Costing commodity delivery for obstetric emergencies in Malawi

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VillageReach

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I. Introduction

In Malawi, there are presently barriers to ensuring the efficient and timely transport of blood in instances of maternal hemorrhaging. Unmanned Aerial Vehicles (UAVs) may represent a feasible approach for addressing transportation-related barriers when responding to cases of maternal bleeding. This assessment aims to provide insights into the costs associated with using UAVs to transport blood in instances of maternal bleeding between the Malawi Blood Transfusion Services (MBTS) in Lilongwe and health facilities in Dowa and Lilongwe Districts. An Excel-based cost modeling tool was used to compare UAV transportation costs to the standard (i.e., ground-based) method of transporting blood by road.

Data were captured using three key approaches: document review, key informant interviews and a data collection survey that captured core system cost inputs. These costs were subsequently assessed for two different scenarios. *Scenario 1* assessed the round-trip costs associated with transporting oxytocin and blood from MBTS to the seven (07) health facilities considered in this assessment. *Scenario 2* assessed the round-trip costs associated with transporting oxytocin and blood from MBTS to the four (04) health facilities situated greater than 30 km (one-way) away from MBTS.

In both scenarios, the monthly estimated cost of transporting blood and oxytocin was approximately 51% lower for the UAV than for the ground-based mode of transportation. This is largely due to the following factors:

1. UAVs have a lower base cost relative to the LandCruiser (i.e., the four-wheeled vehicle used in this assessment) for transporting blood.
2. UAV can take a more direct path between MBTS and health facilities and are not impacted by traffic jams of poor road conditions—thereby reducing vehicle and personnel costs.
3. The UAV used to in this model was battery-operated so expensive fuel costs were not considered for this mode of transportation.

Significant cost drivers for the LandCruiser were the expensive cost of the vehicle itself, as well as fuel costs. Personnel costs of the UAV system were greater than those for the LandCruiser due to projected high personnel costs for a specialized UAV system. Vehicle cost was also significant (though to a lesser degree than for the LandCruiser) in the UAV system. Additional significant costs included batteries, chargers and landing pads—all costs that are irrelevant for the LandCruiser. Future analyses should examine the ways in which vehicles may be leveraged for multiple different use cases as this could result in significant cost reductions for both the UAV, as well as the ground-based transportation system, however, it is important to note that for emergency purposes, it is important that a dedicated vehicle, whether land vehicle or UAV, is available at any given time, in order to avoid delays and potential lives lost. It is important to acknowledge that UAV technology is still maturing and the vehicle as well as associated equipment costs are expected to decline as the technology continues to mature. This assessment explores the feasibility of UAV application in instances of maternal bleeding and provides early insights into the financial implications of delivering blood and oxytocin by UAV. Future analyses should continue exploring deeper into the transportation and systemic barriers to ensuring reliable availability of blood in instances of maternal bleeding.

II. Study Background

VillageReach, NextWing Corporation, the Malawi Ministry of Health, the Malawi Blood Transfusion Service (MBTS) and the Pharmacies, Medicines, and Poisons Board (PMPB) are collaborated to assess the feasibility of using unmanned aerial vehicles (UAVs) to transform the medical commodity distribution network in Malawi. The assessment explored the feasibility of integrating UAVs into the existing health supply chain in Malawi in order to improve the availability of blood products and injectable oxytocin in instances of maternal hemorrhage. Rapid and reliable transport of these commodities facilitates more impactful response to instances of maternal hemorrhaging—a leading cause of maternal mortality—and, furthermore, has the potential to immediately and profoundly improve the health of reproductive-age women in Malawi. This report highlights the cost implications associated with applying UAVs to deliver blood and injectable oxytocin in instances of maternal hemorrhage.

Maternal hemorrhaging may account for up to 35% of all maternal deaths[I]. The 2017 DHS report indicates that Malawi has one of the highest maternal mortality ratios in the world at a rate of 497 deaths per 100,000 live births[II]. In 2015, an inquiry into maternal deaths in Malawi revealed the following factors as key contributors to maternal mortality: difficulty being transported to referral facilities (12%), lack of essential obstetric drugs at facilities (5%) and non-availability of blood transfusion when needed (14%).[III] Furthermore, recent evidence indicates that, for all births, maternal hemorrhaging tends to occur at a frequency between 2% and 6%.[IV] For additional context, a 2018 evaluation in Lilongwe observed an 8.3% rate of maternal hemorrhage.[V] Furthermore, maternal hemorrhaging requires immediate intervention. One of the core difficulties when it comes to urgently and impactfully addressing these deaths is the unpredictable rate at which they occur. To illustrate this point, consider that the estimated average time to death is just 2 hours when postpartum maternal hemorrhage occurs.[VI] Although obstetric complications may be unpredictable, they are often preventable when appropriate treatment is available through administration of blood, intravenous fluids and/or injectable oxytocin.[VII, VIII]

