Photo: Ken Kistler

Framework for the evaluation of cost-effectiveness of drone use for the last-mile delivery of vaccines

Review, comparison and benchmarking of last-mile logistics costs for pharmaceuticals, vaccines and associated commodities.
The case for or against drones for vaccine delivery.

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ACRONYMS AND ABBREVIATIONS

BCG	Bacille Calmette-Guérin vaccine
DALY	Disability-Adjusted Life Year
DLS	Dedicated Logistic System
DPT3	3 doses of combined Diphtheria, Pertussis, Tetanus vaccine
EPI	Expanded Programme on Immunization
GPS	Global Positioning System
GVAP	Global Vaccine Action Plan
HPV	Human papillomavirus vaccine
IPV	Inactivated polio vaccine
LMIC	Low and Middle Income Country
M	Measles vaccine
OPV	Oral polio vaccine
Pentavalent	Diphtheria-tetanus-pertussis-haemophilus influenza type B-hepatitis B vaccine
PEP	Post-Exposure Prophylaxis
PCV	Pneumococcal conjugate vaccine
QALY	Quality-Adjusted Life Year
ROI	Return on Investment
RV	Rotavirus vaccine
SAGE	Strategy Advisory Group of Experts on Immunizations
SDG	Sustainable Development Goal
TT	Tetanus toxoid
UAV	Unmanned Aerial Vehicle
UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
UPDWG	UAV for Payload Delivery Working Group
UPS	United Parcel Service
WHO	World Health Organization

EXECUTIVE SUMMARY

Per WHO data from 2016 up to 1.5 million deaths each year could be prevented though improvements in global vaccination coverage. In 2015 only 27% of the member states of the Global Vaccine Action Plan (GVAP) reached the coverage and equity targets for DPT3 of a coverage of ≥90% on national level and a coverage of ≥80% in every district.

One of the reasons identified is the challenge to provide access to vaccines in last mile settings where road infrastructure is limited or non-existent. Insufficient, unreliable cold storage capacity to accommodate the increased quantities and volumes of vaccines required due to new introductions has also been reported as a challenge.

A limited number of cost evaluations of drone use for medical delivery has been performed to date. All of them suggest considering drones as a complement mode of delivery in addition to the existing supply chain system. Scenarios that can benefit from drone use differ. Ideally, modeling is used to identify bottlenecks and determine how to integrate drones in the most cost-effective way as both land transport and drones have different strengths, such as higher payload for land transport versus increased speed and flexibility for drone transport.

Different drone types such as fixed-wing, multi-rotor and hybrid drones have been tested in pilot medical delivery projects. A variety of models exist with a variability in flight range, speed, payload, landing capabilities and cost. Different business models are available ranging from purchasing to leasing.

Drones, permitting a higher frequency of delivery, could be used to avoid vaccines stock-outs at health facilities. Cost savings that can offset the potentially higher cost of the implementation of drone use are possible, when the inventory holding time is reduced and hence the inventory holding cost as well. Waste of unused expired vaccines or vaccines compromised in quality because of failures in cold storage due to unreliable electricity can also be minimized by more frequent drone deliveries. When only a limited cold storage capacity is available and neither the installation of an additional cold storage equipment is possible, nor a more frequent delivery of vaccines with traditional means of transportation due to limitations in driver and vehicle availability, drones could be used to assure continuous vaccine availability. Drones could also increase access to vaccines in areas that are not connected by road infrastructure at all or year-round.

For deliveries of small payloads such as emergency shipments drones can save costs compared to motorcycle deliveries. Cost savings for drone use can result from reduced drone operation costs, not requiring fuel and from decreased human resources costs, as one person can operate several drones at a time and drones are faster. In places where fuel prices are high or fuel availability is not always guaranteed drones can provide an advantage.

Future evaluations, however, should go beyond cost and supply chain performance and look at health-related outcome indicators such increased vaccination coverage, morbidity, mortality, DALYs or even monetary benefits.

Furthermore, operational constraints of this new technology as well as constraints of pending regulations and uncertain local acceptability need to be considered when planning an implementation of drone use for the last mile delivery of vaccines.

1. INTRODUCTION

Significant efforts are needed to increase both, coverage and equity of vaccine supplies and services in low and middle income countries. Introducing new vaccines as per WHO recommendations for routine immunization can be a challenge for countries due to the increased volumes of the newer vaccines. This is placing strains upon the capacity of existing supply chains. (1,2)

Gavi's 2016-2020 strategic goals seek to accelerate equitable uptake and coverage of vaccines by improving the availability, potency, and cost-efficiency of vaccine supply chains. Therefore, Gavi is committed to promoting new and innovative methods to increase the capacity of supply chains to safely deliver vaccines, while at the same time seeking to achieve improvements in the overall cost-effectiveness of vaccination services. (1)

Various options have been considered for adapting to the increases in vaccine volumes. Those included expanding the existing infrastructure of cold rooms, refrigerators and vehicles and re-examining the fundamental architecture of the supply chains. There has been growing use of stochastic modeling software such as HERMES to seek to predict the possible costs and effects of reducing and consolidating the absolute number of levels of intermediate storage facilities, and the frequency, velocity, flexibility and methods used for distribution, especially to the points of service delivery. (2–4)

Recently, the use of drones for last mile distribution has been put forwards as an innovative approach to improving delivery effectiveness and potentially reducing the associated costs, especially in situations where the existing road infrastructure is insufficiently developed. Early trials of drones have now begun to test their technical feasibility for the delivery of relatively small volumes of key health commodities. They are being piloted to transport blood specimens from remote sites to diagnostic facilities or to deliver blood products from a central storage to various health facilities. (5) Each variant of these drone-based delivery systems has limitations of payload, range, speed, safety and security, as well as requirements for a management and support infrastructure that impacts total costs and operational effectiveness. (5,6)

The objective of this document is to guide in decision making around when and under what circumstances to consider the use of drones for the last mile as a viable alternative taking into consideration cost-effectiveness and limitations.

2. METHODOLOGY

The present report is based on a non-systematic review of literature (both scientific and published and unpublished grey literature) and on feedback from experts in the field.

Published literature search

A comprehensive non-systematic search of peer-reviewed articles in Pubmed and in Wileys Online Library which includes the Health Economic Evaluations Database (HEED) was conducted. Key words used for the search are displayed below:

- Drone AND (cost OR econom*)
- unmanned AND (cost OR econom*) (This will include Unmanned aerial vehicle –UAV- and unmanned aircraft system – UAS-)
- Remotely piloted AND (cost OR econom*)

This broad keyword search in English with no time limitation, due to the novelty of this mode of transport, was applied because a preliminary research revealed that the number of publications on cost-effectiveness studies for drones used in delivery is very limited and no relevant article was found. The results from the broader search were then reviewed for further keywords such as health, vaccine, delivery, and transport to decide on the relevance of the publication concerning the last mile delivery of vaccines by drones.
Vaccine supply chain background information was searched in Pubmed using keywords "vaccine AND supply chain" or "immunization AND supply chain".
Furthermore, WHO, UNICEF and PATH websites were consulted for background information on vaccination coverage and challenges of the vaccine supply chain in the last mile.

Google and Google Scholar search

To identify drone suppliers, drone projects and experts that can potentially contribute content to the study question, the below keywords were used in various combinations in the Google and Google Scholar search engine.

- Drone or Unmanned or UAV or UAS or Remotely Piloted Aircraft
- Health or vaccine or medical
- Delivery or logistic
- Economic evaluation or cost-effectiveness

Grey literature search

Karen McNulty, UPS Secondee to Gavi and supervisor of this Master Final Project provided the list of stakeholders shown in table 1 below and facilitated my introduction to the UAV for Payload Delivery Working Group (UPDWG) to identify further potential contributors of grey literature relevant to the study question, both published and unpublished. In addition, I visited the Humanitarian UAV Network UAViator website regularly and subscribed to the International Association of Public Health Logisticians (IAPHL) mailing list to be updated about ongoing and planned drone pilot projects. Those activities resulted in the identification of the contributors in table 2.

