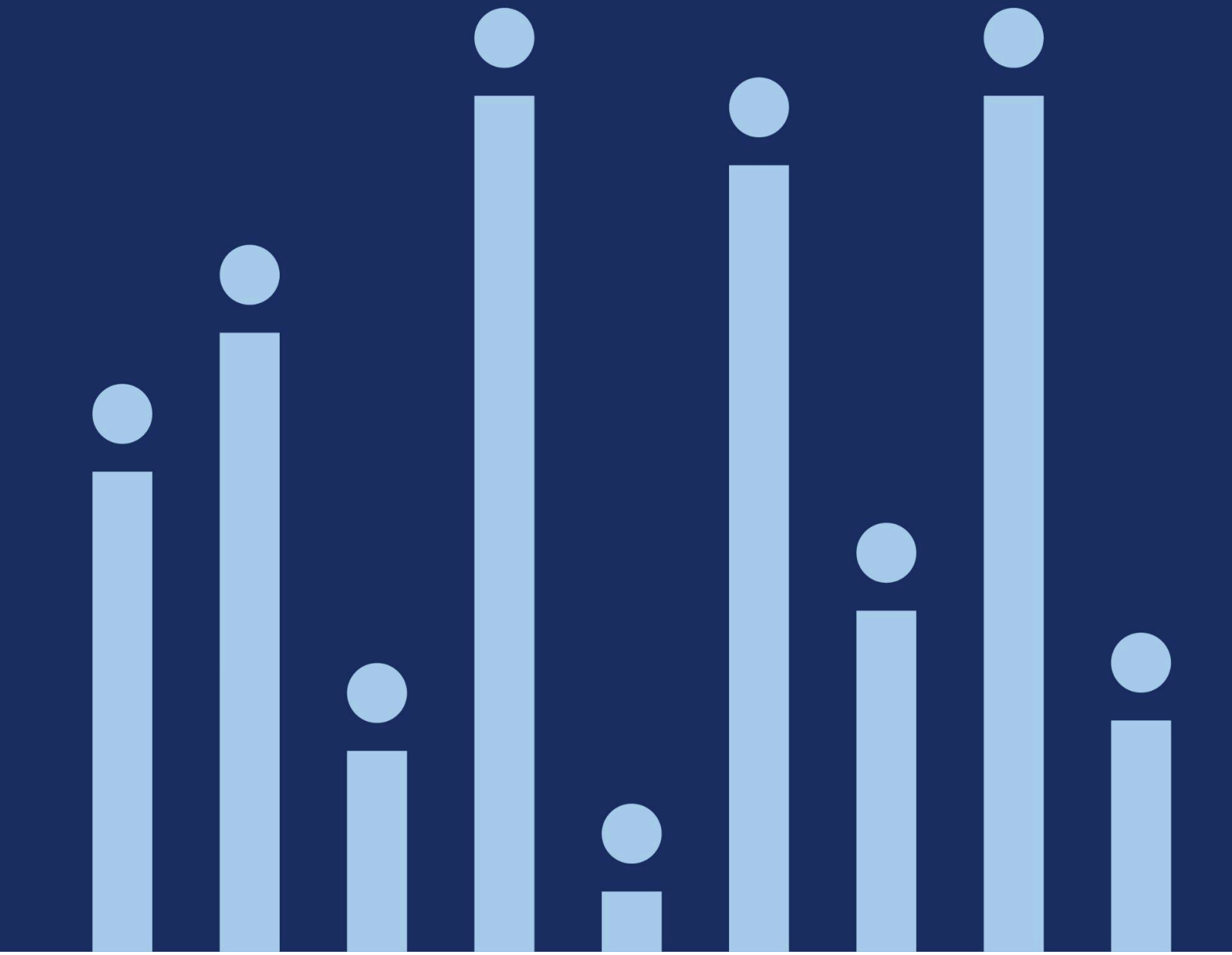

Malawi Drones for Health Randomised Control Trial:

Baseline Report

USAID FROM THE AMERICAN PEOPLE

IDinsight

VillageReach

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VILLAGEREACH

About VillageReach

VillageReach transforms health care delivery to reach **everyone**. We develop solutions that improve equity and access to primary health care. This includes making sure products are available when and where they are needed and primary health care services are delivered to the most under-reached. Radical collaboration with governments, the private sector and other partners strengthen our ability to scale and sustain these solutions. Our work increases access to quality health care for more than 70 million people in sub-Saharan Africa. VillageReach has offices in Malawi, Mozambique, DRC, and Seattle (USA). Visit **www.VillageReach.org** to learn more.

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Executive Summary

Problem statement:

Transportation challenges in remote and hard-to-reach areas hinder the provision of quality healthcare by impeding the delivery of essential medical supplies. To address these challenges, the integration of drone transport has emerged as a promising solution, particularly in countries like Malawi, where traditional ground transportation is unreliable due to long distances and difficult road access. Swoop Aero, a drone service provider, has partnered with the Malawi Ministry of Health (MoH) and the Department of Civil Aviation, with support from VillageReach, and funding from USAID's Development Innovation Ventures (DIV) to expand the drone network and integrate drones into the national health supply chain system.

To assess the impact of drone services on the supply chain and proxy health outcomes, IDinsight has partnered with VillageReach and the Malawi MoH to conduct a two-arm randomised controlled trial (RCT).

Purpose of the document:

The purpose of the document is to present the findings of the baseline survey, offering insights into the existing condition of the supply chain in hard-to-reach facilities in Malawi.

Evaluation Design:

The evaluation includes 209 rural, hard-to-reach health facilities across 23 districts, with 99 facilities randomly selected to receive access to bi-directional drones in addition to traditional transportation methods, while 110 facilities serve as the control group, continuing to rely solely on traditional means of transport. Baseline data collection has been completed, and endline data collection is planned to start in approximately six months after the last facility gains access to drone flights. The endline measurements will rely on digitisation of paper records collected directly from facilities as well as interviews with health worker staff. The evaluation objectives encompass both supply chain outcomes (on tracer products consisting of medicines, vaccines and rapid diagnostic tests) and proxy health outcomes (vaccinations and patient referrals due to stockouts), serving as the main indicators to determine the success of the intervention.

We conduct power calculations using the baseline data and find the evaluation is powered to detect reasonable effects sizes on supply chain indicators and health proxies.

Baseline results:

The randomization produced a well balanced sample. The sampled health facilities predominantly consist of government-run facilities and are small health centres. These facilities are situated in truly remote areas, with an average travel time of 81 minutes by car to reach the nearest paved road.

The selected tracer products for the evaluation are typically stocked in these facilities, indicating that the tracer list represents products relevant for the vast majority of health centres. However, stockouts are a significant issue, with facilities reporting shortages of medical products between 6-20% of the time. This results in 8-13% of patients being referred to other facilities due to product stockouts. This imposes both financial and health burden on patients who are already likely experiencing weakened health due to their symptoms. Moreover, the turnaround time for lab samples is currently high; it takes about 34 days for the facilities to receive lab results from the time of sample collection, which can be a significant public health concern especially for contagious diseases. These findings highlight the potential for bidirectional drones to significantly improve healthcare delivery and positively impact the overall efficiency of the health system.

1. Introduction and Context

Transportation challenges can disrupt the provision of quality healthcare in remote or hard-to-reach health facilities. When vaccines, medicines, rapid tests, and other medical supplies cannot reach rural communities, and patient samples cannot be rapidly transported to a laboratory for analysis, the health of entire communities is at stake. This means that children may fall sick and die from malaria or diarrhoea, especially during the rainy season, pregnant women may not survive complications of pregnancy or childbirth, and infectious diseases like HIV, tuberculosis (TB), polio, and COVID-19 may spread faster. Ensuring the existence of an effective and efficient mechanism of moving priority health commodities to remote and hard-to-reach locations is key to optimising supply chain management.

Drone transport for medicines and other health commodities has the potential to fill a crucial gap to ensure sustained availability of products in remote and hard-to-reach areas where traditional ground transport is difficult. Governments in sub-Saharan Africa have started to explore the use of drones as an integrated component of a robust transportation network to address the long-standing challenges in the national supply. **Drone transport is not meant to replace the traditional ground transportation of commodities.** Instead, it integrates into the existing system to fill gaps and ensure a more efficient supply chain system.

The case for drone deliveries is especially promising for rural areas of Malawi where the existing ground methods of transportation for medical products has led to unreliable access to medical products for remote health facilities. This is due to the long distances to remote areas and unreliable road access, especially during the rainy season.

Swoop Aero, a drone service provider, has developed a two-way drone transport solution that has been used to serve remote areas of DR Congo, Malawi, Mozambique, and other countries globally. Swoop Aero drones first flew in Malawi in late 2019 under a short-term grant from USAID's Global Health Supply Chain (GHSC) program (in 2 northern districts), and later, in 2020, as part of another short-term project funded by UK Aid and UNICEF (in 2 southern districts). Swoop Aero continued to operate in Malawi during the COVID-19 pandemic, and self-funded operations for 6 months.

Since May 2021, in collaboration with VillageReach, a non-profit health organisation that builds people-centred solutions to improve equity and access to care especially in under-reached communities, Swoop Aero has partnered with the Malawi Ministry of Health (MoH) and the Department of Civil Aviation (DCA) to expand the drone network and integrate drones into the national health supply chain system. Funding was provided by many donors via Focusing Philanthropy, including UPS Foundation. By early 2022, the Swoop Aero network had grown from one district health office and 13 health facilities, to three district health offices and 40 health facilities. Later in 2022, USAID's Development Innovation Ventures (DIV) awarded Swoop Aero a grant to support the national expansion and conduct a rigorous evaluation.

VillageReach, with support from IDinsight, a mission-driven global advisory, data analytics, and research organisation, is leveraging Swoop Aero's scale-up to conduct this evaluation. It will be a **two arm randomised controlled trial (RCT)** that aims to investigate the **impact of on-demand bi-directional drone services on supply chain and proxy health outcomes in Malawi**.

- The evaluation includes 209 rural, hard-to-reach health facilities across Malawi, encompassing 23 (out of 29) districts.
- As part of the RCT, 99 facilities have been randomly selected to receive access to drones - in addition to traditional means of transport for medical products - while the 110 remaining facilities will maintain status quo (continuing to receive all medical products by traditional means of transport) and serve as the control group.

To our knowledge this is **the first randomised control trial (RCT) of medical drone deliveries.**[1] RCTs are rarely feasible given that drone network expansion plans usually follow a cost-minimising approach, and governments tend to prioritise health facilities based on need (i.e. the most hard-to-reach get drones first). This is a unique opportunity to rigorously **assess the value that drones add to health supply chains and quality of care.** This evidence will not only inform current drone operations in Malawi but also provide input into future strategic positioning of this innovation for serving hard-to-reach areas in other geographies.

This report has two purposes: (1) **to detail the planned evaluation design** and (2) **to present results from the baseline survey** to provide an understanding of the current status of the supply chain among hard-to-reach facilities in Malawi.

- Baseline data collection for the evaluation took place between December 2022 and April 2023, with a pause around the holidays and the new year.
- Endline data collection is planned to start approximately six months after the last facility gains access to drone flights

[1] We have become aware of a second RCT that is in the design phase and will launch baseline mid-2023 in Madagascar for a different type of drone and with a different supply chain model.

2. Evaluation Methodology

2.1 Research Questions

The primary goal of the RCT is to quantify the causal impact of bi-directional drone transport services of medical products (medicines, vaccines, and rapid test) and lab samples on supply chain and health outcome (proxy) indicators.

Specifically, we aim to answer the following research questions:

1. **Supply Chain:**
    a) What is the causal impact of drone transport services (fulfilling on-demand/emergency orders and complementing ground transportation for routine monthly product deliveries) on medicine, vaccine, and rapid test availability in remote, hard-to-reach facilities?
2. **Health Proxies:**
    a) Does access to drone services improve vaccination coverage or vaccine administration?
    b) Does access to drone services reduce patient referral rates (to other health facilities or to private pharmacies) due to medical product stockouts?
    c) Does access to drone services improve the turnaround time of lab sample processing and, as a result, initiation time of treatment?
3. **Perception of drones (process evaluation questions):**
    a) What are the experiences of the drone delivery program according to healthcare workers?
    b) What is the perception of health workers of drones on the supply chain performance?[2]
    c) What are community members' perception of, attitude towards, and satisfaction with the use of drones for delivery of health products at their health facilities?

[2] We will ask respondents to speak about what they feel is working well and what they feel is not working well to get a sense of their overall satisfaction with drone transport and its contribution to the health supply chain

In Figure A1, in the appendix, we display the measurement framework which outlines various healthcare components (prevention, diagnosis and treatment), linked to health conditions of interest and medical products (referred to as tracer products) in scope for the evaluation. In the last two columns, we outline measurement indicators as well as data sources used to measure them.

The list of tracer products was identified via collaboration between VillageReach and the Ministry of Health (MoH), following an evaluation design workshop organised in Lilongwe in September 2022 with all relevant MoH programs and departments.It includes a short list of essential medicines (EM) and donor-funded (DF) products that should be available in every remote facility.