"Appropriate care" largely translates into taking steps to ensure that adequate infrastructure is in place for women to receive timely obstetric care so that potentially life-threatening instances of maternal hemorrhaging can be better managed. In addition to replacing a woman's lost blood, the World Health Organization (WHO) recommends that injectable oxytocin be used to reduce the risk of maternal bleeding. Oxytocin is a time and temperature sensitive medicine that must be maintained at a temperature between 2°C and 8°C. In a 2017 evaluation exploring opportunities to avert maternal mortality in Malawi, Mgawadere et al., found that 97% of maternal deaths were caused by preventable delays such as non-availability of blood, as well as other life-saving commodities.[IX] The vast majority of these delays included factors that impact the speed with which effective care can be provided once a woman has already arrived at a healthcare facility. Unfortunately, many areas in Malawi lack the aforementioned infrastructure to rapidly avail life-saving commodities—a profound barrier when it comes to preventing maternal deaths. Although MBTS is nationally sanctioned to coordinate a centralized system that ensures the provision of quality blood products, key informant interviews revealed that blood is insufficiently available to meet current patient demand in Malawi. For example, blood may not be available at MBTS and/or facilities may be located too far away from MBTS even when blood is available as only 5 MBTS sites exist in the country. Presently, there is no formal mode of transportation to ensure that blood can be transported between MBTS and health facilities when and where there is an instance of maternal hemorrhaging.

An ad-hoc approach that has arisen in attempt to address this inefficiency is the use of family member's blood when no or not enough blood can be provided by MBTS in time. Under this ad-hoc approach, when a woman experiences maternal bleeding, family members are typically asked to donate blood on her behalf. Interview respondents noted that this decentralized approach is not ideal because blood donated in hospital settings does not undergo the rigorous MBTS standards which may introduce the possibility blood-borne disease being transmitted via transfusion. In other instances, the woman may be stabilized and then subsequently referred to a facility that is better equipped to handle transfusions, or that is located in closer proximity to MBTS, though this process can take time and is dependent upon the availability of transport and fuel in the district or a way to transport her from the health center. Additionally, some facilities will use a LandCruiser (or similar 4-wheel vehicle) to collect blood from MBTS as this is a more favorable mode of blood transport than a motorcycle according to interviewees. Key informant interviews revealed that some instances of maternal hemorrhaging go untreated altogether while others may receive only a small fraction of the blood that was lost during the obstetric emergency due to an insufficient availability of blood at MBTS. It is important to note that this assessment did not explicitly focus on ascertaining non-transport related practices or root causes of blood non-availability at MBTS.

In instances of maternal hemorrhaging, ensuring a rapid, reliable and temperature-stable mode of transport for blood and oxytocin has the potential to save lives. In many areas of Malawi, there are substantial barriers that limit the efficient and cost-effective transport of life saving maternal health commodities by ground-based transport alone. Some of these barriers include poor transportation infrastructure, heavy traffic, roads that are periodically unreachable during the rainy season, costly gas to fuel cars and service delivery points that are difficult to access or entirely inaccessible by road. Transportation-related barriers, in particular, pose a significant risk with respect to ensuring that blood and injectable oxytocin are available when these serious, unpredictable but preventable emergencies occur. As indicated above, in addition to these transportation-related challenges, there are also systemic (e.g., poor availability of blood at MBTS; ad hoc practices around management of maternal bleeding cases) and structural (e.g., facility distance from MBTS) inhibitors to ensuring that high-quality blood is rapidly available when maternal hemorrhaging occurs.

UAVs represent a potentially viable mode of transportation because they have the potential to leapfrog many the aforementioned transportation infrastructure related challenges that threaten the availability of life-saving commodities such as oxytocin and blood when maternal hemorrhaging occurs. The primary purpose of this assessment is to provide insights into the cost implications associated with the application of UAVs for transporting blood and oxytocin in instances of maternal hemorrhaging in Lilongwe and Dowa District, Malawi. To contextualize these findings, UAV costs were compared to the standard method of transporting blood and oxytocin via the ground-based transportation that is currently present in the country. In an effort to establish a more comparable point of reference, given the existing systemic challenges and the lack of a well-defined blood delivery system, we costed an optimized ground-based transportation system. However, it should be noted that the ground transport system is not a true reflection of the reality on the ground as it assumes a dedicated vehicle available for emergencies. As the districts are responsible for picking up blood from MBTS and returning it, often there will not be a vehicle or fuel available. Transportation costs for both UAS and ground-based transport are expected to be variable across Malawi based on factors such as geography, existing transportation infrastructure as well as transportation volume.

This assessment is primarily concerned with the costs of the transportation system. It does not attempt to quantify the systemic and/or health benefits that either system (i.e., UAV or ground-based) may confer. For example, speed of transport is not included as a model output and this assessment does not attempt to optimize transport time for blood and oxytocin between facilities and MBTS. Future analyses may reveal that a hybrid system—using an optimized version of the existing ground transport alongside UAVs application in certain use cases—will be more effective and efficient approach for transporting these commodities than UAV or ground-based transport alone. Additionally, we have not attempted to quantify any further benefits that could potentially be gained from swifter commodity transport, such as impacts on mortality. This was based on the fact that MBTS does not have analyzed data on requests for blood readily accessible, as well as due to the fact that the time benefits could not be analyzed as the flights were not completed due to technical issues. More details are listed in the Methodology section. Quantifying and assessing these and other benefits associated with each form of transportation represents a critical step in better understanding UAV use cases in Malawi; however, they are out of scope for this analysis.