Table 1:

Organization	Stakeholders	Position	Selection criteria
Gavi	Ian Sliney	Senior Manager, Health Systems and Immunisation Strengthening	Involvement in UAV delivery pilot project of blood supplies in Rwanda
Gavi	Mozammil Siddiqui	Manager Global Operations Partnership, Private Sector Partnerships	Involvement in UAV delivery pilot project of blood supplies in Rwanda
Gavi	Simon Sternin	Manager Coverage and Equity, Immunization	Involvement in UAV delivery pilot project of blood supplies in Rwanda
Gavi	Hamadou Dicko	Acting Manager, Supply Chain Team, Health Systems and Immunization Strengthening	Involvement in UAV delivery pilot project of blood supplies in Rwanda
UPS/ Gavi	Karen McNulty	UPS Secondee to Gavi, Health Systems and Immunization Strengthening	Involvement in UAV delivery pilot project of blood supplies in Rwanda
UPS	Jerome Ferguson	Director of Autonomous Vehicle Engineering	Involvement in UAV delivery pilot project of blood supplies in Rwanda

Table 2:

Organization	Contributors	Position	Selection criteria
Village Reach	Rachel Powers	Associate, Information Systems	Facilitator of the UAV for Payload Delivery Working Group (UPDWG) roundtable call
Llamasoft	Sid Rupani	Regional Director - Africa, Middle East, Asia	Involvement in development of technology to model and optimize supply chain networks using drones
John Snow, Inc.	Yasmin Chandani	Project Director - inSupply	Working on a Cost Benefit Analysis of Unmanned Aerial Vehicles (UAVs) in Public Health Supply Chains in Tanzania
John Snow, Inc.	Marasi Mwencha	Tanzania Country Team Lead - inSupply	Working on a Cost Benefit Analysis of Unmanned Aerial Vehicles (UAVs) in Public Health Supply Chains in Tanzania
Werobotics	Patrick Meier	Executive Director and Co-Founder	Founder of the Humanitarian UAV Network (UAViators) and author of the book " Digital Humanitarians"
Global Public Health Supply Chain Team	David A. Allan-Matheson	MBA, MSc	Provision of Drone Feasibility evaluation for commercial markets in Africa and Insights for the Future
Global Public Health Supply Chain Team	Michael Morton	MSc	Provision of Drone Feasibility evaluation for commercial markets in Africa and Insights for the Future
Drones for Development	Gerald Poppinga	Co-Founder	Co-Author of Drones for Development Dr.One Proof of Concept and Business Case
Vayu	Julie Bateman	Director of Operations	Provision of working paper on medical use cases for drones
Wingcopter	Ansgar Kadura	Contact Person	Insight in drone operations

Development of the draft framework

The collected published and grey literature related to cost evaluations of drone use in medical delivery was assessed. As the quantity of available information on this topic was deemed very limited, additional searches to provide background information on challenges in vaccine supply chains and current immunization coverage data were performed. Furthermore, information on different drone types, their strengths and limitations as well as information on drone regulations was included in the framework to provide a basis for the decision making beyond the limited available cost-effectiveness information. The results from the available literature review about cost-effectiveness of drones were summarized, analyzed and a table with the main conclusions was created.

Stakeholder feedback and finalization of the framework

The stakeholders listed above (table 1) were asked to provide a written feedback on the draft framework considering content, structure, clearness, and usefulness. Of those, 5 responded with comments and suggestions for consideration. When deemed appropriate, changes to the document were performed to provide the final version of the framework.

3. GEOGRAPHICAL AND COUNTRY FEASIBILITY CONSIDERATIONS


Photos: Heike Würbel

Global inequities in access to vaccines

Per WHO data from 2016 improvements in global vaccination coverage could prevent 1.5 million deaths from vaccine preventable diseases such as diphtheria, tetanus, whooping cough, and measles every year. (7) To reach a higher vaccination coverage it is important to bridge the gap in inequities in access to life saving vaccinations. Per the Strategy Advisory Group of Experts on Immunizations (SAGE) midterm review of the Global Vaccine Action Plan (GVAP) only 27% of the member states reached the equity targets for DPT3 of a coverage of ≥90% on national level and a coverage of ≥80% in every district in 2015. One of the five key challenges identified is ensuring access to vaccines at all places and all times (8). This highlights the importance to find new innovative ways of reaching every district and every health facility.

Madagascar as an example country with last mile challenges in vaccine supply chains

One of the largest equity gaps related to immunization can be found in Madagascar and mainly affects the rural poor population. The immunization supply chain is a challenge in Madagascar due to the challenging environment of the country and the poor infrastructure. Half of the poor live more than 5 km away from a health facility and there are villages as far as 100km away from the next health centre. Some villages can only be reached by foot. Outreach sessions are critical to reach an equitable immunization coverage, however, means of appropriate transportation, fuel and a sufficient number of trained health workers are needed to be able to reach the unvaccinated children in such remote villages. (9)

Drones as an alternative transport mode of transport for vaccines

Photo: Heike Würbel

Drones may be used as an alternative transport option to reach locations with an insufficient infrastructure. A pilot project initiated by the Stony Brook University's Global Health Institute and Vayu, a drone start-up successfully delivered drugs and laboratory samples to remote places in Madagascar in 2016. (10) Places connected by roads that permit vehicles to move at slow speed only, locations that cannot be reached all year due to the rainy season and locations, that cannot be reached by road at all may be considered for drone use. Remote places in mountain areas, desserts, swamps, dense forests, or on islands that can only be reached by transport modes like motorbikes, bicycle, donkeys, camels, on foot or by boat should be taken into consideration. Assuring the cold chain using such transport options is a challenge. Faster drone deliveries could provide a valuable alternative to reach populations that are difficult to reach otherwise (11,12). Where health facilities are not adequately equipped to store medical products, that require cold storage and careful handling during transport, drones could increase the availability of vaccines and save lives. (13)

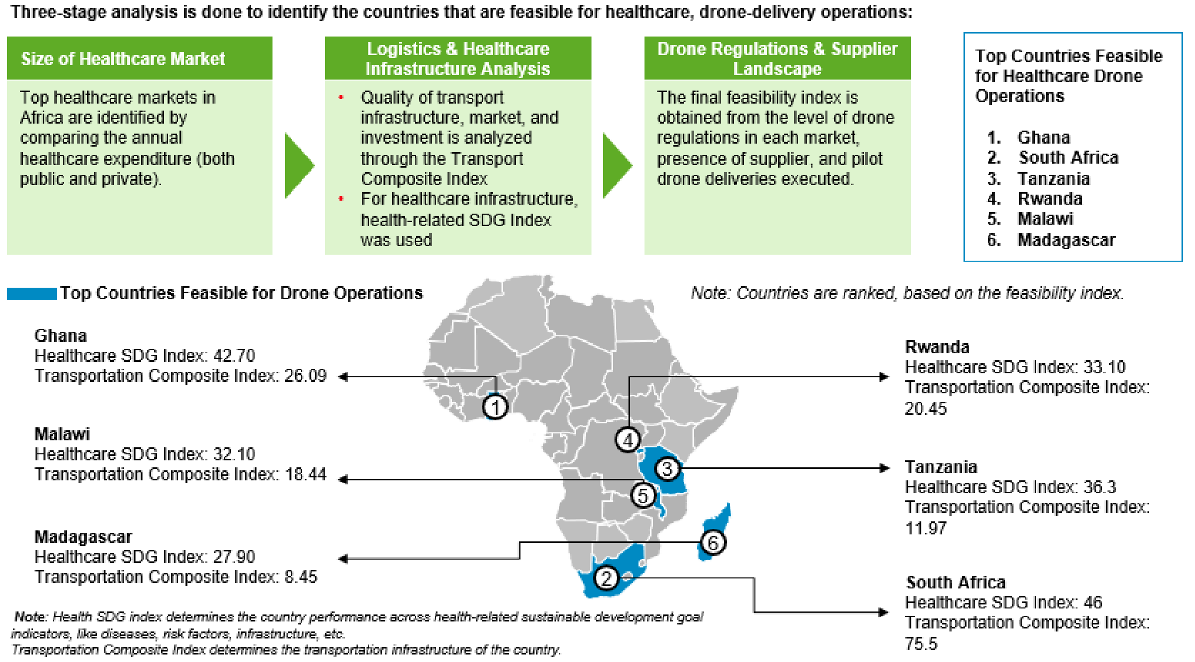
Vanuatu as a second example country with last mile challenges in vaccine supply chains

Also, island countries, such as Vanuatu could profit from the use of drones to reach remote areas and outer islands. The use of drones for the delivery of vaccines instead of boats navigating on the open sea could help avoid stock-outs, ensure vaccines are available when needed and save lives. UNICEF is working with the government of Vanuatu on a pilot drone project with a planned implementation in July 2017. If drones succeed in delivering vaccines and prove to be a cost-effective an implementation is not only foreseen for Vanuatu but also for other pacific island countries starting in 2018. (14)

Countries identified for commercial drone operation in the healthcare sector in Africa

Six countries in Africa (Ghana, South Africa, Tanzania, Rwanda, Malawi and Madagascar) have been identified as feasible for commercial drone operations in the healthcare sector. The analysis considered the size of the healthcare market through comparison of public and private healthcare expenditure. In addition, the logistics and healthcare infrastructure was analyzed. To determine the healthcare infrastructure the Healthcare Sustainable Development Goal (SDG) Index, a composite index of health-related indicators was used. To determine the logistics infrastructure the Transport Composite Index of the African Development Bank was used. The final feasibility was obtained by the level of drone regulations in place in addition to a drone supplier presence or pilot project in the country. (15)

Figure 1:



Slide 7 of 'Drone Feasibility Study and Insights for the Future' (15)

Which countries might benefit from a vaccine delivery by drone to decrease the inequity in access?

