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Medical Drone Delivery in Developing Countries: Case Study Mongolia

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Abstract[1]—Developing countries often have difficulties in the field of medicine, and many of these problems do not relate to missing knowledge but on the transportation possibilities to bring patient, doctor and the necessary medical supplies together. In a research study for the country of Mongolia the advantages of a drone delivery system are shown and the unique challenges such as temperature, elevation and range are discussed to choose a suitable system design for countries with enormous size and low population. Airplane shaped drones with their wider distances seem to be the most promising solution to connect rural areas to the medical logistics network.

Keywords—medical delivery; developing countries; logistics drone; Quadrocopter, airplane drone.

I. Introduction

Medical services require a fast, safe and reliable supply of goods such as vaccines, pharmaceuticals, blood supplies, etc. In general, there are two different supply philosophies: a) the centralized idea where a small amount of warehouses stores all medical supplies for the country, or b) the distributed idea, where all medical facilities have their own warehouse for keeping all supplies that might be necessary [1]. Obviously both logistics systems have advantages as well as disadvantages:

The distributed idea sounds great at first, because every medical facility has directly on hand what they need, but the difficulty is here about what they do not need. Medical supplies usually have a rather short time before they reach their expiry date, therefore a lot of supplies that should be available but were not needed, have to be thrown away, leading to high amounts of supplies travelling to the facilities and similar high amounts that are wasted because they were not used.

The centralized idea tries to solve the problem by making sure that small amounts of warehouses have a better overview of the medical supplies and therefore much less supplies are wasted. The difficulty here is what logistics expert call "the last mile problem" [2]. It means when the medical facility requires the supplies, they must be transported from the warehouse first and are not immediately available. This transport from the warehouse is a critical point, as the transport must be fast, safe and reliable as well, but gets highly influenced by the road condition, traffic and the surrounding environment.

The use of high-end technology in logistics led to the creation of new ideas to solve the problems mentioned above. Drone delivery systems should have the capability to deliver medical supplies faster, safer and more reliable than any other reasonable transport could do. As they are not limited to the typical transport infrastructure (roads, rail-tracks) they are especially an option for developing countries, where available infrastructure creates big challenges for medical supply transportation [3].

II. Medical Drone Delivery

There are different strategies in use by different companies regarding the transportation of goods with drones. For example, Amazon receives high attention in the media for their project to deliver small packages inside of big cities within a few minutes [4]. Based on multi-rotor drone designs (Quadcopter, Octocopter, etc.) the flight stability in cities can be considered reliable and safe. The only challenge of these designs is the limited weight capacity for the delivery. With their speed of about 80km/h and their small working radius they can deliver products over short ranges within minutes.

In terms of medical delivery there are different ideas created by different companies and organizations, using different designs for their drones:

A. Helicopter drone design

Many drone systems are based on drones, that have multiple rotors to control movement and carry the weight. Advantages of these systems are the accurate control of the drone, as it can even stop and stay at one location and can be accurately controlled in its movement

1) AED quadrocopter: There are Quadrocopter that carry Automated External Defibrillators (AED) for first aid treatment of heart attacks. Placed in many locations in public buildings in the developed world these AEDs could save many lives in the future as heart attacks must be treated by carefully places electric shocks as fast as possible. Research has shown that the drone can be up to 75% faster than an ambulance [5].

2) Matternet: A drone system currently tested in Haiti and parts of Africa. The concept is based on a large number of quadrocopter drones, several landing sites and an intelligent network for automated communication. A single drone can carry about 2 kg over a distance of 10 km within 15 min. After that it has to land on a landing site and can automatically give the package to another (fully charged) drone, that can deliver it again to the next landing site. As a result a whole network of landing sites and drones can make an effective delivery network for communities that are living in relatively close distance to each other [6].