2.2 Intervention

The intervention consists of three main components:

1. **On-demand bi-drectional drone deliveries:** These bi-directional drone transport services are meant for on-demand, emergency orders. "Emergency orders" include medical emergencies as well as any instance where medical products that facilities stock become stocked out in between their routine, monthly bulk deliveries. Under the current system, each facility receives the monthly bulk deliveries via ground and/or water transport. All medical products are provided by the Malawi government and the District Health Office (DHO) without charge to facilities. Each DHO stocks and manages products for all the health facilities in their district autonomously; thus if a facility is low on stock, they request the product from their DHO, and the DHO approves or does not approve the delivery. **The drones will serve as a 'top up' mechanism if facilities run low on stock** before their next ground delivery is due to arrive.[3] The drones perform **two main functions** (1) **to deliver ordered medical products** from DHO to facilities (2) **to pick up lab samples** from facilities and deliver them to the designated labs. The drones are fully integrated into the supply system and are an additional option for transportation between DHO and its health facilities.
    a. **Onboarding training:** Prior to receiving deliveries, all involved parties (health facilities and their corresponding DHO) are on-boarded onto the drone delivery system. Swoop Aero delivers training to the designated health facility and DHO staff on how to safely receive and send the drone back, what to do in case of a problem with the drone, etc. On average, about three people receive this training, and the number of trained personnel is bigger in larger facilities.

[3] There are a few restrictions around ordering: 1) Drones cannot pick up lab samples from a health facility on days when Riders for Health plans to visit these facilities 2) CHAM facilities are not allowed to order essential medicines via drones because they use non-government supply chains to procure those products.

2. **Supply chain refresher:** VillageReach provides training on supply chain management consisting of a few hours on how to order products (orders are placed through Whatsapp groups) and how to manage the products once received on site, with a reminder about required documentation and reporting.
3. **Community Sensitization:** VillageReach also trains the DHOs on answering questions about drones from the local communities. The health education teams at each DHO then conduct sensitizations in the communities that are due to receive drones - this is also a requirement by the DCA before any flights can start. The DCA wanted to ensure that the community members and leaders fully understand the potential advantages and drawbacks of using drones in their community. Engagement with the communities continues throughout the project, and VillageReach and the DHO staff seek opportunities for direct community feedback so the program can improve over time.

Once facilities receive the onboarding training, they are able to place orders for medical product deliveries or lab sample pick up. The following procedures are followed for medical product ordering and sample processing:

Placing orders for medical products:

1. Trained health facility staff send a Whatsapp message to Swoop Aero outlining the products they would like to order (in some cases, the DHO may place the order on behalf of the facility). The Whatsapp group includes the designated/trained staff from health facilities, DHOs, Swoop Aero and VillageReach. There is one Whatsapp group per district and a drone hub serves one or more neighbouring districts. Swoop Aero is expected to operate seven drone hubs countrywide as part of the RCT.
2. If an order is placed for medical product deliveries to the facility, the DHO Pharmacy Staff approves or does not approve the order. If they approve the order, they check if they have it in stock at the District Hospital pharmacy. If the product is stocked out at the District Hospital pharmacy, the order cannot be placed and the facility is informed of a 'central stockout'.
3. If the order is approved and the product is in stock at the District Hospital pharmacy, Swoop Aero obtains the medical products from the District Hospital pharmacy, packages them in the drone, and sends the drone to the facility. Communication among all parties is done via Whatsapp so the facility knows when to expect the drone (Swoop Aero aims to make all deliveries within 24 hours, or faster if it is a medical emergency).
4. The facility receives the products along with any documentation that they need to sign. The products are then 'pooled' together with any other products that the facility received through any other means of transport. In other words, the facility stores, manages, dispenses, and reports on the products received by drone the exact same way as the products received by other means of transportation.

5. If the facility has any medical, pharmacy, or other types of reports they would like to send to the DHO, or if they have lab samples that urgently need to go to the district laboratory, then health workers can send them back by drone on the drone's return flight.

Pick-up of laboratory samples:

1. Health facility staff send a Whatsapp message to request a drone for sample pick up. This typically happens when there is urgent need to analyse the samples, and it falls on the days when Riders for Health (R4H) is not already scheduled to pick up samples at the facilities.[4]
2. The drone lands onto the facility premises or nearby at a designated location.
3. Facility staff package the samples following all usual biosafety rules (i.e. triple packaging) into the drone, and press the action button to send the drone to the district lab.
4. District lab receives the samples via drone and follows their usual process from there (either analysing the samples, or transferring them to a more specialised lab, depending on the type of sample).
5. Health facility receives the results via R4H motorcycles or via drone (on demand). The lab processing times vary depending on the type of sample, the volume of work, and the availability of trained staff and lab reagents and supplies.[5]

2.3 Sample Selection and Randomization

VillageReach, with support from the Ministry of Health, identified an initial list of 212 hard-to-reach health facilities (mostly health centres but also a handful of rural community hospitals) in the 23 districts that make up the project area.[6] There are no other 'hard-to-reach" facilities in these districts.

These facilities were grouped into seven "hubs" based on location. Each hub will be served by a single and distinct drone network. In March 2022, VillageReach randomly assigned the 212 facilities to either the treatment (drone) or control (non-drone) group, aiming roughly for approximately 100 health facilities in the treatment group and the rest in the

[4] R4H has a network of motorcycles that are contracted to visit facilities once or twice per week mainly for pick ups of HIV and TB samples

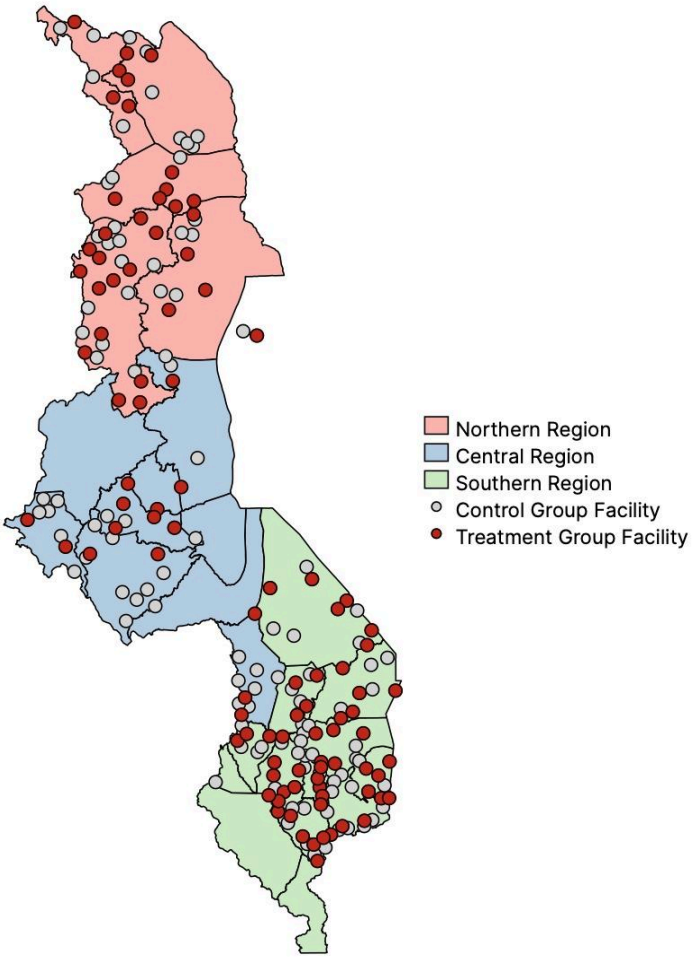
[5] While not in scope for the RCT, the drones are often called upon to pick up monthly medical and pharmacy reports - which all health facilities must turn in by the 5th of the month to the DHO. Since the facilities targeted by the drones are often in rural remote areas, this is a service that facilitates the work of health workers and benefits the health system overall, rather than directly benefiting the patients.

[6] Swoop Aero was already operating in 2 other Southern districts, and another drone service provider was expected to expand into 4 Central districts. So the RCT project area is made up of the 23 remaining districts (Malawi has a total of 29 health districts).

control group.[7] The randomization into experimental groups was done within each hub to ensure a balanced number of treatment and control facilities within a hub.

Three facilities in the sample were later identified as health posts as opposed to health centres post-randomization. Health posts differ from health centres because they do not directly stock medical products as they are small structures used for patient outreach. As a result, they are ineligible for drone transport and were excluded from the RCT. Two of these facilities were control facilities and one was a treatment facility bringing the **total eligible facility sample to 209 facilities (110 control, 99 treatment).** The map of the facilities in the sample as well as treatment assignment is shown in Figure 2.1.

Figure 2.1 Map of RCT health facilities in Malawi



[7] SwoopAero's serving capacity could not exceed 100 facilities for this expansion round. To increase statistical power of the evaluation and include all hard to reach facilities in the project area, all 212 facilities were included.

2.4 Baseline Data Collection

Between December 2022 and March 2023, VillageReach (with technical support from IDinsight) visited all treatment and control facilities and collected baseline data from the 209 facilities in the study. By the start of the baseline data collection, nine treatment facilities (~9%) reported that they started receiving drone orders.[8] Due to the requirements of the other donors to the drone program, it was impossible to wait for the baseline data collection to be completed before starting the delivery for those nine facilities, and it is possible that some of the baseline estimates already reflect some treatment effects due to drones services. However, this will not undermine our ability to quantify the unbiased impacts at endline. In addition, the program was still in nascent stages at the time of baseline data collection since Swoop Aero faced delays in being able to implement the program fully due to insufficient drones and equipment, as the company switches from the current Kookaburra drones to the new Kite drone model (expected to be introduced in Malawi by June-2023). Swoop Aero's internal monitoring data revealed that the sub-sample of nine facilities[9] that have placed drone orders before baseline requested an average of 21 orders (15.7 for medical products and 5.3 for pickup of lab samples) from Swoop Drones between June 2022 and March 2023. Given that they were already enrolled in the program, these facilities were surveyed first for baseline data collection.

Where possible, baseline data was collected from historical records in the facilities by digitising administrative paper records for supply chain and vaccine administration for the baseline period, with the earliest month being June 2022. In cases where June 2022 administrative data was not available on site at the facilities, enumerators digitised the next available month between July and October 2022.[10] There were variables for which collecting "true" baseline data for every facility was not possible (either due to data unavailability or reliance on facility personnel recall). However, because the program was not fully operational during this time even among the small percentage of facilities who had access to the program, we do not believe it significantly biased the baseline estimates.

The two main goals of the baseline were to:

1. Document status quo in the facilities before the drone program scales up
2. Validate whether administrative data sources provided by the Ministry of Health can be used as reliable data sources for the evaluation, and under what conditions.

The survey was administered to the appropriate personnel within the facility (e.g. medical product survey was delivered to a worker responsible for medical products, patient referral outcomes were asked to healthcare providers, etc.). The baseline consisted of the following sections:

[8] Question formulation in the baseline survey: "Has this facility received any medical drone orders?"
[9] One facility was surveyed before they started placing drone orders from December 2022 onwards
[10] We chose to digitise the following and not the previous months given anecdotal evidence of records being more difficult to find for earlier months, if they were not available for June.

1. **Health facility characteristics,** such as number of people working at the facility, remoteness, facility capacity (e.g. number of patients it can serve), facility type (hospital vs health centre), ownership (government vs private vs faith-based non-profit organisations), availability of fridges for storing medical products, and facility infrastructure
2. **Supply chain practices**:
    a) Product availability/stockout information covering key tracer products: medicines, vaccines, rapid tests. This section consisted of asking facility staff whether a product was stocked in the facility in the past year and relying on historical stock card records to access information on stockouts for the baseline month
    b) Stock management practices (e.g. whether stockcards are kept, whether the facility follows first in first out principle when using medical products)
    c) Physical count of current stock on the day of visit to independently verify most recent information recorded in stock cards
    d) Transport modes for various medical products
3. **Health proxies:**
    a) Patient outcomes due to medical product stockouts (relying on facility staff recall in the past one month and past six months)
    b) Digitization of the number of vaccines administered to patients and whether there were any patients in the past month who were not vaccinated because the facility ran out of vaccines.
    c) Lab samples collected and sample turnaround time (TAT) which measures the time between when the patient sample was collected to the time when the results were received back from the lab.

2.5 Endline

The endline data collection will take place about six months after all facilities have been enrolled in the drone program. In our original proposal, we planned on relying on administrative datasets electronically available through the MoH. However, in our extensive data quality checks using baseline data, we have discovered that the datasets exported are not complete nor always accurate. The MoH is looking into why the electronic database OpenLMIS's reports are not currently exporting complete data, even in cases when the facility raw data was reportedly entered into the system. We expect this problem to be solved before the end-line. However, for the moment, we have decided to **rely first and foremost on digitising records directly from the facilities**. We have found that paper records are well maintained and are an accurate reflection of medical product availability. If the OpenLMIS national database issues are resolved, it will form a secondary analysis, allowing us to look at data over many months.

