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Implementation of a drone delivery system for healthcare in Mexico: international precedents and domestic considerations.

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ABSTRACT.

One of the Mexican healthcare system's principal problems is providing access to its rural communities. Drone delivery has repeatedly proven to be a compelling and cost-effective solution to this problem elsewhere, yet there is currently no scholarship connecting global developments in drone technology to problems in the Mexican healthcare system. This paper is to outline lessons learned from drone systems in several countries, providing information on the potential target communities, technical drone and nest specs, goods of delivery, and regulation of a drone system for healthcare in Mexico.

KEYWORDS.

Drone, UAV, logistics, healthcare, medicine, rural, accessibility.

I. INTRODUCTION.

In Rwanda, drones have cut median delivery times from 139 minutes to 41 minutes, reducing mortality rates for mothers suffering from in-hospital postpartum hemorrhage by 51%.[1] In

[1] Jeon, H. Harrie et al. "Leapfrogging for Last-Mile Delivery in Health Care." *SSRN Electronic Journal*, 2022. https://doi.org/10.2139/ssrn.4214918; Nisingizwe et al. "Effect of Unmanned Aerial Vehicle (Drone) Delivery on Blood Product Delivery Time and Wastage in Rwanda: A Retrospective, Cross-Sectional Study and Time Series Analysis." *The Lancet Global Health* 10, no. 4 (2022). https://doi.org/10.1016/s2214-109x(22)00048-1;

Ghana, drones have shortened vaccine stock-outs by an average of 60%, improving vaccination rates in districts covered and reducing infectious diarrhea cases by 42%, earning the drone system the US Department of State's Awards for Corporate Excellence.[2] In Vanuatu, a UNICEF test program was 100% successful in vaccine delivery, proving "unequivocally that drones are technically and operationally able to contribute to minimizing logistical bottlenecks in the 'last-mile' delivery of vaccines," and saving the life of a mother with a timely delivery of oxytocin that otherwise would not have arrived in time: healthcare workers turned to the provisional drone system in an emergency, and it came through, even though it was only set up to test routine vaccine delivery.[3]

Yet there is not a whisper to be heard about the prospect of such a system in Mexico. The lack of research on healthcare drones in Mexico is difficult to explain: one of Mexico's greatest healthcare problems is providing access to rural communities, which is just what drones are best suited to do. Indeed, this paper is indirectly inspired by another that set out to analyze healthcare drones in the US, Canada, and Mexico[4] but had to drop Mexico from its list because (amazingly)

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[2] Connor et al. "Measuring Zipline's Impact on Health Access, Availability, and Supply Chain in Ghana." IDinsight, June 6, 2022. https://www.idinsight.org/publication/measuring-ziplines-impact-on-health-access-availability/; Pedro Kremer et al., "An impact assessment of the use of aerial logistics to improve access to vaccines in the Western-North Region of Ghana," June 19, 2023, https://www.sciencedirect.com/science/article/pii/S0264410X23007016; U.S. Embassy in Ghana, "United States Honors Zipline Ghana with the Award for Corporate Excellence," U.S. Embassy in Ghana, December 8, 2021, https://gh.usembassy.gov/united-states-honors-zipline-ghana-with-the-award-for-corporate-excellence/.

[3] "PROJECT REPORT Vanuatu Drone Trial: Phase 1 and 2." UNICEF, September 2019. https://www.updwg.org/wp-content/uploads/2020/10/UNICEF-Vanuatu-Drone-Report-Final-Executive-Summary.pdf.

[4] Bradley Hiebert et al., "The Application of Drones in Healthcare and Health-Related Services in North America: A Scoping Review," MDPI, July 4, 2020, https://www.mdpi.com/2504-446X/4/3/30.

it found “no documents” on Mexico.[5] Thus, the purpose of this paper is to go a small way toward filling in the present lacuna in scholarship, considering the prospects of a drone delivery system for healthcare in Mexico.

II. METHODOLOGY.

We sought out published papers pertinent to past, current, and future uses of drones for healthcare, or to current challenges faced by the Mexican healthcare system. This paper makes use of ****,[6] which analyzed the drone systems in Vanuatu, Malawi, Rwanda, and Ghana, and drew lessons applying to the use of drones in healthcare in general.