Outputs from this assessment include the following:

- Monthly estimated cost of transporting blood and oxytocin using UAV
- Monthly estimated cost of transporting blood and oxytocin using ground-based transport
- Cost per serious maternal emergency using UAV
- Cost per serious maternal emergency using ground-based transport

Finally, it is important to note that these findings are intended to provide a framework with which to assess the costs of the UAS in comparison to the existing transportation system. While this evaluation has the potential to provide important insights into the cost implications of applying UAVs to transport commodities for maternal bleeding, additional assessments must be conducted in order to further determine if and how UAVs may be integrated into the existing health system. In an attempt to respond to some of the questions around how to create a long term integrated cross-sectoral system, the Ministry of Health and Population Reproductive Health Directorate and VillageReach also conducted key stakeholder interviews for a business case analysis. The analysis is provided in a separate report.

III. Methodology

Assessment Sample

The geographic scope of this costing assessment includes Malawi Blood Transfusion Services as well as health facilities in Dowa District and Lilongwe District. More specifically, data for this assessment were captured from MBTS, the six (06) facilities in Lilongwe District and the two (02) facilities in Dowa District that have active maternity wards, that possess the requisite resources for carrying out blood transfusions and that are supplied blood products by MBTS. The full list of health facilities incorporated in this analysis can be found in Appendix A. While the results of this assessment may not necessarily represent nation-wide costs for distributing blood and oxytocin in instances of obstetric emergency, they provide important initial estimates for logistical costs.

Data Collection

This assessment began with a document review exploring peer-reviewed literature, grey literature and other articles on the subject of maternal hemorrhaging in Malawi, as well as the strategies that are presently in place to address these challenges. We also reviewed reports, editorials and news articles detailing potential use cases of UAVs in the context of public health systems.

Data collection took place from February to March 2019. An Excel-based data collection instrument was used to guide data collection for this assessment. Informal and unstructured key informant interviews were also used to capture complimentary data for this assessment. These interviews were conducted in-person or via electronic means with key informants from NextWing (i.e., the UAV supplier), MBTS and VillageReach staff persons in Malawi. In instances of incomplete or unclear responses, VillageReach staff reached out to informants to acquire additional clarification. An alternative approach for addressing missing or incomplete data inputs was to estimate costs using existing understanding of typical costs in Malawi (e.g., typical salaries for drivers and health facility staff persons) and/or findings from relevant existing literature (e.g., cost per kilowatt of energy). The approach for addressing missing data was informal and the costing data that were captured using this approach were specific to the time period when they were collected.

Cost estimates for UAV inputs were initially collected through discussions with NextWing as well as through observations during UAV flights that took place in March 2019 in Malawi. See Appendix B for additional details about the cost-modeling tool. The modeling tool costs the supply chain from MBTS to the SDPs to deliver blood and oxytocin, and from the SDPs back to MBTS for return of the UAV. This approach incorporates cost inputs related to vehicle costs as well as the required personnel time for transporting the aforementioned commodities. Additional assumptions are outlined below. All cost inputs and outputs are reported in USD. To convert currency from Malawian Kwacha to USD, we used an OANDA exchange rate of 724 MWK per 1 USD.

Data Analysis

Cost analyses were conducted using a proprietary Microsoft Excel-based discrete event simulation modeling instrument. The VillageReach tool models supply chain costs. We calculated and compared the costs of transporting blood and oxytocin by UAV to the existing ground-based means of transport currently available for use in Malawi. Although findings from this costing assessment are not intended to be representative of nation-wide costs for transporting blood products and oxytocin, they do provide some initial estimates that may inform future evaluations that may help define the potential role that UAS may occupy in the Malawi health system.

Table 1. Cost analysis inputs

Facility Details
GPS Coordinates for each location
Round-trip distance (km) to MBTS[1]
Time to execute round trip distribution from MBTS
Blood and oxytocin unit requirements [2]
Vehicle Characteristics and Costs
Vehicle range[3]
Vehicle base costs
Cost of other required equipment[4]
Expected useful lifetime
Per km vehicle insurance cost
Lifetime usage limit
Per km fuel cost
Per km routine maintenance cost
Personnel Costs
Number of personnel dedicated to travel
Monthly salary for personnel involved in commodity transport
Per diem for personnel involved in commodity transport

Only costs that were directly related to the distribution of blood and oxytocin were incorporated into this assessment. For example, if a driver spends 15 hours in a month distributing these commodities, only that proportion of his monthly salary (15 hours/120 hours) will be included in the final analysis. Similar principles are applied to determine the per kilometer costs associated with transporting commodities for obstetric emergency. Finally, we assume that for each distribution of blood and oxytocin, the vehicle is subsequently returned to MBTS. Thus, the delivery costs in either direction are identical.

Model outputs include the following:

[1] In the UAV model, the Haversine formula [haversin(θ) = sin²(θ2)] was used to determine straight line distance between each facility and MBTS. The haversine formula is used to determine the straight-line distance between two points using their respective latitude and longitude. In the ground-based model, GoogleMaps and key informant interviews were used to determine the distance (by road) between the relevant facility and MBTS.