As at baseline, the enumeration team will visit each facility at endline. The endline survey will focus on the following:

1. **Digitisation of product stock cards** for quantification of program impacts on product availability for medicines/tests/vaccines. The data will be digitised for the predetermined 3 months prior to the visit[11]
2. **Digitisation of vaccination report books** to quantify program impacts on the number of vaccines administered (both static and outreach) for predetermined 3 months prior to the visit
3. **Digitisation of patient care and treatment registers** for information on patient treatment (e.g. diagnostic tests that patient took, dates of samples taken and results received)
4. Interviews with health workers to understand general patient **referral patterns** related to stockouts (not tied to specific medicines) and referral patterns for specific tracer products. This section will also include a qualitative component
5. **Process indicators related** to the drone program (e.g. usage of drone transportation and reasons for non-usage, satisfaction with the program, suggestions for improvements, etc.)
6. **Qualitative interviews** to understand if/how the drone program affected quality of care in facilities

[11] About 19% of facilities don't have stock cards for all vaccines (15% in treatment, 21% in control, p-value from a 2-sided test is 0.21) partially due to the fact that they keep electronic records. At the time of the report writing the research team did not have access to the administrative dataset (called eHIN) but we will continue its pursuit. The dataset has been requested from the EPI department at MoH and the request is being processed.

3. Baseline Results

3.1 Balance Table and Facility Characterization

In Tables 3.1A, 3.1B and 3.1C, we present a comprehensive balance table of facility characteristics and outcomes at baseline for treatment and control groups (column 1 and 2), the difference between the means with statistical significance (column 3) as well as the number of observations for each variable (column 4). At the end of the table we show the p-value from an F-test, a joint test of orthogonality, to understand whether all variables together correlate with the treatment assignment.[12] Overall, **the randomization resulted in groups that are well balanced across observable characteristics**.

As shown in Panel A, the majority of sampled health facilities are government-run facilities (at 76%) and 23% are CHAM (Christian Health Association of Malawi). Those facilities primarily differ from government-run facilities in that CHAM facilities charge user fees for services. Additionally, CHAM facilities use different supply chains for procuring essential medicines and supplies which has implications for administrative data analysis since they are not required to submit monthly OpenLMIS reports for these products. Most facilities are health centres (84%) with about 21 non-Health Surveillance Assistant (HSA) staff members and 12 HSA staff members. About half of the facilities have a dedicated pharmacy assistant responsible for product stock management, reporting and dispensing to patients. In the smaller facilities, the supply chain/pharmacy functions are done by other personnel.

About 74% of the facilities have a good mobile network connection. Since the drone program relies on network (and orders are sent through Whatsapp), lack of good mobile connectivity in 25% of facilities may present a problem for service takeup[13].

The most common source of water is piped water (36%), followed by borehole (28%) and tank (18%). Most of the facilities have an under-five facility (82%) and a maternity ward (85%).

Almost all facilities (95%) have access to electricity (either through the main grid or solar panels).

The facilities are truly remote and on average, the travel time to a nearest paved road using a car is 81 minutes (median is 52 minutes), while the mean reported travel time to the district health office (DHO) using a car is 134 minutes (median 120). In Table 3.2, we

[12] https://blogs.worldbank.org/impactevaluations/tools-trade-joint-test-orthogonality-when-testing-balance

[13] At endline, we plan on performing heterogeneity analysis which may shed light on whether the impacts differ between these types of facilities.

break down the travel distance by dry and rainy season and see significant variation in travel suggesting that the access to the facilities is especially challenging to reach in rainy months. During the rainy season, the mean travel time to the nearest road increased by 30% to 107 minutes, while in the dry season it decreased by 17% with a mean of 68 minutes. The average travel time to the nearest District Health Office (DHO) of 134 minutes increased by 18% to 158 minutes during the rainy season, while in the dry season it decreased by 15% to 115 minutes.

The facilities are also far away from the other nearest facilities, and it would take a patient 107 minutes on average using typical transport to reach the closest facility (which is a significant burden in case patients get referred and don't obtain care they need). The mean population in the catchment area is 24,855 which is roughly the median catchment area population in Malawi (Kozuki et al. 2017).

Next, we turn to the supply chain outcomes. Stock management practices are shown in Panel B (Table 3.2B). Overall, we find that about 30% of facilities perform 3 key stock management best practices[14] suggesting that not all facilities follow prescribed procedures for properly managing stock which may be partially caused by only 50% of facilities having dedicated pharmacy assistants which manages stock.

Availability of stock cards (which are the primary source of historical information on supply chain outcomes) varies between the types of products. On average across products, we have been able to locate stock cards for the tracer medicines, vaccines, and diagnostic tests at 80%, 67%, and 92% respectively. We discuss this in more detail in section 4.1.

The tracer products selected for the evaluation are generally stocked in facilities suggesting that the tracer list represents products relevant for the vast majority of facilities. However, facilities experience significant stockouts; they report being **stocked out of medicines, vaccines, and diagnostics tests for 6, 2, and 3 days out of 30, respectively,** which is equivalent to 8-20% of the days in a month (panel C). Lack of medical products results in patient referrals (to other health facilities to which patients may not be able to travel to or to private pharmacies where they have to pay for medicines out of pocket) and the vast majority of facilities report having to refer at least one patient[15] in the past one month due to product stockout (86%, 58%, and 77% of for medicines, vaccines and rapid test, respectively). In total, between **8-13% of patients get referred out**

[14] Stock management best practices include: 1) the pharmacy assistant or other stock worker received training; 2) using a three lock system for the pharmacy; 3) storing expired and unusable stock away from usable stock). The variable reported in the balance table equals 1 if the facility performs all of these best practices and 0 otherwise

[15] The indicator is based on the following questions: 1) "In the past 1 month, how many patients sought care from you at this facility? Please also include patients that were seeking care but you referred before they were treated. It's okay to estimate." 2) Of those patients, how many were referred to other facilities or asked to come back later ONLY because the required [medicines/vaccines] were NOT available at this facility on that day? Please think of all cases in which you would have been able to treat/help the patient if you had access to the needed medical products.Please do not count patients which were referred for other reasons, such as a lack of medical equipment or a lack of trained staff. It's okay to estimate". We calculated a binary indicator that was equal to 1 if the number of patients reported in question (2) was greater than or equal to 1 and that was 0 otherwise.

due to product stockouts.

The average number of samples collected for HIV Viral Load (VL), HIV Early Infant Detection (EID), Tuberculosis (TB), Cholera, and Polio was 64 samples. The average TAT to receive the test results is high of about 34 days across all tests, so there is potential for the bidirectional drones to meaningfully shorten this time.

The total number of 1,267 vaccine doses administered in June 2022. Out of all facilities, while 93% reported having enough vaccines in the last outreach across all vaccines typically stocked, there were still facilities that had supply chain issues.[16] As a result, the number of patients who did not receive the vaccination during the outreach is quite high at 140 in total across all vaccines, suggesting that drones could be useful in eliminating this issue completely.

[16] The question formulations in the baseline survey were: (1) “In your last outreach effort did you have enough [vaccine name] for everybody that wanted to get vaccinated?”, (2) How many patients didn't get vaccinated with [vaccine name]?

Table 3.1A Balance table (Panel A)

Variables	(1) Overall	(2) Mean Control	(3) Treatment	(4) Difference Units	(5) %	(6) p-value	(7) N
Panel A: Facility Characterstics							
Facility Ownership: % CHAM	0.23	0.23	0.24	0.02	7%	0.84	209
Facility Ownership: % Government	0.76	0.77	0.75	-0.03	-3%	0.72	209
Health Center	0.84	0.81	0.88	0.07	9%	0.37	209
Number of total non-HSA staff	21.47	21.63	21.29	-0.33	-2%	0.78	209
Nuber of HAS	12.18	11.73	12.69	0.96	8%	0.30	209
Has at least 1 pharmacy assistant	0.49	0.48	0.51	0.02	5%	0.75	209
Infrastructure							
Number of fridges	1.81	1.76	1.87	0.11	6%	0.78	209
Has a working ambulance	0.16	0.19	0.12	-0.07	-37%	0.13	209
Has a good mobile network connection	0.74	0.74	0.74	-0.01	-1%	0.83	208
Source of water: Piped water	0.36	0.35	0.38	0.04	11%	0.72	209
Source of water: Borehole	0.28	0.32	0.23	-0.09	-27%	0.16	209
Source of water: Tank	0.18	0.17	0.19	0.02	11%	0.60	209
% with access to electrical supply	0.95	0.94	0.96	0.02	2%	0.40	209
Has an Under-five facility	0.82	0.83	0.81	-0.02	-2%	0.62	209
Has a Maternity	0.85	0.80	0.90	0.10*	12%	0.09	209
Location							
Reported travel time to the nearest paved road using a car (in minutes)	81.96	81.02	83.02	2.00	2%	0.98	207
Reported travel time to the DHO using a car (minutes)	134.26	136.06	132.24	-3.81	-3%	0.64	206
Typical travel time for lab samples to the lab (minutes)	157.40	133.18	184.32	51.14*	38%	0.08	209
Patient Volume							
Population in the catchment area	24855.14	24544.90	25199.86	654.96	3%	0.73	209

Notes: Includes strata fixed effects by drone hub. Stars denote statistical significance (* -10% level, ** -5% level, ***-1% level). Typical travel time for lab samples in minutes is winsorized at the 1% level.

Table 3.1B Balance table (Panel B)

Variables	(1) Overall	(2) Mean Control	(3) Treatment	(4) Difference Units	(5) %	(6) p-value	(7) N
Panel B: Supply Chain							
Stock Management							
Performs key stock management best practices (binary)	0.30	0.28	0.32	0.04	15%	0.45	209
Availabillity of June 2022 stockcards							
Medicines	0.80	0.79	0.80	0.01	1%	0.76	209
Vaccines	0.67	0.71	0.64	-0.07	-10%	0.26	209
Rapid tests	0.92	0.93	0.91	-0.01	-1%	0.74	209
Stock management: Number of tracer products stocked in the past 1 year							
Medicines (out of 22 in total)	20.30	20.25	20.35	0.10	0%	0.86	209
Vaccines (out of 13)	11.24	11.25	11.22	-0.03	0%	0.75	209
Rapid tests (out of 5)	3.28	3.31	3.25	-0.06	-2%	0.42	209
Stockouts: Average number of stockout days out of 30 (across all products)							
Medicines	6.03	6.23	5.80	-0.43	-7%	0.36	209
Vaccines	1.87	1.55	2.23	0.68	44%	0.16	178
Rapid tests	3.41	3.26	3.58	0.32	10%	0.51	207

Notes: Includes strata fixed effects by drone hub. Stars denote statistical significance (* -10% level, ** -5% level, ***-1% level).

Table 3.1C Balance table (Panel C)

Variables	(1) Overall	(2) Mean Control	(3) Treatment	(4) Difference Units	(5) %	(6) p-value	(7) N
Panel C: Health Proxies							
Patient Referrals due to stockouts in the past 1 month							
At least 1 patient was referred because product was stocked out							
Medicines	0.86	0.86	0.86	-0.01	-1%	0.98	209
Vaccines	0.58	0.55	0.61	0.05	9%	0.51	209
Rapid tests	0.77	0.81	0.72	-0.09	-11%	0.15	209
% of patients referred because a product was stocked out							
Medicines	0.13	0.12	0.15	0.03	25%	0.27	209
Vaccines	0.10	0.10	0.09	-0.01	-7%	0.73	209
Rapid tests	0.08	0.07	0.09	0.01	18%	0.48	209
Samples							
Total number of samples collected (HIV VL, HIV EID, TB, Cholera, Polio)	64.00	67.09	60.57	-6.53	-10%	0.23	209
Average percent of lab test results received (HIV VL, HIV EID, TB, Cholera, Polio)	0.88	0.88	0.88	0.00	0%	0.95	200
Average sample turnaround time in days (HIV VL, HIV EID, TB)	34.11	36.10	31.90	-4.20	-12%	0.39	204
Vaccines							
Total Number of Vaccines Administered (both static + outreach) in June 2022	1266.90	1307.45	1221.86	-85.59	-7%	0.62	209
Last outreach effort							
Had enough vaccines in the last outreach (across all vaccines typically stocked)	0.93	0.94	0.92	-0.02	-2%	0.29	205
Number of patients who didn't get vaccinated (sum across all vaccines typically stocked)	139.35	183.38	90.42	-92.96	-51%	0.32	209
Average percentage difference (absolute value)					**10%**		
F Test, P-value			**0.90**				
F-test, number of observations			**209**				

Notes: Includes strata fixed effects by drone hub. Stars denote statistical significance (* -10% level, ** -5% level, ***-1% level). Average sample turnaround time in days is winsorized at the 1% level.

