2. Identify and compile existing maps of hard-to-reach areas or create new maps including mapping seasonal cut-offs and variations in time needed to transport commodity by road
8.3. Overlay demand data with maps of prioritized geographies to refine prioritized use cases and geographies
8.4. Advocate for realignment of health facility catchment areas according to proximity rather than political district, where this optimizes transport

Recommendation 9: Build coordination around optimizing transport for prioritized use cases, including but not limited to the use of UAVs

In order to ensure that coordination between different sectors is sufficient, logistics working groups should be established with a holistic focus. For example, the Drugs and Medical Supplies Commodity Technical Working Group exists and discusses supply chain. Other logistics working groups exist but they do not currently include all of the departments across the MOHP and they also do not include representatives from MBTS. In order to optimize transport, it is important to work towards integrated systems, which requires extensive coordination across programs. Transport, whether by vehicle, UAV, or boat should all be discussed at these meetings.

Key next steps:

9.1. Establish a cross-sectoral or at least cross-departmental logistics working group that discusses all forms of transport for different use cases, including medicines, diagnostic samples, and blood
9.2. Determine the governing body best fit to coordinate this logistics working group

5.5 Financial, infrastructure, and human resources needed

Recommendation 10: Expand the use of UAVs beyond public health and develop public-private partnerships both within public health and across sectors are key to ensuring sufficient financial resources for the ongoing use of UAVs to transport public health products and services.

In addition to uses which support the strategic aims of the MOHP, the RPA Steering Committee should also engage the Ministry of Agriculture, Irrigation and Water Development; the Department of Forestry; and consider other Ministries to identify potential other uses of UAVs to diversify financial and political support. Potential additional use cases include agricultural mapping, water resource management, and malaria vector control. To help generate support from additional Ministries, the RPA Steering Committee should present evidence generated through UAV studies to interested Ministries, Senior Management, and donor groups. In order to facilitate eventual diversification of the use of UAVs, manufacturers will need to ensure that payload boxes can safely and securely accommodate multiple uses.

Respondents also agreed that, although the private sector is limited in Malawi, engaging the private sector is critical to the financial sustainability of UAVs in public health supply chains. Public-private partnerships that benefit all partners should be pursued. These may include pharmaceutical companies whose products could be delivered to new markets by UAVs or who could financially support UAV operations as part of their corporate social responsibility program. Another potential use case for public-private partnerships is a UAV that can deliver health products as well as provide mapping services. One estimate for the price of UAV mapping in Malawi is $5-$10 per hectare, which could generate revenue to help support the purchase, operations, and maintenance of UAVs.

Key next steps:

10.1 The RPA Steering Committee should engage additional ministries and private sector companies to gauge interest in using UAVs for multiple purposes

10.2 Identify at least one potential cost-sharing model and develop a full business model to operationalize the resource sharing agreement

Recommendation 11: Promote the development of the hardware and software needed to operate and maintain the necessary UAV technology in country

For the NextWing UAV test flights, NextWing brought their UAV and all accompanying hardware and software from out-of-country, including importing the batteries necessary to fly the UAV from South Africa, which were originally imported from China. In order to make repairs and to upgrade the UAV, it is necessary to take the UAV back out of Malawi. The UAV community should work towards prioritizing UAV technology that uses materials available locally, such as aluminum foil, while still maintaining high performance and reliability. The UAV community should also explore ways to promote the development of the necessary hardware and software in country, which may include procurement of a 3-D printer or incubating small businesses that can produce batteries or other materials that meet the specifications of the UAVs. As stated in other recommendations, this would require extensive in-country capacity building.

Key next steps:

11.1. UAV manufacturers should begin to work towards technology that can be repaired locally.

11.2. Stakeholders should initiate a program to incubate small businesses that can produce batteries or other materials that meet the specifications of the UAVs.

Recommendation 12: Develop and implement a capacity-building plan to ensure ongoing maintenance and operations in country

In coordination with the MOHP Human Resources Management and Development Directorate, the UNICEF African Drone and Data Academy, and the Malawi University of Science and Technology, the government should develop and implement a capacity-building plan, including specifying any new job functions which need to be created to coordinate and operate the UAVs. A national-level manager would be needed, as well as regional-level coordinators who would oversee network serving multiple facilities in each region.