We sought out the following background information about Mexico: geography, topography, and climate; population statistics, including economic indicators and population dispersion; transportation infrastructure, especially airports, trains, and roads; health outcomes, institutions, and infrastructure; governmental structure and potential sociopolitical complications; and special requirements and difficulties in implementing a healthcare drone system.

Collating data and analysis from a broad range of general scientific resources including Google Scholar, Scopus, ScienceDirect, PubMed, Web of Science, and the bibliographies of papers already discovered, we built out a database that forms the basis of the claims and recommendations presented in this paper.

III. ANALYSIS.

a. Background considerations.

Mexico, officially “The United Mexican States,” is a federation of 32 states including Mexico City. It covers 1,972,550 km^2 in southern North America, with a population of 129.9

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[5] We discovered one document that might qualify: Al-Ayyad, Muhammad, Amani Al-Ghraibah, and Husam Alkhatib. “Transportation of Donated Hearts by Drone in Comparison to Road-Bound Vehicles in Mexico City.” The Open Biomedical Engineering Journal, December 31, 2019. https://openbiomedicalengineeringjournal.com/VOLUME/13/PAGE/142/. This is properly considered a paper on urban traffic, not on drones, though.

million.[7] Mexico's real GDP is $1.41 trillion, and its real GDP per capita is $11,091.[8] Mexico has the 2nd-highest level of income inequality among the 36 countries in the OECD,[9] and the UN classifies Mexico's economy as "developing" and "upper-middle-income."[10]

Mexico's capital is Mexico City, in and around which 22 million people live, making it the fifth-largest metropolitan area in the world.[11] 81.6% of Mexico's population is urban.[12] Mexico spans seven climatic regions, from tropical wet to arid, along with deserts, mountains, and rainforests.[13] It shares the Rio Grande and Colorado Rivers with the United States and has a coast on the Gulf of Mexico to the east and one on the Pacific Ocean to the west.

Mexico's history long predates the arrival of European conquistadores, with illustrious civilizations including the Aztec and Maya dating back to prehistory. With the arrival of Spanish explorers in 1511 began a complex relationship marked both by devastating antagonism and fruitful cooperation that still bears crucially on modern Mexico, including on its health system (as will be described shortly). 62% of Mexicans are Mestizos (mixes of

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[7] "Mexico," The World Factbook, August 1, 2023, https://www.cia.gov/the-world-factbook/countries/mexico/.

[8] "GDP (Current US$) - Mexico," World Bank Open Data, 2022, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD; "GDP per Capita (Current US$) - Mexico," World Bank Open Data, 2022, https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=MX.

[9] "Inequality - Income Inequality - OECD Data," OECD, 2021, https://data.oecd.org/inequality/income-inequality.htm.

[10] "World Economic Situation and Prospects 2022," United Nations Department of Economic and Social Affairs, 2022, https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/WESP2022_ANNEX.pdf, 154, 156.

[11] *World Urbanization Prospects 2018: Highlights (*United Nations, 2019), 17.

[12] "Mexico," The World Factbook.

[13] Burton, Tony. "Mexico's Seven Climate Regions: Geo-Mexico, the Geography of Mexico." Geo-Mexico, October 10, 2013. https://geo-mexico.com/?p=9512.

Amerindian and Spanish), 21% are predominantly Amerindian, 7% are Amerindian, and the remaining 10% are of another race, mostly European.[14]

Mexico's health system is currently an uneasy alliance between public and private healthcare providers. "Health services are provided mostly by the [Ministry of Health] at state and federal levels, often with access and quality limitations," writes the WHO.[15] Those who want and can afford better service than the public health system provides typically pay "out-of-pocket on a fee-for-services basis."[16] Private insurance is rare. Thus, those with the most to spend on healthcare operate outside the public health system and also outside the insurance system. This fragmentation may contribute to preventing large health organizations from accumulating the resources necessary to develop innovative practices such as drone delivery systems. Mexico's current health expenditure, which includes both private and public spending, is less than in the average country, sitting at 6.24% of its GDP, compared to 10.89% on average.[17] This comes out to $538.57 per capita.[18]

The access and quality limitations of the public health system are worst in rural areas. "The Mexican health system faces shortages and inconsistencies in health resources, problems that are growing in rural areas…Resource imbalances particularly affect rural areas and small cities, where insecurity and lack of infrastructure are constant problems," writes the WHO.[19]

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[14] "Mexico," The World Factbook.