Table 3.2 Measurements of remoteness during rainy and dry seasons

	Mean	N
Travel Time (in minutes)		
To the nearest road	81.96	207
Rainy Season	106.76	168
Dry Season	67.54	168
To the nearest DHO	134.26	206
Rainy Season	158.26	167
Dry Season	114.64	167
To DHO for emergency	152.36	208
Rainy Season	185.50	169
Dry Season	127.40	169
For patient to travel to nearest other facility, using typical transport	107.02	207
Rainy Season	118.21	168
Dry Season	91.70	168
Typical one way travel time to transport Lab Results Reports from the facility to the DHO (in minutes)	168.58	209
Rainy Season	186.64	171
Dry Season	166.20	171

3.2 Transport of medical products

In Table 3.3, we present the reported typical transport for resupplying medical products outside of routine monthly deliveries. We asked facilities to report all types of transport that they typically used for resupplying medicines, rapid tests, vaccines, sending lab samples, and receiving lab results to and from the facility.[17] **Ground vehicles and motorbikes are the most common modes of transport used across all categories of transported items.** A small percentage of facilities in the sample report using drones (those are the 9 facilities which received some drone deliveries before the baseline survey).

[17] The question formulation in the baseline survey was: "What are the typical modes for resupplying [pharmaceutical products & medicines/vaccines] (if the facility runs low on stock and needs to order more in between monthly deliveries)?"

Table 3.3 Typical transport for resupplying products or transporting samples and lab results

	Medicines/ Rapid tests	Vaccines	Samples	Lab results
Ground (vehicles)	89.0%	68.9%	24.4%	46.9%
Groud (motorbikes)	56.9%	55.5%	86.6%	67.9%
Ground (bikes)	2.4%	7.2%	7.7%	6.7%
Drones	4.3%	2.4%	2.9%	3.3%
Ground (buses)	14.8%	4.8%	2.4%	-
Electronically	-	-	-	7.7%
Other	4.3%	3.8%	3.8%	3.8%
N=	209	209	209	209

Note: In the "Other" category for medicines/rapid tests, 6 out of 9 facilities reported that they used boats or speed boats to transport medical products in between routine monthly deliveries. In the "Other" cateogry for vaccines, 4 out of 8 facilities reported that they used boats of speeds boats to resupply vaccines in between routine monthly deliveries.

3.2 Lab test results: turnaround time (TAT)

In Table 3.4 we report key indicators on lab test results TAT and percentage of lab test results received.[18] During the baseline data collection visits, enumerators asked to see the lab sample registers to record the total number of samples collected in June 2022. We collected this data for HIV Viral Load (VL), HIV Early Infant Diagnosis (EID), TB, COVID-19, Polio, and Cholera samples. On average, facilities collected more HIV VL load samples (46.1 samples) than any other sample. This is followed by TB samples (14.6 samples) and then HIV EID samples (3.2 samples). Notably, COVID-19 samples were not collected by any of the facilities in our sample.

[18] **Question formulation:**
Number of samples collected and Number of test results received - "Enumerator Please collect the following figures for [sample name]: Total number of [sample name] samples collected in the facility in June 2022; Total number of [sample name] samples rejected at the lab in June 2022".
TAT - "[Enumerator] find the last 3 results batches of [sample name] samples that were collected, and results received before July [2022] that has at least 1 patient with a detectable pathogen and the list of patients associated with them for those 3 batches. Batch 1 should be the most recent batch with at least 1 patient with a detectable pathogen, Batch 2 should be the next batch after batch 1 with at least 1 patient with a detectable pathogen, Batch 3 should be the one after batch 2 with at least 1 patient with a detectable pathogen. For each results batch, go down the register and find the first patient with a detectable pathogen. If you cannot find a patient with a detectable pathogen in any batch on or after June 2021, please select the last three batches with at least 1 patient without a detectable pathogen. For that patient, record the following information from the lab register: (1) Date when the sample was collected (2) Date when the patient received the results (3) Date when the patient started (or switched) treatment"

Next, enumerators asked a facility worker for access to care and treatment registers for patients treated at the facility to understand the time it took for the patient to get the results back and start/change medical treatment. This often required moving around the facility to find the different departments and the relevant HIV or TB care and treatment registry records. Enumerators looked for the three most recent sample results batches[19] with at least one patient with a detectable pathogen in their sample. For each of the three batches, enumerators recorded the date the patient's sample was collected, the date the facility received the patient's results, the date the patient received their results, and the date the patient started or switched treatment regimens.[20]

The average turnaround time for samples collected in the facilities in the sample are quite large on average but they vary considerably across samples. HIV Viral Load samples have the longest turnaround times at each checkpoint. The time between sample collection and the facility receiving the results was 57.7 days. The time between sample collection and the patient receiving their results was 86.6 days. HIV EID samples had average turn around times that were approximately half of those for HIV VL at each point in the process. TB samples had the shortest turnaround times with facilities receiving results an average of 12.8 days after sample collection, and patients starting treatment 27.9 days after sample collection. The time to treatment initiation for TB appears to be driven by two factors: (1) TB samples sometimes need to be sent for genotyping by an expert prior to communicating results to patients; (2) after facilities receive results, patients need to find transport to make it to the facility which increases the time to treatment initiation given how remote some of these facilities are. **While it is the shortest TAT out of all samples, the disease is really contagious and the results should ideally be obtained within a few days.**

[19] For samples sent for processing outside of health centres, results are typically received by health centres as a group of results called "results batches"

[20] We calculated the difference in days between these dates and when the sample was collected and averaged this difference across the three batches of results. For HIV Viral Load, it was common that the date the patient started their treatment was before the date the most recent sample was taken. This is because HIV Viral Load is a routine test for patients who have tested positive for HIV. As a result, for HIV Viral Load, when the patient's "date of treatment initiation" was before sample collection date for the current sample we replaced this turnaround time figure for treatment initiation with the turnaround time for the patient receiving their results.

Table 3.4: Lab results turnaround time and percent of samples received

June 2022	HIV: Viral Load	HIV: EID	TB	PCR	Polio	Cholera
Number of samples collected	46.06	3.21	14.63	0.00	0.08	0.02
TAT (average across 3 batches)						
Patients that tested positive and negative						
Time between sample collection and facility receiving results (Days)	57.73	26.83	12.78			
Time between sample collection and patient receiving results (Days)	86.60	46.05	17.14			
Patients that tested positive						
Time between sample collection and patient starting or switching treatment (Da	90.01	43.50	27.90			

Note: For turnaround time indicators, the facilities in our sample did not collect any COVID-19 samples so these values are not reported. We did not collect turnaround time data for Polio and Cholera. Turnaround time is winsorized at the 1 percent level to address spurious outliers.

Question formulation:
Number of sample collected and Number of test results received - "EnumeratorL Please collect the following figures for [sample_name]: Total number of [sample_name] samples collected in the facility in June 2022; Total number of [sample_name] samples rejected at the lab in June 2022".

TAT - "[Enumerator] find the last 3 results batches of [sample name] samples that were collected, and results received before July [2022] at least 1 patient with a detectable pathogen and the list of patients associated with them for those 3 batches. Batch 1 should be the most recent batch with at least 1 patient with a detectable pathogen, Batch 2 should be the next batch after batch 1 with at least 1 patient with a detectable pathogen, Batch 3 should be the one after batch 2 with at least 1 patient with a detectable pathogen. For each results batch, go down the register and find the first patient with a detectable pathogen. If you cannot find a patient with a detectable pathogen in any batch on or after June 2021, please select the last three batches with at least 1 patient without a detectable pathogen. For that patient, record the following information from the lab register: (1) Date when the sample was collected (2) Date when the patient received the results (3) Date when the patient started (or switched) treatment"

3.2 Stock management & patient referrals due to stockouts

3.2.1 Medicines

There are two types of medicines within Malawi's healthcare system: **Donor funded/Vertical program (DF/VP)** and **essential medicines (EM)**. Donor-funded/Vertical program products are donated to Malawi's health system by international organisations, governments, or other external sources. These products are often provided as part of specific health programs or initiatives, such as HIV, TB, Malaria, Reproductive Health or Immunization. Donor-funded products can vary in terms of their availability, as they are often dependent on external funding and donations, but they are generally more consistently available in facilities compared to essential medicines and supplies, which are government funded. Essential medicines are usually government-funded and are considered to be necessary and effective for addressing the most common health problems in Malawi not already covered by a specific health program.

3.2.1A Stock management and stockout days

During the in-person surveys, we asked pharmacy assistants or drugstore clerks (or anybody else who had access to the stockroom) to report whether or not the facility stocked a particular medication at any point within the past 12 months. In Figure 3.1, we plot the percentage of facilities that report stocking each product at least once in the past 12 months as well as the average number of stockout days among the facilities that

reported stocking that product. Donor-funded/Vertical products (DF/VP) and essential medicines (EM) are coded in yellow and blue, respectively. The products are ordered in descending order by the percentage of facilities that stocked the product within each group of medical products. The number of stockout days (out of 30) for products that facilities report stocking at least ones are reported underneath. We also report the averages for each medicine type at the bottom of the graph.

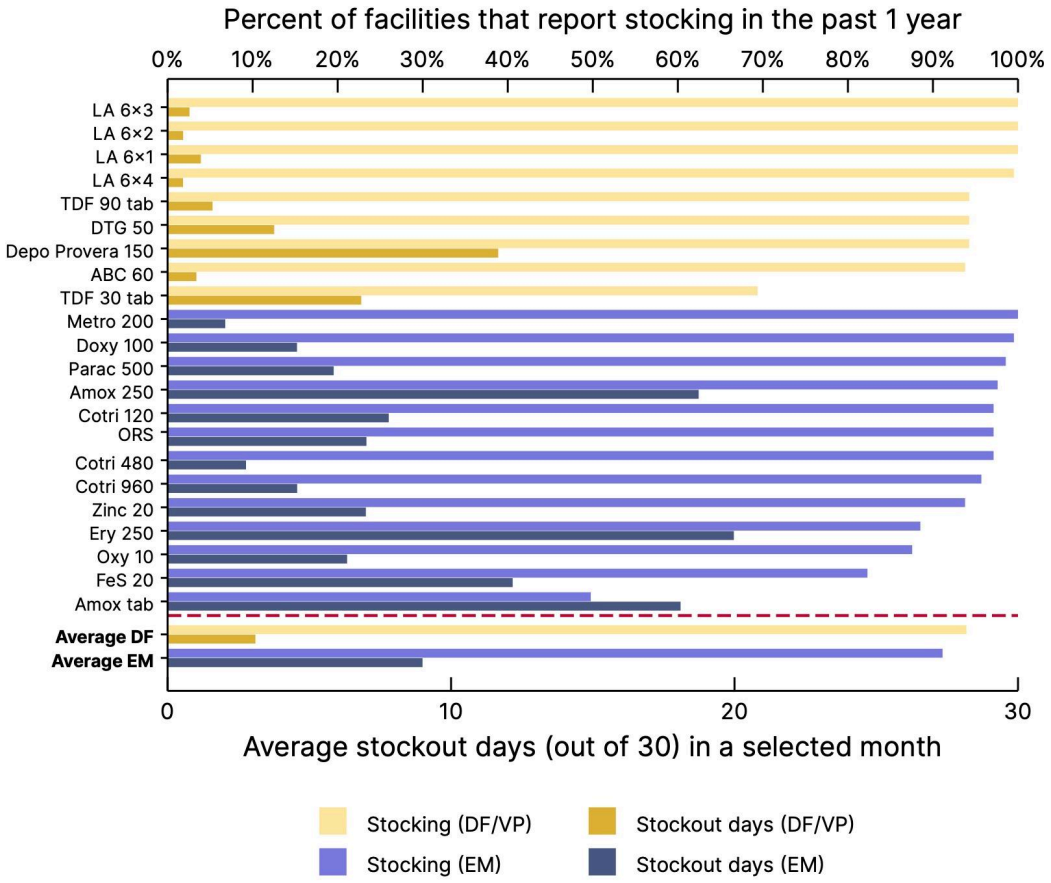
On average, facilities report stocking 20 out of the 22 initial tracer medicines selected. Donor-funded/Vertical program (DF/VP) medicines are reported as stocked in the past year by a slightly larger share of facilities than essential medicines. However, for both donor-funded and essential medicines, more than 90% of facilities had stocked the products at some point in the last 12 months, suggesting that the tracer product list selected with MoH are widely used for service provision.

The average number of stockout days for each product in one month was calculated by visiting the stockout room and digitising information recorded on stock cards. The enumerators recorded the start and end dates of a product stockout for the earliest month of data available at the facility between June 2022 to October 2022.[21]

There are some notable differences in product stocking and stockout days across products. While donor products/vertical and essential medicines are used by about the same fraction of facilities, availability of essential medicines is much lower, with average stockout days being around 9.0 days, while for donor-funded products, the number is 3.1 days. Depo-Provera is recorded with the highest number of stockout days at 12 days among donor-funded products. Erythromycin (20 days) had the largest number of stockout days for essential medicines, indicating that it was typically stocked out for more than half of the month.

[21] We calculated stockout days by referencing a facility's stock card records and recording the dates when a facility had no stock on hand for a particular product for the month of interest. Enumerators recorded the start date and end date of the stockout period and the number of days were calculated programmatically in STATA to reduce the likelihood of measurement error. We searched for records for the same month: June 2022. If June 2022 stockout data was unavailable, we picked the earliest month of data that was available on stock cards between July and October 2022. Observations with 0 stockout days are included. Enumerators were asked to capture the full length of a stockout that overlaps with the month selected. Therefore, if a stockout started before the selected month and/or ended after the selected month, enumerators recorded start and end dates outside of the month selected. However, we report in all stockout figures the number of stockout days within a selected month to ease comparability across facilities and with administrative datasets like OpenLMIS that report stockout days within a given month.

