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A Project of JSI Research & Training Institute, Inc.

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UAV use cases: Potential applications in Ukerewe Islands, Tanzania

February 2020

Outline

- Research questions
- Background
  - Overview of Ukerewe
  - Process/methodology used
- Data collected
  - Flows of products
  - Transport costs
- Analysis/Results
  - Recommended use cases
  - Routes
- Potential health impact (example of blood)

Research questions

1. What are the most cost-effective use cases and number of UAVs required for each use case?

2. Between which origins and destinations does delivery by UAV make most sense?

3. What are the number of flight estimates per use cased for a specified time period, e.g., monthly?

Summary of Key Findings

- Examining commodity categories individually, costs are higher to deliver all categories by UAV

- Layering use cases can provide efficiencies and cost savings by allocating fixed costs across a greater number of flights and maximizing utilization in terms of capacity and time

- Public transport is widely used for public sector transport and is relatively inexpensive, keeping transport costs low. UAVs are most cost effective on routes to distant facilities on the small islands and between the DH and Mwanza.

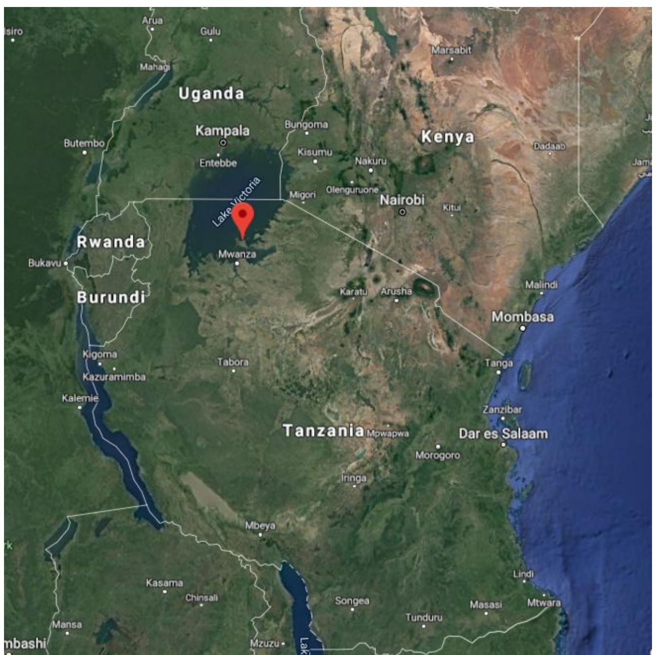
- While still higher cost, the most cost effective use case examples include lab samples to selected destinations and life-saving items and blood deliveries.

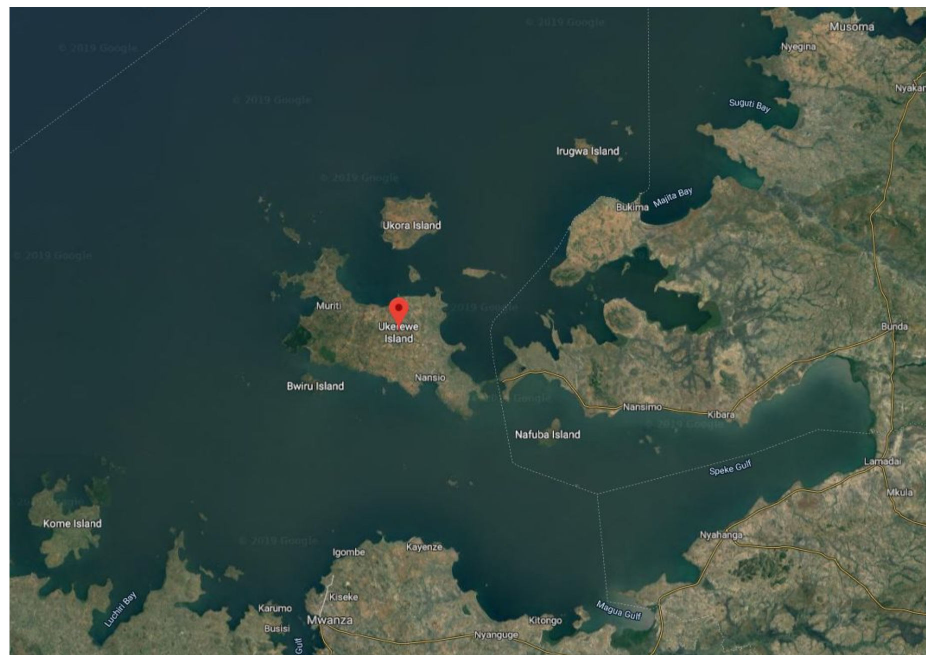
- Deployment of drones to delivery emergency blood for transfusion at health facilities in Ukerewe island reduces the number of deaths by almost 80% compared to traditional transport

BACKGROUND

Overview of Ukerewe Islands

- 38 small islands: 34 are inhabited; 15 have permanent settlements; 6 islands have health facilities.
- 37 facilities: 1 district hospital, 4 health centers, 32 dispensaries
- Total population is 412,621 (Census 2012 projections for 2018).





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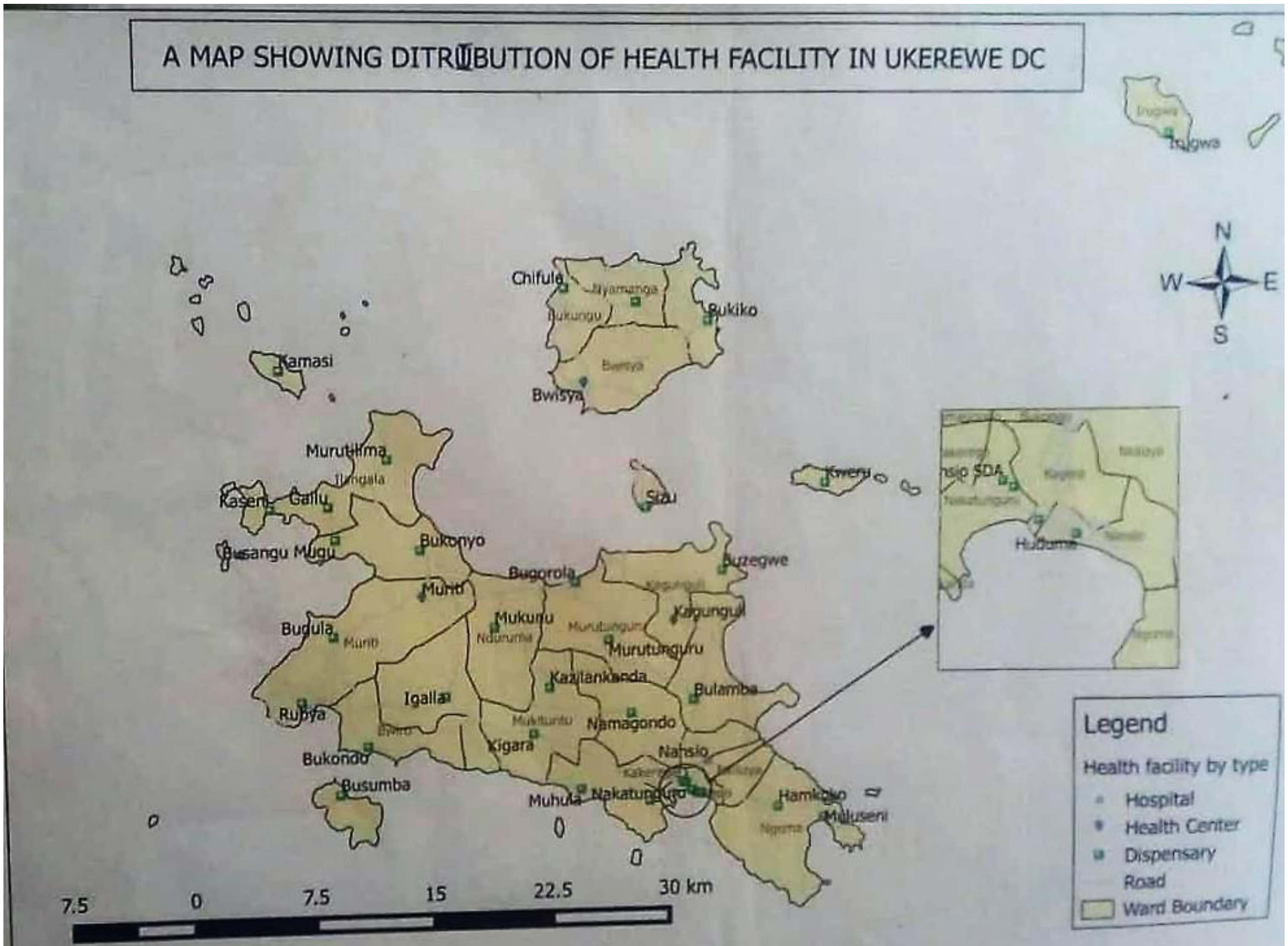
Health facilities in Ukerewe



Ukerewe represents distribution challenges

Local boats are used to transport health products between islands

Roads on the islands are also a challenge….