[2] There was poor data availability for the number of deliveries in which maternal bleeding occurred. The figures used in the model were based on the actual number of deliveries observed in 2018 as well as existing literature (including literature on facilities in our sample) on the average proportion of deliveries that result in maternal bleeding.

[3] Flight distance before battery must be changed or charged is 35km. This is only applicable for UAVs.

[4] Battery, charger and landing device for UAV

- Monthly estimated cost of transporting blood and oxytocin using UAV
- Monthly estimated cost of transporting blood and oxytocin using ground-based transport
- Cost per serious maternal emergency using UAV
- Cost per serious maternal emergency using ground-based transport

Costed Scenarios

Costs were analyzed for two distinct scenarios. In each scenario, ground-based LandCruiser costs were analyzed to provide baseline cost estimates. It is important to note that baseline costs were established to provide a more comparable point of reference against which UAV costs could be compared. Presently, there is no dedicated transportation system implemented by MBTS to ensure the safe delivery of blood to facilities in need. The existing system for ensuring availability of blood in instances of obstetric emergency is characterized by ad hoc distribution practices that may, at face value, appear less costly than those attributed to the UAV model. Key informant interviews revealed significant issues of system effectiveness and responsiveness. Costing this ad hoc system would, therefore, reveal the lower costs associated with a system that does not presently address current need for blood in instances of maternal bleeding. In an effort to establish more comparable points of reference, the baseline considered in this assessment features more predictable and practices that can be modeled against which to compare UAV costs.
Scenario 1 assessed the round-trip costs associated with transporting oxytocin and blood from MBTS to the seven (07) health facilities considered in this assessment. *Scenario 2* assessed the round-trip costs associated with transporting oxytocin and blood from MBTS to the four (04) health facilities situated greater than 30 km (one-way) away from MBTS. Vehicles (LandCruiser or UAV) used hub and spoke routes to travel from MBTS to deliver blood and oxytocin to each health facility. The model assumes that all trips begin at MBTS and, after having executed a distribution, vehicles immediately return to MBTS.

The model is designed to consider core costs associated with relevant equipment utilization. This is achieved by incorporating costs that correspond only to the distance that is actually traveled by the vehicle. The distance traveled reflects the burden of operating time that is imposed upon the vehicle. Monthly fees are assessed based on the vehicle's transportation requirements. One key model assumption is that the per kilometer costs will remain constant for the life of the vehicle. Vehicle and battery replacement are automatically projected and scheduled based on actual utilization. Once the vehicle has reached the limit of its operational lifetime, it will be exchanged for a new vehicle with a new upfront commitment. For example, if the expiration period for a vehicle elapses, then that vehicle must be exchanged for a new one with associated upfront costs being factored into the model.

See **Appendix C** for details on additional assumptions incorporated into this model.

Scenario 1: Transportation costs to ALL (N=07) health facilities in sample

In Scenario 1, we examined costs for transporting blood and oxytocin to each of the seven health facilities in the sample. We used projections from 2018 birth data to establish estimates for the number of instances of maternal hemorrhaging we might expect to observe in one year. We subsequently converted this figure into a monthly average. Annual estimates for the number of instances of maternal hemorrhage are assumed to be equivalently spread across the year with no seasonality.

Vehicles (i.e., both the UAV and the LandCruiser) take a hub (i.e., MBTS) and spoke (i.e., health facilities in the sample) approach to delivering blood and oxytocin to each facility and then immediately returning to MBTS where it is assumed that the vehicle will be housed. This assumed approach is based on what would ideally happen, as currently vehicles are sent from the health facility to MBTS and back, which can take long periods of time, which can have implications on lives saved. We assumed that UAVs were capable of travelling from MBTS to each facility using the shortest possible route—straight-line distance. In reality, UAVs may have to slightly deviate from the shortest possible route due to physical obstacles (e.g., tree, pole or bird), no fly zones, or airspace restrictions. Because LandCruisers cannot travel from one point to another using the shortest possible distance, we refined data from Google Maps with information from key informant interviews to establish estimates for the shortest distance between MBTS and the sampled health facilities.

Scenario 2: Transportation costs only to health facilities (n=04) located > 35km away from MBTS

Scenario 2 used the same basic assumptions as those outlined in Scenario 1; however, Scenario 2 modeled the costs associated with transporting blood and oxytocin only to the facilities in our sample that were located greater than or equal to 35 km away from MBTS. Forty-five kilometers is the estimated maximum distance that a load-bearing UAV is capable of traveling before needing to touch down in order to change or charge the battery. This scenario explores costs associated with transporting commodities for obstetric emergency only to those facilities in our sample that are located further away from MBTS. This scenario assesses costs of transporting commodities to these facilities because these facilities—being located further away from MBTS—may face greater transportation related challenges due to their distance. Challenges that these facilities, in particular, might face include higher transportation costs as well as more substantial times associated with transporting commodities between MBTS and the facilities.