[15] Ángel et al. *Mexico: Health System Review*. Copenhagen: WHO Regional Office for Europe, 2020, xxiii.

[16] Ibid., xxiv.

[17] "Current Health Expenditure (% of GDP)," World Bank Open Data, 2020, https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS; "Current Health Expenditure (% of GDP)," World Bank Open Data, 2020, https://data.worldbank.org/indicator/SH.XPD.CHEX.GD.ZS.

[18] "Current Health Expenditure per Capita (Current US$) - Mexico," World Bank Open Data, 2020, https://data.worldbank.org/indicator/SH.XPD.CHEX.PC.CD?locations=MX.

[19] Ángel et al. *Mexico: Health System Review*, xxix.

Although 18.4% of Mexico's population is rural, Mexican "hospitals are concentrated in urban areas, with only 46 (3.3%) located in rural localities."[20]

Rural residence, indigenous ethnicity, and poverty are all associated in Mexico, and all are also associated with worse health outcomes. "Income inequality and poverty are persistent health challenges" in Mexico, as poverty "disproportionately affect[s] rural residents."[21] Meanwhile, "Mexico's Indigenous populations…live throughout the country, often in small, isolated communities. Indigenous Peoples compare less favourably to the general population with regard to poverty and health status indicators."[22] Efforts to bridge the urban-rural delta in healthcare were made as early as 1930, yet rural Mexico is still due for great upgrades in its health services.[23]

It is true that Mexico's health problems are not only—nor even mostly—those of under-coverage. Mexico ranks second in the world in overall prevalence of obesity, and its 5 most common causes of death are ischemic heart disease, diabetes, chronic renal disease, and hepatic cirrhosis.[24] Efforts to improve the diets and lifestyles of Mexico's citizens, which have already begun, are essential, and they are not in competition with other healthcare initiatives. Thus, as Mexico investigates strategies for reducing the burden of its most common ailments, it can and should simultaneously seek to increase the reach of its healthcare system. Drones are the way to do that.

b. Drone system considerations.

i. Target communities.

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[20] "Mexico," The World Factbook; Ángel et al. *Mexico: Health System Review*, xxvi.

[21] Ibid., xxi.

[22] Ibid., 2.

[23] "Mexico: Summary," Columbia University Mailman School of Public Health, January 31, 2023, https://www.publichealth.columbia.edu/research/others/comparative-health-policy-library/mexico-summary.

[24] "Mexico," The Institute for Health Metrics and Evaluation, 2019, https://www.healthdata.org/research-analysis/health-by-location/profiles/mexico.

Although the bulk of Mexico's healthcare burden falls on its cities, drones are not suited to solve the healthcare problems that cities face. The treatment of ischemic heart disease, diabetes, chronic renal disease, and hepatic cirrhosis is rarely constrained by the timely availability of crucial medical supplies. Even if they were, such availability would likely best be provided by traditional methods: Mexico's cities are supported by substantial transportation infrastructure in terms of roads, trains, and airports.[25]

It is worth mentioning that the single published study on drones in healthcare in Mexico nonetheless focused on their use in an urban zone, simulating the delivery of heart transplants by road and by drone in Mexico City, where traffic is among the worst in the world.[26] This study's analysis of drones is uncareful, but its set-up might yet prove promising: drones could fly where cars sit in traffic. In other words, drones could be used where the infrastructure is overtaxed, in addition to where there is little or no infrastructure at all.