B. Aircraft design drones

On the first look aircraft design drones seem to have disadvantages for delivery, as they are less accurate in control and cannot land at any place. But when looking at other fields of drone development the aircraft design is found more frequently because of it advantage to use energy more effectively and therefore to cover wider distances. As aircrafts the drones cannot stop in the air and need special landing preparations and environments.

1) Zipline: A company, that runs the first drone based regular medical delivery service in the world [7]. It is located in the small African country of Rwanda, where all medical facilities can order and receive their supplies, especially transfusion blood. In addition they plan to operate a bigger network in the neighbouring country of Tanzania, where vaccines and essential medicine should be transported to the hardly reachable areas in the countryside.

Their drones have an operating radius of 75 km [7] where they deliver their products with a box and a parachute. After the delivery the aircraft automatically flies back to the station where it can safely land. As a result the technical aspects of the system stay within the service station and the customer does not need to know how to handle these drones correctly. Communication with the drones is based on SIM cards, which allow the use of these drones wherever a mobile-phone operator has a running service.

III. DEVELOPING COUNTRIES AND CASE STUDY: MONGOLIA

"Developing countries" is a term to group countries together that actually are not really fitting together as a group.

There is a list with real rules and revisions about which country gets in and gets out of the group, but that one is only for the "Least Developed Countries" (LDCs). On the official list there are currently 47 countries listed, that are considered "least developed" [8]. Other countries that are not in the list, are often described as developing countries in contrast to the countries that are said to be already finished with their development (such as USA, Canada, Japan or members of the European Union). But still there are countries defined as developing such as Singapore, Israel or the Republic of Korea [9] even though the same organization recognizes their development as even higher than some of the developed countries. The Human Development Report [10] provides a global index on country wide development, where different countries are compared with each other. With Singapore on rank 5 but France, Austria and Spain on the ranks 21, 24 and 27 respectively it is clearly visible that the development can be very different within the group of developing countries.

A. General development

As there is no real definition about development countries it cannot be spoken generally about the development of all such countries, but instead it must be separated in countries, that are in a similar situation. As table 1 shows it is not useful to compare countries in categories such as population, size or density, as there they still can have different development.

TABLE I. EXAMPLE OF COUNTRY STATISTICS

Country name	**Country statistics**		
	Population	***Size***	***HDI***
Finland	5,516,224[a]	338,424 km²	23 [10]
Republic of the Congo	5,399,895[b]	342,000 km²	135 [10]

a. http://www.stat.fi/til/vamuu/2017/12/vamuu_2017_12_2018-02-15_tie_001_en.html, Accessed on May 15th. 2018

b. https://esa.un.org/unpd/wpp/DataQuery/, *Accessed on May 15th 2018*

B. Healthcare development

In the field of Medicine the differences between the countries are as big as they are in general. International standards often cannot be used in developing countries as the requirements are not fulfilled and the environment is not fitting.

- Old vs. new: Modern facilities and equipment meets current standards, but older buildings and devices do not

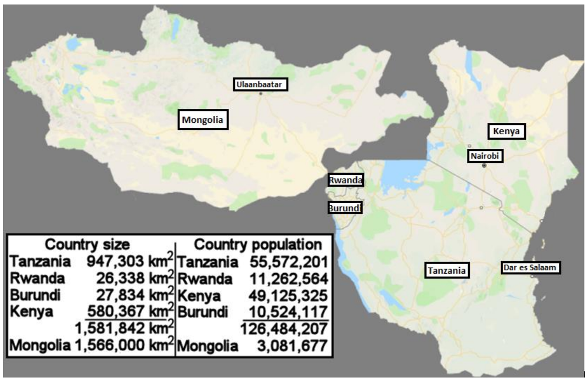

Figure 1: Mongolia in comparison with eastern Africa.

need to be updated, leading to a difference between rich and poor countries.

- Infrastructure: There are some countries that developed a high level infrastructure (e.g. road, rail track, internet, electricity) and others where regions are not fully connected. For transportation and logistics but also medicine in general an infrastructure is important.
- Transportation: Facilities are logistically connection points, where goods and people come together. In terms of medicine the facility only can work when patient AND doctor AND medical goods can be correctly and safely transported to the connection point.