Additionally, the capacity-building plan should identify existing personnel at the health facility, which may include hospital attendants, laboratory technicians, Health Surveillance Assistants, or other cadres of health staff, and the roles and responsibilities that they could be assigned. The personnel receiving the commodities and trading out batters should not include medical assistants or nurses, as they are already over-burdened with responsibilities. The plan should include short-term as well as longer-term activities, beginning with identifying the knowledge and skills needed to initiate repeated deliveries within the current organizational structure, including:

- Receiving UAVs, unloading payload, delivering payload to relevant staff, re-loading payload, communicating with regional UAV network coordinators, sending back the UAV, and recording data about the performance of the UAV
- Recognizing the need for repair or maintenance of the UAV and its related hardware
- Adhering to safety protocols, including understanding weather patterns and determining whether it is safe to launch the UAV
- Liaising with Air Traffic Control (ATC) and DCA to ensure regulations are adhered to

Although initially the UAV manufacturer would lead the piloting of the UAVs in country, the manufacturer should begin identifying in-country individuals immediately upon entry into the country to build capacity and eventually transition responsibility and supervision of flights. The Malawi University of Science and Technology and other in-country technology colleges and universities should be engaged to consider developing a curriculum to train UAV pilots and operators. DCA would need to issue a RPA Operation Certificate to ensure consistent and standardized training for local pilots. In order to be authorized to do this, DCA needs to be supported to become qualified as instructors, supervisors, and regulators, as currently they can conduct the training but cannot provide official certification.

Key next steps:

12.1. Develop detailed capacity-building plan to ensure UAVs can be operated and maintained at local level
12.2. Coordinate with MOHP stakeholders to implement capacity-building plan as it relates to their staff who will support ongoing operations of UAVs
12.3. RPA Steering Committee should engage with the Malawi University of Science and Technology to evaluate need for a UAV training curriculum
12.4. DCA should become certified to design and implement an RPA Operation Certification Course

Recommendation 13: Identify and initiate the process to create new job functions that would be needed to sustain UAV operations and maintenance in the long-term

If the capacity-building plan identifies the need for new job functions, the MOHP would need to work with the Ministry of Human Resources Management and Development to establish job descriptions for the new

functions, after which the department would coordinate with the Ministry of Finance to allocate sufficient funding for the new roles. This would require careful coordination led by one of the departments in the MOHP and buy-in from Senior Management.

Key next steps:

13.1. If needed, initiate the process of creating new job functions through the MOHP
13.2. Determine the departmental budget under which the addition of UAV-specific human resources would fit
13.3. Establish job descriptions for new positions and incorporate UAV-related responsibilities into existing cadres that would support these new positions from within existing health centers

5.6. Government strategy, policy, regulation, and governance needed

Recommendation 14: Support final passage of regulations around the use of UAVs for public health products and services

The DCA developed draft RPA regulations in 2017. These are currently under review by the Ministry of Justice. The DCA was asked to revise the wording to align with the Ministry of Justice's legal language, and they have resubmitted. The DCA should continue to push for the passage of the regulations and begin to enforce the regulations as soon as they are passed.

Key next steps:

14.1 UNICEF, who helped support the DCA in establishing the Drone Corridor and has conducted learning visits for the development of the RPA regulations, should continue to advocate in partnership with the MOHP, who need these for wide scale implementation, and DCA for the final approval

Recommendation 15: Build a culture of transparent evidence generation and data use around the feasibility, reliability, and impact of the use of UAVs

It is critical that UAV implementers and operators transparently share data generated around UAV performance and impact on the health system so that decision-makers and donors can prioritize the most impactful uses of UAVs in the future and so that implementers can learn from each other's successes and failures and avoid duplication of efforts. Several government officials said that the government needs more evidence and needs to be able to show impact. For example, UAV companies agreed that a critical cost driver in evaluating the cost-efficiency of a use case was the expected life cycle of the UAV. VillageReach's cost analysis assumed that the expected lifetime of a UAV was 5 years and 120,000 km, but this remains to be proven in real-world use. As the use of UAVs progresses and expands, the data generated will vary, beginning with a focus on safety and performance data and evolving to include data on supply chain impact. Illustrative indicators are expected to include:

- # of successful and unsuccessful flights
- Maximum distance (in km) and maximum payload delivered (in kg and L)
- % of UAV deliveries made on-time and in-full
- % of targeted health facilities reporting full availability of targeted health commodities
- Cost of delivery per kg and per km, when transported by UAV compared to current and ideal transport systems

- % increase in consumption or use of targeted health commodity or service

Key next steps:

15.1. The DCA should require that UAV implementers who receive permission to test and fly their UAVs in Malawi share their performance and monitoring data
15.2. Implementers such as VillageReach and UNICEF should share any tools and methods used to generate evidence around the use of UAVs to equip others

Recommendation 16: Gradually transition the management of an integrated UAV for payload delivery from a UAV manufacturer to the government or other institution

At present, local capacity is not sufficient to operate and maintain a UAV for payload delivery system. As the use of UAVs is expanded within Malawi, it will be necessary for the government to secure external funding to contract equipment, operations and maintenance from a UAV company through the form of a lease, and progressively transition full ownership, operations and maintenance to a local stakeholder, whether the government or other institution. Most stakeholders agreed that although the government would play a critical role in the introduction of UAVs in Malawi, they do not have the capacity to take the lead in operations and maintenance, and a third-party provider may need to be considered.

Key next steps:

16.1. Compile and share lessons learned from similar models of third-party managed health transport systems, such as Riders for Health
16.2. Continue to evaluate and analyze the cost drivers of procuring, operating, and maintaining a UAV transport system

Recommendation 17: Advocate for mention of the use of UAVs in the Health Sector Strategic Plan, which will lead to departments integrating the use of UAVs into their detailed plans.

The MOHP should include high-level mention of the use of innovative technologies such as UAVs in upcoming Health Sector Strategic Plans, and support departments to integrate specific applications of UAVs into detailed planning documents and budgets. Relevant transport policies within the MOHP will also need to be updated to allow the use of UAVs to transport health products and services. The RPA Steering Committee should support interested departments to advocate for funding from donor groups that may be interested in financially supporting the procurement, operations, and maintenance of UAVs in Malawi, as the government itself does not have sufficient funding available.

Key next steps:

17.1. Advocate for the inclusion of UAVs in upcoming Health Sector Strategic Plans
17.2. Support interested department to advocate for funding from donor groups to financially support the procurement, operations, and maintenance of UAVs

Recommendation 18: Introduce a system to track flight activity in the region and lay the foundation for unmanned traffic management (UTM)

The government is considering requiring Automatic Dependent Surveillance-Broadcast (ADS-B) for tracking the UAVs. In order to enable tracking of all manned and unmanned flights in Malawi, the DCA should introduce the use of a mandatory system that logs all flights and that Air Traffic Control could see at any given time, like AirMap or other similar systems. The tracking system could be used to generate a full record of the activities of any UAV company.

Key next steps:

18.1. Require ADS-B tracking of all UAV
18.2. Conduct a landscape analysis of systems to track and log flight activity
18.3. Select and implement an unmanned traffic management system

6. Conclusion and Next Steps

Overall, the results of the proof of concept study and interviews with key stakeholders identified key next steps for the Malawi government stakeholders and RPA Steering Committee to accelerate the introduction of UAVs into public health supply chains to improve health outcomes. VillageReach aims to support the government by continuing to generate and share evidence to inform optimization and scale-up and building the local capacity to sustain the use of UAVs in Malawi.

1. Continue to generate and share evidence to inform optimization and scale-up
    - Share business case investigation report, including cost analysis report and other annexes and appendices
    - Complete feasibility study to demonstrate safe and reliable UAV transport in the Malawi context
    - Document lessons learned and develop toolkit and checklist for UAV implementers and operators
    - Long-term implementation of one or more use cases
    - Long-term comparative analysis study of health impact and cost of one or more use cases
    - Nationwide cost modeling to optimize one or more use cases
2. Build capacity to sustain the use of UAVs in Malawi
    - Continue building in-country capacity for UAV regulatory approval, maintenance, and operation
    - Develop a human resource strategy

In order to attract sufficient external investment to pursue promising business models for the introduction of UAVs, safety and feasibility must be proven and health and supply chain impacts must be identified. Once achieved, the government should leverage this progress to advocate for public-private partnerships and develop mechanisms to sustainably finance an integrated UAV system. While more evidence is needed to develop a rigorous business case, this document can serve as a guiding document for the government and implementing partners' next steps towards rapidly and reliably providing the life-saving products and services required by people in even the hardest-to-reach, most remote areas.

