THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF SUPPLY CHAIN AND INFORMATION SYSTEMS

DRONE OPTIMIZATION FOR MEDICAL USE IN SUB-SAHARAN AFRICA

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SPRING 2020

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Supply Chain and Information Systems
with honors in Supply Chain and Information Systems

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ABSTRACT

Sub-Saharan Africa is struggling to provide access of life-saving medical resources to its citizens, creating widespread health concerns. The region has seen a high maternal mortality rate, correlating to the lack of medical accessibility. Specifically, there is a lack of adequate blood supply for mothers suffering from post-partum hemorrhaging. By conducting internet research provided by company executives and area experts, as well as public data sources, opportunities in drone transportation of blood are being explored. Industry leader in unmanned aerial vehicles (UAVs), Zipline, is evaluated for its successful implementation in the country of Rwanda. Throughout this thesis the reasons for the company's success are identified and areas for potential improvement are explored. A centralized supply chain, lack of adequate transportation routes and limiting physical conditions, a localized workforce, supporting government regulations, and efficient technology all were found to contribute to Zipline's success in saving lives through drone transportation in Rwanda. The lessons learned from Zipline in Rwanda are applicable across sub-Saharan Africa and help to conceptualize the positive impact drone usage can create in various regions of the continent through the same or similar processes. The recommended strategies provide a sustainable business opportunity, and also serve as guidelines to acting on a humanitarian issue in a socially responsible manner.

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ACKNOWLEDGEMENTS

I would like to thank both Dr. Novack from The Pennsylvania State University for guiding my writing process and Scott Dubin from the USAID Global Health Supply Chain Program for providing me with unmatched expert information on the subject matter. Your help and guidance are much appreciated, and my paper would not have been possible without your input. Additionally, I would like to acknowledge the work of Paul O. Ouma, Robert W. Snow, and Emelda A. Okiro in their publication of Sub-Saharan Public Hospitals Geo-coded Database. Their database is essential for understanding the lack of medical accessibility of those living in Sub-Saharan Africa.

Chapter 1

Introduction

Readily available access to medical resources is uncommon to many areas of this world. Easy access to such products helps increase the overall quality of life while decreasing mortality rates. Of the largest contributing factors to this inability is the lack of consistently reliable transportation routes; roads that are subject to the whims of the weather and power outages threaten temperature-sensitive supplies that can spoil easily. Overcoming this transportation issue provides a solution to medical resource accessibility.

Sub-Saharan Africans suffer from the highest maternal mortality ratio in the world – 533 maternal deaths per 100,000 live births, or 200,000 maternal deaths a year. This is over two thirds (sixty-eight per cent) of all maternal deaths per year worldwide. Hemorrhaging remains the leading cause of maternal mortality, accounting for over one quarter (twenty-seven per cent) of deaths (Maternal Mortality 2019). With hemorrhaging comes the need for blood transfusions, therefor requiring accessibility to the type and quantity of blood needed. This presents a challenge for countries with distanced hospital or medical facilities that are usually also struggling financially. Limited resources and lack of access to appropriate technology are two major challenges that threaten blood safety.

Drones have recently become one of the most impactful new innovations in the supply chain industry. They gained their presence very quickly which came with unforeseen obstacles and regulation hurdles in this brand-new field. This advancement in technology has begun to be tested and used by many pharmaceutical and medical technology companies as a resource to

reach developing nations that lack proper infrastructures. Technological advancements now allow for temperature-controlled transportation of blood by drones that are saving lives.

Many companies have failed in this area. However, research will conclude that market leader, Zipline, has found great success in Rwanda and is continuing to expand its operations with well thought out strategies. Research found that a combination of well-developed technology, operation by locals, a centralized supply chain, need from the country and most importantly support from the government all played a crucial role in the achievements Zipline has made. Recommendations for companies similar to, and including Zipline, identify the opportunity in Sub-Saharan Africa to save thousands of lives. The model used in Rwanda can be scaled across the country not only for blood delivery but also for the delivery of many other medical and pharmaceutical needs to save lives.

Chapter 2

Rwanda

2.1 Geography/Facts and Figures

Rwanda is a small country in East Africa covering 26,338 km2 with a high population density of 498 people per square meter of land. The country is comparable in size to the state of Massachusetts in the United States. Rwanda is entirely landlocked but contains lakes and rivers that cover three percent of its surface area with a mean annual rainfall ranging from forty to fifty-five inches depending on the area. The country is known for its hills which cause a challenge in transportation. Roadways cover around 14,000km with only 2,600km of the roads being paved. In transportation, Rwanda has the highest transport costs in the region, estimated at forty percent

of the value of its imports or its exports, against twelve percent and thirty-six percent for Kenya and Uganda respectively. Another cause for these increased costs can be found in the challenges brought about in ground transportation from flooding, mudslides from the mountainous terrain of the country, and at times activity from the country's active volcanoes. Figure 1 highlights the primary, secondary and tertiary roads of Rwanda.