C. *Case study Mongolia*

Mongolia is a landlocked country in Central/ Eastern Asia with only the Russian Federation and the People's Republic of China as its neighbours. On the map seemingly small it has the size of eastern Africa (Tanzania, Kenya, Burundi and Rwanda together, see Figure 1).

In average the height of the country is 1580 meters above the sea level, but varies strongly from 523 meters above the sea level up to 4374 meters above sea level [11]. It is divided into 21 different districts, named Aimags, plus a multifunctional capital area that have a very different population density each. With 0.38 inhabitants per square kilometre the Aimag of Govi-Altai had the lowest population density of all Aimags in 2012. Still several areas in Mongolia can be described as rural areas without electricity or sanitation. The situation of the population, who are often nomads travelling with their animals, makes it difficult to analyze and improve their lifestyle and medical condition. There are mostly no real roads but instead pathways created by numerous cars driving similar paths over a longer period of time.

Transportation on such conditions can become increasingly difficult, when the weather condition changes the stability of the earth of the pathways. In most of the country, there is no official speed limitation as the road condition limits the speed mostly. When nomads move from one location to the next, following their animals, they often leave any infrastructure behind and cannot be reached in case of emergencies.

But most Mongolian nomads have a mobile phone nowadays and often get at least a weak signal of service. Technologies to locate the position of the phone by its SIM card service in combination of a sent request (e.g. SMS) could be enough information for a delivery job of pharmaceuticals.

The biggest challenge in Mongolia is the temperature change throughout the year. Compared with Kigali, the capital

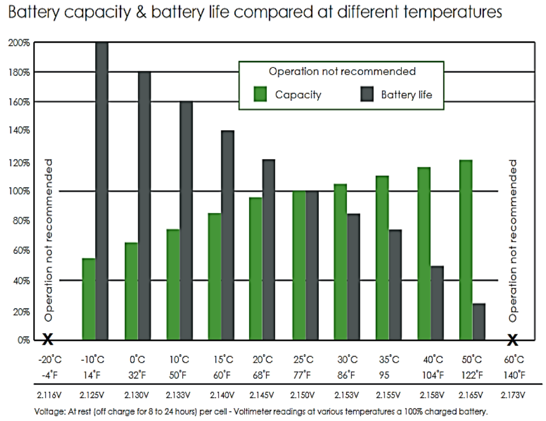

Figure 2: Battery capacity & battery life at different temperatures [15].

of Rwanda, where the Zipline drones are operated, the average elevation of Mongolia is similar, but the Rwanda has average temperatures from 16°C to 28°C throughout the year [12]. In Mongolia the mean temperatures per month vary from -28.5°C to +25°C for Khovd, a province capital in western Mongolia that belongs to the coldest areas within the country[13]. Using batteries to power the drones engines should have a serious impact, as the winter temperatures are going to increase the internal resistance and therefore lower the capacity.

IV. Results and Conclusion

In Mongolia the field of transportation and logistics is only partly developed. There is no national post and package delivery and only a few private companies that are specialized in this field.

In medicine an online service with delivery was created by a company named "Monos", that is running several pharmacies especially within Ulaanbaatar [14]. On demand the bought medicine can be transported by own drives to the customer. But on a bigger scale these services are not applicable on areas outside the capital. In general, there are different problems recognized for the capital area and the other 21 Aimag districts: While outside the capital the infrastructure causes trouble to create a delivery system, the capital faces its biggest problems with the daily traffic.

A drone system is the solution for both problems, as it does not require roads and also does not get stuck in traffic. The only challenges for drone systems are the environment (elevation of the country and the weather condition) as well as the vast distances.