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Process used to answer research questions

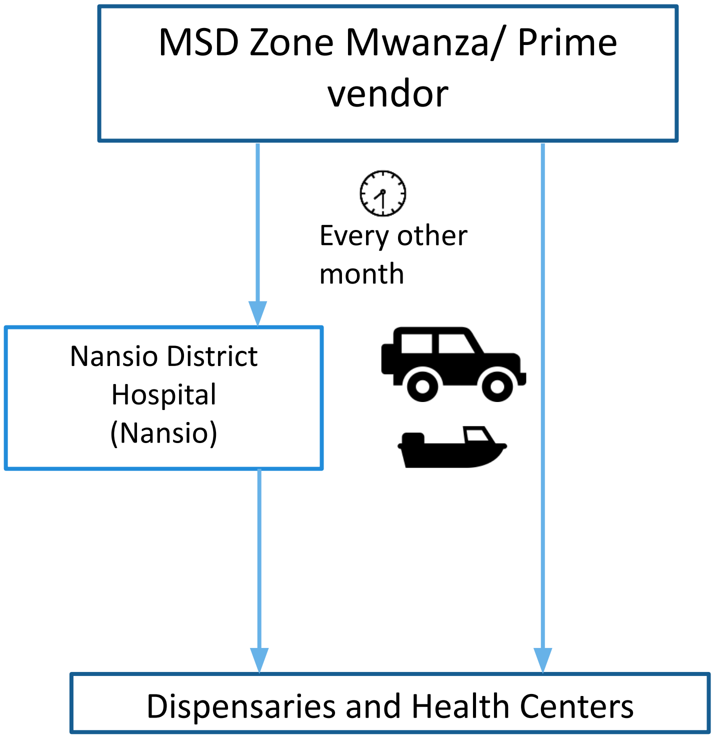
- Collected data
  - Mapped the various flows of products, and identified who is responsible and who pays for each flow
  - Extracted data from the electronic logistics management information systems (eLMIS) on product consumption, and products out of stock
  - Obtained transport costs for each product flow
- Conducted visits to health facilities in Ukerewe
  - Validated product flows, consumption and stockouts, transport costs, and any other gaps in data
- Utilized analytical tool to run scenarios to determine most cost-effective use cases, routing, and flight estimates
- Conducted health impact analysis, focusing on blood for transfusion

How products get to health facilities in Ukerewe

Products move through a variety of systems to reach health facilities in Ukerewe

Product segment	Primary manager of the system
All essential medicines routinely ordered, through the Integrated Logistics System (ILS), and includes a variation for tuberculosis (TB)	Medical Stores Department (MSD), the parastatal entity responsible for distribution to all public sector facilities
Emergency orders (includes any essential medicine ordered outside of routine orders)	MSD
Vaccines	Immunization and Vaccine Department (IVD)
Blood for transfusion, includes samples for testing and whole blood for transfusion	National Blood Transfusion Services
Laboratory samples (blood for viral load testing, sputum samples for TB, dried blood spots for early infant diagnosis of HIV, samples for biopsy testing, etc)	Diagnostics Services Section

Routine distribution

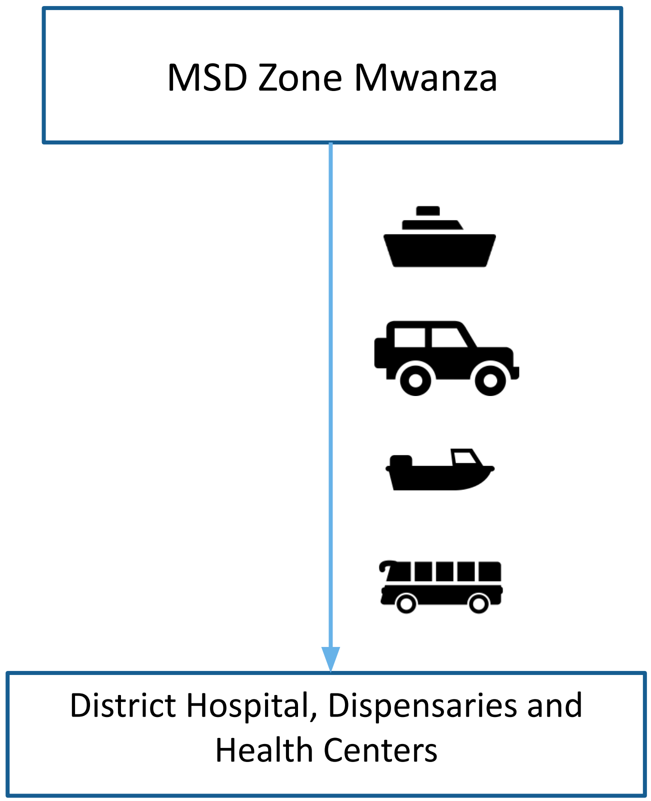


Who pays:
Facilities pay a delivery fee to MSD (MSD paid by MOH in advance and hence deduct the delivery fee)
For vertical program items (ARVs, malaria, etc), donors pay MSD a distribution fee (% value of the medicines supplied)

Who does:
MSD distributes directly to facilities; except for Tuberculosis & Leprosy medicines which are picked up from the district hospital by health facility staff or distributed using DMO vehicle

Given high volumes for routine distribution, this was not considered during analysis

Emergency orders



Commodity flow is direct from MSD to health facility

Who pays:
Facility staff/district staff – round trip transport + cargo fees

MSD covers costs to transport from MSD Zone to the ferry

Delivery fee depends on the weight/ volume , mode of transportation used & number of days a staff stay in Mwanza

Who does:
MSD transports from the warehouse to the ferry
Health facility staff travel to the ferry in Mwanza to collect, then back to their facilities

Vaccines

Routine distribution from Regional to district done by RIVO; Cost included in the RMO annual budget

Routine distribution from District to facility done by DIVO: Cost budgeted in CCHP

Regional Vaccine Store (Mwanza)

quarterly

or

District Vaccine Store (Nansio)

monthly

6 facilities by boat + car
30 facilities by car

Dispensaries and health centers

Regional vaccine store located at RMO office within Sekoutoure regional hospital , the district store is at Nansio DH

In cases of vaccines shortages at the district level, the district vaccine officer travels to Mwanza using public transport (ferry + taxi)

For emergencies at the health facility level, the health facility staff travel to the District Vaccine Store with a cold box to pick up the vaccine

Blood for transfusion: samples for testing and whole blood for transfusion

Samples:
30-50 samples/week; during donation campaigns, which are quarterly, more than 150 samples/week

Packaging and barcoding of samples done at Nansio District Hospital

Who pays for sample transport: Ukerewe District Council

Who does sample transport: Health workers

Samples for testing

National Blood Transfusion Services Lab
(Off Buzuruga road, near BMC,Mwanza)

1x/week

Nansio District Hospital
(Nansio)

??????

Health centers and dispensaries

As needed; roughly 1x/week

Bwisya Health Center
(Ukara island)

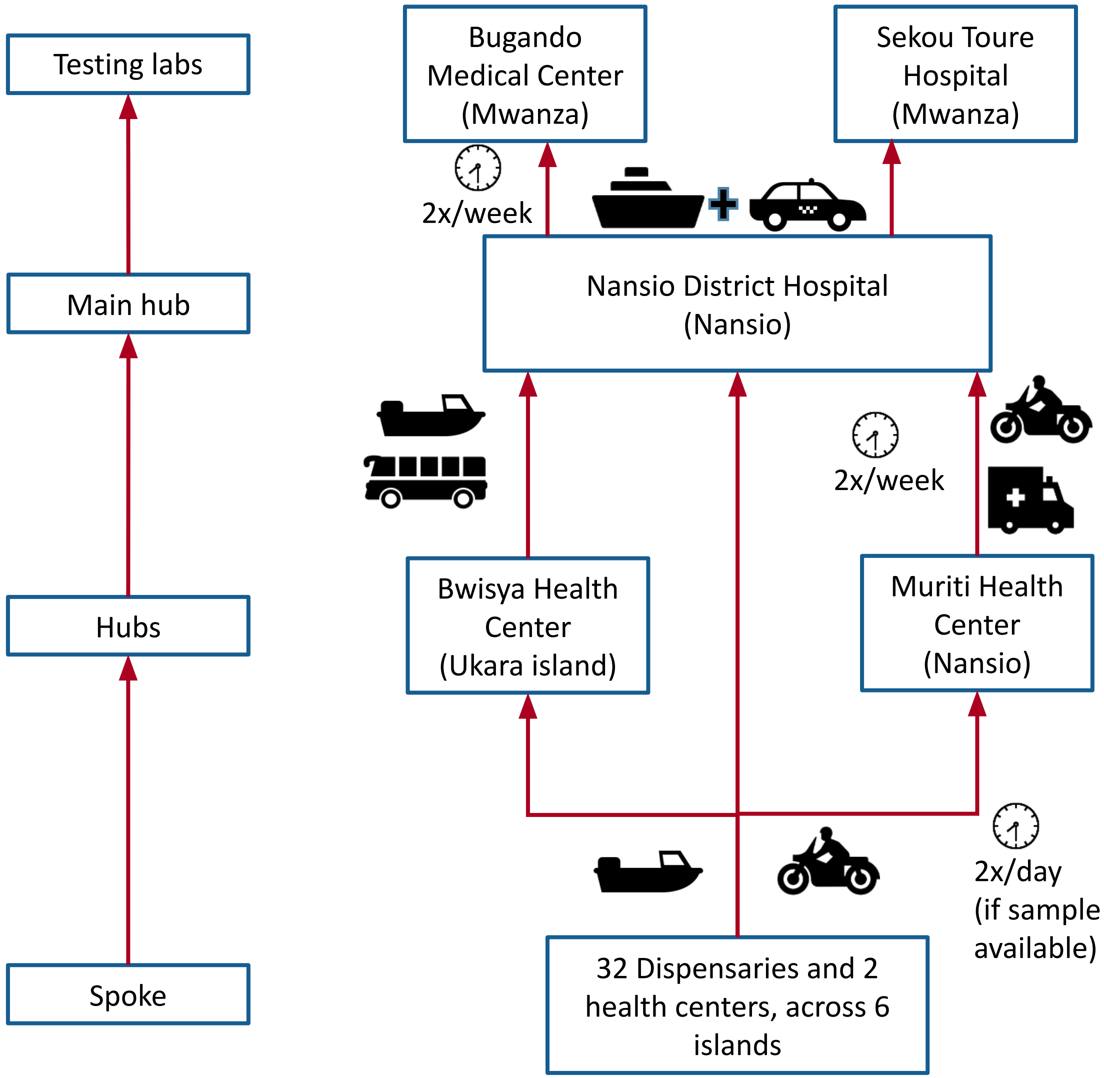
Muriti Health Center
(Nansio island)

Kagunguri Health Center
(Nansio island)

Whole blood for transfusion

Who pays for whole blood transport:
NBTS, transporters do it for free (Nyehunge, Bunda and Zakaria buses as donation)
Who does whole blood transport: Mwanza health worker or transporter, so, it can be either a round trip or just a single direction trip depending on who does it

Lab sample transport



Notes:
Samples must be processed not more than 5 hours after collection
Samples need to reach testing lab no later than 5 days after collection

Samples:
HIV viral load, DBS, hematology, chemistry, sputum samples for TB testing, histology samples
Each hub: 50-100 samples/week

POSTA does the collection of samples from health facilities and deliver lab results back. POSTA is contracted by AGPAHI (Implementing Partner) to do the pickup and delivery of results

In few cases health care workers collects the samples to the hub.