The focus of the above analysis is on commercial drone use and therefore it favors countries with a high Transport Composite and Healthcare SDG Index, however this way of classification may not be the most appropriate for the goal of delivering vaccines equitably to countries most in need, e.g. countries with a low vaccination coverage due to poor road infrastructure and other challenges in the healthcare system. For such a consideration, likely countries with a lower Transport Composite Index, such as South Sudan, Chad, the Democratic Republic of Congo, Ethiopia, Mozambique or Niger (16), to provide a few examples, may benefit even more from the use of drones to increase the vaccination coverage. Identifying countries with particularly low district level vaccination coverage rates, given data are available, might be another approach to identify countries and areas potentially suitable for drone use to increase access.

Drone regulations in low and middle income counties (LMIC) with a DPT3 coverage of <90%

Thirty-three countries eligible by Gavi in 2016 with a DTP3 vaccination coverage of <90% in 2015 were identified and the Global Drone Regulation Database was consulted. Only six of those countries have drone regulations in place: Ghana, India, Kenya, Madagascar, Nigeria and Papua New Guinea as of March, 2017. Benin and Zimbabwe are working on regulations for the operation of drones. Countries such as Chad, Mali, Mauritania, Senegal, Togo and Uganda do not have a dedicated drone regulation in place, but have amended their aviation regulations to add drones. However, it is unclear to date if those are legally binding and effective. Drone regulations in Malawi are unknown, but the government is open to collaborate on drone use. The remaining countries do not have regulations in place or no information is available. (17–19)

CONCLUSIONS

The use of drones to reach the last mile could not only increase the availability of vaccines and hence the vaccination coverage but also lead to a greater equity in access to life saving vaccines for populations living in remote locations, that are not reachable by other means of transport either year-round or in the rainy season.

4. VACCINE CHARACTERISTICS AND SUPPLY CHAIN CHALLENGES

Photo: WHO

The requirement for a vaccine to be transported and stored in a constant cold chain until immunization takes place puts immense strains on the supply chain, particularly in last mile settings in low and middle income countries (LMIC) where high temperatures and a lack of reliable electricity is common. (20) It can be a challenge to assure the 6 rights of logistics in such a setting: To make the right vaccine available at the right moment and right place, in the right quantity and right quality at the right cost.

The challenges of the vaccine supply chain

With the introduction of new expensive and high volume vaccines with sophisticated packaging, such as the pneumococcal conjugate (PCV), the rotavirus (RV) or the human papillomavirus (HPV) vaccine, strains have been placed on the existing supply chain systems due to the increased need for cold storage space. (20) The PCV pre-filled syringe for example requires nearly 20 times the storage space of a 10-dose vial vaccine used in the traditional Expanded Programme on Immunization (EPI). This can lead to storage capacity bottlenecks at all levels of the supply chain and a delayed introduction of new vaccines. (21)

Cold storage capacity

Coping strategies for a limited cold storage capacity due to increased vaccine quantities and volumes include overstocking. Overstock can result in an increased wastage of vaccines and therefore a higher cost for the vaccination program. This is because of system failure due to compromised air flow or because of compromises in stock management practices, not always resulting in the use of the vaccine with the shortest expiration date first. Alternative coping strategies have been described. For example, vaccines are stored in a regional storage facility that has a sufficient storage capacity instead of the district facility. However, this may lead to a stock-out in another regional health facility with less storage capacity or even at the district level. Supplies should be distributed according to need and not according to the storage capacity. Another coping strategy described is the reduction of the buffer stock level. This is also not recommendable, as it can equally result in stock outs, unless there are alternative options available to quickly replenish the needed stock. Suggested short term solutions for cold storage capacity constraints are the purchase of additional cooling equipment. (20)

Cold storage equipment and vaccine vial wastage

Besides a sufficient storage capacity, it is crucial to have continuous access to electricity or kerosene to run the cooling equipment. Solar powered refrigerators are an alternative. It is important to monitor the temperature constantly and have a proper maintenance in place. A failure of a cooling equipment can result in a damage of thousands of dollars particularly if the stored vaccines include newer, more expensive vaccines. The higher cost of the newer vaccines make an improved supply chain planning necessary to prevent unnecessary costs resulting from vaccine wastage, which was estimated by WHO to consist of up to 50% in some countries, considering both open and closed vials. (9,20) While closed vial wastage should not exceed 1% at each service level and can be decreased by supply chain improvements, open vial wastage depends on the vaccine type and WHO policy on the use of opened multi-dose vials and a higher wastage is acceptable particularly in remote locations and for outreach activities to avoid missed opportunities. (22)

Distribution consideration

An alternative to resolve the challenge of a limited storage capacity at a health facility is to change the delivery frequency, the route or mode of transport or the facilitator of delivery to meet the vaccination demand and schedules. Outsourcing of delivery has been considered in some low and middle income countries as a solution. (20) Different distribution options exist. A push system allows the supplying entity to decide about the quantity of resupply to be provided. The pull system on the other hand allows the lower level, for example the health facility to decide on the required quantities of resupply. The decision is a trade-off between up-front investment and the need for capacity building for the push system, generally resulting in greater reliability and less direct investment costs for the pull system, but a higher burden for the health workers, who need to do the calculations and in some cases need to pick up the supplies. (4) An example of a push system is the Dedicated Logistic System (DLS) implemented by VillageReach in Mozambique, that freed health workers from picking up vaccines at district level giving them more time to provide healthcare. This was possible by training a small workforce responsible for logistics and inventory management across a number of health centers. (3)

Modeling software

In recent years, a growing use of stochastic modeling software such as HERMES has been observed to seek to predict the possible costs and effects of reducing and consolidating the absolute number of levels of intermediate storage facilities, and the frequency, speed, flexibility and methods used for distribution, especially to the points of service delivery. (2,3)

Supply chain investments

Even though the above described challenges resulting in frequent bottlenecks in the supply chain threaten the vaccine availability, quality and access, investments in supply chain optimization have received little attention in the past decade. It is however necessary to improve the supply chain systems to be able to increase the vaccine coverage and reach a higher percentage of the population with vaccines. (20)

Can drones help to overcome some of the described supply chain challenges?

New ways of vaccine delivery could be a potential solution for some the above described challenges. Drones could provide vaccine supplies in case of stock outs or critically low stock levels. They can deliver vaccines at a higher frequency and speed compared to traditional land transport. Decreased inventory holding costs and a higher frequency of delivery can reduce the cost of this innovative mode of delivery. Besides the need for new cold chain equipment could be delayed (23). After analysing the data of the Tanzanian Immunization & Vaccination Department from 2015, Zipline drone implementation was suggested for use in periods of an increased vaccine demand for example during vaccination campaigns and to increase the coverage of vaccines that do not meet the coverage target. (24) Vayu, a drone manufacturer, describes the use of drones as an opportunity to deliver vaccines to remote health facilities on an “as-needed” basis during shortages. Waste can be reduced through frequent small deliveries. The potential benefit on the quality of the vaccine generally requiring refrigeration also during transport due to the shorter transport times was also specified. Drones could additionally be used to provide vaccines in emergency situations such as outbreaks of vaccine preventable diseases. (13)

CONCLUSIONS

To conclude, vaccine cost, temperature requirements, packaging configuration, availability of appropriate local cooling equipment and maintenance as well as demand and frequency of deliveries play an important role for the implementation of effective supply chain systems and are crucial to avoid disrupted supply chains on one hand and wastage on the other hand. Innovative modes of delivery, such as drones could improve the performance of the existing immunization supply chain systems.