But drones that are powered by batteries will differ in flight radius from autumn to spring, as the temperature affects the capacity of the battery [15]. At 0°C it can be said that the capacity is only 65% , going down to only 50% at -18°C (Figure 2). It cannot be said, if a reliable and safe operation can be guaranteed during winter. The increased battery life cannot be seen as an advantage, when the capacity limitations lead to regular complete shutdown of operation.

The aircraft design from Zipline company is the only real practical possibility to cover wider areas of the country. Drones that fly from one landing platform to the next, which are about 10 km apart from each other, can be useful in countries with high population, where the next town or village is always less than 10 km away. But in Mongolia even the 75 km radius of Zipline designs does not always cover enough space to reach

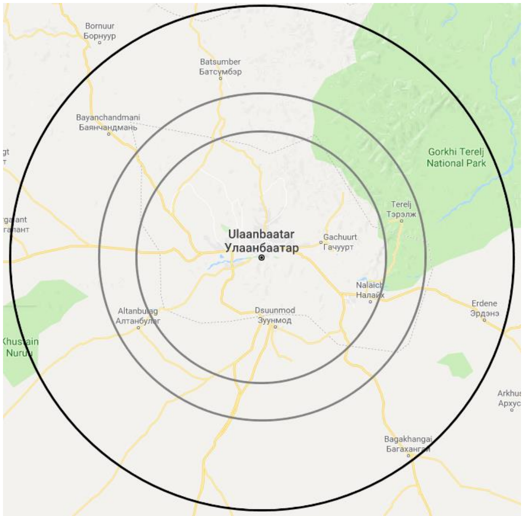

Figure 3: The Mongolian capital Ulaanbaatar with circles of the radius, depending on the capacity of the battery: 75km (100%), 48.75 km (65%) and 37.5 km(50%)

the next town in a certain direction (Figure 3, next page).

A possible solution would be an extension of the existing Zipline system, to allow an aircraft to start at one service station

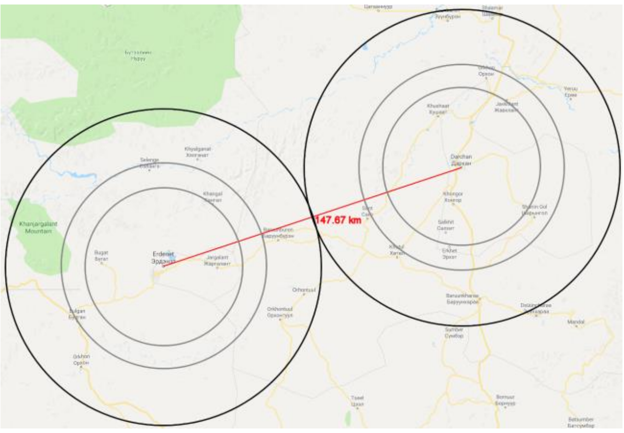

Figure 4: Erdenet (left) and Darkhan (right), each with circles of the radius, depending on the capacity of the battery: 75km (100%), 48.75 km (65%) and 37.5 km(50%)

and land on another one. To avoid damage to the transportation good due to the sudden stop of the aircraft, the goods can be

released with the parachute before the landing procedure is started. This would be an idea for smaller warehouses, which could exchange their products and aircraft in the best possible way. For example the second and third biggest agglomerations in Mongolia are the cities Darkhan and Erdenet. Even though they are the most populated areas apart of Ulaanbaatar, each of their population makes less than 10% of the capital population. But as they are about 148 km away from each other, it could be possible to establish an connection between both cities to share their goods, at least during the warm summer season (Figure 4).

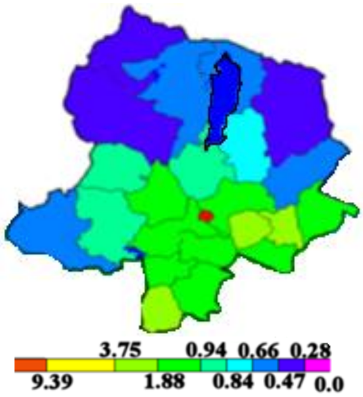

Figure 5: Khuvsgul aimag with population densities for each sub-district (in inhabitants per square kilometre).