Additionally, Scenario 2 was of particular interest to model because the response time for addressing instances of maternal bleeding can be as low as 2 hours. The remaining facilities in our sample were located relatively proximate to MBTS. For example, the one-way duration of the trip from the MBTS to Area 25 is approximately 30 minutes by ground but can take as long as 45 minutes to 1 hour in high traffic. Bwaila was the facility located closest to MBTS with the one-way duration of the trip between the two buildings taking fewer than 10 minutes by car. Facilities located closer to MBTS may be considered less at risk of transportation-related barriers to ensuring that maternal bleeding is urgently and effectively treated. The costs associated with UAV delivery may be less justifiable in instances when blood is transported between MBTS and a facility that can be accessed with relative ease and speediness using existing ground-based means.

As noted, presently, MBTS does not possess a dedicated delivery system for the transport of blood in instances of obstetric emergency. In the existing system, an ambulance may be used to directly transfer a patient in need to a referral hospital nearer to MBTS where the transfusion can be executed. However, key informant interviews revealed that this practice does not occur in a routine fashion. In some instances, a vehicle may be dispatched from the facility in need to MBTS and then the blood is subsequently returned to the facility where the transfusion will occur. For the facilities considered in Scenario 2, it can take two hours or longer to carry out such trips using conventional modes of transportation. This scenario explores costs specifically for the facilities where response time is especially challenging considering their distance from MBTS.

Inputs for both Scenario 1 and Scenario 2 are outlined in Table 2 below.

Table 2. Model inputs.

	Scenario 1 : All Facilities		Scenario 2 : Far Facilities	
Node Information	LandCruiser (Baseline)	UAV	LandCruiser (Baseline)	UAV
Number of nodes	8	8	4	4
Kilometers/Month	13,868	10,017	13,076	9,484
Emergencies/Month	203	203	103	103
Avg. % of payload volume	100%	100%	100%	100%
Vehicle costs and characteristics				
Vehicle range	Unlimited	40km	Unlimited	40km
Payload capacity	Unlimited	2 Blood Units	Unlimited	2 Blood Units
Number of vehicles	1	1	1	1
Vehicle cost	$59,426	$ 16,000	$59,426	$ 16,000
Personnel costs				
Number of personnel	1	1	1	1
Monthly salary/person	$96	$239	$96	$239
Per diem	0	0	0	0

IV. Findings

Scenario 1: When considering all seven-health facilities in the sample, UAV delivery was 51% less costly than the LandCruiser for transporting blood and oxytocin in instances of maternal hemorrhage in Lilongwe and Dowa **(See Figure 1)**.

Scenario 2: When considering only the four health facilities located at least 35 km away from MBTS, UAV delivery was 51% less costly than the LandCruiser for transporting blood and oxytocin in instances of maternal hemorrhage in Lilongwe and Dowa District **(See Figure 1)**.

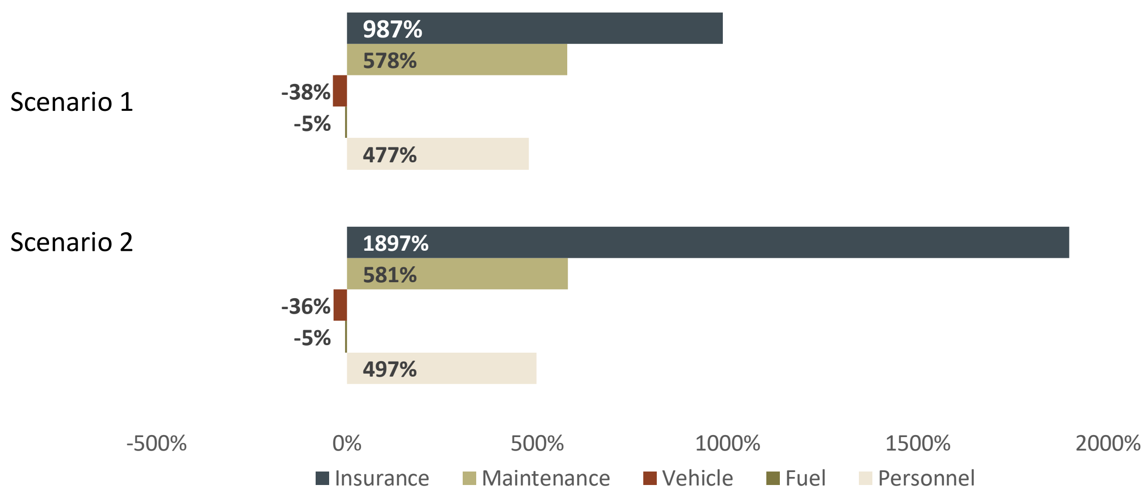
Figure 1. Total monthly UAV costs as percentage of baseline (LandCruiser) costs.