Other findings from field visits

- Life saving medicines were available (Mg sulphate, oxytocin inj, IV fluid, Artesunate inj), no stock out in 2019. Redistribution is a quick fix of stock out
- Only 4 blood transfusion centers in the district
- Antivenom only kept at district hospital; all snakebite cases referred to the DH cause are expensive and there are low sporadic demand & anemia cases to the centers.
- Delayed delivery of orders from prime vendors, most facilities hesitate to procure from PV
- Free transportation of whole blood by some transport agents; bus & ferry as part of corporate social responsibility

STATUS QUO TRANSPORTATION COSTS

Key assumptions and parameters used to estimate cost of current transport system

Key assumptions

- 2 years historical demand by quarter
- 2 years stock out rates by quarter
- Historical case load for selected patient emergencies
- Current modes, days, detailed costs to distribute commodities
  - Between Mwanza and Ukerewe District Hospital and facilities
  - Between Ukerewe District Hospital and facilities

Commodities types included

- All vaccines (routine distribution)
- Life-saving items
  - Oxytocin for post-partum hemorrhage (PPH)
  - Magnesium sulphate for eclampsia and pre-eclampsia during childbirth
  - Rabies and anti-venom serum
  - IV fluids for fluid replacement in cases of cholera outbreak
  - Artesunate injection for severe malaria
- Lab samples
  - VL testing and DBS strips
- Blood for transfusion and samples

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Estimated trips and costs were grouped by destination, as it is a determinant of demand, number of trips, and costs

Category	Total Trips	Cost/Trip	Ann. Cost	Volume/Trip (L)	Assumptions
Vaccines					Quarterly distribution to DH (1 distribution requires 3 trips each); Monthly distribution from DH to all facilities using milk runs (visiting multiple facilities in one outing)
District Hospital	12	226	2,717	38,849	
Big Island	312	27	8,576	349	
Small Islands	108	49	5,261	349	
Life-Saving Items					Includes oxytocin, mag sulphate, artesunate, and IV fluids sourced from DH. No stockouts at DH for these items. Rabies & anti-venom are sourced from MSD/vendor and are in addition to these trips, costs, and volumes. Details provided later in this document.
District Hospital	0	107	0	- 0 -	
Big Island-near	80	1	104	1.5	
Big Island-far	180	24	4,383	1.5	
Small Islands	90	74	6,665	1.5	
Lab Sample Pickup					DH: 3 trips per week; HFs send samples 1+ times / week; “Near” facilities are within 10 km drive of DH, no per diem, low delivery cost
District Hospital	144	107	15,402	4.0	
Big Island-near	1,152	1	1,503	0.6	
Big Island-far	2,592	24	63,110	0.6	
Small Islands	468	74	34,660	1.2	
Blood					Only 3 health centers and the hospital carry out blood transfusion services; DH transports samples only to Mwanza; no routine blood distribution from Mwanza (only for rare blood types)
District Hospital	48	107	5,134	6.0	
Big Island	192	26	4,925	4.2	
Small Islands	96	78	7,496	9.6	

Per trip and annual costs in USD; exchange rate 1 USD = 2300 TZSH. There may be some errors due to rounding

ANALYSIS AND RESULTS

Summary of key findings

- Examining commodity categories individually, costs are higher to deliver all categories by UAV.
  - Categories with very high quantities of products result in relatively low cost per flight but significantly more flights and UAVs required to deliver the same quantities as the status quo. The net results are higher costs
  - Small volumes and infrequent demand results in few flights with high costs per flight
- Layering use cases can provide efficiencies and cost savings.
  - The base case absorbs fixed costs and startup capital costs, while additional layered use cases incur incremental operations costs
  - Increasing the number of flights per UAV reduces overall per flight costs
  - Combining products per flight maximizes capacity (lt or kg) of vehicle
- UAVs are most cost effective on routes to distant facilities, including to facilities on the small islands, and routes between the District Hospital and Mwanza.
- While still overall higher cost, the most cost effective examples include –
  - Lab samples are lower cost for selected routes and the lowest percent increase
  - Life-saving items and blood are the lowest dollar increase

Summary of key figures

Annual Values

Category	Destination	Liters Delivered	Kgs Delivered	Current Costs	Cost/ trip	UAV Costs	Cost/ flight	No. Flights
Vaccines	District Hospital	466,188	200,081	2,717	226	1,660,409	33	50,028
	All Health Facilities	4,188	62,910	13,837	33	78,878	5	15,960
	All Facilities			*16,554*	*38*	*1,739,287*	*26*	*65,988*
Life-Saving	District Hospital (a)	3	1	1,336	111	2,654	221	12
(incl. Rabies)	All Health Facilities	542	291	19,259	46	78,253	186	420
	All Facilities (b)			*20,595*	*48*	*80,907*	*187*	*432*
Lab Samples	District Hospital	576	115	15,402	107	16,771	116	144
	All Health Facilities	3,370	983	99,272	24	316,560	75	4,212
	All Facilities (c)			*114,674*	*26*	*333,331*	*77*	*4,356*
Blood	District Hospital	288	58	5,134	107	10,618	221	48
	All Health Facilities	1,987	994	12,422	43	69,977	182	384
	All Facilities (b)			*17,555*	*52*	*80,595*	*187*	*432*

a) No stock outs of selected life-saving commodities recorded at the DH during the period reviewed.
b) Higher percentage increase over current costs, but lower dollar increase
c) Lower percentage increases over current costs, but higher dollar increase
Cost to deliver to future health facilities is assumed to be same as All Health Facilities cost per trip or per flight.

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Additional assumptions and parameters used to estimate cost of UAV transport system

UAV specifications, capabilities, costs (data as of late 2017)

- Cargo capacity 12 L and 4 kg
- Range 100 kms
- Equipment life cycles 1,000

Costs

- Initial capital $75,000/ UAV
- Cost per UAV incurred in year 1
- Variable costs include staff time, electricity, internet, maintenance

Road network circuity factor vs straight line flight path: 1.6

Health facilities on the Big Island are segmented according to distance from distribution point:

- Near: within 10km driving from DH (8 facilities). These facilities reach the DH quickly and do not incur costs for per diem or full days of staff time
- Far: further than10km driving from DH (18 facilities)

2 hrs on average to complete 1 flight, including prep, pack/unpack, flight = 1,200 max flights per UAV/ year

Delivery of vaccines + supplies by UAV would require considerably more resources than the current system

Status Quo Transport Costs

Destinations	Trips/Year	Avg Cost/ Trip	Ann. Cost	Vol (L)/ trip	Wt (kg)/ trip
District Hospital	12	226	2,717	38,849	16,673
Big Island	312	27	8,576	349	150
Small Islands	108	49	5,261	349	150
All Facilities	432	38	16,554		

UAV Transport Costs for Equivalent Volumes

Destinations	Flts/Year	Avg Cost/ Flt	Ann. Cost	Vol (L)/ flt	Wt (kg)/flt
District Hospital	50,028	33	1,660,409	9.3	4
Big Island	11,856	4	45,164	9.3	4
Small Islands	4,104	8	33,714	9.3	4
All Facilities	65,988	26	1,739,287		

Status quo costs reflect operating costs only; no capital or depreciation is included. UAV costs do not include initial capital investment or depreciation to enable comparison of equivalents

Includes all routine vaccines as well as diluents, syringes, and safety boxes.

Status quo uses cold boxes and vaccine carriers. UAV uses packaged unit weights and dimensions, and includes a buffer for appropriate packaging during the flight.

- Due to the large quantities (incl. diluents and supplies) the UAV system would require a multiple of more than 100 flights per land trip to deliver the same quantity.
- The high number of flights drives down the average cost per flight, but savings are outweighed by the number of flights required.
- Vaccines + diluents are approx. 10% of total vaccine volume (L). Delivering these items to facilities separately from the supplies is still more than 3 times the current costs (approx. $40k).

Costs in USD; there may be some errors due to rounding

Delivery of life-saving items could be combined with other items due to infrequent demand and low capacity requirements

Status Quo Transport Costs – excluding Rabies vaccine

Destinations	Trips/Year	Avg Cost/ Trip	Ann. Cost	Vol (L)/ trip	Wt (kg)/ trip
District Hospital	0	107	0	0	0
Big Island-near	80	1	104	1.5	0.82
Big Island-far	180	24	4,383	1.5	0.82
Small Islands	90	74	6,665	1.5	0.82
All Facilities	350	32	11,152		

UAV Transport Costs for Equivalent Volumes – excluding Rabies vaccine

Destinations	Flts/Year	Avg Cost/ Flt	Ann. Cost	Vol (L)/ flt	Wt (kg)/flt
District Hospital	0	221	0	0	0
Big Island-near	80	176	14,041	1.5	0.82
Big Island-far	180	181	32,554	1.5	0.82
Small Islands	90	185	16,685	1.5	0.82
All Facilities	350	181	63,280*		

* Capital cost shared with rabies and anti-venom serum. See next slide for combined costs.

Status quo uses public transport, considered an "all inclusive" cost. UAV costs are inclusive of capital investment and depreciation to enable comparison.

All products sourced from the DH. No stock outs at DH for these items during the period reviewed.

- Infrequent needs and small quantities results in few flights, meaning more fixed costs are born by each flight and provides little opportunity for savings.
- Low number of flights and small volume also means annual quantities can be delivered using only one UAV.
- Capacity utilization is less than 20% in terms of weight and volume, enabling other items to be combined with these items during the same flight.

Cost per flight or trip to deliver rabies vaccine & anti-venom serum are higher than all other categories for all modes of transport

Status Quo Transport Costs

Destinations	Trips/Year	Avg Cost/ Trip	Ann. Cost	Vol (L)/ trip	Wt (kg)/ trip
District Hospital	12	111	1,336	0.24	0.08
Big Island	52	104	5,403	0.24	0.08
Small Islands	18	150	2,703	0.24	0.08
All Facilities	82	115	9,442		
Total Life-Saving	*432*	*48*	*20,595*		

UAV Transport Costs for Equivalent Volumes – Rabies vaccine & Anti-venom

Destinations	Flts/Year	Avg Cost/ Flt	Ann. Cost	Vol (L)/ flt	Wt (kg)/flt
District Hospital	12	221	2,654	0.24	0.08
Big Island	52	212	11,016	0.24	0.08
Small Islands	18	220	3,957	0.24	0.08
All Facilities	82	215	17,627*		
Total Life-Saving	*432*	*187*	*80,907*		

* Capital cost shared with life saving commodities. Cost per flight analyzed separately due to different transport cost structure.