Figure 3.1: Medicine stock management and stockout days



Reasons for not stocking medicines

During the survey, if a facility reported that they did not typically stock a product in the past 12 months, we asked the reasons for why the product was not stocked. We report the results of these questions in Table 3.5. There are very few facilities that report not stocking medications. The product that was not stocked the most was Amoxicillin dispersible tablets (105 facilities reported not stocking it), with the main reason being lack of availability at a higher level. For the rest of the products,

For the other tracer medicines, facilities listed two common reasons that they did not stock a product: (1) **not having a mandate to stock the product** (2) **medicine being fully stocked out at the central level**. For example, Amoxicillin dispersible tablets (medicine with the highest number of facilities which do not report stocking it) were typically not stocked because the product was not available at a higher level. TDF (Tenofovir Disoproxil Fumarate/Lamivudine) – typically prescribed during antiretroviral therapy (ART) – were not stocked in 64 facilities with the most prevalent reason being that they do not provide ART treatment services. Another example is Depo-Provera which was not stocked by 12 facilities that do not provide family planning services.

Table 3.5 Reasons for not stocking medicines

	Number of facilities that report not stocking the product in the past 12 months (N =)	We do not have patients that require this product	The product is not available at the higher level	We order a close substitute instead	The product is expensive	Other
Amox Tablets	105	0%	93%	1%	1%	5%
TDF 30 tab	64	28%	5%	0%	0%	67%
FeS tab	37	0%	89%	0%	0%	11%
Oxy 10	26	15%	0%	0%	0%	85%
Ery 250	24	0%	100%	0%	0%	0%
Zinc 20	13	0%	85%	8%	0%	8%
ABC 60	13	0%	8%	0%	0%	92%
TDF 90 tab	12	0%	8%	0%	0%	92%
DTG 50	12	0%	0%	0%	0%	100%
Depo Provera 150	12	0%	17%	0%	0%	83%
Cotri 960	9	0%	0%	0%	0%	100%
Cotri 480	6	0%	100%	0%	0%	0%
Cotri 120	6	0%	0%	0%	0%	100%
ORS	6	0%	50%	0%	17%	33%
Amox 250	5	0%	80%	0%	0%	20%
Para 500	3	0%	67%	0%	0%	33%
Doxy 100	1	0%	100%	0%	0%	0%
LA 6x4	1	0%	100%	0%	0%	0%

Note: In "other" the most listed listed for not stocking a medical product was that ART, family planning, or other treatment program services were not provided at the facility. The DHO only provides products to a facility for programmed products. Averages shown include CHAM facilities that have different stocking practices to other facilities.

3.2.1B Patient referrals due to medicine stockouts

Further, we aimed to understand how stockouts of medications affect patients and administered a module which asked health facility workers details about the last patient who was affected by stockouts. We report the results in Table 3.6 where we present the percent of respondents who had a patient they could not help in the past 6 months due to a medicine stockout. We then asked respondents to record which of the tracer medicines was stocked out the last time they could not help a patient as well as list any other medicine that were stocked out. Nearly **92% of respondents reported that they could not help at least 1 patient in the past 6 months because of a stockout of medicine.** We then asked what medicines were stocked out during that visit. **Essential medicines were mentioned to be stocked out more frequently when patients needed the medicines compared to donor-funded/vertical programs** (EM were mentioned 16.8% of the time, on average, compared to 4.9% for donor-funded/vertical program products). The top three essential medicines that were stocked out the last time a patient needed them were Erythromycin (30% of respondents who referred a patient in the past 6 months), Iron Sulphate (29%), and Paracetamol (28%). The three most common donor-funded medicines that were stocked out the last time a patient needed them were Tenofovir pack of 30 tablets (17%), Depo-Provera (8%), and LA 6×1 (4%).

Around 49% of facilities listed at least one product other than the 22 tracer products. The most common non-tracer product mentioned as stocked out was Gentamicin (12%) and Aminophylline (9%). There were many non-tracer products listed as stocked out but on average each product was reported as stocked out by a small share of healthcare workers (1.6% of facilities on average).

Table 3.6 Patient outcomes in case of medicine stockouts

Variables	Overall Mean	N
Patient they could not help in the past 6 months due to stockout		
Had a patient they could not help because of a stockout	91.9%	209
What medicine(s) were stocked out the last time a patient needed them?		
Essential Medicines (EM)		
Ery 250	29.5%	193
FeS tab	28.5%	193
Para 500	27.5%	193
Amox Tablets	25.9%	193
Zinc 20	20.2%	193
Amox 250	19.7%	193
ORS	11.4%	193
Metro 200	9.8%	193
Cotri 480	9.3%	193
Oxy 10	8.8%	193
Cotri 120	5.7%	193
Doxy 100	4.7%	193
Essential Medicines (EM) Average	**16.8%**	
Donor Funded/Vertical Program (DF/VP)		
TDF 30 tab	16.6%	193
Depo Provera 150	8.3%	193
Cotri 960	4.1%	193
LA 6x1	4.1%	193
LA 6x4	3.6%	193
TDF 90 tab	3.1%	193
ABC 60	2.6%	193
LA 6x3	2.6%	193
LA 6x2	2.1%	193
DTG 50	1.6%	193
Donor Funded/Vertical Program (DF/VP)-funded average	**4.9%**	
Non-tracer medicines	49.22%	193
Gentamacin	12.44%	193
Aminophylline	9.33%	193
Diazepam 5mg/ml	3.63%	193
Acilovir	3.11%	193
Phenobarbitone	2.59%	193
Benzylpenicilin	2.59%	193
Atropine	2.07%	193
Calamine lotion	2.07%	193

Note: Medicines with reported stockouts of < 2% of facilities are not included in the table.

Further, we asked the healthcare workers if they did anything to resolve the stockout and patient outcomes. In Table 3.7, we present the results of these follow up questions. The

most common way to deal with a stockout was to ask the patient to get the medicine independently (52.1% of the time), with "placing order with the DHO pharmacy" being the second most common reason (40.1% of the time). Travelling to DHO can be a significant challenge to facilities which on average takes 134.3 minutes according to facility reports (Table 3.1A). Besides being a significant time effort which takes away from patient care, it can also be a financial burden placed on healthcare workers since they often have to pay for transport costs out of their own pocket. This is essentially the problem that drones are well equipped to solve and facilities will be able to move away from an ad-hoc, burdensome process to a more consistent and sustainable one.

The best way to capture 'how long it takes' for products to reach facilities in the absence of drones is still through stockout duration. However, to get a sense of what facilities typically do to resolve stockouts we asked some follow-up questions to the respondents about what they did to resolve the stockout the last time they could not help a patient. We report the results of these questions in Table 3.7. We asked the respondent what they did to resolve the stockout as well as what happened to the patient they could not help because of a medicine stockout. On a vast majority of occasions (75.5% of the time) lack of medicine resulted in patients being referred to another facility after receiving some treatment. Only 14.1% of facilities reported referring the patient without giving them treatment.

Table 3.7 Medicine stockout resolution

	Overall Mean	N
What did you do to resolve the stockout?		
Told patient to get it from store/market/pharmacy or another health facility	52.1%	192
Placed an emergency order to the DHO pharmacy	40.1%	192
Bought in nearby store/market/pharmacy	4.7%	192
Order from other (partner, health facility, or health area)	1.6%	192
Placed an order with drones	1.0%	192
Nothing	0.5%	192
What happened to this patient?		
Patient was referred to another facility but first received some treatment here	75.5%	192
Patient was referred to another facility without any treatment	14.1%	192
Other	6.8%	192
Patient was given a different medicine which was equally effective	2.6%	192
Patient could not be treated, was sent home and told to come back later	1.0%	192
Patient was given a different medicine which was not equally effective	0.0%	192

3.2.2 Vaccines

The 14 vaccines selected during initial consultation meetings with the Ministry of Health in Malawi are all donor–funded. These vaccines are for routine immunisation of children, but also for COVID-19, human papillomavirus (HPV), malaria and rabies.

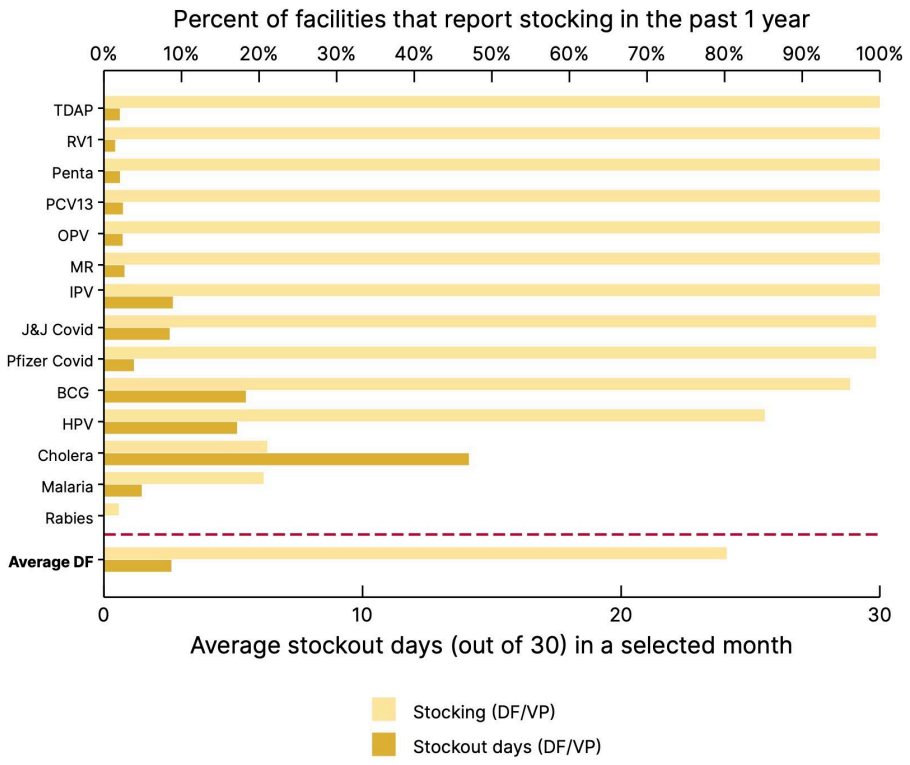
3.2.2A Stock management and stockout days

In Figure 3.2 we display the average percent of facilities that report stocking a vaccine in the past 12 months and average number stockout days in 1 month for facilities that reported stocking the product. The figure displays means separately by product as well as provides an average across all products.

On average, facilities report stocking 11 of the 14 of the tracer vaccines selected. The vaccines with the lowest percent of facilities that report stocking the product over the past 12 months were HPV, Cholera, Malaria and Rabies vaccines. Only 21% of facilities reported stocking malaria vaccine in the past year which is unsurprising given that the program is still in the piloting stages and has not yet been rolled out. Cholera vaccine is also not frequently stocked (with 21% of facilities reporting stocking it) which is driven by the fact that cholera vaccines are only distributed to facilities in case of cholera outbreaks.

The average number of stockout days for the tracer vaccines are generally small, with most products reported as being stocked out for fewer than 5 days. Only Cholera has an average number of stockout days above 10 days with an average of 14 days stocked out in the month.

Figure 3.2: Vaccine stock management and stockout days



In Table 3.8 we examine the volumes of vaccines to understand which vaccines are delivered at higher rates. To collect this data, we asked a facility worker who typically administers vaccines to refer to the vaccines registries and report how many vaccines were administered for each tracer product they typically stock at the facility (static) and as part of outreach efforts. OPV and TD are the vaccines with the largest number of vaccines administered. The most administered vaccines include those recommended for children under 1 (OPV, Penta, PCV13, RV1).

Table 3.8 Number of vaccines administered in June 2022

	(1)
	Number of vaccines administerd in June 2022 (Static and Outreach)
OPV	213.28
TD	208.12
Penta	177.41
PCV13	174.52
Malaria	136.89
RV1	117.32
J&J Covid	108.82
MR	103.94
Pfizer Covid	74.70
BCG	59.14
IPV	58.52
Cholera	38.72
Rabies	9.50
HPV	1.65
Average	**105.90**

Note: A facility is flagged as reporting administering the vaccine if they have a non-missing value for the number of static vaccines administered or the number outreach vaccines administered

Reasons for not stocking vaccines:

In Table 3.9 we report the reasons listed by facilities for why they reported that they did not stock a tracer vaccine in the past 1 year. Notably, more than 140 facilities typically did not stock the Rabies, Cholera, and Malaria vaccines. For these vaccines, between 5-22% of facilities reported that this is because the product was not available at a higher level due to central stockouts. Other reasons included the fact that the HPV is a vaccine typically administered during school-based HPV vaccination campaigns and not stored in facilities. Some facilities also reported that HPV is not stocked due to limited demand from patients at the facility. For Rabies, qualitative responses recorded in the "Other" field highlighted that patients exposed to rabies are typically referred to the district hospital for vaccination or ordered only when there is demand. Cholera vaccines are typically stocked when there is an ongoing outbreak of Cholera. Qualitative responses indicate that facilities in districts that are experiencing a current outbreak are selected to receive cholera vaccines. Otherwise, the facility does not stock the vaccine.