Yet it is not uses like these that are most promising. Drones are most useful for hard-to-reach last-mile delivery, especially with relatively small payloads. When, as in a city, the patients all live within a mile (or a few) of the delivery center, drones are otiose. Low-tech solutions like green corridors for ambulances and old-fashioned delivery vehicles like bicycles appear more useful for urban healthcare logistics challenges than do drones.[27]

The drone systems in Vanuatu, Tanzania, Rwanda, and Ghana, which are among the most effective and thoroughly studied in the world, are all designed to improve delivery to

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[25] Lief Simon, "Infrastructure in Mexico," Live and Invest Overseas, 2020, https://www.liveandinvestoverseas.com/country-hub/mexico/infrastructure-in-mexico/.

[26] Al-Ayyad, Al-Ghraibah, and Alkhatib. "Transportation of Donated Hearts by Drone in Comparison to Road-Bound Vehicles in Mexico City"; "Traffic Index by City 2023 Mid-Year," Numbeo, August 2023, https://www.numbeo.com/traffic/rankings.jsp.

[27] "Green Corridor System." Donate Life, 2023. https://www.donatelife.org.in/green-corridor-system.

remote regions.[28] Thus, any drone system set up in a city like Mexico City (even if it were based on a promising thesis on healthcare logistics) would not be able to take advantage of the learnings from years of operations in rural areas. This is no knock-down argument against healthcare drones in cities, but it is an acknowledgment of the greater uncertainty of urban drone systems.

The onerousness of Mexico's drone regulations would further challenge the realization of a drone system anywhere near a dense population center. Mexico prohibits the flight of drones within 9.2 km of all aerodromes, over "people and animals," and beyond the line of sight of the pilot.[29] These regulations will have to be eased for any drone program at all to be implemented in Mexico, but many fewer compromises on them will be required in rural areas than in urban ones. These regulations are comparable to those in other countries with operational healthcare drone systems, as described later, but those other countries have made exceptions to give their drones the freedom to be useful.

It is therefore the rural citizenry of Mexico, mentioned already, that stands to benefit most from the integration of drones into its healthcare system. Rural Mexico's "lack of infrastructure" is cited as a significant impediment to its health system.[30] Moreover, it fails to "provide access to technology and innovative medicines," exacerbating its resource shortages.[31]

Thus, a healthcare drone system in rural Mexico would be easier to set up and make a greater impact than in urban Mexico. Although there are some potential uses for drones in urban healthcare, especially when population growth outpaces infrastructure growth, the lowest-hanging fruit is in rural Mexico.

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29 "Drone Laws in Mexico," Drone Laws, June 28, 2023, https://drone-laws.com/drone-laws-in-mexico/.

30 Ángel et al. *Mexico: Health System Review*, xxix.

31 Ibid., xxix.

A narrative account of "The Challenges of Rural Transportation in Mexico" emphasizes the necessity of upgrading Mexico's rural healthcare logistics system.[32] The authors write that a lack of access to basic resources limits "opportunities for significantly improving and maintaining social and economic well-being," continuing, "Improvement of access and poverty reduction are correlated."[33] Although the purpose of the present is to consider the potential uses of drones in healthcare in Mexico, obviously, a drone system might also deliver food, water, educational materials, or other essential resources to disconnected communities.

One fundamental constraint on the quality of rural healthcare in Mexico is the lack of qualified professionals. Those seeking healthcare in rural Mexico often find "a lack of qualified medical personnel. Given the distance from urban centers and the low population density, rural doctors divide their time on a schedule in different health centers, which means no health service is available in a given community on certain days; residents have to go to nearby towns or wait for the doctor to come back to their town."[34] Drones would not necessarily ease this problem. However, insofar as doctors are merely the distributors of essential healthcare supplies, drones would alleviate personnel shortages. Moreover, even when doctors are available, the medicine they would prescribe sometimes is not. "Since medicine is often not available at the [rural] health centers," people often have to travel long distances on their own to get it.[35] A straightforward solution to this problem is to leapfrog the shoddy rural road system by delivering essential healthcare supplies by drone. Drones would lessen the inventory requirements

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[32] Roberto Aguerrebere and Agustín Bustos R, "The Challenges of Rural Transportation in Mexico," ReVista: Harvard Review of Latin Americ, November 6, 2021, https://revista.drclas.harvard.edu/the-challenges-of-rural-transportation-in-mexico/.