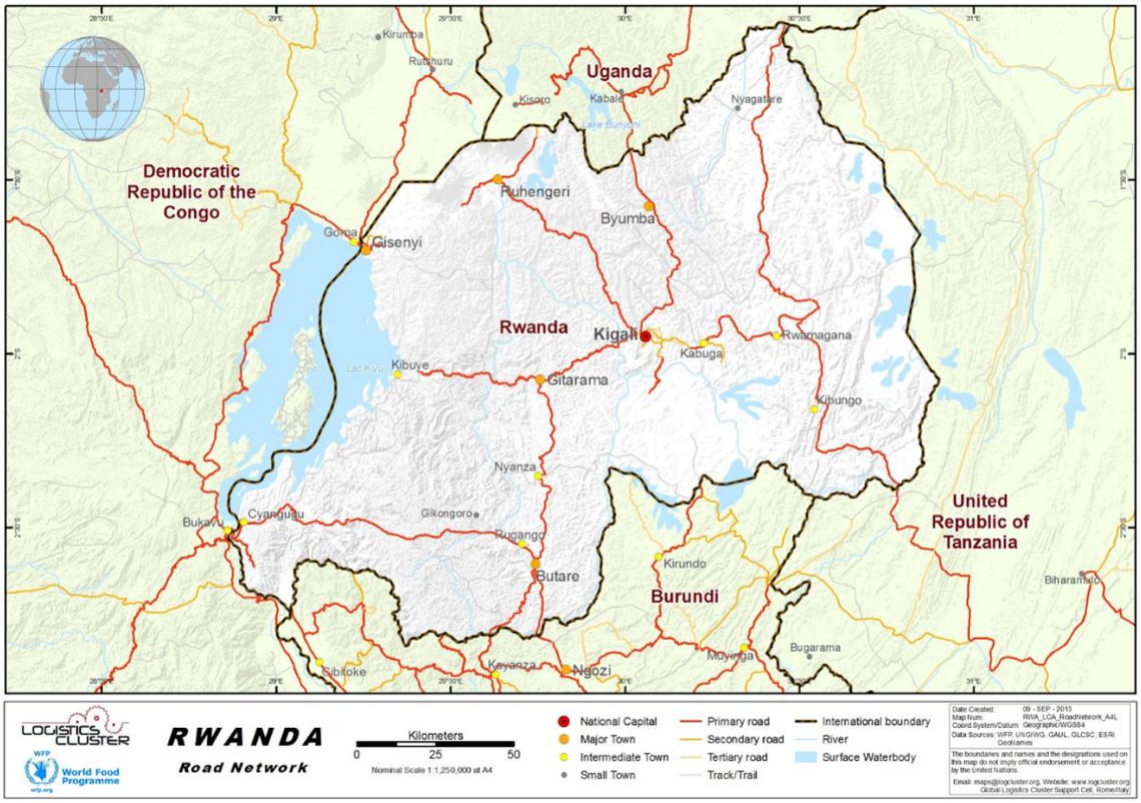

Figure 1 Rwanda Road Network

Primary roads, which are suitable for heavy long-haul trucks, connect the capital Kigali with Rwanda's five provinces. Many of these primary roads are steep, most predominantly in the Northern and Southern provinces, and therefore travel times along these roads are found to be increased. Secondary roads are usually able to be utilized by smaller trucks but require four-wheel-drive during rainy seasons especially on roads in mountainous areas (June to September). During the long rainy season these roads can be difficult to travel due to their short width and

steepness. Being such a small country, the distances from Kigali to the provincial towns are not very far in relative terms but can take longer to travel to than expected due to these conditions. There are only five documented passenger cars per 1,000 people in the country, extremely limiting local's transportation as well (Digital Logistics Capacity Assessments 2019).

2.2 Population

The Fourth Rwanda Population and Housing Census, 2012 (RPHC4) established that the population of Rwanda in 2012 was 10,515,973 residents, of which fifty-two percent were women and forty-eight percent men. Rwanda is broken into five provinces; Northern, Eastern, Western, Southern, and Kigali. From there the provinces are broken down into districts and then further into sectors. The most populated province is the Eastern Province with 2,595,703 inhabitants, followed closely by the Southern Province with 2,589,975 inhabitants and the Western Province with 2,471,239.

With the exception of the province of Kigali City, the majority of the population of each province lives in rural areas (83.5 percent) while only 16.5 percent live in urban areas. The population of men outnumber women living in Kigali by about 40,000. This is due to the job availability in the predominantly urban province (Rwanda Fourth Population and Housing Census 2012).

2.3 Maternal Mortality

Maternal mortality refers to deaths due to complications from pregnancy or childbirth. The maternal mortality rate in Rwanda is constantly improving. As of 2017, the maternal

mortality rate was 248 maternal deaths per 100,000 live births. This is the forty-fourth highest maternal mortality rate in the world. Sub-Saharan Africans suffer from the highest maternal mortality ratio with an estimated 533 maternal deaths per 100,000 live births, or 200,000 maternal deaths annually. This number accounts for more than one two thirds (sixty-eight percent) of maternal deaths worldwide per year. Maternal deaths can be prevented in almost all cases. This is apparent from the huge disparities found in the lifetime risk of maternal death across regions and between the richest (1 in 5,400) and poorest countries (1 in 45) (Rwanda Country Profile).

As shown in Figure 2 below, the most frequent cause of maternal deaths in Africa is hemorrhaging (uncontrolled bleeding), accounting for over one quarter (twenty-seven percent) of deaths. As a result from significant blood loss from hemorrhaging, transfusions are crucial for the survival of patients suffering from hemorrhagic shock. Approximately eighty-six percent of births occur in rural areas, far from necessary medical assistance and an adequate blood supply. Seventy percent of Rwandan mothers give birth at home unassisted, increasing the risk of complications while distancing them further from hospitals. This, therefore, decreases the amount of time doctors had for life-saving measures to be carried out. Most of these mothers could have survived, had their doctors had access to blood for their hemorrhaging patients and enough time (Rwanda Country Profile).