Status quo uses public transport, considered an "all inclusive" cost. UAV costs are inclusive of capital investment and depreciation to enable comparison of equivalents.

Products are not stored at the DH; facilities must source items from Mwanza or the supplier as needed.

- Similar to other life-saving items, low quantities and infrequent demand for rabies and anti-venom contribute to high per trip costs. However, longer trips to Mwanza are more efficient than others.
- Combined, all life-saving items could be delivered using one UAV and hence, total costs are low vs. other categories.
- Due to low capacity utilization, these items may provide savings and efficiencies if other items are included with them during transport.

While nearly three times the total cost, lab samples may provide examples of cost effective delivery by UAV for some facilities

Status Quo Transport Costs

Destinations	Trips/Year	Avg Cost/ Trip	Ann. Cost	Vol (L)/ trip	Wt (kg)/ trip
District Hospital	144	107	15,402	4	0.8
Big Island-near	1,152	1	1,503	0.6	0.2
Big Island-far	2,592	24	63,110	0.6	0.2
Small Islands	468	74	34,660	1.2	0.3
All Facilities	4,356	26	114,674		

UAV Transport Costs for Equivalent Volumes

Destinations	Flts/Year	Avg Cost/ Flt	Ann. Cost	Vol (L)/ flt	Wt (kg)/flt
District Hospital	144	116	16,771	4	0.8
Big Island-near	1,152	71	81,528	0.6	0.2
Big Island-far	2,592	76	197,288	0.6	0.2
Small Islands	468	81	37,744	1.2	0.3
All Facilities	4,356	77	333,331		

Status quo uses public transport, considered an "all inclusive" cost.

UAV costs are inclusive of capital investment and depreciation to enable comparison of equivalents.

Health facilities deliver/ collect samples from the District. The District delivers/ collects from Mwanza.

- Destinations with regular flights (1-2/week) and longer distances, such as deliveries between the DH and Mwanza, and from the DH to the small islands, are have costs most similar to the current transport system.
- High numbers of flights requires more UAVs.
- If limiting routes for UAV delivery, the upfront capital cost of the UAV would have to be absorbed by those routes, effectively increasing per route cost.

Costs in USD; there may be some errors due to rounding

Delivery of blood and samples by UAV requires more flights than currently for some facilities due to cargo capacity constraints; total costs are relatively low

Status Quo Transport Costs

Destinations	Trips/Year	Avg Cost/ Trip	Ann. Cost	Vol (L)/ trip	Wt (kg)/ trip
District Hospital	48	107	5,134	6	1.2
Big Island	192	26	4,925	4.2	2.1
Small Islands	96	78	7,496	9.6	4.8
All Facilities	336	52	17,555		

UAV Transport Costs for Equivalent Volumes

Destinations	Flts/Year	Avg Cost/ Flt	Ann. Cost	Vol (L)/ flt	Wt (kg)/flt
District Hospital	48	221	10,618	6	1.2
Big Island	192	179	34,382	4.2	2.1
Small Islands	192	185	35,595	9.6	2.4
All Facilities	432	187	80,595		

Status quo uses public transport, considered an "all inclusive" cost.

UAV costs are inclusive of capital investment and depreciation to enable comparison of equivalents.

Health facilities deliver/ collect blood and samples from the District. The District delivers/ collects from Mwanza.

- Infrequent needs and small quantities result in more fixed costs are born by each flight and provides little opportunity for saving.
- All deliveries could be completed using one UAV, making total costs relatively low vs. other categories.
- These dense items face weight limitations. The small islands require more than one flight to deliver equivalent quantities. The additional flights required drives up costs.

Layering use cases would leverage existing uncommitted time, reducing costs per flight; excess cargo capacity remains
Example 1: Lab samples as base case

Destinations	Flts/ Year	Avg Cost/ Flt	Year 1 Cost	Capacity utilization	Time utilization	UAVs Required
Base case: Lab Samples						
District Hospital	144	170	24,500	33%	12%	
Small Islands	468	134	62,866	10%	39%	
Total	*612*	*143*	*87,366*		*51%*	*1*
Layering use cases using uncommitted time:						
Life-Saving items						
Big Island-far	180	7	1,304	20%	15%	
Small Islands	90	12	1,060	20%	8%	
Total Incremental	*270*	*9*	*2,364*		*23%*	
Cumulative	*882*	*102*	*89,730*		*74%*	*1*
Rabies						
District Hospital	12	48	571	2%	1%	
Big Island	52	38	1,988	2%	4%	
Small Island	18	46	832	2%	2%	
Total Incremental	*82*	*41*	*3,391*		*7%*	
Cumulative	*964*	*97*	*93,122*		*80%*	*1*

Higher than costs noted earlier as more fixed costs must be absorbed by these flights

Excludes Near facilities

Layered use cases incur only incremental operational costs, lowering total cost per flight

Low capacity utilization for all categories provides opportunity to carry additional goods at the same time with zero additional cost.

Flights during year 2 and onward would incur only operating costs until the useful life of the UAV has been reached, estimated at approx. 1,000-1,200 flights

Layering use cases
Example 2: Blood and samples as base cases

Destinations	Flts/ Year	Avg Cost/ Flt	Year 1 Cost	Capacity utilization	Time utilization	UAVs Required
Base case: Blood & Samples						
District Hospital	48	221	10,618	50%	4%	
Big Island	192	179	34,382	53%	16%	
Small Islands	192	185	35,595	60%	16%	
Total	*432*	*187*	*80,595*		36%	*1*
Layering use cases using uncommitted time:						
Life-Saving items						
Big Island-far	180	7	1,304	20%	15%	
Small Islands	90	12	1,060	20%	8%	
Total Incremental	*270*	*9*	*2,364*		23%	
Cumulative	*702*	*118*	*82,959*		59%	*1*
Rabies						
District Hospital	12	48	571	2%	1%	
Big Island	52	38	1,988	2%	4%	
Small Island	18	46	832	2%	2%	
Total Incremental	*82*	*41*	*3,391*		*7%*	
Cumulative	*784*	*110*	*86,350*		*65%*	*1*

Excludes Near facilities

Blood delivery could be completed for all facilities and have uncommitted flight time as well as excess capacity with each individual flight.

Constraint analysis: the affect of capacity and time limitations on number of flights and costs

What is the affect on number of trips if cargo capacity is increased from 4 to 10kg?

Vaccines

- Delivery requirements would decrease from 66,000 flights to 51,500 flights
- Costs would decrease from US$1.7 to US$1.35 million
- An estimated 40+ UAVs would be required

Blood and samples

- Deliveries would decrease from 432 to 336
- Cost would decrease by approx. $1,100

No change for other categories as they would operate with excess capacity

Increasing volume would have no impact, as weight is the main cargo constraint

Can number of flights be increased to further reduce costs? What is the affect?

The estimated equipment life is approximately 1,000 flights

Estimated time to complete one flight, including prep, packing, unpacking, flying, is 1.5-2 hours = max 1,200 to 1,600 flights per year

Layering use cases only provides cost efficiencies up to these ceilings. Additional flights above these ceilings would require an additional estimated $75k per UAV.

To increase the cost effectiveness of the UAV

- maximize the cargo capacity in all directions
- use milk runs (utilize excess capacity by including cargo for more than 1 facility and reduce total mileage traveled) instead of hub and spoke routes for routine deliveries, e.g., for lab samples or blood samples

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Break even analysis: At what price would a UAV be cost effective in Ukerewe?

Factors	
Status Quo Transport Cost	152,824
UAV Transport Cost	494,833
Flights required/year	5,220
Flights possible/year	1,200

Average cost/flight: $95

Total flight cost: $113,755

Est. UAV cost $19,012

Considers weighted estimated costs and transport requirements for lab samples, life saving items (incl. rabies), and blood/ blood samples.

Results are valid for distribution to/ within Ukerewe only.

Cost per km varies by geography and distribution of health facilities.

UAV costs analysis using lower UAV capital costs of $20K vs 75K

Destination	Liters Delivered	Kgs Delivered	Current Costs	Cost/ trip	@75K		@20K		No. Flights
					UAV Costs	Cost/ flight	UAV Costs	Cost/ flight	
Vaccines									
District Hospital	466,188	200,081	2,717	226	1,660,409	33	1,660,409	33	50,028
All Health Facilities	4,188	62,910	13,837	33	78,878	5	78,878	5	15,960
All Facilities			16,554	38	1,739,287	26	1,739,287	26	65,988
Life-Saving (incl. Rabies)									
District Hospital (a)	3	1	1,336	111	2,654	221	1,127	94	12
All Health Facilities	542	291	19,259	46	78,253	186	24,781	59	420
All Facilities			20,595	48	80,907	187	25,907	60	432
Lab Samples									
District Hospital	576	115	15,402	107	16,771	116	9,498	66	144
All Health Facilities	3,370	983	99,272	24	316,560	75	103,833	25	4,212
All Facilities			114,674	26	333,331	77	113,331	26	4,356
Blood									
District Hospital	288	58	5,134	107	10,618	221	4,507	94	48
All Health Facilities	1,987	994	12,422	43	69,977	182	21,088	55	384
All Facilities			17,555	52	80,595	187	25,595	59	432

Lowering initial capital costs for UAV has an effect of decreasing the UAV costs per flight and hence the total costs.

Commodity categories of life-saving, lab samples and blood responds significantly when UAV costs are lowered to $20K. Generally lab samples are good use cases for UAVs

Vaccines are not affected by lowering of UAV capital costs.