5. DRONE CHARACTERISTICS

Drone types

Drones may be classified into three main prototypes, the fixed wing, the multi-rotor and the hybrid drone. The main characteristics or the three types are described in the table below.

Table 3:

Fixed Wing Drone	Multi-Rotor Drone	Hybrid Drone
e.g. Zipline, Wings for Aid	**e.g. Matternet, Flirtey**	**e.g. Drones for Development, Vayu**
Aeroplane-like	Quad-copter, helicopter or octo-copter	Combines advantages of Fixed Wing and Multi-Rotor
Faster (up to 100 km/h)	Shorter flight time	Faster (up to 100 km/h)
Longer distances (up to 150 km)	Shorter distance (up to 20 km)	Longer distances (up to 80 km)
Payload (1.5-4.5 kg)	Payload (up to 4.5 kg)	Payload (up to 5 kg)
Require landing strip and catapult	Vertical take-off and landing	Vertical take-off and landing
Can only go one way; cannot return supplies	Battery replacement on the way optional; could return supplies	Battery replacement on the way optional; could return supplies
Parachute option to drop supplies	Generally cheaper	Generally more expensive


(6,25–27)

Drone cost and operation considerations

The cost varies and depends on the manufacturers' business models. Drones can be purchased or leased.

Table 4:

	Zipline	Matternet	Vayu	Drones for Development Dr.One
Immediate cost	Model on a per flight basis with a minimun number of flights agreed upon. Drones are not for sale	USD 5,000-USD 7,500 per drone	USD 30,000 per drone	USD 5,000 per drone. Cost are expected to decrease with scale-up
Further cost	No long-term capital or maintenance costs	Cost for infrastructure e.g. landing stations or maintanance costs if needed for battery, motor or propeller	Replacement cost of battery after 1000 cycles	The life time of a drone is expected to be 5 years, the battery life 12 month

(28)

Drone specific trainings for personnel at the health facility on changing batteries, charging the drone or programming it for the flight back to the distribution facility are not required for Zipline since the drone uses a parachute to drop the supplies and flies back to the launching station. Also, costs resulting from theft or damage to the drone during landing are estimated less in this case. (6)

Drones currently limited in their payload, range and flight time can benefit from performance improvements in lithium battery technologies. Costs for batteries are expected to decrease over time. (23)

Cargo drone companies

Table 5 summarizes characteristics for various drones with successful medical delivery pilot projects or planned cargo delivery prototypes.

Table 5:

Drone	Payload	Range	Speed	Model	Use	Country Tested
Zipline	1.5 kg	150 km	100 km/h	Fixed wing drone with parachute; requires launching and landing area	Blood products; plans to expand to medicines and vaccines	Rwanda
Vayu	2.2 kg	60 km	75 km/h	Hybrid with VTOL	Lab samples	Madagascar
Matternet	2 kg	20 km	50 km/h	Quadcopter	Lab samples	Various
Flirtey	2.5 kg	32 km	No information	Hexacopter	Medical supplies; Pizza	USA; New Zealand
Wingcopter	2 kg	100 km	130 km/h	Hybrid with VTOL	No information	Germany
Drones for Development	2 kg	100 km	100 km/h	Hybrid with VTOL	Medication	Ghana
Quantum System TRON	2 kg	160 km	80 km/h	Hybrid with VTOL	No information	Dubai
Wings for Aid	100 kg	200 km	No information	No information	Humanitarian delivery	No information
Afrotec EPFL Red Line Drone	10 kg	50 km	No information	No information	Medical and emergency deliveries	No information
Kestrel Autel Robotics	2 kg	100 km	65 km/h	Hybrid with VTOL	No information	No information
UPS Workhorse Horsefly	4.5 kg	No information	> 72 km/h	8-Rotor octocopter plus truck	Mock medicine delivery	USA
DHL Microdrones	2 kg	8.3 km	70 km/h	Tiltwing aircraft	Parcel delivery	Germany

(25–38)

CONCLUSIONS

Every drone is different with regards to capabilities such as range, payload and cost. Also, operational differences and the differences in the business models may play an important role in the decision which drone fits best the respective purpose. Therefore, the first step is to analyze the need and then decide on the best mode of transport taking into consideration traditional means of transportation with their advantages such as increased payload as well as the different available drone types and their characteristics.

6. LIMITATIONS AND CONSTRAINTS OF DRONE USE

Operational constraints

Drones are a promising innovation for the delivery of vaccines in last mile settings as described above, however, limitations and constraints should also be taken into consideration, when evaluating the cost-effectiveness of the use of drones. As described above there are limitations in operations, such as limited payload and limited flight range. Besides many drones are still prototypes and the reliability of operation remains to be proven. Trained personnel at health facilities may be required to operate the drone, change and charge batteries depending on the service model chosen. In addition, qualified personnel are needed at the distribution points to perform repairs and maintenance. (6) Replacement drones and spare parts for repair should be available to not jeopardize the operation schedule of delivery.

Furthermore, a functioning mobile network and Global Positioning System (GPS) are crucial and may not be available in all locations. Safety concerns exist regarding the management of collision avoidance and obstacle mitigation. Feasible current solutions described are the establishment of pre-defined safe routes in accordance with the national civil aviation authority. Depending on the drone system, various options including parachute landing, when the motor fails or other emergency landing options as a manual override of autonomous flight operations are available if needed. Another option is the use of geofencing, a technology that places limitations on where drones can fly to avoid collision, however not all drone manufacturers have considered collision capabilities for their drone operating systems yet. (28) Safety however should be a priority. And in this context liability should also be addressed.

The weather conditions may be another constraint. (6) However, according to the reported feedback of Karen McNulty from a conference call with Zipline their drones are able to fly in difficult weather conditions such as heavy rains. In only one instance the aircraft had to return for a second attempt at landing, but otherwise the conditions did not impact delivery time or quality[1].

During vaccine transport the cold chain needs to be assured. Handling instructions need to be established following product specification temperature requirements also for drone flights. Successful pilot flights maintaining temperature ranges between 1-10°C by using wet ice have already taken place. (39)

Acceptability considerations

Socio-cultural aspects influencing the perception and acceptability of drone use in local communities need to be assessed to make sure they are not a limitation to the successful use of drones for the delivery of vaccines. However, pilot projects in many countries have shown that the local communities rather embraced this new technology given they were informed about the intended use prior to the implementation. Concerns about drone use in conflict zone exist, however, no hostility in existing cases of drone use in conflict zones has been described to date. The Humanitarian UAV Network Guidelines on Conflict Sensitivity can provide further guidance in case drone delivery is considered in such a setting. (6)

Photo: Heike Würbel

CONCLUSIONS

Drones are a fascinating innovative mode of delivery; however, the novelty brings along constraints that need to be considered prior to the implementation. Regulations may not be available to the needed extend and operational limitations need to be taken into consideration as many drones are still prototypes. However, those constraints are expected to decrease with time. Socio-cultural acceptance may not necessarily be a constraint given community involvement is part of the implementation activities.

[1] Information provided as a comment by Karen McNulty during the discussion of the framework. The added wording in the draft, dated 22nd May 2017 was confirmed on 24th May 2017.