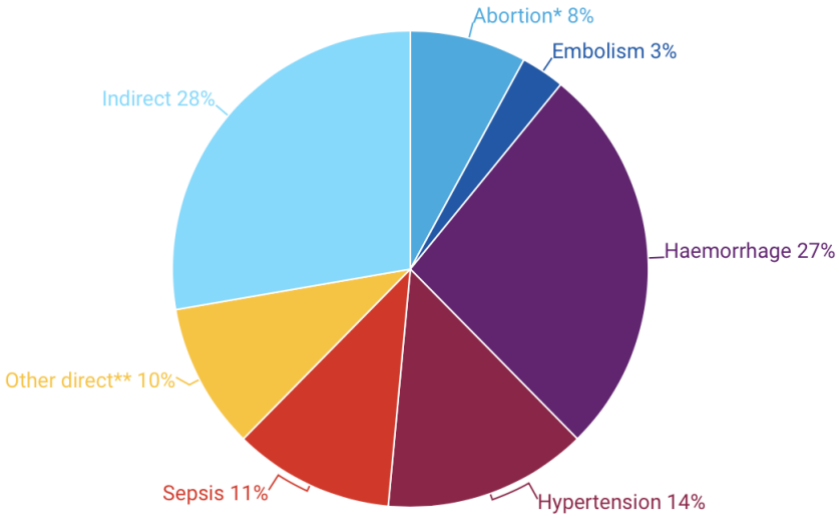

Figure 2 Cause of Maternal Death

2.4 Hospitals

The medical and healthcare condition in Rwanda has been improving but shows there is still a lot of room for life-saving improvements. Figure 3, seen below, has been created for the purpose of this thesis, utilizing data from a Harvard Sub-Saharan Public Hospitals Geo-coded database. The figure locates on the map of Rwanda all public hospitals, which are managed by governments at national levels or locally at municipality or local authority, faith-based (FBO) and non-governmental organizations (NGOs). Before the database used to generate this map was created, there was no complete geo-coded inventory of hospital services in Africa in relation to how populations might access emergency care services. The study assembled a geocoded inventory of public hospitals across forty-eight countries and islands of sub-Saharan Africa from 100 varying sources, Rwanda is one of these countries. A cost distance algorithm based on the location of 4908 public hospitals, population distributions, and road networks were used to compute the proportion of populations living within a combined walking and motorized travel

time of 2 hours to emergency hospital services (People across Africa Have to Travel Far to Get to a Hospital. We Worked out How Far 2020).

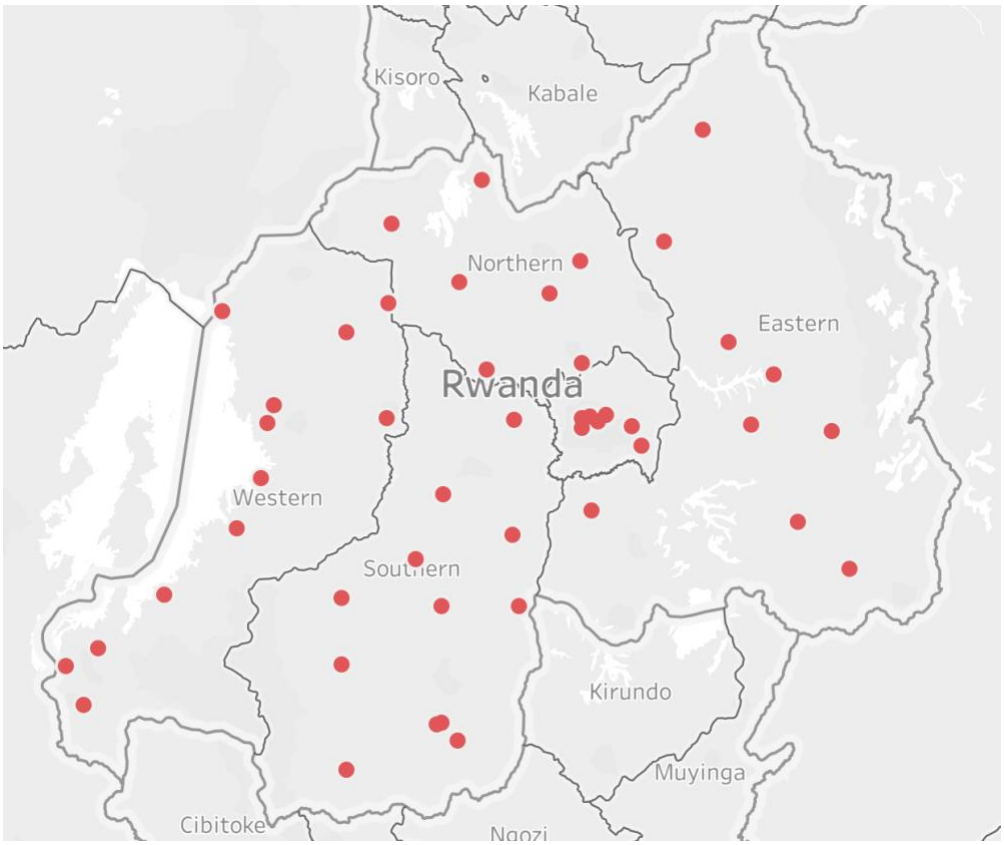

Figure 3 Rwanda Harvard Database Hospital Map

According to Rwanda's Ministry of Health, of the units of blood delivered throughout the nation, almost half are for complications from childbirth. In most areas in the country, hospitals lack the budget to provide the medical necessities or the electricity to maintain refrigerator temperature control of their blood storage. It is common that they may not even have the right type of blood at all.