UAV costs analysis for projected future demand as of 2025

Category	Destination	As of 2019		As of 2025		As of 2019			As of 2025		
		Liters Delivered	Kgs Delivered	Liters Delivered	Kgs Delivered	UAV Costs	Cost/ flight	No. Flights	UAV Costs	Cost/ flight	No. Flights
Vaccines	District Hospital	466,188	200,081	533,652	229,035	1,660,409	33	50,028	1,900,569	33	57,264
	All Health Facilities	146,580	62,910	168,000	72,103	78,878	5	15,960	89,257	5	18,060
	All Facilities					1,739,287	26	65,988	1,989,826	26	75,324
Life-Saving	District Hospital (a)	3	1	3	1	2,654	221	12	2654	221	12
(incl. Rabies)	All Health Facilities	542	291	636	341	78,253	186	420	75,253	186	420
	All Facilities (b)					80,907	187	432	80,907	187	432
Lab Samples	District Hospital	576	115	1,022	216	16,771	116	144	16711	116	144
	All Health Facilities	3,370	983	5,756	1,264	316,560	75	4,212	316,560	75	4,212
	All Facilities					333,331	77	4,356	333,331	77	4,356
Blood	District Hospital	288	58	490	101	10,618	221	48	7,284	152	48
	All Health Facilities	1,987	994	3,802	1,901	69,977	182	384	75,490	112	672
	All Facilities					80,595	187	432	82,775	115	720

Increased demand as of 2025 has no impact on the status quo transport costs as the system is flexible enough to accommodate the increased volumes and weights

Changes in volumes and weights for commodity categories exceeding the standard drone capacity of 12L and 4kg per trip has an impact on total UAV costs as it will require more trips and hence more flights

Lab samples are not affected as the increment is within the drone capacity

Other factors to consider

- Public transport is an inexpensive mode of transport and is used widely for transport of public health commodities. However, schedules can be limited and generally inflexible in the event of urgent needs, limiting the health center's ability to respond as needed.

- While the cost of salaries and per diem are included in transport costs where applicable, the opportunity cost of serving patients is not quantified. Health care workers are tasked with the delivery and collection of goods. For facilities near the collection points, the impact is likely negligible. However, for distant facilities and/or those with limited personnel, travel time requirements can be significant, effectively replacing time serving patients.

Near and Far Health Facilities

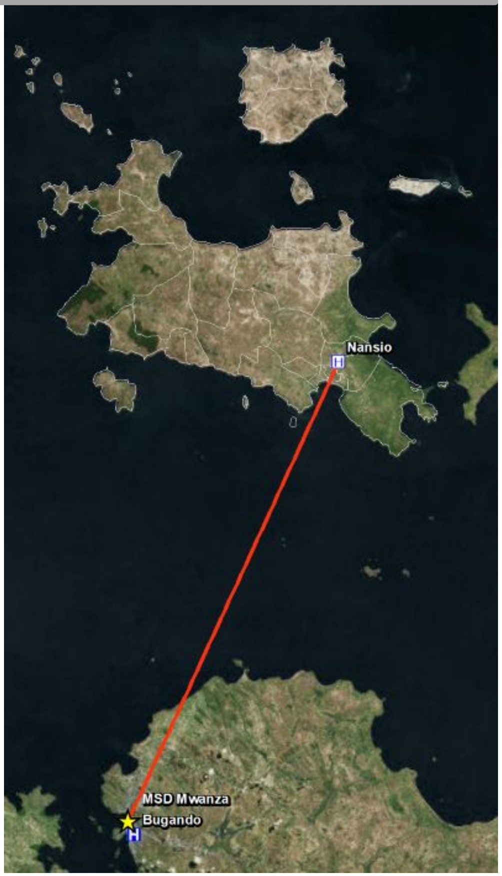
Near facilities are those within approx. 10km driving from the DH.

They are easy/ quick to reach and have low delivery costs.

Current delivery modes would remain more effective in terms of time and cost.

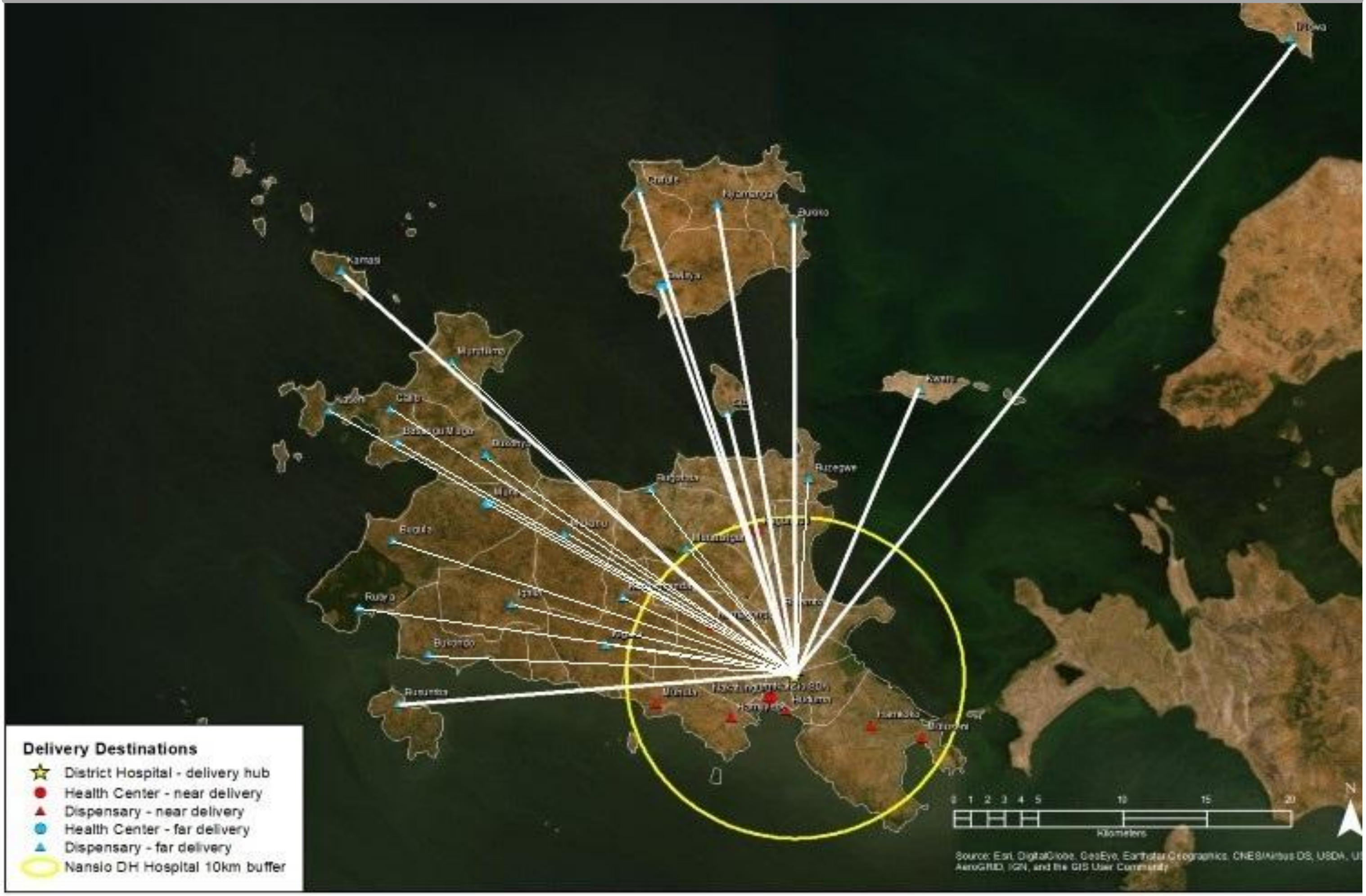
The most cost effective use cases for UAVs are for longer flights to further destinations, including the small islands and sites in Mwanza

Lab samples are most cost effective on these routes if used as the base use case for UAV delivery.



The most cost effective use cases for UAVs are for longer flights to further destinations, including the small islands and sites in Mwanza

Life-saving items would use these routes if used as a layered use case.



HEALTH IMPACT ANALYSIS

Overview

- **Objective:** To determine the health impact (in terms of deaths averted) if blood is sent by UAV compared to traditional transport, based on existing needs in Ukerewe
- **Emergency product considered:** Blood for transfusion
- **Data sources:** Four (4) healthcare facilities which provide transfusing services
  - Muriti, Bwisya and Kagunguli health center and Nansio district hospital.

Methodology

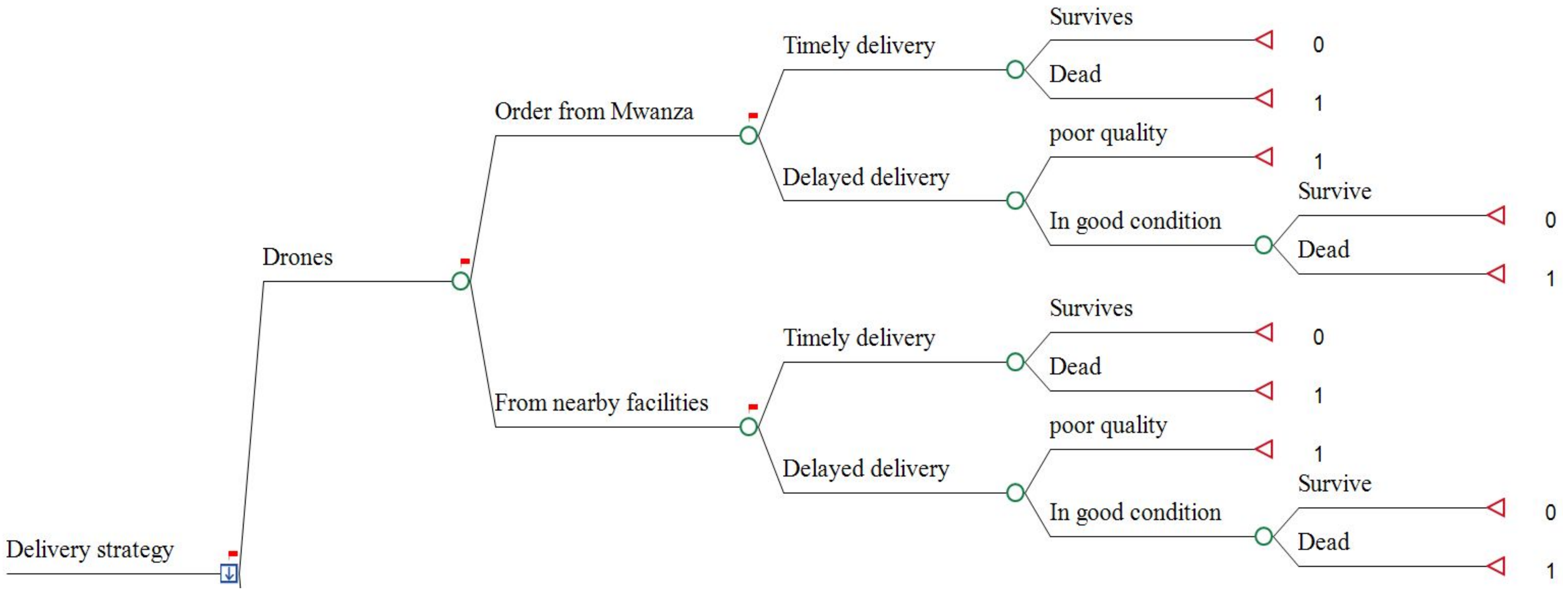
1. Determined the unmet need for blood transfusion (emergency orders required of blood), based on current data
   - number of cases requiring blood transfusion and the amount of blood required
   - amount of blood collected each week
   - amount of usable blood available
2. Compared the time it takes for traditional transport vs. drone for an order to arrive, in case the product is not available when it is needed.