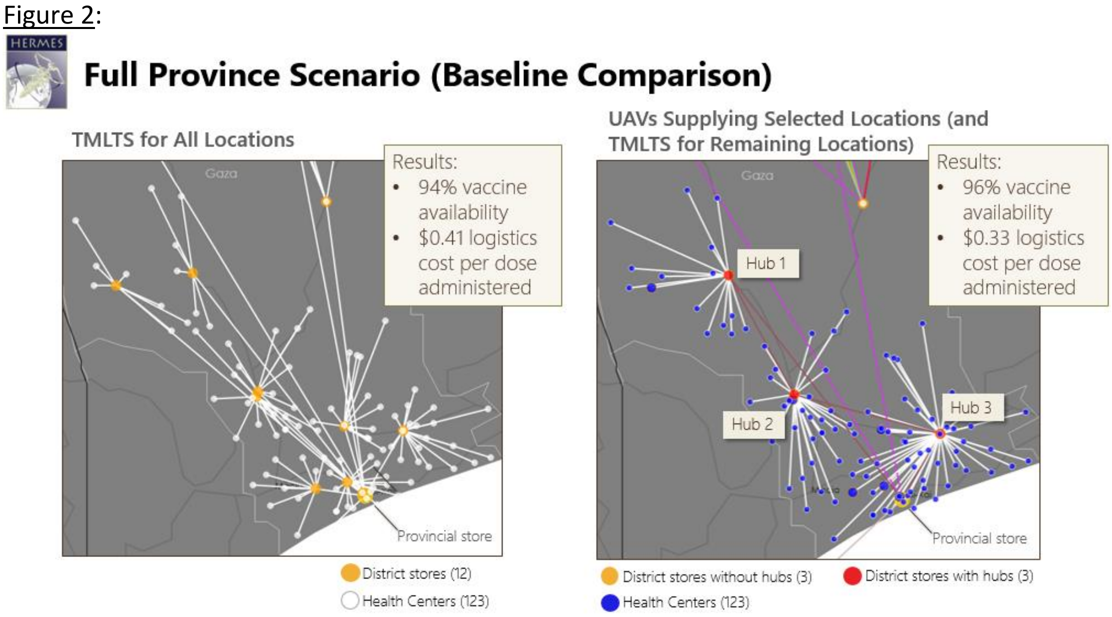
7. PUBLISHED COST EVALUATIONS OF DRONE USE

Below the results from four cost evaluations of drone use for medical delivery are described.

‘The economic and operational value of using drones to transport vaccines’ HERMES modeling

A Hermes modeling approach was used by Haidari et al. to predict the costs and benefits of vaccine delivery in the Gaza province, Mozambique using drones versus traditional delivery on land. The results showed that drone use could increase vaccine availability by 2% and reduce the logistics cost per dose of vaccines administered by 0.08 USD from 0.41 USD in the baseline scenario to 0.33 USD, a reduction of approximately 20%. (40)

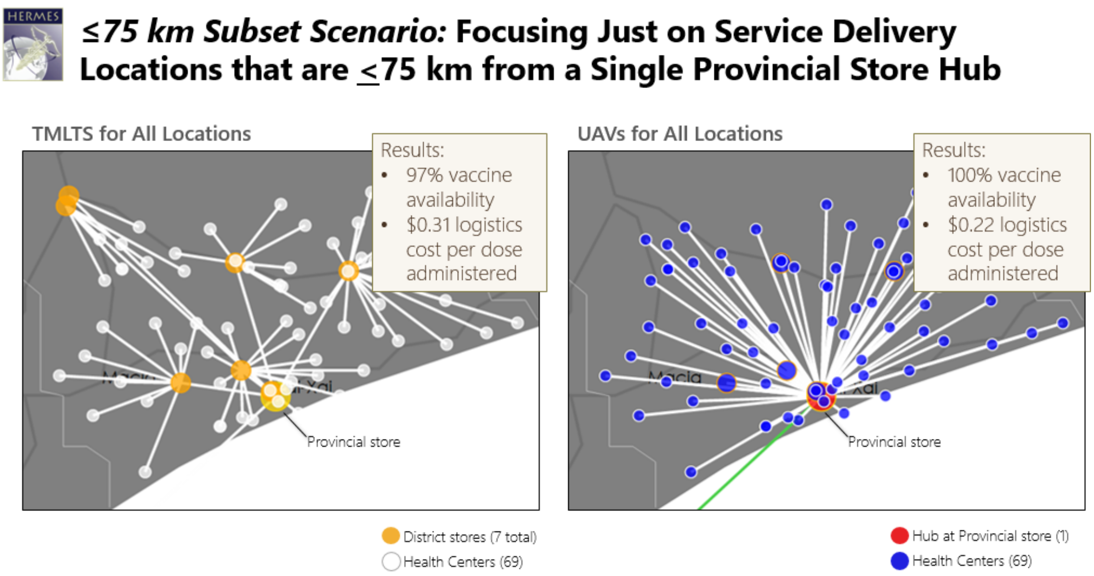
Figure 2:



Slide 9 of ‘HERMES UAV Simulation Modeling Mozambique vaccines’ (41)

In the scenario shown below vaccine availability increased even by 3% and cost decreased by 0.09 USD.

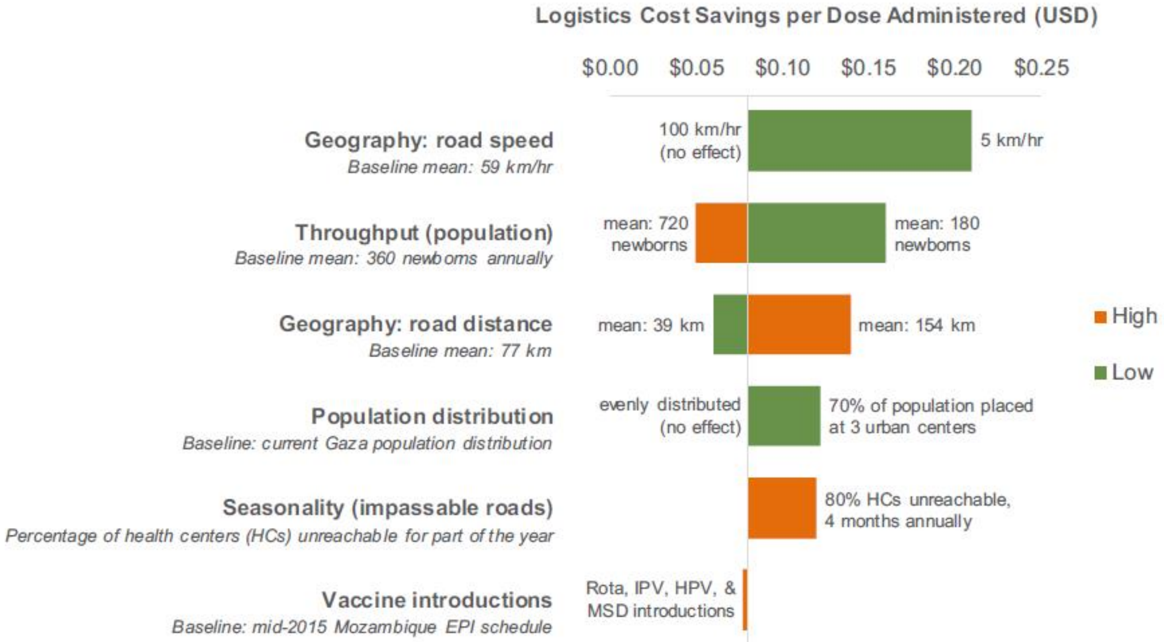
Figure 3:



Slide 10 of ‘HERMES UAV Simulation Modeling Mozambique vaccines’ (41)

Setting up a drone hub is a major cost factor, however human resources cost savings, per diem savings as well as drone transport costs savings can make the use of drone cost-effective if used often enough to overcome the capital cost of the system installation and maintenance. The modeling was performed for a wide range of parameters, and cost saving thresholds were identified. Cost savings increased when the distance travelled for land transport increased and the road speed decreased. A decrease of the number of newborns by half also increased the savings. The payload threshold for cost savings introducing new vaccines doubled from 0.2 L to 0.4 L, however remained still under 1.5 L assumed in baseline and currently available. A limited capacity of the health centers to hold one monthly supplies favored drone use due to the higher frequency of delivery. Drone use was also favorable when health facilities were not accessible for a 4-month period by other means of transport. (40)

Figure 4:



Slide 11 of 'HERMES UAV Simulation Modeling Mozambique vaccines' (41)

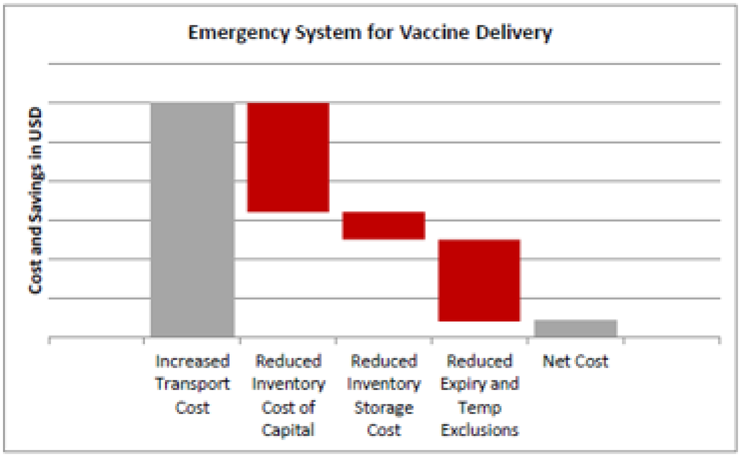
The maximum cost for the drone to produce cost savings over traditional land transport for an EPI vaccine delivery in Gaza province, Mozambique assuming no flight delay should not exceed 8.93 USD per round trip and a hub cost of 60,120 USD per year to be cost-efficient. For a 50% probability of a flight being delayed for two weeks the thresholds should not exceed 7.09 USD per round trip and 45,090 USD annually per hub. (40)