Appendix A: List of business case interview respondents

Ministry of Health and Population representatives

1. Dr. Charles Mwansambo, Chief of Health Services, MOHP Secretary for Health
2. Fannie Kachale, Director, MOHP Reproductive Health Directorate
3. James Kandulu, Deputy Director HTSS (Diagnostics) and Desk Officer For Drones MOHP
4. Brown Chiwandila, Martin Maulidi, Stanley Ngoma, Alice Ndalama and Paul Nyasulu Program Officers, MOHP HIV/AIDS Directorate
5. Dr. James Mpunga, Director, and Dr. Mirriam Nyembe, Head of Reference Laboratory, MOHP TB
6. L. Njaya, Director, MOHP Human Resource Management Directorate
7. Dr Ethel Rambiki, District Medical Officer, Lilongwe District Health Office
8. James Palupandu, Chief Laboratory Officer, and Ndileke, Senior Laboratory Officer, Malawi Blood Transfusion Service (MBTS)

Other government agencies

9. Hastings Jailosi, Chief Flights Operations Officer, Department of Civil Aviation

Donors and NGOs

10. Judith Sherman, HIV and UNHC Manager, UNICEF
11. Lumbani Makwakwa, Supply Chain Specialist, USAID
12. Sarah Pannel, Team Leader – Learning and Innovation Team, DFID
13. Philip Kamatenga, Country Director, GHSC-PSM
14. Ms V. Chiumia, Program Manager, Riders For Health
15. Kameko Nichols, Independent Consultant (JSI contractor)

Private sector representatives

16. Diego Miralles, Chief Operating Officer, and Vasil Petrov, Chief Technical Officer, NextWing
17. Ansgar Kadura, Wingcopter
18. Oriol Lopez and Adam Klaptocz, RigiTech
19. Aaron Farber and Timothy Amukele, Latitude
20. Owen Cardew, Precision Air

Appendix B: Guiding questions for individual business case interviews

Instructions: The guiding questions below are intended to generate discussion to inform the initial business case, but they are NOT intended to limit the discussion. Please take notes on your conversation, both the responses to the guiding questions below as well as to other relevant topics discussed. Not every stakeholder should answer every question, otherwise it would take a full day. Target the questions based on the respondent.

Please explain to the respondent that you are interested in their recommendations for the next steps in the use of UAVs because they are a member of the RPA Steering Committee.

Name of respondent:

Organization of respondent:

Type of organization (public, private, NGO, donor):

Title of respondent:

Date of interview:

Name of interviewer:

Most promising scenarios

Health products

1. **Process:** What is the process the RPA Steering Committee or the Ministry of Health and Population should take to decide which health products or services to transport by UAV? What criteria should be used? Who would make the final decisions and how will he/she/they disseminate and implement those decisions?
2. Research suggests that health products which have a high financial value, high life-saving potential, unpredictable demand, and/or are expensive or difficult to store at the health facility should be prioritized for UAV transport. Do these criteria seem appropriate? Why or why not? What else would you suggest?
3. During the Steering Committee meeting in February 2018, we received feedback on what products might be good use cases. However, it would be great to understand if the thinking is the same. Based on the criteria you identified previously or your own additional criteria, what health products or services do you think should be prioritized for transport by UAV? (Please be as specific as possible. For example, if the respondent says, "lab samples," please ask which tests, for which diseases.) Why these products?

Geography

4. **Process:** How should the RPA Steering Committee/government decide where to transport products by UAV, in addition to using ground transport? What criteria should be used? Who would make the final decisions and how will he/she/they disseminate and implement those decisions?
5. Research suggests that areas with a density of health facilities and where road access is difficult have potential to be cost-effective. Do these criteria seem appropriate? Why or why not? What else would you suggest? Some use cases might have different criteria- what might those be?
6. Based on these criteria or your own additional criteria, where do you think UAVs should be used to transport public health products? Why these areas?

7. Do you have any other recommendations on criteria that could be used to determine which products should be transported by UAV and where products should be transported by UAV?

Optimization and Scale up of UAVs integrated with the existing transport system

8. What would the government need to know in order to determine the most optimal routes and combination of use cases?
9. What policies and guidelines would the government need to develop to allow for an integrated UAS?
10. If the pilot is successful, what should the government/partners/donors take as the next steps for scaling up and further testing an integrated UAS?

UAV specific recommendations

11. What would you see as the immediate next steps for setting up long-term implementation of transport of medical commodities by UAV?
12. What would be needed from a drone manufacturer perspective, to develop an integrated UAS?
13. What further regulations, checklists, etc. would be needed?
14. What supplies would need to be available in country or easily imported?
15. What further improvements in the technology are needed to increase impact and cost effectiveness?