[33] Ibid.

[34] Ibid.

[35] Ibid.

of remote clinics by enabling just-in-time delivery, reducing expirations and storage costs while also reducing stock-outs.

Mexico has above-average internet usage, but it is concentrated in urban centers, which might challenge drones operation in rural Mexico.[36] Ghana and Rwanda, the countries with the largest drone systems, have committed to improving their digital infrastructure, and it is possible that Mexico will need to do the same to enable a drone system.[37] Experts on the connectivity requirements of drones are needed to comment further. Of course, a commitment to improving internet access in rural Mexico would have benefits well beyond the enablement of a drone system and should be considered part and parcel of a general push to improve rural accessibility.

ii. Drone and nest specs.

The first question to answer in drafting technical specifications for a drone system is whether they must have vertical take-off and landing (VTOL) capacity. VTOL allows drones to drop off and pick up healthcare supplies, whereas drones without VTOL can only swoop low and drop goods with a parachute attached. Drones without VTOL are fixed-wing, while those with VTOL are either multi-copter or hybrid. Fixed-wing drones are more fuel-efficient, but multi-copter drones have greater maneuverability. Fixed-wing drones require take-off and landing infrastructure: runways or catapults and hooks.

To decide between VTOL and non-VTOL drones, Mexico must decide whether it wants to pay a premium for a two-way logistics solution, and it must also decide whether it can

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[36] "Mexico - Internet and Digital Economy," International Trade Administration, September 23, 2022, https://www.trade.gov/country-commercial-guides/mexico-internet-and-digital-economy; "Individuals Using the Internet (% of Population)," World Bank Open Data, 2021, https://data.worldbank.org/indicator/IT.NET.USER.ZS.

[37] Queen Xorlali, "Government Keen on Bridging Ghana's Internet Usage Gap- Ursula," GhanaWeb, August 2, 2023, https://www.ghanaweb.com/lifestyle/xorlali/Government-keen-on-bridging-Ghana-s-Internet-usage-gap-Ursula-126107; "Rwanda - Giga," Giga, 2019, https://giga.global/rwanda/.

afford a higher up-front cost and commit to the location of distribution centers for the lower marginal costs of fixed-wing drones.

The healthcare drone systems in Ghana and Rwanda, which are the largest in the world, both use the American company Zipline, which does not offer VTOL capacity. Malawi, however, implemented a drone test program that exclusively investigated the uses of drones for biological sample pick-up, and found it quicker and more reliable than ground transportation.[38] Thus, there is a successful precedent for both VTOL and non-VTOL systems. There are typically more deliveries than pick-ups, so it is often sensible for a drone system to be optimized for delivery. However, especially in countries where the disease burden is high, two-way logistical systems are essential. Without knowledge about the average distance from labs to remote clinics, the relative prevalence of diseases, the demand for various supplies in rural areas, and the goods that the system in question will deliver, it is impossible to make a confident argument for either VTOL or non-VTOL drones.

iii. Goods.

Drones have recently been used to deliver blood, vaccines, antibiotics, oxytocin, and PPE, among other goods, both in emergencies and as a part of routine servicing, to healthcare facilities in Vanuatu, Malawi, Rwanda, Ghana, India, and Haiti. Like any legitimate logistical solution, drone delivery works for a range of goods. However, drones are highly cost-sensitive to their weight. Companies spend millions in R&D shaving off grams from their chassis, so they cannot easily or cost-effectively accommodate goods of arbitrary shapes and sizes. Thus, any healthcare system interested in integrating drones into its logistics network should have a clear idea of what its drones will deliver, choosing drones with technical specifications that allow them to accomplish their deliveries as quickly, cheaply, and reliably as possible.

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[38] "Costs Associated with the Use of Unmanned Aerial Vehicles for Transportation of Laboratory Samples in Malawi," VillageReach, June 2016, https://www.villagereach.org/wp-content/uploads/2017/06/Malawi-UAS-Report_MOH-Draft_-FINAL_14_07_16.pdf.