Table 3.9 Reasons for not stocking vaccines

	Number of facilities that report not stocking the product in the past 12 months (N =)	We do not have patients that require this product	The product is not available at the higher level	We order a close substitute instead	The product is expensive	Other
Rabies	**173**	1%	5%	1%	12%	83%
Malaria	**157**	1%	13%	0%	0%	86%
Cholera	**148**	5%	22%	0%	0%	74%
HPV	**29**	0%	14%	0%	0%	86%
Pfizer Covid	**6**	0%	50%	33%	0%	17%
BCG	**1**	0%	0%	0%	0%	100%

Note: In the "Other" field, facilities highlight that HPV vaccines are typically administered during campaigns or that the population they serve is reluctant to take the vaccine. For Malaria vaccines, facilities typically report that they were not selected as a pilot facility for the vaccine. Many facilities report that they do not stock Cholera vaccines because no patient currently needs the vaccine, in line with reports that Cholera vaccines are typically supplied when there are outbreaks. Rabies vaccines are typically administered at the DHO, which is why facilities report not stocking the vaccine.

3.2.2B Patient referrals due to vaccine stockouts

In Table 3.10 we report the results which outline how patients may be affected by vaccine stockouts. To gather this information, we spoke with health facility workers who typically administer vaccines. **Around 76.7% of respondents reported that they had to refer at least one patient in the past 6 months because a vaccine that they needed was stocked out**. The two most common vaccines that were stocked out were the Rabies and Cholera vaccine with 46.6% and 41.6% of facilities reporting not having it in stock, respectively. This reflects the unique supply chain practices of those vaccines. As mentioned in the previous section, rabies vaccines are only ordered on-demand and cholera vaccines are distributed to facilities only in cases of outbreaks. HPV vaccines (mentioned by 39% of facilities) are usually distributed through school drives, however, there seem to be cases of patients coming to seek those vaccines and not being able to receive them due to stockouts. The most common way facilities reported resolving a vaccine stockout was also to refer the patient somewhere else (46%) or to place an emergency order to the DHO pharmacy (46%). Drone services are uniquely positioned to fill in the gaps in current supply chain and allow for vaccinations to receive necessary vaccines at the time of need.

Table 3.10 Vaccine stockout resolution

Variables	Overall Mean	N
Patient they could not help in the past 6 months due to stockout		
Had a patient they could not help because of a stockout	76.6%	209
What vaccine(s) were stocked out?		
Rabies	46.6%	161
Cholera	41.6%	161
HPV	38.5%	161
Pfizer Covid	34.8%	161
Malaria	33.5%	161
BCG	14.3%	161
MR	13.0%	161
TD	11.8%	161
OPV	10.6%	161
J&J Covid	10.6%	161
IPV	8.1%	161
RV1	6.2%	161
Penta	4.3%	161
PCV13	2.5%	161
Other	1.9%	161
What did you do to resolve the stockout?		
Told patient to get it from store/market/pharmacy or another health facility	46.3%	160
Placed an emergency order to the DHO pharmacy	45.6%	160
Placed an order with drones	1.9%	160
Nothing	1.9%	160
Order from other (partner, health facility, or health area)	1.9%	160
Bought in nearby store/market/pharmacy	0.6%	160
Refer to the DHO	0.6%	160
Uknown (Reported that they delayed)	0.6%	160

In Table 3.11 we report the results of the follow-up questions we asked respondents about patient vaccination outcomes after referral. We asked respondents what typically happens to patients who don't get a vaccine the first time around. 62% of facilities reported that the patients delay the vaccination by 1 week. 20% of facilities reported delaying the vaccination by more than 1 month. Very few facilities reported that the patient never got their vaccine. We then asked the respondent what happened to the last patient that was referred and **58% of facilities reported that the patient was told to come back**, which can place significant burden on mothers because they likely live far away, don't always have means of transport and may walk miles with their babies on their backs, and may have other children and household chores to attend to. 39% of facilities referred the patient to another facility to receive their vaccination.

Table 3.11 Patient outcomes in case of vaccine stockouts

	Overall Mean	N
What typically happens to patients who do not get vaccinated the first time around?		
Never get that vaccine	0.5%	209
Delay by about 1 week	62.2%	209
Delay by >1 week and <1 month	11.5%	209
Delay by more than 1 month	19.6%	209
Other	6.2%	209
What happened to this patient?		
Was told to come back later to the same facility	58.1%	160
Was referred to another facility for vaccinations	39.4%	160
Other	2.5%	160

3.2.3 Rapid Tests

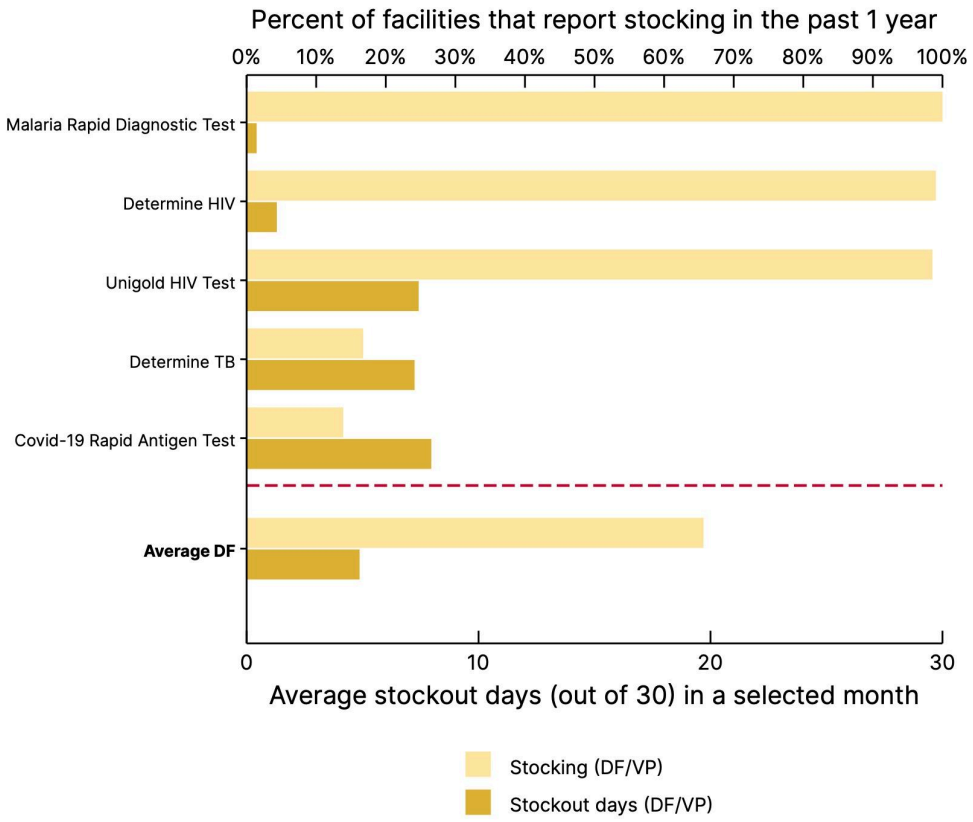
The Ministry of Health selected five tracer rapid tests: for HIV, Malaria, Tuberculosis (TB) and COVID-19. All of the rapid tests selected are donor funded/vertical program products.

3.2.3A Stock management and stockout days

In Figure 3.3 we report the percent of facilities that report stocking the rapid test over the past 12 months, and the average number of stockout days in 1 month. All facilities reported stocking Malaria Rapid Diagnostic Test (MRDT) in the past 12 months. Virtually all facilities reported stocking Determine HIV and Unigold HIV rapid tests. Stocking of Determine TB and Rapid COVID-19 rapid tests was much lower with 16.7% and 13.8% of facilities reporting that they stocked rapid tests in the past year.

Average stockout days are low for diagnostic rapid tests. The average number of stockout days for MRDT is the lowest (at 0.4 days), followed by Determine HIV (1.3 days), and Determine TB rapid tests (7.2 days) in 1 month.

Figure 3.3: Rapid test stock management and stockout days



Reasons for not stocking rapid tests

In Table 3.12 we report the common reasons that a facility reported not stocking a tracer rapid test in the past 12 months. Out of the facilities that reported not stocking Determine TB and COVID-19 rapid test, most of these facilities listed that tests were never stocked at this facility or patients are referred to a TB/COVID-19 testing facility or the DHO, or facility personnel is not trained to provide the testing service. The second dominant reason was the product was not available at a higher level with about a quarter of facilities reporting that the product was centrally stocked out.

Table 3.12 Reasons for not stocking rapid tests

	Number of facilities that report not stocking the product in the past 12 months (N =)	We do not have patients that require this product	The product is not available at the higher level	We order a close substitute instead	The product is expensive	Other
Covid-19 Rapid Antigen Test	151	5%	25%	1%	0%	70%
Determine TB	150	2%	21%	1%	0%	75%
Unigold HIV Test	3	0%	0%	0%	0%	100%
Determine HIV	2	0%	0%	0%	0%	100%

Note: The most common reason listed for not stocking a rapid test is that testing services for the disease are not provided at the facility

3.2.3B Patient referrals due to rapid test stockouts

In Table 3.13 we report the results from how stockouts of tests affect patients seeking testing services. About **86% of facilities reported that they had referred a patient in the past 6 months because a rapid test that was needed was stocked out.** The most common tracer rapid tests that were stocked out when a patient needed them was the COVID-19 test (35% of facilities report not having it in stock when the patient needed it). The next most common product that was not available was "determine TB" suggesting that these products are commonly needed for patient care. Additionally, 51% of facilities reported that a non-tracer rapid test was stocked out when a patient needed it. The three most common non-tracer rapid tests listed were pregnancy tests, Bioline Syphilis, and VDRL Syphilis tests. The most common way facilities resolved a rapid test stockout was also to refer the patient somewhere else (43%) or to place an emergency order to the DHO pharmacy (41%).

To determine what happened to patients who were referred, we asked respondents what happened to a patient who was referred because a rapid test was stocked out. 70% of facilities reported that patients were referred to another facility which places both financial and time burdens on patients who are likely already weakened by sickness symptoms. 19% of facilities reported that the patient was treated without the diagnostic test. When a symptomatic patient visits a facility during a test kit stockout, doctors are forced to weigh the consequences of withholding treatment - possibly leading to exacerbated symptoms or disease spread - against the risk of misdiagnosis and exposing the patient to medication side effects. These situations can be avoided by having adequate availability of testing kits.

Table 3.13 Patient outcomes in case of rapid test stockouts

Variables	Overall Mean	N
Patient they could not help in the past 6 months due to stockout		
Had a patient they could not help because of a stockout	86.1%	209
What rapid test(s) were stocked out? (Select all that apply)		
Covid-19 Rapid Antigen Test	35.2%	182
Determine TB	31.9%	182
Determine HIV	11.0%	182
Unigold HIV Test	8.8%	182
Malaria Rapid Diagnostic Test	4.9%	182
Non-tracer rapid tests		
Pregnancy test	19.2%	182
Bioline syphilis	18.7%	182
VDRL syphilis test	4.4%	182
Hep B	1.6%	182
Hep C	1.1%	182
DBS bundle	1.1%	182
Cholera	0.5%	182
Vitect	0.5%	182
Oraquick HIV	0.5%	182
CD4 Count	0.5%	182
Typhoid	0.5%	182
What did you do to resolve the stockout?		
Told patient to get it from store/market/pharmacy or another health facility	49.4%	180
Placed an emergency order to the DHO pharmacy	41.1%	180
Bought in nearby store/market/pharmacy	2.2%	180
Placed an order with drones	2.2%	180
Nothing	2.2%	180
Order from other (partner, health facility, or health area)	1.7%	180
Uknown (Reported that they delayed)	0.6%	180
What happened to this patient?		
Patient was referred to another facility for testing	70.0%	180
Patient was treated without the diagnostic test	18.9%	180
Other	11.1%	180

4. Administrative Data Quality Checks

The evaluation will rely on digitization of paper records in facilities. In this section we evaluate availability, and where possible, accuracy of paper records.

4.1 Stock cards

4.1.1 Stock card Availability

Each facility is supposed to maintain a stock card for every medical product supplied. The stock cards are updated daily about incoming and outgoing products. Though there is no formal requirement, the stock cards are encouraged to be stored in each facility for several years and then centrally disposed of at the DHO. In Table 4.1, we present the availability of stock cards for medicines, vaccines and tests. We first calculate the percentage of cards available for all the tracer products that a facility stocks (e.g. if a facility stocks 10 tracer products but only has 9 stockcards, then the stock card availability rate is 90% for that facility), and then construct an average across facilities. We find that **for medicines and tests, the current stock card availability is extremely high** (over 99% of products typically stocked), suggesting that facilities do keep records of products in real-time. However, some facilities do not retain historical cards, and we were only able to find baseline (June 2022) data for 80% and 92% of medicines and tests, respectively. If June data was not found, the field team digitised data for the following months (July-October 2022).