Financial and human resources and infrastructure

Financial resources

16. What process would your agency or company follow in order to allocate your own funding to;
    a. purchase,
    b. operate, and
    c. maintain the use of UAVs?
17. Can you please describe this process, including the decision-makers involved and amount of time needed.
18. Does your agency or company have plans to secure funding to purchase, operate, or maintain the use of UAVs? If yes, can you please describe?
19. Are there any government agencies outside of the MOHP or any private actors that you think might be interested in the use of UAS? If yes, for what uses? If yes, do these groups have funding available to support the use of UAS?
20. Has your agency or company ever worked with another agency / MOHP department/program or company to cost-share a project? Does this seem feasible to you, for example, if your agency shared the costs of purchasing a UAV or other equipment with another agency or a private actor? How might this work?
21. In your opinion, what approach should the government and invested stakeholders take as immediate next steps and what long-term solutions may be feasible?

Human resources

22. If your agency or company decided to use UAVs to transport health products, who would be involved in the day-to-day operations?
23. What new knowledge and skills set would these individuals need to carry out these roles? What cadres of personnel would be best fit to operate UAVs? Would an additional cadre need to be

added to the establishment? If so, which government department is best suited to advocate for that addition?

24. What change management practices will be required in the transportation system management to integrate UAVs?
25. In general, how do you think the RPA Steering Committee can mobilize the financial and human resources and infrastructure needed to use UAVs? Do you have any other recommendations about how the RPA Steering Committee should plan for the financial and human resources or infrastructure needed to use UAVs?

Government strategy, policy, regulation, and governance

26. What information or indicators do you think the RPA Steering Committee, government, or other regulatory body needs to track when UAVs are used to transport products on an on-going basis, in order to know that the use of UAVs is having the desired effect and to help make system improvements?
27. Are there any government strategies that should include UAVs? If yes, which ones and why? When will these strategies be updated and by whom?
28. As the RPA Steering Committee supports the ongoing use of UAVs in Malawi, do you expect any challenges with policy or regulations around the use of UAVs? Are there any gaps in the policies or regulations that the RPA Steering Committee should address?
29. How should government manage risk and mitigate negative impacts of integrating UAVs?

DCA-specific questions

30. What are the next steps to ensure that UAV traffic is coordinated with other types of aircraft? Will there be any challenges as the use of UAVs increases? If yes, how might these challenges be mitigated?
31. What capacity would Government (DCA and police) require and at what level(s) to effectively regulate and enforce regulation to ensure safe use of UAVs? Do you have any other recommendations about the government strategy, policy, regulation or governance needs in order to expand the use of UAVs in Malawi?

Appendix C: Summary of Next Steps

Demonstrate the feasibility of transporting health products by UAV in Malawi	
1. Conduct community awareness and outreach	1.1. The MOHP, VillageReach and other implementers who have already conducted community perception assessments should share data collection methods, tools, and resulting outreach strategies. 1.2. DCA and the MOHP should require that community awareness strategies be based on a perceptions assessment for any future implementers
2. Share local technical information with UAV manufacturers	2.1 To address the current issue of GPS interference, UAV implementers and operators should consult MACRA for full details of frequencies in use in targeted test flight areas and to compile the GPS locations for all cellular phone towers throughout the country. 2.2 The RPA Steering Committee should develop a toolkit and checklist for UAV implementers and UAV operators with key information from lessons learned, key contacts, challenges that they may face (including but not limited to GPS interference), and possible solutions to overcome those challenges. 2.3 The RPA Steering Committee should share information with any incoming UAV providers and facilitate any further information gathering needed to adapt their technology to local conditions, including both software and hardware changes. 2.4 The RPA Steering Committee should support NextWing and other providers to test their updated technology in Malawi. 2.5 The RPA Steering Committee should share technical lessons learned beyond UAV implementers and operators within Malawi to include the global community through the UAV for Payload Delivery Working Group (UPDWG) as many of the challenges and lessons learned may be applicable throughout the region.
3. Interoperable UAV systems	3.1 UAV providers to work with supply chain and other key stakeholders to develop software that interoperates with existing systems. 3.2 The government, the MOHP, and DCA should ensure cross-departmental integration through existing technical logistics working groups.
4. Progressive UAV testing	4.1 UAV providers should continue to work towards improving technology to demonstrate that they can safely and repeatedly fly the minimum 1 kg of payload a distance of 45 km in the local environment. 4.2 While addressing the technology issues with the existing technology, UAV providers should also explore the possibility of expanding to larger payloads and longer distances.
Most promising UAVs scenarios	
5. Prioritize cost-efficient, lifesaving products	5.1 Conduct a larger-scale study that analyzes the most promising use cases for lives saved, health impact, and costs in comparison to the current transportation system. 5.2 Researchers should share and validate results with the RPA Steering Committee and then disseminate results widely through peer-reviewed publications.
6. Prioritize hard-to-reach or under-served areas	*6.1* Analyze existing maps of hard-to-reach areas and cross-reference existing data on burden of maternal hemorrhage and flight radius of a blood distribution center to identify priority geographies *6.2* Compare map of hard-to-reach areas which have a high burden of maternal hemorrhage to existing data on burden of other health conditions prioritized for service by UAV to identify potential for layering use cases