Blood is among the first goods and arguably the best good delivered by drone. Its demand is unpredictable, which means that all hospitals would like to keep a large supply on hand in case of emergency. However, it expires fairly quickly and is expensive to procure, which means that no country can afford to overfill the shelves of every remote clinic. Thus, Rwanda's drone system originally focused on delivering blood and expanded from there. It would make sense for Mexico's drone system to begin with blood deliveries.

Other emergency organs are also promising candidates for drone delivery: they are valuable and they require timely delivery, so drones' speed is highly valued. In 2021, Canada made headlines by completing the first-ever lung delivery by drone, delivering in 5 minutes what takes up to 25 by road, which is a relatively small improvement compared to those possible in countries with worse roads than Canada.[39] Blood's advantage is that it is relatively light, while other organs, especially hearts and lungs, may ask too much of modern drones, which generally have maximum payloads below 15 pounds.[40] In any case, in contrast to in many countries, most organ donors in Mexico are family members of the recipient, so the transportation of organs across the country would not appear to be a common problem.[41] As for blood, Mexico has very low rates of donation, so it would appear that the procurement, not the distribution, of blood is the greatest limitation of the current system.[42]

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[39] Ashleigh Stewart, "How Lungs Delivered by Drone Saved an Ontario Man's Life," CBC News, October 13, 2021, https://www.cbc.ca/news/canada/toronto/drone-lung-delivery-toronto-1.6209330; Caren Chesler, "What the First Lung Delivered by Drone Means for Transplant Science," Scientific American, April 1, 2023, https://www.scientificamerican.com/article/what-the-first-lung-delivered-by-drone-means-for-transplant-science/.

[40] Evan Ackerman and Michael Koziol, "In the Air with Zipline's Medical Delivery Drones," IEEE Spectrum, April 30, 2019, https://spectrum.ieee.org/in-the-air-with-ziplines-medical-delivery-drones; "Kite," Swoop Aero, 2022, https://swoop.aero/technology/kite/; "Wingcopter 198," Wingcopter, 2023, https://wingcopter.com/wingcopter-198. These papers put the maximum payload of Zipline at 1.75 kg; of Swoop Aero at 5 kg; and of Wingcopter at 13 kg.

[41] Megan Crowley-Matoka, *Domesticating Organ Transplant: Familial Sacrifice and National Aspiration in Mexico* (Durham, NC: Duke University Press, 2016).

[42] "Donación de sangre en México, ¿voluntaria o no?," Gabinete, 2019, https://gabinete.mx/images/datadato/donacion/ST_donacion_sangre_2019.pdf.

Vaccines are another promising product for drone delivery in Mexico. Indigenous populations are much more vulnerable to diseases preventable by vaccine than non-indigenous populations (and tend to be more rural, as discussed above).[43] Indeed, a study on inequities in Mexican vaccination found "clear and alarming deterioration in equitable access to basic childhood vaccines in Mexico," as "results from analyses related to place of residence and to socioeconomic status demonstrate increases in immunization inequities from 2012 to 2018 and again from 2018 to 2021."[44] 15.2% of caregivers with children off the primary immunization schedule in Mexico cited a lack of vaccine availability as the cause.[45] And even when vaccines are delivered, there may be opportunities for significant cost savings, as vaccines are relatively light and straightforward to transport by drone. A study in Mozambique found the delivery of vaccines by drone cost-superior to by traditional road transport under a wide range of parameter estimates.[46] Thus, it is possible that vaccine distribution by drone in Mexico is cheaper, not to mention faster and more reliable.

Drone delivery of healthcare products makes possible entirely new logistical strategies. In Vanuatu, healthcare professionals who ran vaccine clinics would estimate the number of vaccines they would need, pack an icebox, and lug it to whatever remote location the clinic would take place at. With drones, they could arrive at the location, count the

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[43] José Luis Torres et al., "La Salud de La Población Indígena En México," La salud de la población indígena en México, 2014, https://www.researchgate.net/profile/Beatriz-Zurita-Garza/publication/267856093_La_salud_de_la_poblacion_indigena_en_Mexico/.