Llamasoft presentation 'Unmanned Aerial Vehicles (UAVs) in supply chains'

Llamasoft, a company specialized in the development and marketing of systems to model and optimize supply chains has presented suggestions for the analysis of drone use in a global health context for various product types. Shipment characteristics of different product types as well as characteristics of the transport mode were taken into consideration. Llamasoft modelled various scenarios to facilitate the decision in which scenarios the use of Zipline drones in Tanzania could be considered. Cost savings for the delivery of blood products by a Zipline drone were postulated due to hidden personnel and transport cost of van transport for an emergency blood delivery and due to the improved response time by drone delivery. The response to critical stock levels and stock-outs of vaccines was also assessed. Llamasoft calculated an 8.2% probability of vaccine stock-out per month in Tanzania and postulated, that the use of drones for vaccine delivery, permitting a higher frequency of delivery to health centers can eliminate stock-outs.

Combining the use of drones with a reduction of inventory holding time, could lead to a decrease in inventory holding costs of over 30% that could offset the increased transport cost of drone use. Inventory holding costs include the cost of capital (10-20%), the cost of inventory storage, including equipment and electricity (4-6%) and the cost of wastage of damaged and expired vaccines at a health center (12%+).

Figure 5:



Slide 31 of 'UAVs in Supply Chains' (23)

The reduced cold storage capacity requirement would also delay the need to procure new cooling equipment. Another benefit of the drone use described is the responsiveness or speed of delivery. For life saving products such as rabies post-exposure prophylaxis (PEP), which are often not available at health facilities due to stock-outs and unpredictable need, drone delivery could increase availability and save lives, particularly when alternative modes of land transport are not always available when needed. (23,42)

Dr. One proof of concept for health commodity delivery

Dr. One is a proof of concept study that was performed in collaboration with UNFPA and other partners such as the governments of the Netherlands and Ghana to assess whether "Drones for Development" could provide cost savings when used in addition to the traditional transport of medical products by motorbike to remote places in Ghana. The executive summary describes the Dr. One model as financially sustainable and cost-effective, when drones are used as a complementary mean of transportation at small scale. Cost savings as well as time savings were shown.

Three out of the five scenarios investigated in this proof of concept study are of interest for the assessment of the question whether drones can be cost-effective for vaccine delivery: The 'Delivery of vaccines for an immunization campaign', the 'Out of stock delivery' and an 'Emergency delivery of treatment'. The evaluation describes the use of drones for the different scenarios of medical delivery as cost-effective amounting to 4,129 USD savings per drone and year in the Builsa district of Ghana. Four criteria were described that favor the Dr.One concept: Low and middle income countries, insufficient infrastructure, a challenged health system and a high percentage of rural population.

Drones could save lives, in areas where motorbikes cannot go or when roads are inaccessible in the rainy season. The cost evaluation of the Dr.One concept concludes that the costs of a trip by a drone are below the costs of a motorcycle journey for the same payload. On the other side, when the payload is higher than double the payload the drone can carry, the motorcycle is the more economic option. The biggest cost savings in the Dr.One concept can be contributed to the savings in fuel and the difference in vehicle speed leading to lower operator costs. The assumed overall cost for the motorbike was estimated to be 0.25 €/km and the cost of the drone 0.224 €/km. Further cost savings are possible due to the shorter distance of approximately two thirds of the motorcycle distance that a drone needs to cover. Costs for human resources, maintenance and repair of both vehicles types and in the case of Dr.One training costs were considered. The proof of concept study concluded that the marginal cost would decrease with a higher number of drones used. This is due to cost savings in human resources, since operations and maintenance can be centralized, allowing one or few operators to schedule and monitor various flights. Other advantages of the Dr.One concept described include an improved training of health workers and a better stock control and ordering process due to an improved access to internet. Potentially the community could also profit from the access to the internet and drones could be used to deliver other important items needed by the communities or travelers in emergency situations. (27,43)

VillageReach cost analysis for drone transport of lab samples

VillageReach partnered with UNICEF, the Government of Malawi and Matternet to assess the "Costs Associated with the Use of Unmanned Aerial Vehicles for Transportation of Laboratory Samples in Malawi." The results show that only one scenario out of four favors the use of drones over traditional last mile transport, in this case, the use of motorcycles. This scenario did neither consider motorcycle loops to different health facilities, nor the capacity for motorcycles to transport other items on the trip which however is likely be the case in a real scenario. To be able to compare the costs of both modes of transport directly it was assumed that the motorcycles returns to the hub in the same way drones do, with a maximum hub to health center distance of 25 km. In this case, when the weight of the sample did not exceed the payload of the drone, drone use was deemed more favorable because of the shorter distances to be covered, the higher speed and the resulting reduction in vehicle- and personnel-related costs.

Table 6:

Scenario 1	Scenario 2	Scenario 3	Scenario 4
Loops	Loops	Hub & spoke routes <25 km	Hub & spoke routes <25 km
Low # of samples (within maximum drone payload)	Higher # of samples (above maximum drone payload)	Low # of samples (within maximum drone payload)	Higher # of samples (above maximum drone payload)
Delivery includes other items	Delivery includes other items	Dedicated delivery	Dedicated delivery
Pro motorcycle transport	Pro motorcycle transport	Pro drone transport	Pro motorcycle transport
The motorcycle can carry other items and the per km cost of the motorcycle was estimated to be below the drone cost per km.	The motorcycle can carry other items and the per km cost of the motorcycle was estimated to be below the drone cost per km. More drones are needed to manage the high payload resulting in a higer cost.	Shorter distance and higher speed lead to vehicle and personnel-related cost savings in drone use that outweigh the higher per km cost of the drone.	Shorter distance and higher speed lead to vehicle and personnel-related cost savings in drone use that are not high enough outweigh the higher per km cost of the drone.

Conclusions highlighted the importance of studying the bottlenecks of the existing supply chain systems and considering the use of both drones and motorcycles together in the optimal logistic system to benefit from the strengths of each of the two transportation modes. The report also reflects on what can be done to improve future drone cost evaluations and suggests to consider not only cost but also benefits since positive outcomes could outweigh the cost. Important cost drivers identified include personnel and vehicle cost. The fuel cost alone was contributing to 20% of the total cost. Changes in fuel cost may favour drone use. Also changes in battery cost and other drone related equipment costs which are expected to decrease over time can make drones a more favorable mode of transport in the future. (12)

CONCLUSIONS

All the above evaluations assessed whether the cost of delivery by drone is cheaper than the cost of a traditional delivery by road, however did not consider the advantages associated with the improved health status of the population through increased availability of the vaccines by this innovative delivery method, a situation that would suggest increased cost-effectiveness. The HERMES modeling includes considerations such as vaccine availability, however does not translate this increased availability into improvements in health outcomes such as mortality avoided for example. Such additional considerations will be described in greater detail in section 9.

8. ANALYSIS AND DISCUSSION OF PUBLISHED COST EVALUATIONS

Tabular summarized cost saving considerations

The table below summarizes the capabilities of the drones used for the cost evaluations described in section 7, the scenarios assessed and the main cost drivers.