Another challenge is the coverage of a complete Aimag area. Khuvsgul Aimag is one of the northern territories on the border to Siberia. With 100,628 km² in size the district alone is taller than the Republic of Korea (South Korea). When applying mathematics on the problem it is shown that at least six service stations would be required to cover the entire area (Formula 1 and 2). But then every station must be placed at a perfect location, where a maximum of 5,09% of the whole district is covered by more than 1 station (Formulas 3, 4 and 5).

$$\pi * r^2 = \pi * (75km)^2 \approx 17{,}670\ km^2 (1)$$

$$\frac{100{,}628\ km^2}{17{,}670\ km^2} = 5.69 \rightarrow\ 6\ (2)$$

$$6 * 17{,}670km^2 = 106{,}020\ km^2\ (3)$$

$$106{,}020km^2 - 100{,}628km^2 = 5392km^2 (4)$$

$$\frac{5{,}392km^2}{106{,}020km^2} = 5.09\%\ (5)$$

Of course it is not possible to arrange the service stations in practice in a way that they could cover all the area and only have 5% overlapping or covering neighbouring Aimags. There will be more necessary to cover the majority of the province area, taking the population distribution within the Aimag into consideration (Figure 5).

But Khuvsgul province is known to be one of the coldest Aimags in Mongolia, therefore the temperature effect on the flight radius must be considered again (Formulas 6 and 7 for 0°C, Formulas 8 and 9 for -18°C).

$$\pi * r^2 = \pi * (48.75\ km)^2 \approx 7{,}466\ km^2 \quad (6)$$

$$\frac{100{,}628\ km^2}{7{,}466\ km^2} = 13.48 \rightarrow\ 14 \quad (7)$$

$$\pi * r^2 = \pi * (37.5\ km)^2 \approx 4{,}417\ km^2 \quad (8)$$

$$\frac{100{,}628\ km^2}{4{,}417\ km^2} = 22.78 \rightarrow\ 23 \quad (9)$$

For the people living in the rural areas of the Aimags the solution would be very helpful as there is not in every town an own hospital and doctors often do not have the correct medicine to help the people locally. A delivery system for medical goods would therefore rapidly improve the medical support in the covered areas.

As a general conclusion it can be stated that the technology of drones has a high potential for supply chains in medicine in developing countries, but the detailed design must take the unique situation of each country into account. A potential difficulty for Mongolia are the high distances between the spots of civilization in the big countryside that surrounds them. Nomads living in these nature-based environment could never be supported with medical goods from the surface and can hope for SIM card based technology for their exact location and delivery with the help of drones.

The comparison in terms of environmental conditions showed that the elevation should not have a high influence on the flight conditions, but the temperature does, when the drone is operated by batteries. Winter temperatures could in worst case result in sudden energy outage during the delivery, creating unpredictable risks. Whether it is possible to isolate the battery long enough from the cold temperatures during the delivery should be part of further investigation.

Another research team at the Mongolian University of Science and Technology is currently trying to address these problems by preparing drones with gasoline engine. These drones require to have a bigger size to stay controllable and to include the gasoline tank [16,17].

All together comes a list of requirements, that must be fulfilled by the drone concept, to be useful for countries such as Mongolia:

- Stable and reliable operation in typical weather conditions, such as wind
- Temperature independent power supply of the drone to allow operation during the cold winter
- Simple operation and high distance coverage to reach and interact with highly scattered rural population (e.g. Nomadic lifestyle).

Especially the cold temperature in winter and the enormous distances remain to be challenges in the development of a drone delivery system for Mongolia.