[44] Gutierrez, Juan Pablo, and Mira Johri. "Socioeconomic and Geographic Inequities in Vaccination among Children 12 to 59 Months in Mexico, 2012 to 2021." Revista Panamericana de Salud Publica, January 30, 2023. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9899057/.

[45] Ebenezer V Cruz-Romero and Aarón Pacheco-Ríos, "Causas de Incumplimiento y Retraso Del Esquema Primario de Vacunación En Niños Atendidos En El Hospital Infantil de México 'Federico Gómez,'" Atención Familiar, March 16, 2016, https://www.sciencedirect.com/science/article/pii/S1405887116300785.

[46] Leila A. Haidari et al., "The Economic and Operational Value of Using Drones to Transport Vaccines," *Vaccine* 34, no. 34 (July 25, 2016): 4062–67, https://doi.org/10.1016/j.vaccine.2016.06.022.

number of patients, place a delivery for exactly as many vaccines as they needed, and receive a shipment within 30 minutes.[47]

Mexico has recently been struggling with shortages in medicines.[48] Although the mismanagement that has led to this shortage runs deeper than logistics, the integration of drones into Mexico's healthcare logistics would shorten the distance from manufacturer to patient, making it easier to match supply with demand. This simplification would also give corrupt actors fewer places to hide, which is a problem that the current system, whose errors have led to the recent shortages, wished to solve. There is no indication that corruption in healthcare logistics in particular is a problem, but given that corruption is a "widespread" problem across Mexico, "both at the federal and subnational levels," it would seem that simplifying the healthcare delivery system could only help.[49]

The preponderance of the movement in any healthcare logistical system is centrifugal, moving materials from centralized distribution centers toward increasingly remote point-of-service centers. However, there are important exceptions to this. Mexico, for example, suffers from high rates of Hepatitis A, Hepatitis E, and Typhoid fever, all of which are most accurately tested for in a lab, which means that samples must somehow be taken from the patient to the lab.[50] It would be helpful for a drone system to pick up samples

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[47] "UNICEF Vanuatu Drone Report," UPDWG, September 2019, https://www.updwg.org/resource/project-report-vanuatu-drone-trial-phase-1-and-2/unicef-vanuatu-drone-report-final-for-md375-4/.

[48] Irene Tello Arista, "El Desabasto de Medicamentos En México Fue Ocasionado Por Las Malas Decisiones Del Gobierno," The Washington Post, February 16, 2021, https://www.washingtonpost.com/es/post-opinion/2021/02/15/desabasto-de-medicamentos-mexico-cancer-covid/.

[49] Inaki Albisu Ardigo, "Mexico: Overview of Corruption and Anti-Corruption Efforts," U4 Anti-Corruption Resource Centre, October 20, 2019, https://www.u4.no/publications/overview-of-corruption-and-anti-corruption-efforts-in-mexico; "Mexico Finds yet More Corruption in Health Regulatory Agency," AP News, February 15, 2023, https://apnews.com/article/politics-caribbean-mexico-city-business-crime-e0707efc63f4aa10dca86da45f38b298.

[50] "Mexico Major Infectious Diseases," Index Mundi, 2021, https://www.indexmundi.com/mexico/major_infectious_diseases.html.

from hard-to-reach rural locations and drop them off at labs. Two-way logistics requires different drone technology, as discussed above, so a system that wishes to pick up samples must make other concessions. However, rural-to-urban logistics faces the same challenges as its reverse, so a drone system that can improve test turnaround times is desirable and must be considered.

A drone system that is limited to any one use, whether it be blood, hearts, vaccines, or antibiotics, would not be worthwhile. Thus, Mexico should plan for a drone system to deliver some combination of the aforementioned goods. Because drones' greatest strength is their speed and reliability in delivering to areas that cannot count on ground transportation, it is logical for drones first to be used to deliver emergency medical supplies. Blood seems an excellent candidate, as do snake anti-venom and oxytocin for childbirth complications.[51] Eventually, drones may expand to help cut costs in routine vaccine and medication delivery, simplifying logistical operations and making possible new paradigms that reduce waste and squeeze out corruption. A small-scale test program would provide great insight into the uses that would benefit the Mexican healthcare system most.

iv. Regulation.