Assumptions:

- a "late delivery" is anything more than 2 hours
- a "late delivery" would most likely lead to a fatal outcome (i.e. assumed case fatality rate of 90% following delayed blood transfusion)
- traditional transport reduces quality of product more than UAVs
- assumed case fatality rate of 5.2% for patients receiving blood transfusion

(Drammeh et al, 2018. Estimating Tanzania's National Met and Unmet Blood Demand From a Survey of a Representative Sample of Hospitals. Transfus. Med Review. 32 (1)

Decision tree model

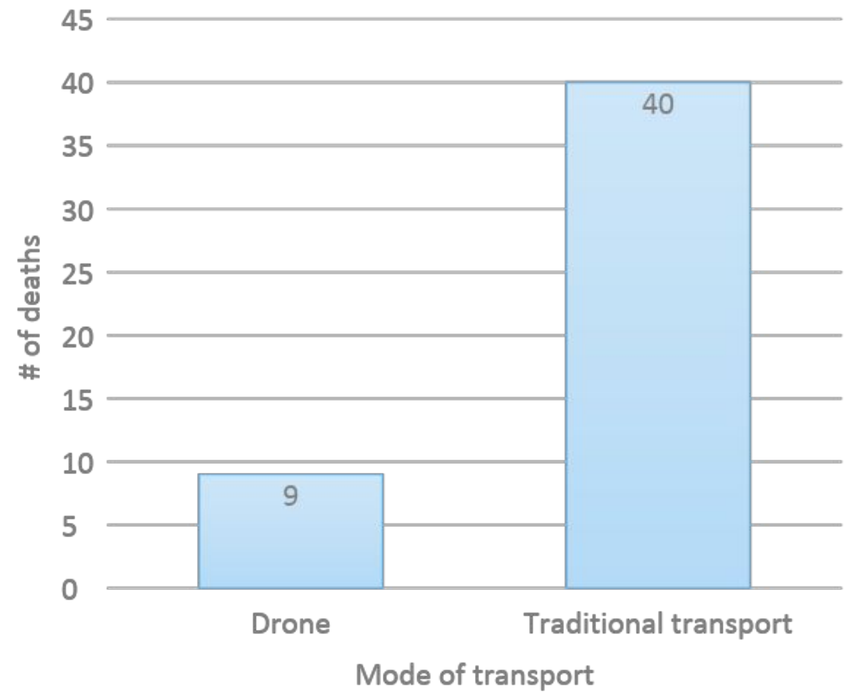


Results

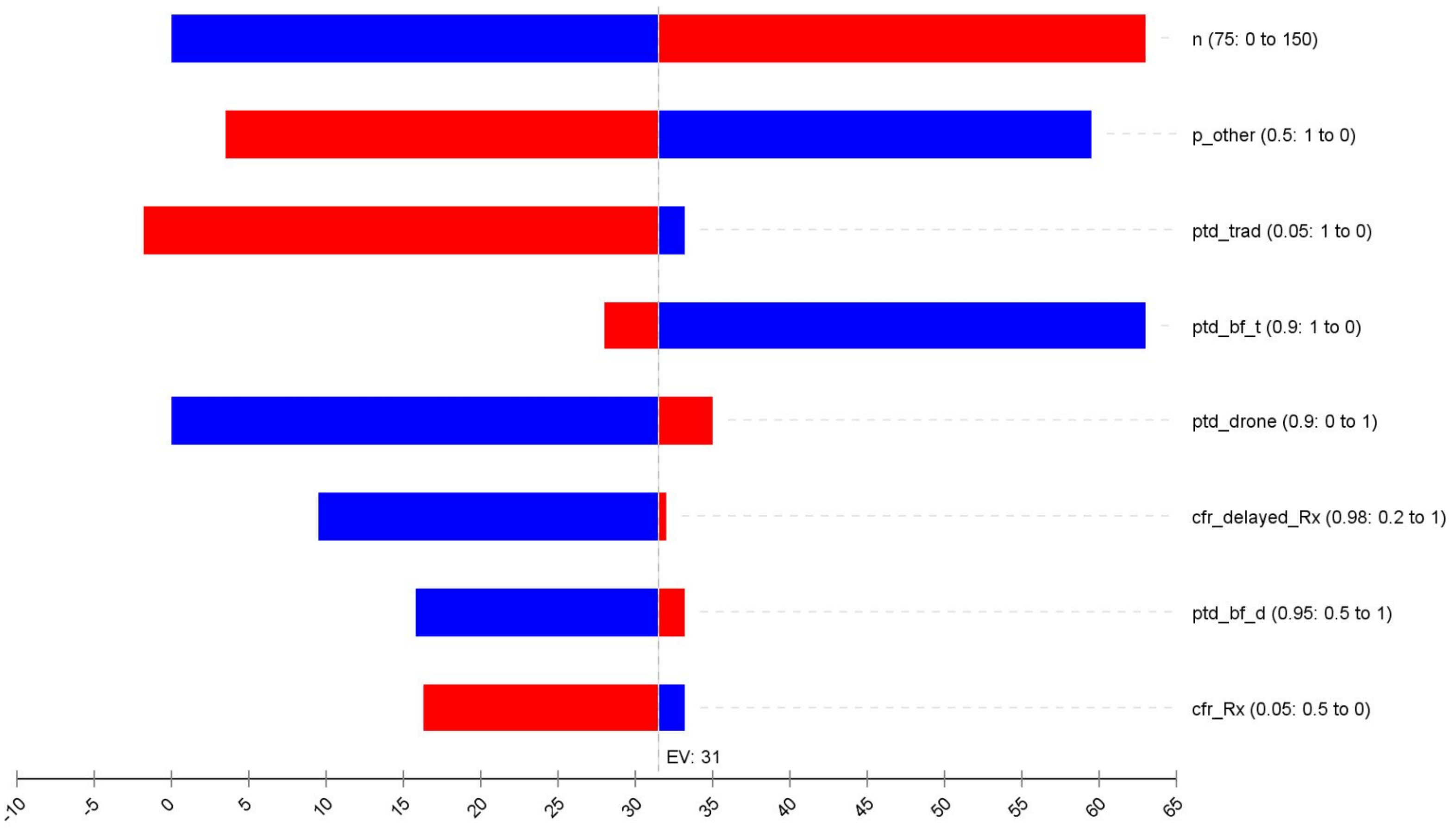
Unmet need for blood

- Number of cases requiring transfusion is 55/week, equivalent to 100 units of blood/week
- Blood collected is 116 units/week
- Proportion of blood screened 85% =100 units/week
- Proportion of screened blood fit for use 90% = 90 units/week
- Unmet need for blood 100-90 = 10 units/week, equivalent to 5 cases/week or 260 units/year
- 71% of blood consumed by preg. women & <5 years children
- Assuming 40% is for emergency =75 cases/year
- Units of blood received from other health facilities is 18/month=5 units/week

Base-case health impact



Sensitivity analyses-Tornado diagram



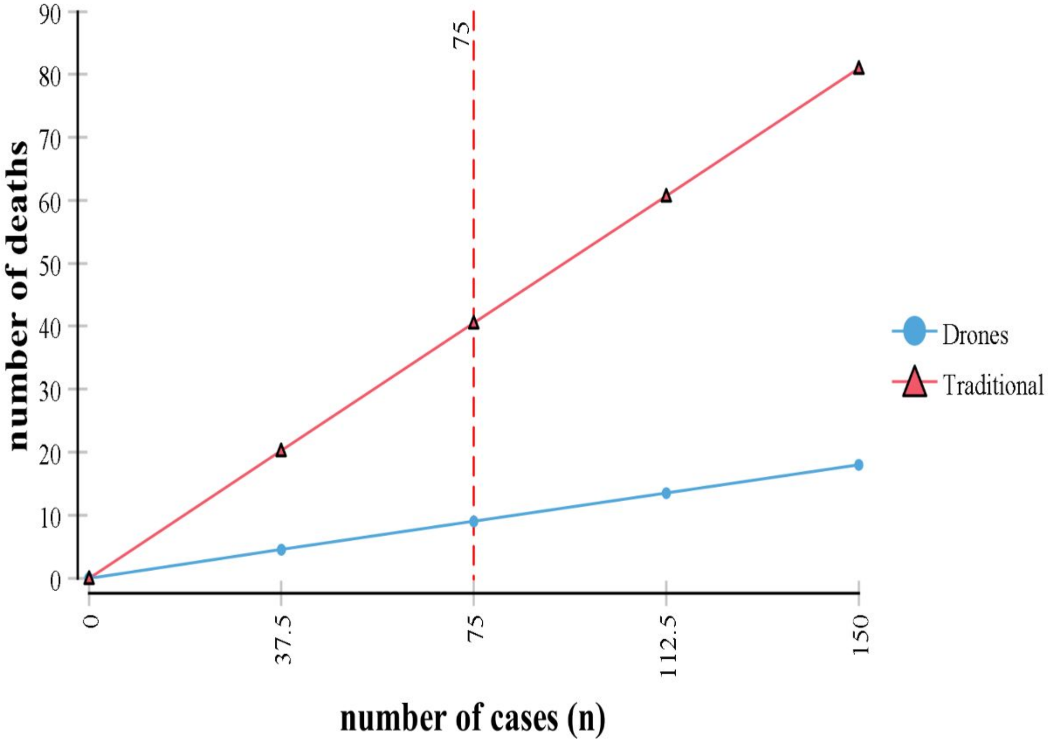
n-# of cases; *p_other* -probability of receiving from other facilities; *cfr-delayed_Rx* -case fatality rate with delayed transfusion; *ptd_drone* -probability of timely delivery by drone; *EV*- expected value/deaths averted