References

[1] Saharidis, GKD. (2011) “Supply Chain Optimization: Centralized vs Decentralized Planning and Scheduling”. *in: Pengzhong Li (2011) Supply Chain Management. InTech. ISBN: 978-953-307-184-8*

[2] Allen, Brigitte (2012) “Improving freight efficiency within the ‘last mile’: A case study of Wellington’s Central Business District” *(Thesis, Master of Planning). University of Otago. Acessed: March 18th 2018. Available online at: https://ourarchive.otago.ac.nz/handle/10523/2247*

[3] Govindaraj R, Herbst CH.(2010) "Applying Market Mechanisms to Central Medical Stores : Experiences from Burkina Faso, Cameroon, and Senegal". *Health, Nutrition and Population (HNP) discussion paper;. World Bank, Washington, DC. © World Bank. Accessed: March 18th 2018. Available online at: https://openknowledge.worldbank.org/handle/10986/13608 License: CC BY 3.0 IGO*

[4] Amazon. “Amazon Prime Air”. *Accessed: March 18th 2018. Available online at: https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011*

[5] Siddique H. (2017) "Defibrillator-carrying drones could save lives, research suggests". *The Guardian International edition. Tuesday, 13th of June 2017. Accessed: March 18th 2018. Available online at: https://www.theguardian.com/technology/2017/jun/13/defibrillator-carrying-drones-could-save-lives-research-suggests*

[6] Raptopoulos A (2013). "No roads? There's a drone for that". *TED conference. Accessed: March 18th 2018. Available online at: https://www.ted.com/talks/andreas_raptopoulos_no_roads_there_s_a_drone_for_that*

[7] Rinaudo K (2017). "How we're using drones to deliver blood and save lives." *TEDGlobal 2017. Accessed: March 18th 2018. Available online at: https://www.ted.com/talks/keller_rinaudo_how_we_re_using_drones_to_deliver_blood_and_save_lives*

[8] Committee for Development Policy, "List of least developed countries". *Accessed: March 18th 2018. Available online at https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/ldc_list.pdf*

[9] Committee for Development Policy, "Complete dataset", *Accessed March 18th 2018. Available online at https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/page/LDC_data.xls*

[10] United Nations Development Programme, "The Human Development Report 2016". *Accessed March 18th 2018. Available online at http://hdr.undp.org/sites/default/files/2016_human_development_report.pdf*

[11] National Registration and Statistics Office. "Mongolian statistical yearbook 2016." *Ulaanbaatar, Mongolia, 2017. ISBN 978- 99978-801-1-6 p.12. Accessed: March 18th 2018. Available online at: http://www.1212.mn/BookLibraryDownload.ashx?url=Yearbook_2016.pdf&ln=En*

[12] World Meteorological Organization. "World Weather Information Service - Kigali". *Accessed: April 25th 2018. Available online at: http://worldweather.wmo.int/en/city.html?cityId=254.*

[13] World Meteorological Organization. "World Weather Information Service - Khovd". *Accessed: April 25th 2018. Available online at: http://worldweather.wmo.int/en/city.html?cityId=1137.*

[14] what3words (2017) "More efficient pharmaceutical deliveries in Mongolia with what3words and Monos". *What3words.com. Accessed: March 18th 2018. Available online at: https://what3words.com/partner/monos/*

[15] Discover Energy Corp. "Temperature effects on battery performance & life". *Accessed: April 17th 2018. Available online at: https://www.heliant.it/images/FV/ev_temperature_ effects.pdf*

[16] B.Choijil.TS.Danjkhuu, Y.Obikane (2013) "Sky-Infra Project in Mongolia: Logistics and Environmental monitoring", *APISAT2013,Takamastu, Japan, 2013 Oct, 01-05-1*

[17] Y.Obikane, B.Choijil. (2015) "Sky-Infra Project in Mongolia and Aero-Space Engineering Education Project", *51st AIAA/SAE/ASEE Joint Propulsion Conference, AIAA Propulsion and Energy Forum, (AIAA 2015-3814). Accessed: April 25th 2018. Available online at: https://doi.org/10.2514/6.2015-3814*