	% of Baseline Costs
Scenario 1	-49.1%
Scenario 2	-49.2%

For both scenarios, UAV transportation cost estimates were leaner than those of the ground-based mode of transportation. This is largely due to the fact that the UAV is substantially less costly than the LandCruiser. The LandCruiser is the recommended mode of transportation for the transport of blood because (relative to the motorcycle) transport by LandCruiser results in less jostling and damage to the blood. The base cost of a LandCruiser ($59,426) is nearly 4 times greater than those of the UAV ($16,000). This is an important factor to take into consideration particularly considering the fact that as UAV technology continues to advance, the associated base costs will begin to decrease. In both scenarios, vehicles were 100% allocated to the transport of blood and oxytocin in instances of maternal bleeding. A core assumption for both of the modeled scenarios is that the vehicle (i.e., both the UAV and the LandCruiser) would be based at MBTS and, furthermore, that the vehicle would be solely dedicated to the transport of blood and oxytocin in instances of maternal hemorrhage. Another factor that contributed to elevated ground-based transport were the associated fuel costs (which are largely irrelevant for UAVs). UAVs can take the most direct path between two points—thereby covering fewer kilometers in a shorter period of time than the LandCruiser.

Below, Figure 2 outlines UAV costs as a percentage of the LandCruiser baseline costs for both scenarios and by cost category. In both scenarios, fuel costs for the UAV were substantially lower than those for the baseline system. While overall UAV costs are lower than LandCruiser baseline costs in both scenarios, there is considerable variability when considering elemental costs. Although insurance and maintenance costs were greater for the UAV than the LandCruiser, bottom line costs for these two cost categories were less substantial cost drivers compared to LandCruiser fuel costs. Additionally, personnel costs represented a much more substantial cost in the UAV system compared to the baseline system. This is because a UAV pilot is recommended to coordinate UAV commodity delivery. Although this is a job that does not presently exist, due to the specialized training that is required, the position will likely be staffed by an individual that earns substantially more than a traditional driver. See Appendix C for more details on assumptions of cost inputs. Furthermore, fuel and vehicle costs from the baseline system were so significant that they far exceeded higher personnel costs observed in the UAV scenario.

Figure 2. Cost for UAV transport as a percentage of baseline costs, by cost category.



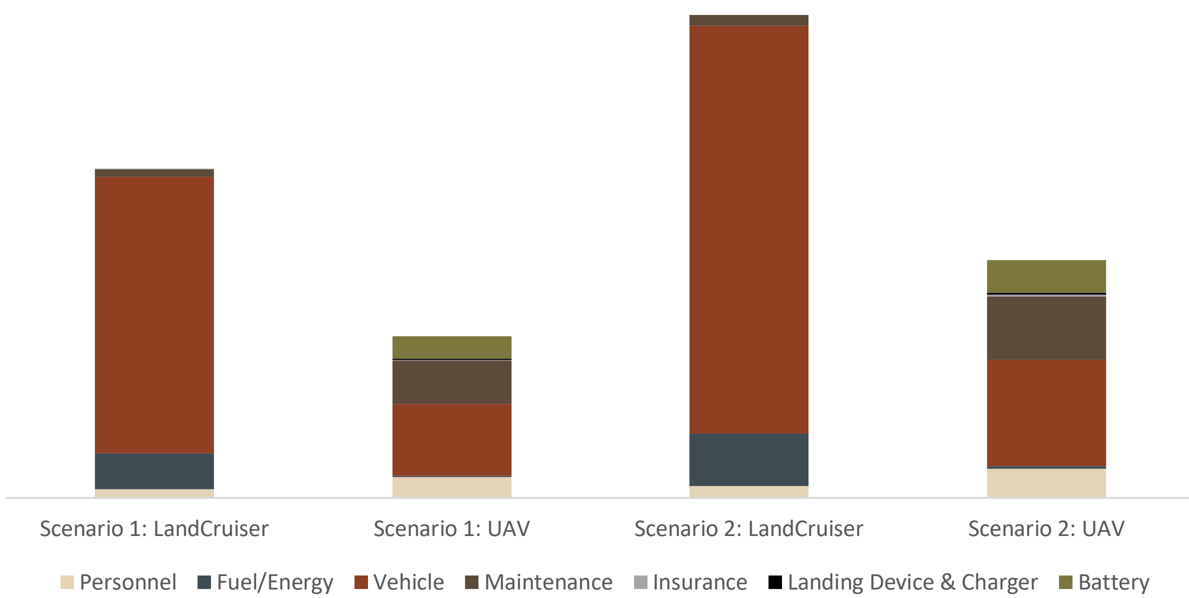
In both scenarios, the cost per kilometer traveled is comparable across the two different modes of transportation. The UAV cost per kilometer was only slightly greater than those of the LandCruiser in both Scenario 1 and 2; however, this moderate cost differential does not have substantial cost implications due to the fact that the UAV has better navigability, thereby traveling fewer kilometers than the LandCruiser. The UAV can take a more direct path between two points and is less constrained by challenging geographical terrain—a feature that helps suppress the overall cost per kilometer travelled for this mode of transportation.

If either vehicle were able to be used for additional logistics systems we would expect to see additional cost savings. Transporting blood in instances of obstetric emergency represents a relatively low volume distribution system. One difficulty of such a system is that it is remarkably sensitive to transportation non-availability. Maternal hemorrhaging represents a serious yet unpredictable health emergency. When maternal bleeding occurs, it is imperative that a vehicle is immediately availed in order to ensure blood is available when and where it is needed. While efficiencies would likely be observed if multiple different types of commodities or a higher volume of blood was transported, maternal hemorrhaging represents a health concern and use case in which resource sharing may be unfavorable. Still, there may be benefits of dedicated supply chains for certain commodities that would outweigh the associated costs. Those potential benefits were out of scope for the present assessment. Future assessments should quantify the potential benefits such as reductions in transportation time and reductions in delays due to unfavorable road conditions. Furthermore, future analyses should ideally link time-related benefits with health outcomes such as maternal mortality and survivorship under different blood distribution models.