In an interview, Dr. Roger Nyonzima, who is the head surgeon at Nyanza Hospital's maternity ward (Southern province), said he sees on average ten births a day in his hospital. At least one third, he says, are cesarean sections that require blood, but at least twice a week he has

an urgent case, where he just does not have enough blood on hand, or not the right type of blood to save his patient. "Before, it took at least three hours to get blood in an emergency," says Dr. Roger Nyonzima. The Nyanza Hospital is about 100 km. from Kigali. "Three hours can make the difference between saving or losing a life. Now we get blood in fifteen minutes. Fifteen minutes, we can work with" (Zipline Is Using Drones to Deliver Medical Supplies 2018).

Chapter 3

Medical and Technical Requirements

3.1 Blood Storage Requirements

Blood is a difficult resource to store efficiently due to its short shelf life and unpredictable demand for all the different blood groups. Blood must be temperature controlled at all times in storage and transportation. Any break from the safe temperature range can increase the dangers for the recipients of the blood products. Although legal requirements on blood storage were unable to be obtained on Rwanda, The U.S. Food and Drug Administration (FDA) has regulated the storage of blood on a medical basis which can be used as a reference. According to the regulations for blood transportation, the container has to have a tamper-proof seal when originally issued and this seal must remain unbroken. Whole blood, red blood cells, platelets, and plasma must be stored continuously at 1 to 6 deg. C and shipped between 1 and 10 deg. C (CFR – Code of Regulations Title 21 2019).

3.2 Government Drone Regulations

The decrease in response time for emergency blood delivery in Rwanda has come from a Government commercial contract with industry-leading drone provider, Zipline in 2016. Rwanda's government decided to adopt a performance-based drone regulation in collaboration with The Rwanda Civil Aviation Authority (RCAA) which manages all aspects of civil aviation in the country. This performance-based regulation gives an unmanned aircraft the capability to access and navigate airspace on a mission-specific basis (KIGALI: Rwanda Takes the Lead in Adopting Performance-Based Drone Regulation). The government is in charge of specifying the standards that need to be met to ensure safety and the drone operators in return demonstrate specifically how they will be able to meet these standards. This regulation is quick and efficient in comparison to other country's drone approval processes. Why is this important? The regulation cuts the time to access airspace and expands the range of possible applications. Under this law, the country is able to reap the benefits of the rapid development of technology. Gaining a certification is tedious and hinders a drone's technological growth. Rwanda has been able to remove the constraints and limitations that drone providers experience in countries such as The United States and Europe as well.

As a reference, in The United States regulations surrounding unmanned aircraft are much stricter. In compliance with the Federal Aviation Administration, a visual line-of-sight (VLOS) is required at all times. The unmanned aircraft must remain within VLOS of the remote pilot in control. Only daylight-only operations, or civil twilight (thirty minutes before official sunrise to thirty minutes after official sunset, local time) with appropriate anti-collision lighting are allowed. The maximum ground speed must stay below 100 mph (eighty-seven knots) which is

much slower than the 150kmph speed utilized for efficiency and success in Rwanda (Summary of Small Unmanned Aircraft Rule (Part 107) 2016). In order to surpass these regulations, drone operators must obtain a waiver. The "Part 135" certification is the only path for small drones to carry the property of another for compensation beyond visual line of sight. All applicants for this waiver must go through the full five-step process; pre-application, formal application, design assessment, performance assessment, and administrative functions. By the time Amazon was able to obtain clearance for its drone, it was multiple versions advanced from the version that had been cleared. Not only must there be government willingness to cooperate, but there must also commonly be support from the Civil Aviation Authority and military. The biggest issue drone companies face is that every country upholds different regulations making the testing and implementation process different in every country (14 CFR Part 135 Certification Process 2020).

Chapter 4

Introduction to Zipline

4.1 Company

The U.S. startup based in South San Francisco, California collaborated with the Rwandan government to provide blood supplies to citizens in need within the country back in 2016. Since then the company has dispatched units of blood products to hospitals that would have required delivery via roads with difficult terrain, losing essential time in the effort to save lives. Zipline's Rwanda headquarters and distribution center are located about an hour drive from Kigali in the small city of Muhanga. Zipline has most recently opened a second distribution center (DC) in the eastern half of the country but little or no data has been collected on the DC for research.

Serving as both a medical warehouse and a drone airport, a Zipline distribution center is capable of hundreds of deliveries each day to any point within a 22,500+ square kilometer (8,750+ square mile) service area. Holding blood in the warehouse has allowed to company to minimize the lead time between order and delivery for end recipients (How it Works 2019).

4.2 Request for Blood Processes

The National Center for Blood Transfusion delivers the blood to the Zipline distribution center that is located twenty km outside of Kigali where it is able to be stored in state-of-the-art blood storage facilities. When a patient at a connected hospital or health facility is in need of blood, a doctor or nurse sends the delivery team at the Zipline distribution center a notification detailing the blood that is required. The team responds to the message, locates, and scans the blood from the storage into the system to inform the Ministry of Health where the blood is going. The blood is then packed into a sturdy cardboard box, pre-attached to a parachute, and then loaded into a "Zip" (autonomous airplanes) to be transported to the medical facility in need. Once the Zip is close to the predetermined destination, the doctors are alerted and then once again one minute before the package arrives to receive the delivery at the drop-off location. Utilizing a very simple paper parachute, the package is then released from a thirty-foot height. After a successful drop-off, the drone circles back to its base following the same trajectory. This process requires no extra physical labor from the hospital's side other than someone who can place the order and pick it up when it lands (How We're Using Drones to Deliver Blood and Save Lives 2017).