Table 7:

Cost Evaluations	Hermes	Llamasoft	Dr.One	VillageReach
Drone flight range	150 km	150 km	100 km	25 km
Drone payload capacity	1.5 L	1.5 kg	2 kg	0.5 kg
Drone compared to	Trucks, motorcycles and public transport	Trucks	Motorcyles	Motorcyles
Scenarios assessed	• Assuming a realistic switch of vaccine delivery from land to drone transport where possible within assumed range and payload of the drone as an alternative to the current standard delivery method	• Vaccine delivery to eliminate stockouts • Blood product delivery • Rabies PEP delivery • Essential medication delivery	• Emergency medicine deliveries • Out of stock deliveries • Additional delivery for vaccination campaigns • ART delivery for pregnant women	• Laboratory sample delivery for HIV testing
Main cost drivers	Hub cost, transport, payload	Transport, personnel, inventory holding	Human resources, fuel/electricity, distance	Personnel, vehicles, fuel, batteries, chargers and landing devices

(12,23,27,40,43)

Different approaches performing the cost evaluations

VillageReach performed a cost-minimization evaluation. The cost of the delivery of lab samples by drone for different scenarios in Malawi was compared to the delivery by motorcycle. Only in one out of four scenarios modeled the drone use resulted in an 18% decrease in cost, while the other scenarios increased the cost. However, measures of effectiveness such as performance improvements in the supply chain through increased speed or health benefits were not considered. Neither did the study consider a combination of motorcycles and drones as the potentially most cost-effective solution in the modeling. Lastly, an average flight speed of 45 km/h, a flight range of only 25 km and a payload of 0.5 kg were assumed, while nowadays drone prototypes with a higher speed, range and payload capacity are available. (12) The following studies used a flight range of minimum 100 km and a payload of minimum 1.5 L.

The combined use of both means of transport, motorbikes and drones was considered in the Dr.One evaluation for various scenarios, assuming a vehicle cost of 5,000 USD for the drone as well as the motorcycle. The detailed complete business case containing the cost evaluation is not publicly available, however the summary available describes that health-related outcomes were not considered in this evaluation. The cost evaluation of the Dr.One concept concluded that the costs of a trip by a drone with a maximum range of 100 km are below the costs of a motorcycle journey for a weight not exceeding twice the maximum payload of the drone, which in this case is 2 kg. (27,43)

The Llamasoft evaluation did not assess the cost of vaccine transport by drone versus land transport generally, but analyzed the specific scenario to use drones to eliminate stock outs in vaccine supply chains concluding that the use of drones for vaccine delivery, permitting a higher frequency of delivery to health centers can eliminate stock-outs. The higher frequency could permit a reduction in inventory holding time that could offset the cost for vaccine transport by drone. (23,42)

The Hermes cost evaluation of drone use for vaccine delivery in Gaza, Mozambique assessed both, cost and performance metrics, such as vaccine availability for the delivery of traditional Extended Program on Immunization (EPI) vaccines, as well as the introduction of new vaccines. The supply chain model considered each vial, personnel involved in supply chain activities, the mode of transport, being a combination of trucks, motorcycles, public transport and drones, the storage facilities, the storage equipment, and the route. The existing supply system was remodeled to include 3 drone hubs to serve 106 out of 123 health centers by drone delivery and 3 district stores to deliver the remaining 17 heath centers by land transport in an area with a lower population density as the most likely implementation scenario. Ideally both means of transport are used depending on the advantages of each. After comparing the cost of drone use to traditional road based transport directly through modeling the distribution from the province store to all sites within drone range, also a sensitivity analysis was performed to describe how changes to various parameters influence the cost. Maximum costs for drone flights and hubs were calculated for different delay scenarios. This publication is the most complete modeling of vaccine cost-effectiveness of drone use publicly available to date. (40)

Table 8: Summarized conclusions of the four available cost evaluations

Summarized Conclusions	Hermes	Llamasoft	Dr.One	VillageReach
Drone use can save costs when used complementary to the existing supply system	✔	✔	✔	✔
Drone use could increase increase product availability when no road based transport option exists (e.g. no vehicles are available, no roads are available or roads are not acccesible year-round).	✔	✔	✔	✔
A delivery within the drone flight range not exceeding the payload is more cost-effective than a motorcycle delivery, when exclusively those items are transported.			✔	✔
A delivery within the drone flight range not exceeding the payload twice the is more cost-effective than a motorcycle delivery.			✔	
Savings for drone use are possible because of decreased operation costs (e.g. fuel) and personnel costs.	✔	✔	✔	✔
Cost savings for drone use are possible due to difference in drone speed compared to road transport.	✔		✔	✔
Cost savings for drone use are possible because of longer road distances compared to flight distances.	✔		✔	✔
Further cost savings for drone use are possible when the payload capacity increases.	✔			✔
The marginal cost for drone use decreases as more than one drone can be operated by the same person.			✔	
A limited capacity at facility level to hold supplies favours drone use.	✔	✔		
Drones can decrease bottlenecks (e.g. stock-outs) in supply chains through a higher delivery frequency.	✔	✔	✔	
A reduction of the inventory holding time for vaccines and hence the inventory holding cost can offset the potentially higher cost for a drone delivery.		✔		
More frequent drone deliveries can minimize the waste of unused expired vaccines or vaccines compromised in quality (e.g. due to failures during cold storage).		✔		
Drones can improve the performance of the delivery (e.g. speed, response time, flexibility).	✔	✔	yes, but not quantified	yes, but not quantified
Recommendation to consider benefits (e.g. health outcomes) in future drone cost evaluations.			✔	✔

(12,23,27,40,43)

9. OUCOME CONSIDERATIONS FOR A COST-EFFECTIVENESS STUDY

Health-related impact

For health-related cost evaluations, not only the cost and immediate performance improvements in supply chain operations such as speed and responsiveness should be considered, but also the health-related impact of the intervention. For example, by using drones it would be possible to reach populations, that are difficult to reach using traditional means of transport (12) and thus increase the coverage of vaccination. The number of individuals vaccinated could be used as a surrogate marker of the health impact. An increased vaccination coverage means less morbidity and mortality due to vaccine preventable diseases and a decrease in disability-adjusted life years (DALYs), a combination measure of morbidity and mortality. The use of DALYs in a cost evaluation would permit an easier comparison with other health-related interventions. (44)

Return on investment (ROI) considerations

A cost-benefit study translates health-outcomes into monetary terms to make the benefits of the new intervention more comparable. An example of such an economic evaluation is the study “Return on Investment from Childhood Immunization in Low- and Middle Income Countries, 2011-20” conducted in 2016 for ten antigens using the Gavi 2014 adjusted vaccine demand forecast. The results show that for every dollar invested in countries supported by Gavi 18 USD are expected to be saved. Those cost savings are possible through direct savings in the medical field such as healthcare cost and lost wages due to illness, but also due to indirect economic benefits. Those include cognitive development, education, and employment. It is possible to include even a wider range of benefits such as the value of a longer and healthier life. This would increase the return of one dollar invested to 48 USD. (45) It is expected that using drones to deliver vaccines that would otherwise not be provided will also save money, although the exact ROI ratio is yet to be determined. Nevertheless, such a cost evaluation could be a helpful tool for decision-makers who are not familiar with the meaning of DALYs and would even allow a comparison with interventions outside the health sector.

Environmental benefits

Another advantage of the use of drones is the environmental aspect. Many drones do not require fuel and drone batteries can be charged using solar energy and thus are an environmental friendly sustainable solution. The use of drones can minimize the carbon emissions through diesel powered cars or motorcycles used traditionally for the last mile delivery. (28)

Quality considerations

Most vaccines require refrigeration throughout the whole supply chain from manufacturer to service delivery to not compromise the quality of the product. The shorter time window for the drone delivery can provide an advantage over traditional transport where refrigerated transport conditions need to be assured for much longer time periods. (13)

CONCLUSIONS

The potential of drones to improve the availability of life saving vaccines for people living in areas difficult to reach should be given greater importance. The cost of drone use should not simply be compared against the cost of traditional means of transport in existing supply chains, but weighted against the improved performance in speed and flexibility that can increase the availability and coverage of vaccines and hence decrease morbidity and mortality.

10. SIMPLIFIED MODELING OF POTENTIAL COST SAVINGS FOR DRONE USE

The creation of a simplified modeling was suggested by Gavi to understand the scale of potential cost savings for drone use in exemplary countries with last mile challenges better. The list of countries for this modeling was provided by Gavi based on internal discussions. The birth cohort number estimated for 2017 was obtained from the respective Gavi country profile, the percentage of the rural population was obtained from IndexMundi demographic country profiles. Those two numbers were used to obtain the best estimate of newborns in rural areas. Gavi suggested to assume that 20% of those areas could be delivered by drones in this modeling.