Technology improvements needed	
7. Improve UAV software and hardware	7.1 UAV manufacturers need to upgrade their hardware, including battery systems to reach the desired distances and ability to withstand a reasonable level of rain and wind 7.2 UAV manufacturers need to improve software to ensure that they can mitigate challenges experienced in the local contexts
Information and coordination to optimize and scale-up the use of UAVs	
8. Compile and collect system optimization data	8.1. Identify and compile existing demand data or collect necessary new data for prioritized use cases 8.2. Identify and compile existing maps of hard-to-reach areas or create new maps including mapping seasonal cut-offs and variations in time needed to transport commodity by road 8.3. Overlay demand data with maps of prioritized geographies to refine prioritized use cases and geographies 8.4. Advocate for realignment of health facility catchment areas according to proximity rather than political district, where this optimizes transport
9. Improve coordination around optimization	9.1. Establish a cross-sectoral or at least cross-departmental logistics working group that discusses all forms of transport for different use cases, including medicines, diagnostic samples, and blood 9.2. Determine the governing body best fit to coordinate this logistics working group
Financial, infrastructure, and human resources needed	
10. Expand use and support of UAVs	10.1. The RPA Steering Committee should engage additional ministries and private sector companies to gauge interest in using UAVs for multiple purposes 10.2. Identify at least one potential cost-sharing model and develop a full business model to operationalize the resource sharing agreement
11. Promote local UAV technology development	11.1. UAV manufacturers should begin to work towards technology that can be repaired locally. 11.2. Stakeholders should initiate a program to incubate small businesses that can produce batteries or other materials that meet the specifications of the UAVs.
12. Local capacity-building plan	12.1. Develop detailed capacity-building plan to ensure UAVs can be operated and maintained at local level 12.2. Coordinate with MOHP stakeholders to implement capacity-building plan as it relates to their staff who will support ongoing operations of UAVs 12.3. RPA Steering Committee should engage with the Malawi University of Science and Technology to evaluate need for a UAV training curriculum 12.4. DCA should become certified to design and implement an RPA Operation Certification Course
13. Create new job functions	13.1. If needed, initiate the process of creating new job functions through the MOHP 13.2. Determine the departmental budget under which the addition of UAV-specific human resources would fit 13.3. Establish job descriptions for new positions and incorporate UAV-related responsibilities into existing cadres that would support these new positions from within existing health centers
Government strategy, policy, regulation, and governance needed	
14. Final passage of UAV regulations	14.1. The donor that has helped support the DCA in establishing the Drone Corridor and has conducted learning visits for the development of the RPA regulations should continue to advocate in partnership with the MOHP and DCA for the final approval

15. Transparent data sharing	15.1 The DCA should require that UAV implementers who receive permission to test and fly their UAVs in Malawi share their performance and monitoring data 15.2 Implementers such as VillageReach and UNICEF should share any tools and methods used to generate evidence around the use of UAVs to equip others
16. Gradually transition UAV management	16.1. Compile and share lessons learned from similar models of third-party managed health transport systems, such as Riders for Health 16.2. Continue to evaluate and analyze the cost drivers of procuring, operating, and maintaining a UAV transport system
17. Advocate for strategic planning around UAVs	17.1 Advocate for the inclusion of UAVs in upcoming Health Sector Strategic Plans 17.2 Support interested department to advocate for funding from donor groups to financially support the procurement, operations, and maintenance of UAVs
18. Introduce flight tracking system	18.1. Require ADS-B tracking of all UAV 18.2. Conduct a landscape analysis of systems to track and log flight activity 18.3. Select and implement an unmanned traffic management system