For vaccines, stock card availability is lower: stock cards are available for 81% of vaccines for the current month; and stock cards are available for 78% of products for any month spanning a period from June to October. Reports from the field team suggest that some facilities do not keep paper records given that they enter the data into eHIN (description below). The team is in the process of obtaining the eHIN dataset, however, at the time of the report we did not have access to it and are unable to comment on whether the records that are missing in facilities are present in the electronic systems.

Table 4.1 Stock Card availability by product type

Historical stock card availability (2022)	Medicines	Vaccines	Rapid tests
Percent of cards available for stocked products			
Any month between June - October	94.35%	77.64%	97.70%
June	79.88%	67.48%	91.98%
Current stock card available for all products typically stocked	99.52%	81.34%	99.04%

Note: Enumerators searched for and digitized baseline period (June 2022) stock cards for all key tracer products a facility typically stocks. When a stock card was not available for June 2022, enumerators digitized the next available month between July 2022 and October 2022. When a facility did not have a stock card for any month between June 2022 and October 2022, the enumerator recorded that "no month of data is available."

4.1.2 Stock card Accuracy

Next, we verify whether data in stock cards actually reflects medicine, vaccine, and rapid test availability in the facilities. When enumerators visited the facilities, they requested access to the stock cards and stock rooms where the medicines are stored. Enumerators were instructed to digitise the number of units of stock on hand that was recorded on the current stock card and then physically counted the number of products on the shelves for each product. If a stock card was not available, enumerators recorded a “don’t know” missing value for the data. We have no records of facilities refusing to give us access to stock cards and the physical shelves to perform this verification.

The results of the verification are reported in Table 4.2 for medicines, Table 4.3 for vaccines, and Table 4.4 for rapid tests. In column 1 we report the average number of units of stock on hand reported on the stock cards. In column 3, we report the average number of units from the physical count of products. In column 5 we report the differences between these two averages with stars denoting statistical significance from a pairwise t-test. For vaccines, we present information only for products which had current stock cards. Overall, we see that **physical counts of medications, vaccines, and rapid tests are extremely close to what is written in stock cards** (with average discrepancies ranging between 0.1% for medicines to 8.7% for vaccines). The differences for vaccines are driven by the Covid-19 vaccines. According to enumerators, COVID-19 vaccines have different reporting requirements than other products and not all vaccines are recorded in stock cards (physical counts are then written records). Lastly, as seen in Table 4.1, a current stock card was not available for all the vaccines a facility reports stocking in 18.7% of facilities. However, in those facilities, current stock cards were available for 47.4% of the vaccines

Table 4.2 Medicine stock card verification

	(1)	(2)	(3)	(4)	(5)	(6)
	Number of items (Visit Day)					
	Paper Records		Physical Count		Difference	Difference (%)
	Mean	N	Mean	N		
Essential Medicines (EM)						
Amox 250	4703.43	204	4669.16	204	34.27	0.7%
Amox Tablets	3386.54	104	3367.31	104	19.23	0.6%
Cotri 120	16564.04	203	16523.44	203	40.60	0.2%
Cotri 480	6275.17	203	6272.45	203	2.72	0.0%
Doxy 100	7615.75	208	7561.90	208	53.85	0.7%
Ery 250	745.41	185	729.23	185	16.17	2.2%
Metro 200	8538.28	209	8461.76	209	76.52	0.9%
Para 500	3698.06	206	3678.64	206	19.42	0.5%
Oxy 10	199.99	183	201.57	183	-1.58	-0.8%
ORS	364.25	203	378.80	203	-14.56	-4.0%
Zinc 20	1812.96	196	1816.62	196	-3.66	-0.2%
FeS tab	1387.35	172	1387.35	172	0.00	0.0%
Essential Medicines (EM) Average	**4607.60**		**4587.35**			
Donor Funded/Vertical Program (DF/VP) Funded						
Cotri 960	62048.35	200	62409.08	200	-360.73	-0.6%
Depo Provera 150	615.4	197	615.06	197	0.34	0.1%
TDF 30 tab	74.25	145	74.25	145	0.00	0.0%
TDF 90 tab	404.71	197	404.59	197	0.12	0.0%
ABC 60	180.28	196	180.23	196	0.04	0.0%
DTG 50	60.06	196	59.91	197	0.15	0.2%
LA 6x1	3796.60	208	3793.48	209	3.12	0.1%
LA 6x2	11480.87	208	11428.69	209	52.18	0.5%
LA 6x3	9900.55	209	9940.78	209	-40.24	-0.4%
LA 6x4	22720.21	208	22604.88	208	115.33	0.5%
Donor Funded/Vertical Program (DF/VP) Average	**11128.13**		**11151.10**			
Overall	**7442.61**		**7595.73**		**-2.17**	**0.1%**

Note: Stars denote statistical significance (* -10% level, ** -5% level, ***-1% level). The units across medications are not comparable and they were recorded in the units which the medications is counted in. For example, depo-provera is counted in kits vs amoxicillin which is counted in tablets.

Table 4.3 Vaccine stock card verification

	(1)	(2)	(3)	(4)	(5)	(6)
	Number of items (Visit Day)					
	Paper Records		Physical Count			
	Mean	N	Mean	N	Difference	Difference (%)
BCG	162.39	192	172.79	192	-10.40	6.4%
IPV	85.34	190	102.03	190	-16.69	19.6%
OPV	211.54	190	227.92	190	-16.37	7.7%
TD	148.73	193	159.64	193	-10.92	7.3%
MR	153.16	192	179.67	192	-26.51	17.3%
Penta	195.28	192	224.85	192	-29.57	15.1%
PCV13	185.68	192	213.18	192	-27.49	14.8%
RV1	130.65	192	125.09	192	5.55	-4.3%
HPV	44.95	163	42.02	163	2.93	-6.5%
Malaria	136.08	37	141.59	37	-5.51	4.0%
J&J Covid	136.91	174	207.51	174	-70.60**	51.6%
Pfizer Covid	43.09	170	69.37	170	-26.28**	61.0%
Cholera	305.88	34	43.53	34	262.35	-85.8%
Rabies	107.75	4	107.75	4	0.00	0.0%
Overall	**146.25**		**144.07**		**-14.26**	**7.7%**
% of products with a current stockcard available (For facilities that do not have all stockcards)	**47.38%**					

Note: Stars denote statistical significance (* -10% level, ** -5% level, ***-1% level). The units across medications are not comparable and they were recorded in the units which the medications is counted in. Observations have been subset to those that had a non-missing value for the paper record and a non-missing value for the physical count. This happened when facilities did not keep papers records for the vaccines or the paper record could not be found when we visited the facility.

Table 4.4 Rapid test stock card verification

	(1)	(2)	(3)	(4)	(5)	(6)
	Number of items (Visit Day)					
	Paper Records		Physical Count		Difference	Difference (%)
	Mean	N	Mean	N		
Determine HIV	434.93	206	432.29	206	2.64	-0.6%
Unigold HIV Test	40.54	205	40.42	205	0.12	-0.3%
Determine TB	39.14	35	39.14	35	0.00	0.0%
Covid-19 Rapid Antigen Test	44.61	28	42.82	28	1.79	-4.0%
Malaria Rapid Diagnostic Test	3230.89	208	3219.87	208	11.03	-0.3%
Overall	**758.02**		**754.91**		**4.52**	**-1.1%**

Note: Stars denote statistical significance (* -10% level, ** -5% level, ***-1% level). The units across medications are not comparable and they were recorded in the units which the medications is counted in. Observations have been subset to those that had a non-missing value for the paper record and a non-missing value for the physical count. This happened when facilities did not keep papers records for the rapid test or the paper record could not be found when we visited the facility.

4.2 Using existing datasets for impact quantification

After the baseline data collection, we have done an extensive check of the two digital administrative data sources: OpenLMIS and DHIS2. OpenLMIS is the Logistics Management Information System (OLMIS) that is used in Malawi to electronically record public health supply chain information. DHIS2, which stands for District Health Information System 2, is a health management information system used in Malawi to collect, manage, and analyse health-related data. We have considered using OpenLMIS for quantification of impact on the medicine supply chain (and medicine available) and DHIS2 for vaccine volume administration (and/or coverage). We have checked both data availability and how the existing data correlates with information we digitised in the facilities during the in-person visits.

During the check, we discovered that there is a glitch in the system during OpenLMIS data export and some information which is available in the system is not properly exported, causing a significant amount of missing information. For this reason **we have decided to avoid relying on OpenLMIS** as a primary data source for impact quantification.

While DHIS2 had low missing rates for some vaccines, not all vaccines were recorded in DHIS2. There were also significant discrepancies between the paper records in the facilities and numbers reported in the system for non-missing records. Given this, **DHIS2 will not be used to quantify the impact on vaccination coverage proxies.** We have also considered using eHIN to quantify impact on vaccine supply chain. The Electronic Health Information Network (eHIN) is a digital platform used in Malawi to support the country's health information management system. The eHIN system is designed to improve the collection, management, and analysis of health data across the country, including data related to vaccine supply. At the time of writing the report, **we do not have access to the eHIN data and cannot comment on whether it's sufficiently accurate**.

Appendix

Appendix A. Evaluation framework and list of tracer products

Figure A1: Evaluation and measurement framework

Healthcare Component	Health Conditions	Tracer Products	Supply Chain		Health Proxy	
			Indicator	Data	Indicator	Data
Prevention	Vaccine-preventable diseases	BCG Vaccine	Number of days without product in the past 1 month	Facility Paper Records	1. Number of vaccines administered in the past 1 month 2. % of patients who were referred due to lack of vaccines in the past 1 month	1. Facility Paper Records 2. Interviews with healthcare workers
		IPV (Inactivated Polio vaccine) - shortages				
		OPV (Oral Polio vaccine)				
		TD (Diphtheria and Tetanus Vaccine)				
		MR (Measles & rubella vaccine)				
		Penta (Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib)				
		PCV13 (Pneumococcal disease)				
		RV1 (Rotavirus)				
		~~HPV Vaccine~~				
		Malaria Vaccine				
		Johnson and Johnson Covid Vaccine				
		Pfizer Covid Vaccine				
		~~Cholera vaccine~~				
Diagnosis: Test Kits	HIV, TB, Malaria, COVID	Determine HIV			% of patients who were referred due to lack of test kit in the past 1 month	
		Unigold				
		Covid 19 Rapid Antigen Test				
		mRDTs (Malaria Rapid Diagnostic Test)				
Diagnosis: Tests		HIV Viral Load	Turn-around-time (Number of days between testing and facility receiving results)		Number of days between testing and starting/switching patient treatment	
		HIV Early Infant Diagnosis (DBS)				
		TB				
		~~Polio~~				
		~~Cholera~~				
		Covid 19 Polymerase Chain Reaction (PCR) test				
Treatment	Maternal health	Oxytocin	Number of days without product in the past 1 month		% of patients who were referred due to lack of medicines in the past 1 month	
		Ferrous Sulphate Tablets				
	Child Health	Oral Rehydration Salts				
		Zinc				
	Malaria	Lumefantrine 120mg/Artemether 20mg,6x1				
		Lumefantrine 120mg/Artemether 20mg, 6x2				
		Lumefantrine 120mg/Artemether 20mg, 6x3				
		Lumefantrine 120mg/Artemether 20mg, 6x4				
	General	Amoxycilin 250 mg				
		Amoxycilin dispersible tablets				
		Cotrimoxazole 120 mg				
		Cotrimoxazole 480 mg				
		Cotrimoxazole 960 mg				
		Doxycycline 100mg				
		Erythromycin 250mg				
		Metronidazole 200mg				
		Paracetamol 500mg				
	Reproductive	Medroxyprogesterone Acetate Injection, 150mg/ml - Depo-Provera				
	HIV	Tenofovir Disoproxil Fumarate/Lamivudine(TDF/3TC), 300/300mg, pack of 30 tab				
		Tenofovir Disoproxil Fumarate/Lamivudine/Dolutegravir (TDF/3TC /DTG), 300/300/50mg,				
		Abacavir/Lamivudine (ABC/3TC) 120/60mg				
		Dulotegravir (DTG) 50mg				
	Other	Anti-Rabies vaccine				