4.2 Drone Physical Structure

The Zips in comparison look like a small propeller airplane with a fixed wing. A fixed-wing drone has a rigid structure which generates lift under the wing due to forward airspeed. This physical composition enables the drones to fly faster and longer than most at 150 kilometers per hour on a single charge. The zips are battery-operated through removable and replaceable battery packs that are in a constant charge at the distribution center. Despite strong winds, rain, or snow the zips are able to operate without interference. The boxes the Zips carry are cold storage containers utilized for their ability to keep the blood temperature controlled. The zips drop their payloads via parachute, instead of landing, to minimize the number of people that need to be trained on how to interact with a drone. The parachute is acceptable due to the lack of fragility in the product being carried.

The drones can currently carry up to two kg of blood in one delivery, either two units of adult blood, or a combination of platelets, plasma, and juvenile blood. With each advancement in the drones and temperature-controlled packaging comes the capability to transport more medical resources.

Proceeding the actual drone flight path an operator secures the drone onto a catapult-like launching mechanism, pre-enters the coordinates of the desired drop-off destination, and with the press of a button is able to send the device into a trajectory of 0 to 100km / hours in half of a second (How it Works 2019). From there on the drone is completely autonomous.

4.3 Transportation Process

Prior to departure, an air traffic controller calls the preapproved flight it into Kigali international airport, adhering to The Rwanda Civil Aviation Authority regulation. A tracking system created through SIM cards in the planes allows Zipline controllers to locate and receive updates at any moment. They can watch the vehicle as it makes a delivery in real-time. This feature is capable due to the utilization of the local cell network. Once the drone has successfully completed its delivery, it flies back to its distribution center, where a wire set fifteen feet above the ground catches the drone tail and pulls the aircraft safely to the ground. It is then collected and prepared to repeat the process over. Each distribution center has the current capacity to make up to five hundred deliveries a day.

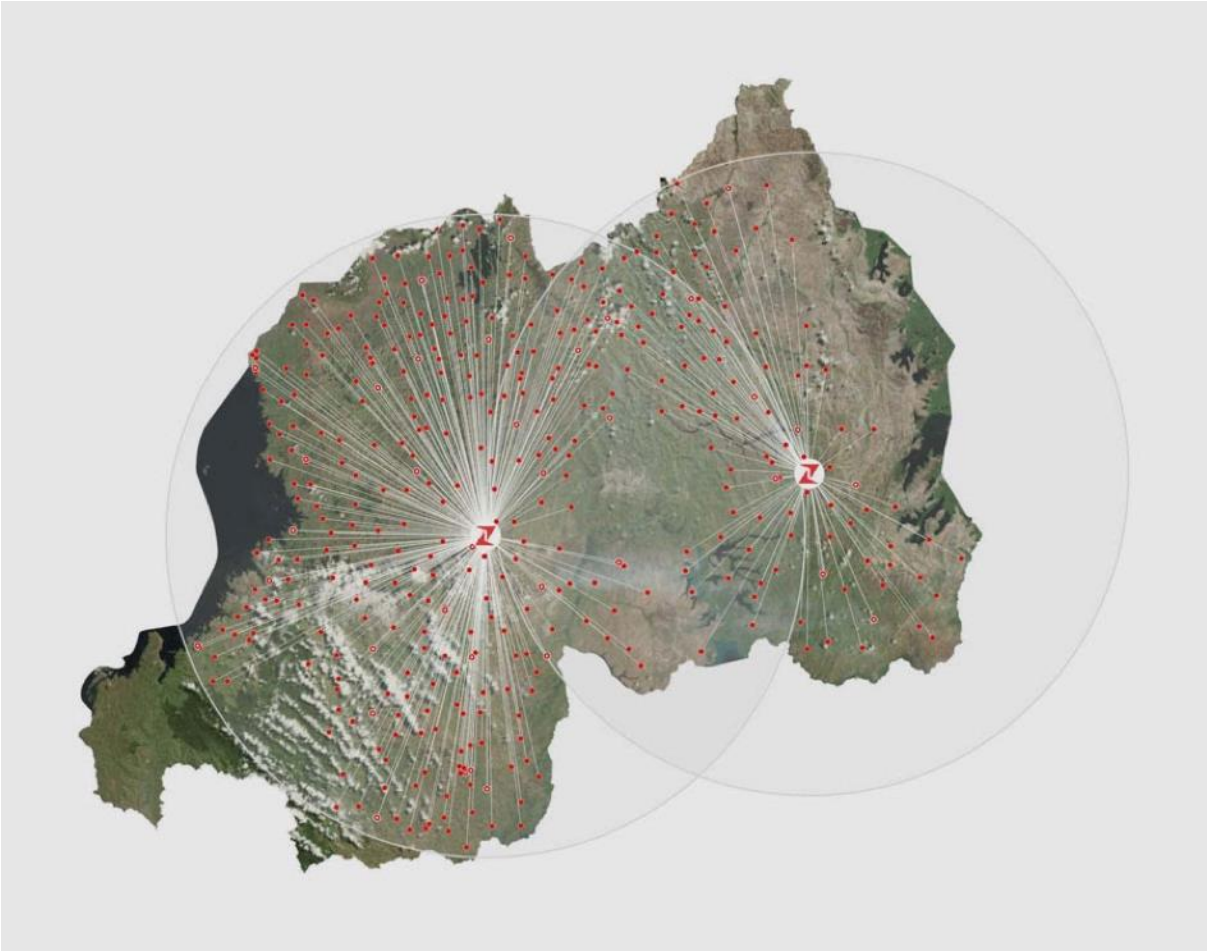

Figure 4 Zipline Distribution Centers

The map in Figure 4 shows Zipline's two distribution centers and the hospitals/facilities they reach with their blood deliveries. The distribution center on the left has most recently been implemented and has little to no data available concerning its operations. When the team at Harvard conducted their project to document all the hospitals in sub-Sharan Africa, they excluded private hospitals because of difficulties in auditing their operations, although these hospitals do provide important critical care services for those who can afford them—notably, in urban areas. Additionally, they excluded services provided to special population groups—notably, military and police service hospitals—and institutional hospitals. Their focus instead

was hospital services targeted at a broad range of emergency or referral care to the general population (People across Africa Have to Travel Far to Get to a Hospital. We Worked out How Far 2020). This explains the difference in hospital locations in Figure 3 and Figure 4, where Figure 3 only represents those facilities documented in the Harvard database and Figure 4 includes the private and specialized hospitals Ziplines reaches as well. With a 75km service radius, the implementation of a second distribution center allows Zipline to reach more patients in need within Rwanda.