This cost modeling exercise revealed that transporting blood and oxytocin using the UAV was the least costly option in both scenarios—when delivering to all facilities in the sample or only to the subset of facilities located further away. However, it is important to note that the cost differential per instance of maternal hemorrhage was observed to be more profound when the UAV is used to transport commodities only to the subset of facilities located further away (i.e., Scenario 2) rather than all facilities that have a maternity and that receive blood from MBTS. This is due to the reducing the volume of flights made by the UAV, so the high costs of UAV application is spread across fewer facilities. Further assessments should continue to explore opportunities for resource sharing for the UAV as well as the ground based transportation system as this would further support cost suppression. Distribution of blood in instances of maternal mortality represents a relatively low volume use case that has the potential to save lives by connecting patients with the life-saving obstetric commodities they need in a timely manner. Although the technology remains immature, it is important to explore the potential financial and health system implications associated with UAV delivery in order to gain a deeper comprehension of the most feasible and cost efficient applications. This includes the ability to have reverse logistics and omni-logistics, for example returning test results or having the UAV continue on to other facilities with additional commodities. Finally, the costs of batteries, chargers and landing devices were important costs in the UAV system; however, they were not relevant to the ground-based system.

One potential benefit that the UAV system may confer is a more stable and cost-efficient energy source (i.e., negligible reliance on petrol) relative to the ground-based system. However, some UAVs do rely on fuel as an energy source—although the fuel requirements per km travelled tend to be less than the requirements for a ground-based vehicle, as the fuel tanks used by UAVs the size of those used for lawnmowers. If fuel costs per liter increases—as has been historically observed in sub-Saharan Africa, then the costs of the ground-based system (in both scenarios) would continue to rise. In such an instance, the UAV would become even more cost-favorable. However, one assumption of this model is electricity availability—this being especially important for harder to reach, often-rural settings in Malawi. In reality, electricity availability is highly variable and could represent a significant challenge with respect to introducing UAVs into the emergency commodity distribution system. In areas without a grid connection, or with frequent power outages, facilities would rely on generators or solar energy to charge UAV batteries. The present assessment only examined costs associated with Electric Supply Commission of Malawi, Limited) (ESCOM) electricity; however, future assessments should similarly consider costs and reliability of alternative energy sources.

Figure 3. Total UAV cost per instance of maternal hemorrhage



V. Conclusions and Limitations

The urgent and unpredictable nature of obstetric emergencies necessitates rapid and reliable modes of transportation—irrespective of if that mode of transportation is ground- or air-based. In alignment with this, it is critical to know that a vehicle will in fact be available when maternal hemorrhaging occurs. Obstetric emergencies of this nature may represent one UAV use-case in which the potential benefits (namely, greater reliability and responsiveness) associated with a more dedicated supply chain may outweigh the corresponding elevated costs. However, the potential benefits that such a use case may confer were out of scope for the present analysis. It is important to continue exploring opportunities and strategies for vehicle resource sharing as this has the potential to dramatically reduce transportation costs for both the UAV as well as the LandCruiser. It is important to gain a deeper understanding of the instances in which UAV deliveries are most justified. For example, the cost of delivering blood and oxytocin from MBTS to nearby facilities is relatively low, so the application of UAVs in such instances may not be justified. However, the range used to indicate facilities located "far away" from MBTS in this assessment was arbitrary and corresponded to UAV flight ranges. It is important to understand the distance at which application of this technology has the greatest potential impact on health financial as well as health outcomes. Additionally, the UAV provider that was used to model UAV cost inputs had a limited payload capacity. The vehicle was capable of transporting only 1 unit of blood; however, this is not ideal as instances of maternal bleeding often necessitate multiple units of blood. In considering potential implementations of UAVs for obstetric bleeding, it is important to identify UAVs with a payload capacity capable of accommodating at least 2 units of blood per trip. Additionally, the UAV must correspond to the payload size and shape that can accommodate at two bags of blood. A larger payload box may increase the cost of the UAV which would furthermore have cost implications compared to the ground-based system. Conducting additional field research as well as sensitivity analyses will likely help to illuminate the preferred range and capability requirements for UAV application in instances of maternal bleeding. For both scenarios explored in this assessment, vehicle costs represented the most substantial cost driver. In the case of UAVs, there is cause to be optimistic that vehicle base costs will begin to be suppressed as these systems mature and more as well as lower-cost UAVs are introduced into the market.