One-way sensitivity: number of cases

- Mortality in both strategies increases with increase in # cases with unmet need for BT

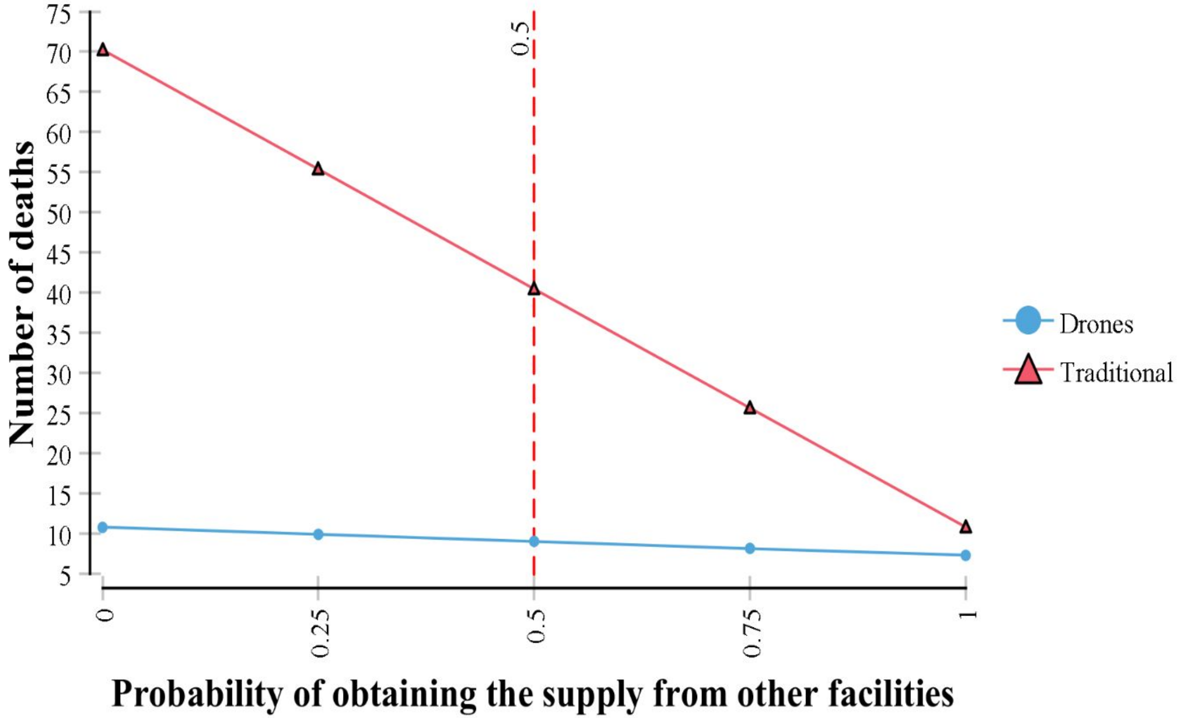
- At baseline n=75
  - 40 deaths, traditional transport
  - 9 deaths in the drone arm
  - Health impact: 31 deaths averted

- When n=150 cases:
  - 81 deaths, traditional transport
  - 18 deaths with drones
  - Health impact: 63 deaths averted



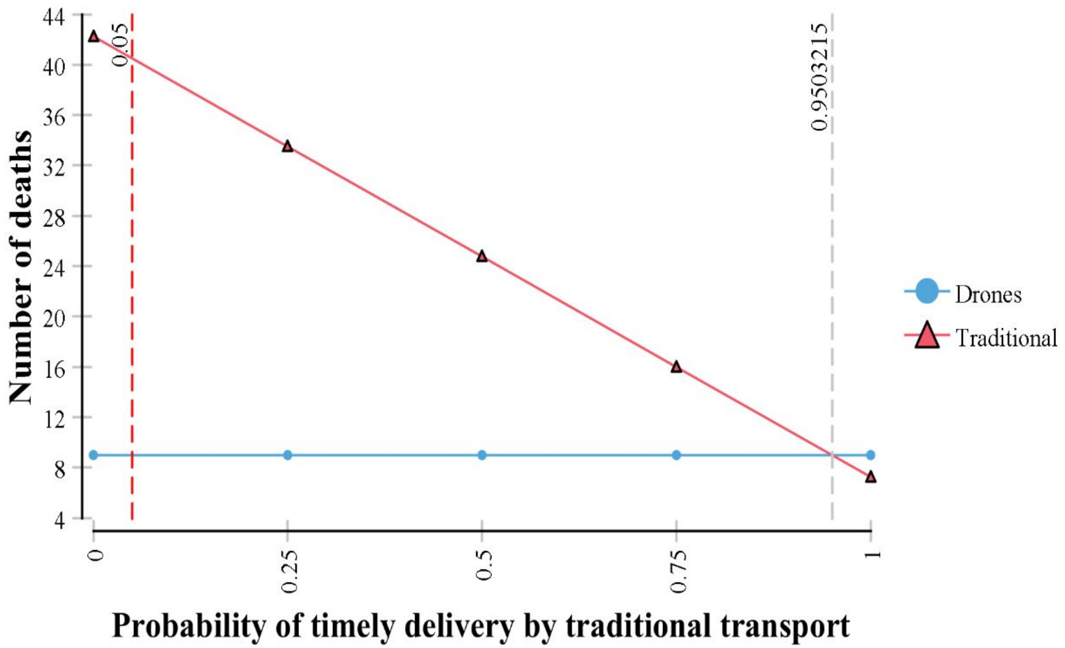
One-way-sensitivity: Sourcing from other facilities

- The unmet need is 10 units/week but they can obtain 5 units/week from other facilities i.e. probability of 0.5
- As the probability of obtaining blood from other facilities increase, the # of deaths decreases as no more blood has to be ordered from Mwanza
- The opposite is also true



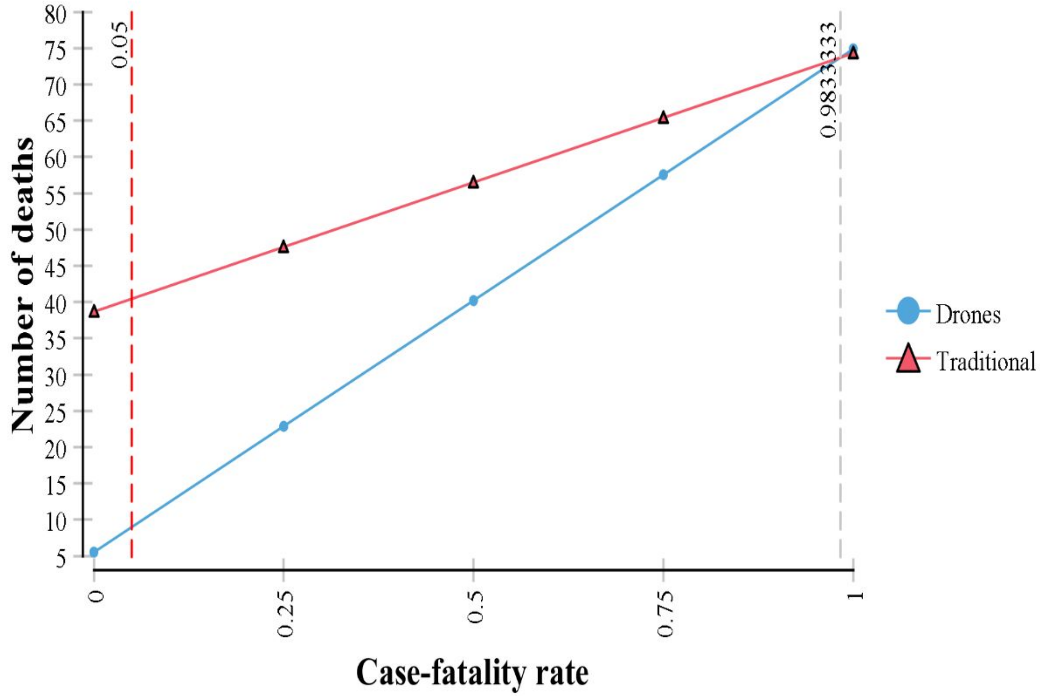
One-way-sensitivity: Timely delivery by ship

- At baseline we assumed that it is very unlikely to transport blood from Mwanza to the facility within 2 hrs i.e. the ship take 4-6 hours and is once/day
- But an increase in this probability (may be when a fast moving boat is used) then the number of deaths decreases.
- When it is unrealistically set at 95% there is no health impact as number of deaths is the same in both arms