Chapter 5

Supply Chain

5.1 Storage

As a country, Rwanda collects on average between sixty to eighty thousand units of blood a year (How We're Using Drones to Deliver Blood and Save Lives 2017). Blood has a short shelf life, requires advanced technical storage, and has a difficult demand predictability, all of which create obstacles. What has been successful in this part of the Supply Chain for Zipline has been the ability to keep blood in a centralized distribution center and then distribute necessary quantities and types of blood from the DC to hospitals and health centers. There are two options the supply chain can choose between from a storage perspective, centralized storage, or storage of blood at all hospitals and health facilities. If blood is to be stocked at large quantities in all facilities, blood will go to waste as only certain types or smaller quantities may be used. If small quantities are stocked at these locations instead, there is a risk of not having the necessary blood needed for a patient. Not only does this present a physical loss but also a financial one as well. From a financial perspective all the hospitals and health facilities must be able to obtain and run the storage equipment necessary while in a centralized storage model only the distribution center would need to do so. Some locations cannot afford the technology necessary to store blood and most cannot afford access to rarely used products, like frozen plasma and platelets to promote clotting, that require specialized freezers. The system, which delivers thirty percent of all blood products used in Rwanda outside the capital Kigali, has

resulted in 100 percent availability of blood products when needed, a ninety-eight percent reduction in waste (i.e., when unused blood products are discarded because of age), and a 175 percent increase in the use of platelets and fresh frozen plasma (Zipline Is Using Drones to Deliver Medical Supplies 2018).

5.2 Acquiring Blood

The final leg of the supply chain distribution process via roadways would be eliminated although the company has found success integrating with the existing supply chain and distribution channels. There is still a manual delivery system in place to transport the acquired blood from blood donation centers to The National Center for Blood Transfusion, and then to the Zipline distribution center. Blood accessibility and capacity had been an issue in Rwanda.

Most recently Rwanda's National Center for Blood Transfusion (NCBT) was awarded the highest, level three, international standards accreditation by AfSBT. AfSBT is the continental body that acknowledges the attainment of international standards, recognizing blood banks as centers of excellence in Africa. This tremendous achievement means NCBT is now an internationally recognized regional center of excellence in blood transfusion practice. Rwanda becomes the second country in Africa after Namibia to achieve this highest level of AfSBT accreditation. AfSBT has also identified Rwanda's NCBT as its Regional Center of Excellence in Blood Banking, making NCBT/RBC an AfSBT Regional Collaborating Center for regional training. No cases of transfusion-transmitted infections have been reported in Rwanda since 2013 when NCBT received Level 1 accreditation from Africa Society for Blood Transfusion. These high standards of blood safety in Rwanda have resulted in a marked decline in the rate of HIV

transmission among blood donors – from an HIV transmission rate of 1.6 percent in 2000 to 0.9 percent in 2015 and 0.6 percent in 2016. NCBT ensures 100 percent screening of all blood donated for transfusion transmissible infections (TTIs) that include HIV, hepatitis B/C, and syphilis (Rwanda's National Center for Blood Transfusion Attains International Standards 2017). This secure system has allowed Zipline to have a healthy and unrestricted supply of blood to transport.

Chapter 6

Challenges in other Areas

6.1 Blood Safety and Obtainability

Although Rwanda may not be facing an issue acquiring blood safely, this may pose as a challenge for other countries in Sub-Saharan Africa. Various contagions, including bacteria, viruses, prions, and parasites can be transmitted through blood transfusions and can be deadly. In order for the reduction of transfusion-transmitted infectious diseases there needs to be health system strengthening efforts as seen in Rwanda. Well-organized, funded, staffed, and equipped blood services are needed to educate, recruit and select donors, collect and process donated blood, prepare blood products, and screen blood donations for various infectious markers and do other tests in a quality-controlled fashion to ensure the blood being transported is safe. This is not available in all areas of the world. Only forty-five percent of low-income countries have specific legislation covering the safety and quality of blood transfusion. In order to ensure patient and transportation safety, all blood donations should be prescreened for HIV, hepatitis B,

hepatitis C, and syphilis. Of all blood donations only 83.2 percent are screened in lower-middle-income countries and 76.2 percent in low-income countries creating a high risk for safe blood transfusions. Obtaining a large enough capacity of blood to aid patients in need is another challenge. Sixty-six countries report collecting fewer than ten donations per 1000 people. Of these, thirty-seven countries are in the World Health Organization (WHO) African Region (Blood Safety and Availability 2019).

6.2 Barriers to Drone Delivery

Experienced drone providers in third world countries see a need for sensitization activities needed to make locals aware. The question is how to do this? However, public sensitization activities alone cannot replace the in-person opportunities to safely view the operations in action. Drone flight personnel must be available to facilitate interactions with the public and should select takeoff and landing sites strategically to facilitate crowd control.