The predicted 0.08 USD logistics cost savings per dose as estimated by the HERMES modeling in Mozambique being the most complete modeling of vaccine cost-effectiveness of drone use publicly available to date were used for the below calculations, acknowledging, that cost structures vary between and within countries. The EPI schedule of the same study was used to determine the number of doses for children in their first year of life. Please refer to the table listing the respective vaccines and doses. (40)

Table 9:

Vaccine	Doses
Bacille Calmette-Guérin tuberculosis (BCG)	1
Diphtheria-tetanus-pertussis-haemophilus influenza type B-hepatitis B (Pentavalent)	3
Measles (M)	2
Oral polio (OPV)	4
Pneumococcal conjugate (PCV)	3
Rotavirus (RV)	2
Inactivated polio (IPV)	1
Total doses recommended per child	**16**

(40)

Country specific additional recommendations such as the yellow fever vaccine for example were not considered for this modeling, since they were not part of the HERMES modeling. The two doses of tetanus toxoid (TT) and the two doses of human papillomavirus (HPV) considered in the HERMES modeling were not included in the modeling below due to the different age range of the target population. Table 10 shows the simplified estimates of potential savings when using drones for the delivery of vaccines for children in the 2017 birth cohort in various countries. (40)

Table 10:

Country	Birth cohort	% Rural Population	Rural Newborns	20% Drone use	Savings 1 Dose	Savings 16 Doses
Guinea	472,039	0.507	239,324	47,865	$ 3,829	$ 61,267
Congo, Dem. Rep.	3,351,364	0.575	1,927,034	385,407	$ 30,833	$ 493,321
Tanzania	2,144,042	0.684	1,466,525	293,305	$ 23,464	$ 375,430
Madagascar	865,588	0.649	561,767	112,353	$ 8,988	$ 143,812
Haiti	262,174	0.414	108,540	21,708	$ 1,737	$ 27,786
Papau New Guinea	218,515	0.87	190,108	38,022	$ 3,042	$ 48,668
India	25,732,835	0.673	17,318,198	3,463,640	$ 277,091	$ 4,433,459
Pakistan	5,482,345	0.612	3,355,195	671,039	$ 53,683	$ 858,930
Bangladesh	3,095,451	0.657	2,033,711	406,742	$ 32,539	$ 520,630
Total					**$ 435,206**	**$ 6,963,303**

(40,46–48)

CONCLUSIONS

Ideally actual country data that allow to identify vaccine supply chain challenges are collected and are reviewed with the assistance of a supply chain company and a drone provider to determine the ideal use scenarios and in country locations to benefit most from the drone implementation.

11. INNOVATIONS

Ecological friendly solutions

Solar-powered delivery drones are an innovative solution worth to consider. Mobisol, a company providing solar charging stations to the rural communities of Rwanda, Tanzania and Kenya is doing a pilot using households on the route with installed solar systems to charge drones for delivery. (49)

Mobile warehouses

The use of mobile warehouses such as vans paired with drones is another promising idea. Here the combined advantages of both delivery methods can be used. Mercedes and Matternet are collaborating to develop such a mobile warehouse. United Parcel Service (UPS) has already performed a successful delivery using a truck drone combination for a package delivery in the United States. (23,36)

Different models to increase the speed of a delivery or decrease the cost when using a hybrid truck-drone approach have been published and deemed most beneficial in less dense regions such as rural and suburban areas. The evaluation of further strategies, such as a drone-only delivery for places close to the warehouse, truck-drone delivery for deliveries to locations further away and the option to use multiple drones on one vehicle could provide valuable information. (50)

Photo: UPS Pressroom

Supply Chain Modeling

Modeling can be a good option to assess a supply chain system, to identify bottlenecks and determine the most cost-effective or efficient way of delivery. Drones should be considered a supplement to conventional means of transportation, such as trucks or motorcycles to reach remote areas, when using modeling approaches to identify potential areas for improvements and cost savings in supply chains. (12)

CONCLUSIONS

Modeling supply chains can be beneficial to determine the most cost-effective way based on the existing supply chain systems in countries to identify bottlenecks and find solutions on how to address them. Besides drones only, combinations with road based transport options should be considered.

12. FINAL CONCLUSIONS

Drone use could save costs in the last mile delivery of vaccines compared to traditional means of transport on land. However, cost savings will depend on a variety of factors including geographical factors, drone characteristics, the supply chain system in place and the vaccine demand.

All evaluations suggest to use drones as a complement to the existing supply chain system and not as a complete replacement of the current mode of transport. Drones can be favorable due to their flexibility in places where no road infrastructure exists or the existing infrastructure is not accessible year-round, because they can increase the availability of vaccines. Also, where road infrastructure permits ground vehicles to travel at slow speed only, drones can provide an advantage. The shorter distance drones need to cover because they can fly directly instead of following roads provides another advantage. Drones, permitting a higher frequency of delivery, can be used to avoid vaccines stock-outs at health facilities. Cost savings offsetting the potentially higher cost of drone delivery are possible when the inventory holding time is reduced and hence inventory holding cost as well. Waste of unused expired vaccines or vaccines compromised in quality due to failures in cold storage due to unreliable electricity can also be minimized by more frequent drone deliveries. When only a limited cold storage capacity is available and neither the installation of an additional cold storage equipment is possible, nor a more frequent delivery of vaccines with traditional means of transportation due to limitations in driver and vehicle availability, drones can be used to assure continuous vaccine availability. For deliveries of small payloads such as emergency shipments drones can be cost-effective compared to motorcycle delivery. Consensus exists that cost savings for drone use can result from reduced operation costs, not requiring fuel and from decreased human resources costs, as one person can operate several drones at a time that can overweigh the higher cost associated with drone use such as a higher drone implementation cost. In places where fuel prices are high or fuel availability is not always guaranteed drones can provide an advantage. The same is could be said about a limited vehicle availability.

Table 11:

Summarized conclusions pro drones	Hermes	Llamasoft	Dr.One	VillageReach
Cost savings are possible for:				
Complementary drone use to current transport options	✔	✔	✔	✔
Deliveries within the drone flight range and payload			✔	✔
Deliveries not exceeding flight range and double drone payload			✔	
Cost savings due to:				
Decreased operation costs (including fuel)	✔	✔	✔	✔
Decreased personnel costs (due to savings in time and distance)	✔	✔	✔	✔
Possibility of the reducing inventory holding time and cost		✔		
Minimization of waste due to higher delivery frequency		✔		
Performance improvements:				
Greater speed (potential use for emergency shipments)	✔	✔	✔	✔
Increased flexibility (can go where no roads exist)	✔	✔	✔	✔
Higher frequency (can decrease stock-out)	✔	✔	✔	

(12,23,27,40,43)

Jerome Ferguson from UPS involved in the Zipline blood product delivery in Rwanda kindly shared some insight on the ongoing project[2]: "For Rwanda, but in all cases, when emergencies arise, the local hospitals will use whichever vehicle is available to procure additional medical supplies. In many cases, they will use the available ambulance to travel to the medical storage depot and return making the ambulance unavailable for true emergencies." Karen McNulty added that the team originally planned for 10% of deliveries to be classified as an emergency and that current trends indicate that 40% of deliveries are

[2] Information received per email on 20th April 2017 by Karen McNulty included the comment of Jerome Ferguson in the review of the draft framework, dated 17th April 2017.

emergencies[3]. Also, she stated that per Zipline the hospitals delivered by drone to date had zero units of blood that have expired, while Rwanda likely spends over $1M for disposal of expired blood products annually[4]. While not absolute proof, this does indicate that consistent and timely deliveries can change behavior in ordering practices and on hand inventory levels.

When considering drone implementation, it is recommendable to use modeling approaches to determine how drone use can best contribute to the existing supply chain system by identifying existing bottlenecks and modeling different scenarios considering the strength of each delivery method. (12) Modeling can contribute to cost savings even when novelties, such as new vaccines for example, are introduced as in the example of Benin, where the removal of a supply level in addition to the creation of additional department stores and loops increased the cost savings even with the new vaccine introduction. (2) Such a modeling approach to identify areas for cost savings in combination with the potential of drones to increase the availability of lifesaving vaccines in locations that are otherwise difficult to reach could thus provide a great opportunity to reach more of the 19.4 million infants still missing out lifesaving vaccinations. (7)

However, to achieve this, in addition, strengthening the skills of the staff managing the supply chains through training to assure smooth operations and avoid stock outs, should not be neglected. Focus should also be given on monitoring the temperature to assure the vaccines do not loose effectiveness. Setting up a tracking system for the collection of demand data with the option to submit electronically can improve supply availability and avoid stock outs. In addition, political commitment to invest in the above described interventions is required to assure financial support for the required investments and to work towards a more equitable vaccination coverage. (14)

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[3] Information received per email on 16th March 2017 by Karen McNulty.
[4] Information received per email on 24th May 2017 by Karen McNulty.

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