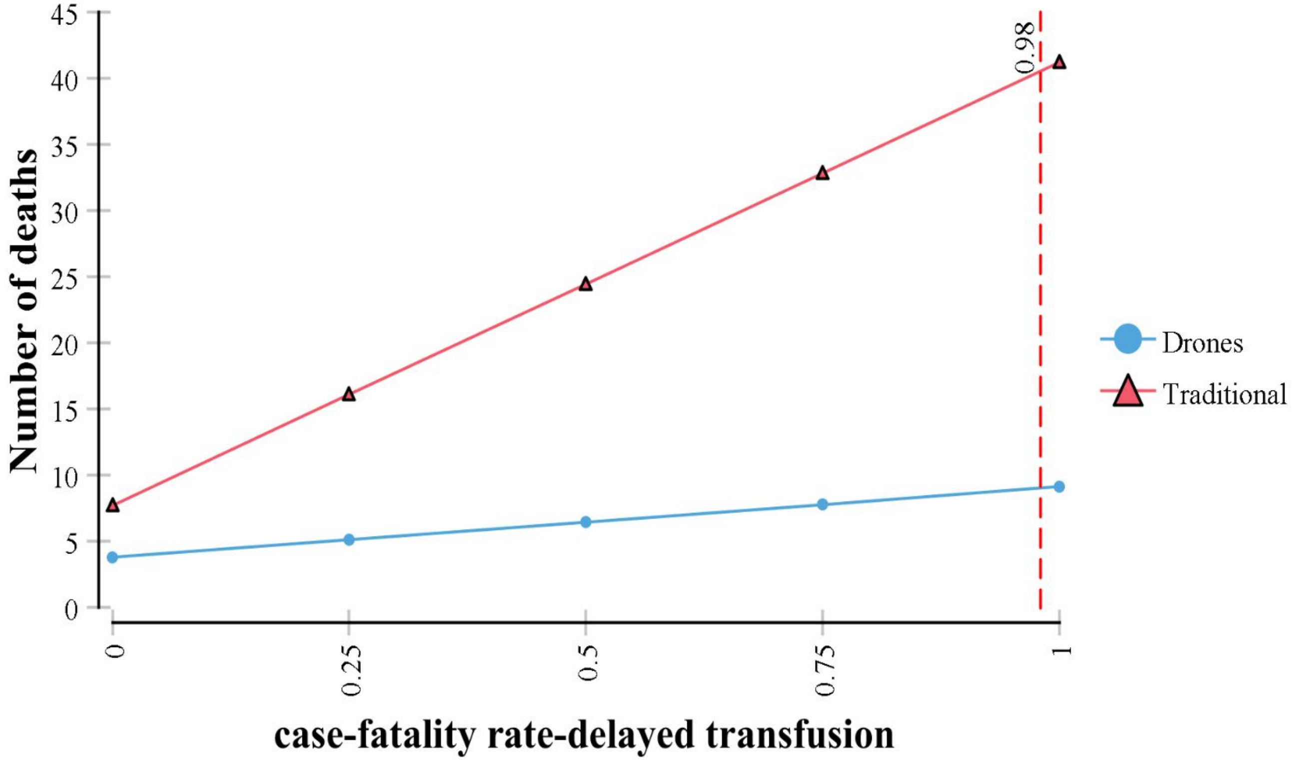
One-way-sensitivity: Case fatality rate

- On average 5% of people receiving blood transfusion in Tanzania dies *(Drammeh, 2018)*
- As CFR▲ mortality also increases, at higher rate in the drone arm
- When CFR is unrealistically at 98% health impact is zero as almost everybody dies in both arms



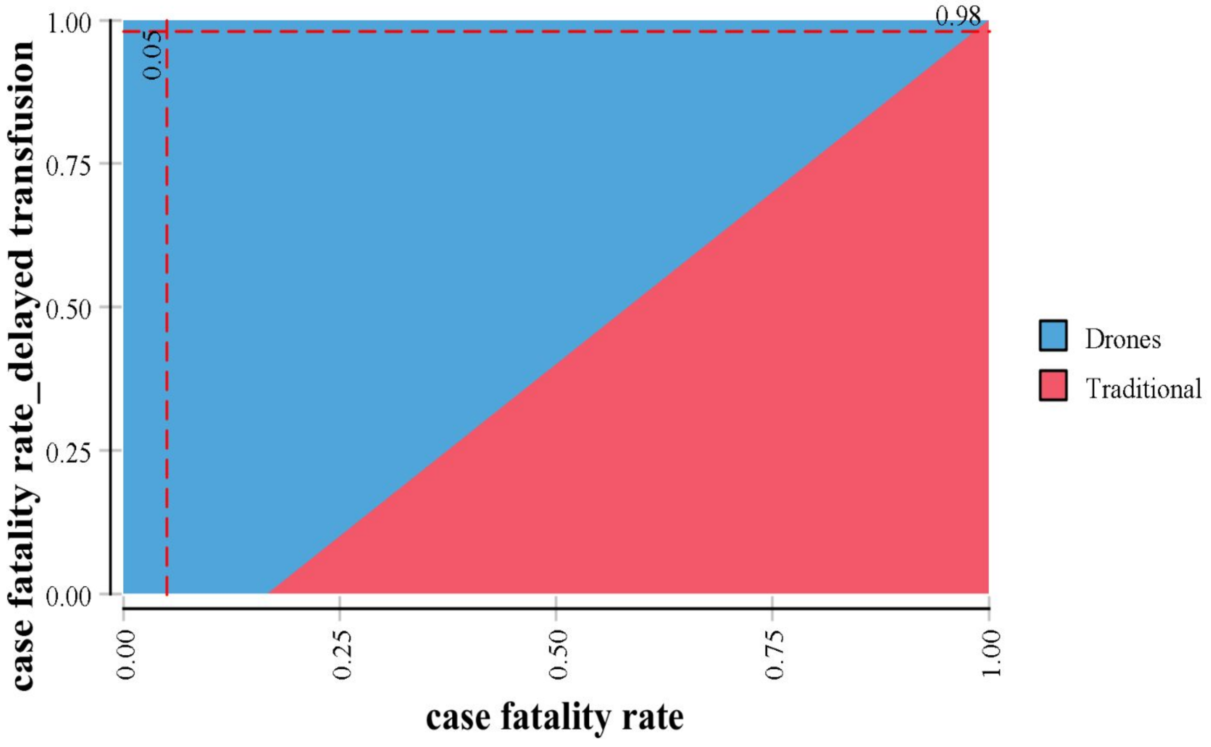
One-way sensitivity: Case fatality rate due to delayed transfusion

- At baseline we assumed a delay of blood transfusion of > 2 hours almost always leads to a fatal outcome i.e. CFR of 98%
- Decrease in this probability, which is unlikely reduces deaths in traditional trans arms more than the drone arm, hence reducing health impact



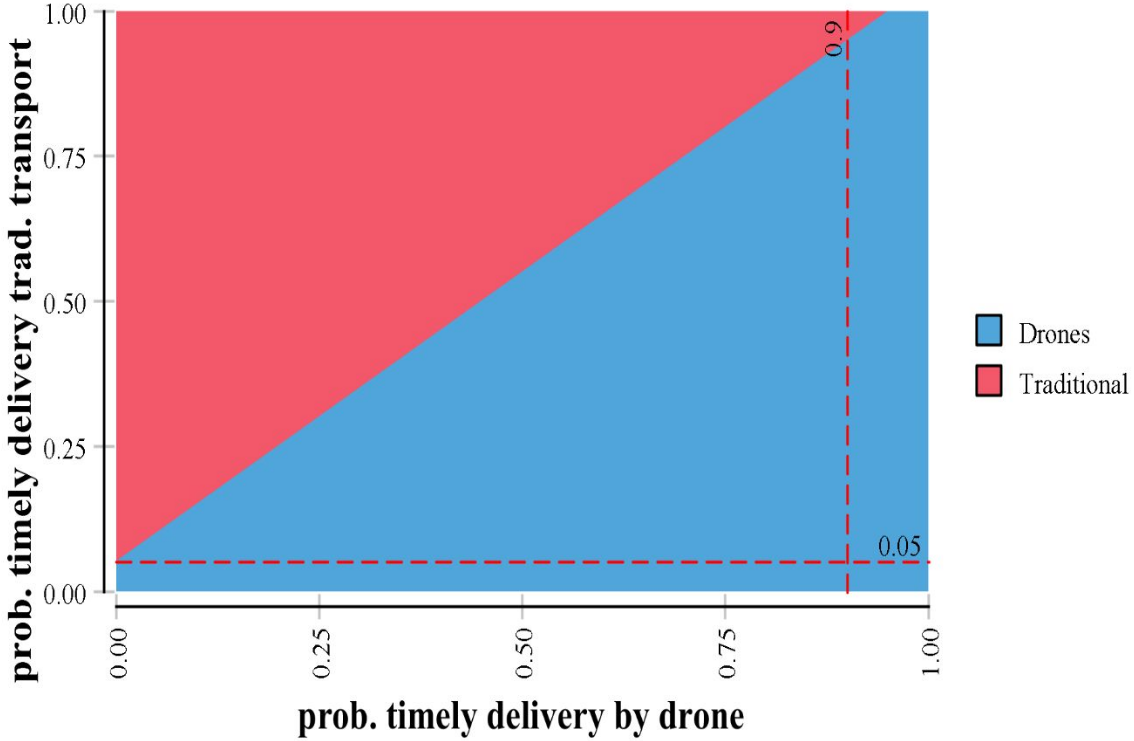
Two-way sensitivity: Case fatality rates

- At baseline café fatality rate was 5% and CFR following delayed transfusion was 98%
- As long as baseline CFR is below 23%, drones reduce mortality rates



Two-way sensitivity: Timely delivery

- At baseline we assumes probability of timely delivery were:
  - Drones 95%
  - Traditional transport 5%
- Drones avert death as long as the probability of timely delivery by drone is higher than that by traditional transport



Conclusion

- Deployment of drones to deliver emergency blood for transfusion in healthcare facilities in Ukerewe island reduces number of deaths by almost 80% compared to traditional transport

- It does this by enhancing timely delivery of emergency blood supplies to the four public health facilities in the district from:
  - Nearby transfusing facilities
  - National Blood for Transfusion Services in Mwanza

- Drones also facilitates delivery of high quality blood as there is high chance of hemolysis when traditional transport is used.
- Health impact increases with increase in number of people with unmet need for blood for transfusion.

Annex

Demand estimation

Category	2019	2025	2019 Vol (L)	2025 Vol (L)	
Vaccines (combined)	9,944,412	11,383,529	155,395	177,883	Based on coverage targets and population growth rate
Emergency Items					For many items, data was incomplete or required adjusting, limiting ability to calculate trends. Growth in health seeking trends will likely outpace population growth rate. Arithmetic or logarithmic growth applied for most items.
Oxytocin	23,000	33,000	318	456	
Mag. Sulphate	532	1,480	7	20	
Artesunate	51,840	60,968	3,732	4,390	
IV fluids	11,185	24,980	6,711	14,988	
Rabies & anti-venom	82	96	20	23	
Lab Samples	5,842	10,349	32,131	56,922	No historical data. Assumes 10% year over year growth.
Blood	3,504	6,208	943	1,670	

Stock out estimation for life-saving items stocked at the District Hospital

Life-Saving Items	Out of Stock Probability	Out of Stock Days	Demand for Period	Unmet Demand per HF per Year
Oxytocin	1.225%	300	18,401	3.36
Magnesium Sulphate	0.82%	100	2,314	0.56
Artesunate	0.79%	170	59,608	8.01
IV fluids	4.38%	1,011	6,329	4.01