6.3 Creating a Cost vs. Benefit Analysis

It is difficult to quantify the cost vs. benefit in this situation as it means comparing lives saved to dollars spent. Some areas to potentially evaluate are how many more lives can be saved by this system than the system already in place? What is the cost of implementing and maintaining this system? The company will not disclose how much the contracts were worth, but the Rwandan government's internal cost analysis estimated the cost to be on par with current costs after considering road transportation costs and the blood products lost from spoilage (Drone Deliveries of Blood Could Transform Healthcare in Africa 2016). Most importantly these

drones are saving time and it is difficult to put a price on time. This is time saved not only in transportation but also the valuable time of care providers as well.

Chapter 7

Why it Works in Rwanda

Having a commercial government contract and regulatory support has contributed the most among many other things to Zipline's success in Rwanda. The majority of Rwanda's population can benefit from the implementation as they lack the quantity and quality of healthcare centers. As shown from the population statistics, the majority of the population lives in rural areas, outside of cities, and need quick access to medical assistance. The physical makeup of the country that contributes to transportation limitations are obstacles such as hills and floods. Zipline has been able to create sufficient jobs for Rwanda's working-age population, which is one of the country's biggest challenges. One hundred percent of the teams working at the distribution centers are local (engineers, operators, etc.). The commercial contracts are signed with the Ministries of Health as well making them sustainable and scalable. Rwanda has low crime rates that create little to no risk of theft or violence. Zipline also guarantees doctors access to rarely used products, like frozen plasma and platelets to promote clotting, that require specialized freezers—machinery that most Rwandan hospitals cannot afford.

Chapter 8

Development

To combat their country's local drone legal restrictions, many providers look to test their products in foreign countries with looser regulations. When they do, many fail to realize that they are intruding on that foreign country's airspace and resources. Companies need to create a partnership for delivering services and providing jobs to the local citizens and not just using the area for testing grounds for outside projects. "Instead of saying: 'We have a drone and we want to bring it to your country, 'it should be: 'What are your country's needs and how can we develop something that works for you?'". Having an in-country partner to launch and run the project while also managing relations with government, industry, and other stakeholders, is also very important.

There are a wide variety of countries in which this model can be utilized. Countries where natural disasters like flooding or tornadoes occur often causing disruptions to land transportation, could greatly benefit from drone implementation in the same manner. Most importantly, a large population of Sub-Saharan Africa could decrease mortality rates and improve their standards of living as they too lack access and transportation to medical necessities. The same delivery process could potentially be used for the collection of blood from donors to be transported to The National Center for Blood Transfusion for proper testing and storage. This could increase accessibility to willing and safe donors. In regards to lab testing, drone transportation can decrease the time it takes for tests to be delivered to physicians in cases such as early infant diagnosis and tuberculosis samples for testing, as well as micropipettes for HIV testing, emergency medicines, vaccines, and syphilis test kits. The quicker the tests are processed, the quicker a diagnosis can be made and aid for the patient can be provided.

Many people are questioning if this same model would be effective in the US? No, not to the same extent but due to lack of infrastructure and room for improvement in the health field, it will have high life-saving outcomes for third world countries. Blood and medical supply shortages affect rural hospitals in the U.S. just as they do in Rwanda and this model could benefit these areas but that would call for a push for government approval.

Chapter 9

Conclusion

"The reality is, moms die in every country in the world from lack of blood. Rwanda was just the first country to do something about it" (Dr. Roger Nyonzima, head surgeon at Nyanza Hospital's maternity ward). There is a desperate need for other governments to pass laws, and companies to form contracts to enable these processes to be tested, implemented and improved on a medical need basis.

Timely access to emergency care can significantly reduce mortality. The Harvard study estimated that 286 million (twenty-nine percent) people and sixty-four million (twenty-eight percent) women of child-bearing age in Sub-Saharan Africa are located more than two hours from the nearest hospital. Only seventeen countries reached the international benchmark of more than eighty percent of their populations living within a two-hour travel time of the nearest hospital (People across Africa Have to Travel Far to Get to a Hospital. We Worked out How Far 2020). If more woman can access medical essentials through drone delivery, their likelihood of survival is higher in life-threatening pregnancies.

By investing in an aerial logistic network, Rwanda now has a developed system they can utilize for other parts of their economy such as agriculture or e-commerce or transportation of other medical necessities such as medicines, vaccinations, and disease testing to continue improving the quality of life for its citizens.

The largest barriers to adoption of drone-based delivery systems include differences in state laws about when, where, and how drones can be used and who can operate them. Well-developed and tested technology, employment of locals, a defined need from and benefit to the country, and most importantly support for the government can help mitigate and overcome these barriers. Some research areas to look into moving forward are how to quantify the cost/benefit of service delivery, creating local buy-in/how to increase awareness of UAVs in the health sphere and respond to misconceptions, and how to build local capacity in such a new field.

Zipline has successfully discovered how to work with Rwanda's civil aviation regulator, integrate with the public healthcare supply chain, set up distribution centers, and run maintenance. As great of success Zipline has had as a sustainable company in Rwanda, most importantly they have saved hundreds of lives by improving accessibility to blood resources drastically. It is ultimately not about the technology or the business; it is about enhancing human life.