Figure A1: Product names and Abbreviations

Full Name	Abbreviation
Medical Products	
Amoxycilin 250 mg	Amox 250
Amoxycilin dispersible tablets	Amox Tablets
Cotrimoxazole 120 mg	Cotri 120
Cotrimoxazole 480 mg	Cotri 120
Cotrimoxazole 960 mg	Cotri 960
Doxycycline 100mg	Doxy 100
Erythromycin 250mg	Ery 250
Metronidazole 200mg	Metro 200
Paracetamol 500mg	Para 500
Medroxyprogesterone Acetate Injection, 150mg/ml - Depo-Provera	Depo Provera 150
Tenofovir Disoproxil Fumarate/Lamivudine(TDF/3TC), 300/300mg, pack of 30 tab	TDF 30 tab
Tenofovir Disoproxil Fumarate/Lamivudine(TDF/3TC), 300/300mg, pack of 90 tab	TDF 90 tab
Abacavir/Lamivudine (ABC/3TC) 120/60mg	ABC 60
Dulotegravir (DTG), 50mg	DTG 50
Lumefantrine 120mg/Artemether 20mg,6x1	LA 6x1
Lumefantrine 120mg/Artemether 20mg, 6x2	LA 6x2
Lumefantrine 120mg/Artemether 20mg, 6x3	LA 6x3
Lumefantrine 120mg/Artemether 20mg, 6x4	LA 6x4
Oral Rehydration Salts	ORS
Zinc sulphate 20mg	Zinc 20
Oxytocin 10 IU/ml, 1ml,Ampoule	Oxy 10
Ferrous Sulphate Tablets (Coated)	FeS tab
Vaccines	
BCG Vaccine	BCG
IPV (Inactivated Polio vaccine)	IPV
OPV (Oral Polio vaccine)	OPV
TD (Diphtheria and Tetanus Vaccine)	TD
MR (Measles & rubella vaccine)	MR
Penta (Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib)	Penta
PCV13 (Pneumococcal disease)	PCV13
RV1 (Rotavirus)	RV1
HPV Vaccine	HPV
Malaria Vaccine	Malaria
Johnson and Johnson Covid Vaccine	COVID J&J
Pfizer Covid Vaccine	Covid Pfizer
Cholera vaccine	Cholera
Rabies vaccine course	Rabies
Diagnostic tests	
Determine HIV	Determine HIV
Unigold HIV Test	Unigold HIV Test
Determine TB	Determine TB
RealTime SARS-CoV2	RealTime SARS-CoV2
Malaria Rapid Diagno	Malaria Rapid Diagno
Samples	
HIV: Viral Load	HIV: Viral Load
HIV: EID	HIV: EID
TB	TB
Covid-19 PCR	Covid-19 PCR

Appendix B. Technical Risks

We foresee the following potential challenges that the evaluation team may face, outline the implications and offer solutions where applicable.

- **Central stockouts of medications.** The intervention aims to improve delivery speed of medical products. However, in some instances products may be stocked out centrally. In this case, the impacts may be attenuated due to lack of differences between treatment and control facilities.
- **Relying on administrative data supplied by MoH**: We review the quality and completeness of the datasets. We have reviewed two (out of three) administrative data sources that can be used for impact quantification to assess their quality and completeness. While the data sources are not 100% complete or accurate, we believe they are sufficiently complete and accurate enough for impact quantification *if* we do not find any differences in reporting information between treatment and control groups at endline. We plan on conducting full checks at endline to verify the comparability of reporting rates between the experimental groups. If the reporting rates are statistically different from each other, administrative data will not be used. Statistically different reporting rates would suggest that the treatment itself changed the reporting behaviour. This would make it difficult to determine whether providing drone access or better stock management practices were responsible for changes in our outcomes of interest. In that case, we will only rely on data collected from paper records in the facilities which we found to be accurate.
- **Spillovers: Sharing of medical products across facilities**: While it is theoretically possible that nearby facilities are sharing medical products, in practice, this is unlikely to happen. The facilities in the sample are extremely remote with average travel time to the nearest paved road of 81 minutes (which increases to 106 minutes during the rainy season). The facilities are also far away from each other, and, on average the travel time between the facilities using typical transportation is about 107 minutes. Given these distances, we see it to be unlikely that facilities would be sharing products. Furthermore, facilities are actually not allowed to do that within the current system so we do not anticipate this to be the case.
- **Spillovers: Additional resources shifted to control facilities.** There is a possibility that the resources currently spent by each District Health Office (DHO) on ground transport deliveries for all their health facilities will be directed to a greater extent towards those in the control group. As a result, the supply chain in the control group may become better, leading to underestimation of the impact. We do not expect this to be the case because the **drones do not conduct routine monthly deliveries in Malawi -** the DHO still does this using limited financial resources and ground vehicles. **The drones are only fulfilling emergency orders in the middle of the month** if the facilities in the treatment group are about to run out of stock (by contrast, in the control group, health workers would be expected to pick up the

products from the DHO in the middle of the month). Nevertheless, we will conduct a few qualitative interviews with the DHOs and health facilities to understand whether this is the case and will make a qualitative assessment of whether this factor affects the final estimates.

- **More patients choosing to seek healthcare from drone-served facilities:** It is possible that patients will choose facilities which are served by drones because of better availability of medical products. In this case, the treatment facilities may experience a surge of patients or will attract patients that are sicker on average. In this case, the burden on treatment facilities will be higher and they may experience more frequent medical shortages. While we cannot exclude this possibility, the travel time to the nearest facility of an average patient is about 107 minutes, suggesting that facilities are far away enough and likely serve non-overlapping populations. We will investigate this possibility during qualitative interviews with healthcare workers at endline.
- **Control facilities receive drone services directly:** There is a low chance of control facilities receiving drone supplies during the study period due to the fact that Swoop Aero has capacity and budget limitations during this expansion round. Another possibility is that control facilities are served by other drone companies which provide services in Malawi. The risk of contamination is not high. MoH is aware of the RCT and the importance of preserving the control group. Secondly, VillageReach works closely with MoH and will remain a strong advocate of the research study. If any concerns arise, we expect that VillageReach will be promptly informed and will be able to contribute to the discussions.
- **Low usage of drone services:** If there is insufficient usage of drone services (either due to lack of knowledge, awareness, habit or other factors), the impact estimate will be attenuated. SwoopAero and VillageReach are conducting extensive training at the rollout to ensure that the facilities are well equipped to use the drone services.

Appendix C. Defining Main Indicators

As per the evaluation objectives, the main indicators which will decide whether the intervention is successful will span both **supply chain outcomes** and **proxy health outcomes**. In Table 2.6, we present 5 indicators which concisely evaluate the intervention across vaccines, medicines, rapid tests and lab samples. We will include impact estimates on all tracer products individually to understand how the drone intervention affected individual products separately. We only use summary indicators across major themes to minimise the number of hypotheses being tested which would necessitate applying multiple hypotheses adjustment to the main indicators.[22]

We will declare that the intervention is impactful on the indicator if the p-values on the indicators of interest are smaller than 0.05.

Table 2.6 Main indicators defining success of the intervention

	Supply Chain	Health Proxy
Medicines Vaccines Rapid tests	**Indicator 1A**: Average stockout days out of the past 30 days across all tracer products (each product is weighted equally)	**Indicator 1B:** Average % of patients referred in the past 1 month due to stockout (average is calculated within vaccines/rapid tests/ medicines first, and then averaged across the 3 product categories) **Indicator 1C:** Number of vaccines administered *OR* **Indicator 1D:** Coverage rate
Lab Samples	**Indicator 2A**: Turn-around-time (TAT) - the time lapse between collecting the sample from patient and facility receiving results (regardless of whether a patient tested positive or negative). Average across HIV VL, HIV EID, TB	**Indicator 2B:** Time between lab samples being collected and starting/switching treatment for positive patients. Average across HIV VL, HIV EID, TB.

[22] Per Leroy et al. 2022, multiple hypotheses adjustments in complex randomised control trials are not necessary if the tested outcomes are derived along different nodes of the theory of change and paths to impact. However, we will apply false discovery rate (FDR) adjustment to all other estimates following Benjamini et al. (2006)# in a single batch. This will help mitigate the risk of false positives, while minimising losses to statistical power.

Indicator construction

Indicator 1A: Average stockout days out of the past 30 days across the tracer medical products (index indicator)

The indicator will be constructed as a simple average where all products are weighted equally using underlying data on individual medical products.

- First, we will obtain information on the number of days in the past 30 days (possible values will range from 0 to 30) that the facility experienced a stockout for each tracer product that a facility is expected to stock.
- Next, the number of stockout days within the past 30 days will be averaged across all tracer products. If a facility is mandated to stock the product but does not (which is usually related to supply issues), the number of stockout days will be replaced with 30. If the facility is not mandated to stock the product, the number of stockout days will be missing.
- If we have data for multiple months, then the same calculation will be done for each month. We will not use OpenLMIS data for the main quantification of impact, but rather rely on primary data collection. However, we will include OpenLMIS data analysis in the report (as an alternate or secondary analysis) to see if the main findings replicate.

Indicator 1B: Patient referrals due to supply shortages in the past 1 month

Percentage of patients referred due to supply shortages in medicines, vaccines, and rapid tests: At endline, we will ask the health facility worker in charge of dispensing and/or treating patients, to think of the number of patients that tried seeking healthcare from the worker. Next, we will ask how many patients were sent away because medicines, vaccines and rapid tests were not available at the time. The percentage will be calculated by dividing the number of patients referred by the total number of patients who sought health services. The fraction will be calculated separately for each type of product and then averaged across 3 types of products.

Indicator 1C: Coverage rate and total number of vaccines administered

There are two types of vaccines that are in the current product tracer lists: (1) those with mandated for specific populations - children and are priority for WHO (e.g. BCG, IPV), and (2) those that do not have mandates (e.g. cholera, COVID etc). The coverage rate is more easily available for the first type of vaccine. To look at vaccines comprehensively, we will use the coverage rate for type 1 vaccines and number of vaccines administered for type 2 vaccines.

Coverage rate will be obtained by dividing the total number of vaccines administered in the facility in that month by the target population for that particular vaccine obtained from the EPI/DHIS2 and/or facilities themselves. At the time of writing the report, we do not

have access to the target population data at the facility level[23], however, we anticipate being able to recover this information for the endline. After calculating the coverage rate for each facility for each vaccine, we will calculate the average coverage rate across relevant vaccines which will be the final measure. Prior to creating the final average measure, we will benchmark coverage rates against WHO immunisation rates for Malawi to determine whether the calculations reflect average patterns in the country.

For the remainder of vaccines, we will use the number of vaccines administered as the primary measure which will be obtained by adding up all of the vaccines that the facility reports distributing. The outcome will be winsorized[24] at 1% to account for outliers.

As with the OpenLMIS dataset, we will not use DHIS2 for quantification of impact on the number of vaccines administered because we did not find it to be accurate.

Indicator 2A: Turn-around-time (TAT) - the time lapse between collecting the lab sample from the patient and the health facility receiving the lab test results (regardless of whether a patient tested positive or negative). Average across HIV VL, HIV EID, TB.

At baseline, the enumerators looked for the three most recent sample result batches for those tests with at least one patient with a detectable pathogen in their sample. For each sample type (HIV VL, HIV EID, TB), we recorded the date when the sample was collected and when the lab test result was received for the latest sample in each of the last three batches, which resulted in three data points per sample type. If the enumerator could not find any results batch with at least one patient with a detectable pathogen on or after June 2021, the most recent results batch received by the facility were selected instead. However, for the endline we will look for the three most recent sample results batches regardless of whether a patient tested negative or positive. We believe that this will be a more reliable indicator for capturing if there are differences in how quickly sample results are sent back to the facility after collection. We will construct an average for each batch across the sample types which will result in 3 observations per facility.

Indicator 2B: Time between lab samples being collected and starting/switching treatment for positive patients. Average across HIV VL, HIV EID, TB.

The combination of expedited delivery facilitated by drones and the potential efficiency gains in communication between health workers and patients due to reduced travel time to and from the District Health Office (DHO) for emergency order processing can lead to improved overall performance and more time spent on patient care. The faster delivery time enabled by drones allows for quicker access to medical supplies, while the time saved from

[23] Prior to conducting the baseline survey, we aimed to use the administrative data (DHIS2) for the coverage rate, however, our examination of the data revealed unexplained discrepancies between the facility and the administrative records.

[24] Winsorizing a variable is a statistical technique used to deal with outliers in a dataset. It involves replacing extreme values of a variable with the next highest or lowest value.

reduced travel can be utilised by health workers to relay test results back to patients more promptly. The indicators will be constructed as they were at baseline. Enumerators will ask a facility worker for access to care and treatment registers for patients treated at the facility. Enumerators will look for the three most recent sample results batches with at least one patient with a detectable pathogen in their sample. For each of the three batches, enumerators will record information on the most recent patient: the date the patient's sample was collected, the date the health facility received the patient's results, the date the patient received their results, and the date the patient started or switched treatment regimens. The time is calculated as the number of days between the time the patient did lab work and the day when the patient received the result or switched/started medication. We will first calculate time for each test and then average across all the conditions. As with TAT, there will be 3 data points across 3 batches.

Selection of tracer products

The final tracer product list will be selected before the endline using (a) order data (b) extensive consultations with the Ministry of Health. We may consider excluding products that are well supplied by the existing system and not ordered through drones (e.g. some vaccines), or products with limited use (e.g. cholera vaccines/testing may not be needed in the absence of cholera outbreaks). The final list of products will compose those on which we expect to see impacts and those that represent minimal standards of care that should be available in every facility.

Further, we will consider which products should be included for a subset of facilities served by religious organisations (CHAM facilities) because at the time of baseline, they cannot order essential medicines through drones since they use a different supply chain system to procure those products. For those facilities (~about a fifth of the sample), the tracer product list may only be composed of donor-funded products that can be ordered via drones.

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