Data availability represented a significant challenge in this assessment. It is important to establish a higher resolution understanding of the true scope for obstetric emergency in Malawi. In conducting this assessment, we observed poor visibility into the number of maternal deaths attributed to maternal hemorrhaging as well as poor visibility into the number of units of blood requested from MBTS and received by health facilities specifically for instances of maternal bleeding. While the data that shows what was distributed from MBTS does exist in paper form, it would take extensive data mining and cleaning to identify those specific to maternal hemorrhaging, as it would require cross checking with the health facilities on the date and cause of the requested blood. This would still not demonstrate how much was requested but was not received. Improving visibility into such data is a critical step for addressing these preventable maternal deaths. Additionally, transportation represents just one aspect of the health system; however, key informant interviews revealed bottlenecks unrelated to transportation infrastructure. In order to address preventable instances of maternal death, bottlenecks across the entire health system must be taken into consideration and appropriately addressed. For example, key informant interviews indicated that MBTS has an insufficient supply of blood to meet demand. If this is indeed the reality, then addressing transportation bottlenecks in isolation will do little to meaningfully circumvent these preventable instances of maternal hemorrhage. Furthermore, in certain use cases, UAVs could play an important role for reducing transport time—particularly to facilities that are difficult to access. However, these use cases must be assessed, costs and benefits should be quantified and carefully considered and decision-makers should be meaningfully and deeply engaged when considering the ways in which UAVs may be applied to address preventable maternal deaths in Malawi.

Despite some limitations of this assessment, the findings outlined in this report contribute to a growing knowledge base that attempts to quantify the relative costs of UAV transport within the context of public health systems in limited resource settings. While it is important to begin establishing a deeper understanding of the feasibility of this technology, it is important to acknowledge the disruptive and immature nature of UAV delivery for distributing life-saving commodities.

It is important to note that this analysis considered a hypothetical ground-based system based on interviews with key informants. Detailed data on the costs of the actual system are unavailable because there is no dedicated system for distribution of commodities for obstetric emergency. To further comprehend the bottlenecks in the existing system, further analysis is required. Delivery of blood and oxytocin in instances of obstetric emergency may represent a use case in which the high cost of UAV delivery may be justifiable. Further analyses are needed to explore the most efficient potential applications of this technology—not only with respect to costs, but also considering the potential benefits that UAVs may offer for improved quality of care, timeliness of care and the potential for improved health outcomes particularly among the underserved. As noted, there was limited visibility into maternal hemorrhaging specific blood requirements. Data on the number of 2018 births per facility were used to estimate the number of instances of maternal bleeding considered in our cost model. There was also poor visibility into the number of units of blood requested by a facility were specific to maternal bleeding. Additionally, key informant interviews revealed that when blood was requested from MBTS there may be a discrepancy between the amount of blood requested and the amount of blood that was loss by the woman in need. A costing model with greater precision could be built with improved visibility into these data inputs.

Another limitation in assessing the costs of the ground-based system was poor visibility into maintenance costs for unexpected vehicle breakdowns. Maintenance costs are likely greater than what is estimated and, furthermore, additional maintenance may extend vehicle lifetime beyond estimates provided in this model. Gaining greater visibility into maintenance costs will sharpen cost estimates for true system costs.

Finally, the scenarios modeled in this assessment did not include the upfront costs associated with procuring, importing and introducing UAVs into the system. These fixed costs should be further assessed if specific budgets are established for UAV deployment. However, these budgets do not presently exist and so they were not considered in this assessment.

VI. References

[I] Countdown to 2015: Maternal, Newborn and Child Survival [Internet]. WHO and UNICEF, 2012. Available at: http://www.countdown2015mnch.org/documents/2012Report/2012- Complete.pdf.

[II] National Statistical Office - NSO/Malawi and ICF. 2017. Malawi Demographic and Health Survey 2015-16. Zomba, Malawi: NSO and ICF. Available at: https://dhsprogram.com/pubs/pdf/FR319/FR319.pdf

[III] Mataya, R. and the Malawi National Confidential Committee on Enquiry into Maternal Death. (2015). Blantyre, Malawi: University of Malawi College of Medicine. Available at: http://mdsr-action.net/wp-content/uploads/2016/04/MOH_2016_Final-Malawi-CEMD-Report-18-09-14.pdf

[IV] Wormer KC, Bryant SB. Pregnancy, Acute Postpartum Hemorrhage. [Updated 2018 Oct 27]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2019 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK499988/

[V] https://www.acog.org/-/media/Departments/Global-Womens-Health/AIM_Malawi_Program_Summary_November2017.pdf?dmc=1&ts=20190305T2322460480

[VII] Knight M, Kenyon S, Brocklehurst P, et al. : Saving Lives, Improving Mothers' Care - Lessons learned to inform future maternity care from the UK and Ireland Confidential Enquiries into Maternal Deaths and Morbidity 2009–12.Oxford: University of Oxford,2014.

[VIII]Enquète Nationale Confidentielle sur les Morts Maternelles, France 2007–2009.*Rapport du Comité National d'experts sur la Mortalité Maternelle (CNEMM)*2013.

[VIII] Geubbels, E. (2006). Epidemiology of maternal mortality in Malawi. *Malawi Medical Journal*, *18*(4), 208-228.

[VIII] Mgawadere, F., Unkels, R., Kazembe, A., & van den Broek, N. (2017). Factors associated with maternal mortality in Malawi: application of the three delays model. *BMC pregnancy and childbirth*, *17*(1), 219.