Appendix A

Sub-Sharan Public Hospitals Geo-coded database

Country	Region	Facility Name	Renamed facility type	Owner	Lat	Long	LL Source
Rwanda	East	Nyamata District Hospital	District Hospital	Govt.	-2.1384	30.0799	GPS
Rwanda	East	Kiziguro District Hospital	District Hospital	Govt.	-1.7666	30.3848	GPS
Rwanda	East	Ngarama District Hospital	District Hospital	Govt.	-1.5460	30.2429	GPS
Rwanda	East	Gahini District Hospital	District Hospital	Govt.	-1.8407	30.4832	GPS
Rwanda	East	Rwinkwavu District Hospital	District Hospital	Govt.	-1.9640	30.6141	GPS
Rwanda	East	Kirehe District Hospital	District Hospital	Govt.	-2.2674	30.6536	GPS
Rwanda	East	Kibungo Referral Hospital	Hospital	Govt.	-2.1659	30.5394	GPS
Rwanda	East	Nyagatare District Hospital	District Hospital	Govt.	-1.2981	30.3262	GPS
Rwanda	East	Rwamagana Provincial Hospital	Regional Hospital	Govt.	-1.9503	30.4331	GPS
Rwanda	Kigali City	Caraes Ndera National Referral Hospital	National Referral Hospital	Govt.	-1.9547	30.1690	GPS
Rwanda	Kigali City	Kacyiru District Hospital	District Hospital	Govt.	-1.9331	30.0752	GPS
Rwanda	Kigali City	Kibagabaga District Hospital	District Hospital	Govt.	-1.9308	30.1120	GPS
Rwanda	Kigali City	King Faisal National Referral Hospital	National Referral Hospital	Govt.	-1.9439	30.0951	GPS
Rwanda	Kigali City	Masaka District Hospital	District Hospital	Govt.	-1.9956	30.1913	GPS
Rwanda	Kigali City	Kigali CHUK National Referral Hospital	National Referral Hospital	Govt.	-1.9565	30.0604	GPS
Rwanda	Kigali City	Muhima District Hospital	District Hospital	Govt.	-1.9367	30.0585	GPS
Rwanda	North	Butaro District Hospital	District Hospital	Govt.	-1.4089	29.8366	GPS
Rwanda	North	Nemba District Hospital	District Hospital	Govt.	-1.6377	29.7867	GPS
Rwanda	North	Ruli District Hospital	District Hospital	Govt.	-1.8296	29.8494	GPS
Rwanda	North	Byumba District Hospital	District Hospital	Govt.	-1.5893	30.0551	GPS
Rwanda	North	Ruhengeri Referral Hospital	Hospital	Govt.	-1.5058	29.6367	GPS
Rwanda	North	Kinihira Provincial Hospital	Regional Hospital	Govt.	-1.6619	29.9886	GPS
Rwanda	North	Rutongo District Hospital	District Hospital	Govt.	-1.8148	30.0598	GPS
Rwanda	South	Gakoma District Hospital	District Hospital	Govt.	-2.3497	29.9177	GPS
Rwanda	South	Kibilizi District Hospital	District Hospital	Govt.	-2.6486	29.7834	GPS
Rwanda	South	Butare CHU National Referral Hospital	National Referral Hospital	Govt.	-2.6120	29.7352	GPS
Rwanda	South	Kabutare District Hospital	District Hospital	Govt.	-2.6073	29.7473	GPS
Rwanda	South	Remera Rukoma District Hospital	District Hospital	Govt.	-1.9387	29.9099	GPS
Rwanda	South	Kabgayi District Hospital	District Hospital	Govt.	-2.1045	29.7506	GPS
Rwanda	South	Kaduha District Hospital	District Hospital	Govt.	-2.3333	29.5262	GPS
Rwanda	South	Kigeme District Hospital	District Hospital	Govt.	-2.4793	29.5258	GPS
Rwanda	South	Nyanza District Hospital	District Hospital	Govt.	-2.3526	29.7493	GPS
Rwanda	South	Munini District Hospital	District Hospital	Govt.	-2.7134	29.5355	GPS
Rwanda	South	Gitwe District Hospital	District Hospital	Govt.	-2.2470	29.6893	GPS
Rwanda	South	Ruhango Provincial Hospital	Regional Hospital	Govt.	-2.1937	29.9055	GPS
Rwanda	West	Kibuye Referral Hospital	Hospital	Govt.	-2.0670	29.3463	GPS
Rwanda	West	Kirinda District Hospital	District Hospital	Govt.	-1.9349	29.6253	GPS
Rwanda	West	Mugonero District Hospital	District Hospital	Govt.	-2.1808	29.2927	GPS
Rwanda	West	Kabaya District Hospital	District Hospital	Govt.	-1.7472	29.5373	GPS
Rwanda	West	Muhororo District Hospital	District Hospital	Govt.	-1.9485	29.3618	GPS
Rwanda	West	Shyira District Hospital	District Hospital	Govt.	-1.6820	29.6291	GPS
Rwanda	West	Bushenge Provincial Hospital	Regional Hospital	Govt.	-2.4451	28.9858	GPS
Rwanda	West	Kibogora District Hospital	District Hospital	Govt.	-2.3262	29.1322	GPS
Rwanda	West	Gisenyi District Hospital	District Hospital	Govt.	-1.7021	29.2623	GPS
Rwanda	West	Gihundwe District Hospital	District Hospital	Govt.	-2.4830	28.9147	GPS
Rwanda	West	Mibilizi District Hospital	District Hospital	Govt.	-2.5676	28.9537	GPS
Rwanda	West	Murunda District Hospital	District Hospital	Govt.	-1.9068	29.3761	GPS

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- AWESOME Excellence in Education Scholarship, 2019
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- National Undergraduate Supply Chain Case Competition, 2019, 2nd place
- Spanish Basic Learning Program Certificate in Recognition of Outstanding Work in Spanish

Professional Experience

- Johnson & Johnson, Supply and Demand Planning Co-Op, 2018, Fort Washington, PA
- KPMG, Product Operation and Procurement Advisory Intern, 2019, New York, NY

Leadership

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- Alpha Chi Omega, IFC/Panhellenic Dance Marathon (THON) Finance Chair

Association Membership/Activities

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