Current regulations in Mexico, if followed completely, would ground nearly any prospective healthcare drone system. As mentioned previously, Mexico prohibits the flight of drones within 9.2 km miles of all aerodromes, over "people and animals," and beyond the line of sight of the pilot.[52] However, Rwanda and Ghana have the same

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[51] Nina Mendez-Dominguez et al., "Emergency Treatment for a Venomous Snakebite Accident in Rural Southern Mexico," Rural and Remote Health, April 10, 2019, https://www.rrh.org.au/journal/article/4701; Thomas E Benzoni, "Labor and Delivery in the Emergency Department Medication," Medscape, June 13, 2022, https://emedicine.medscape.com/article/796379-medication?form=fpf.

[52] "Drone Laws in Mexico," Drone Laws.

prohibitions and enjoy famously effective healthcare drone systems.[53] Clearly, both countries have carved out regulatory exceptions for their government-sponsored healthcare logistics systems. The details of the agreements are not known, but as these programs are state-sponsored, they can simply be designed so as to avoid any problems (such as interference with the flight of airplanes) that ordinarily fall to regulation to prohibit.

In the US, commercial drones operate in class G airspace, which has a maximum altitude of 400 feet.[54] Thus, collision with aircraft is only a concern near aerodromes, where aircraft take off and land. Other concerns for regulators include the danger to those below in the event of a loss of power and the loss of connectivity due to interference or poor connection. In the setting of healthcare delivery, where the system will be built by or in close collaboration with the government, though, these are risks for the architects of the system, not for regulators, to mitigate.

This paper deals only with drones in healthcare delivery, so the implications of suffocating regulation on the prospects of drone delivery writ large are beyond its scope. In the context of this paper, one need not worry about special regulatory carveouts stifling innovation or entrenching monopolies because any contract with a government health system picks winners and losers by its very nature. The dynamics of regulation and competition as they relate to other uses of drones deserve further consideration, but not here.

4. REQUESTS FOR FURTHER ACTION.

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[53] "Drone Laws in Rwanda," Drone Laws, June 30, 2023, https://drone-laws.com/drone-laws-in-rwanda/; "Drone Laws in Ghana," Drone Laws, June 27, 2023, https://drone-laws.com/drone-laws-in-Ghana/.

[54] "Airworthiness Criteria: Special Class Airworthiness Criteria for the Wingcopter GmbH 198 US Unmanned Aircraft." Federal Aviation Administration, March 17, 2022. https://www.federalregister.gov/documents/2022/03/17/2022-05608/airworthiness-criteria-special-class-airworthiness-criteria-for-the-wingcopter-gmbh-198-us-unmanned; Ackerman and Koziol, "In the Air with Zipline's Medical Delivery Drones."

This paper leaves a huge number of blanks to fill in. Since it is the first paper properly dealing with healthcare drones in Mexico, nearly all the scholarly work in this area remains to be done. The most pressing question is under what conditions drones will be cost-effective. There is no question that a state-of-the-art drone can save time if sent on a direct path while a rusted-out delivery truck meanders along a dirt road. It is not certain, however, to what extent a large-scale drone system can improve routine healthcare availability to rural citizens in a country where they are desperately underserved.

Although there are many academic questions to be answered from a computer, the most important data can be collected—and the greatest impact can be made—by getting boots on the ground and building out a drone system. The technical requirements for this are not terribly demanding. Many of the relevant problems have already been solved in the countries that have implemented drone delivery systems for healthcare. What is most needed is for people with influence in the Mexican healthcare system to take the urban-rural divide seriously and to understand the promise of drone technology to bridge that gulf.

In particular, a drone test with the following characteristics would be desired: VTOL capacity, to investigate the utility of both pick-up and drop-off and also to reduce the up-front capital requirements for the test; emphasis on goods whose demand is urgent, such as blood, snake anti-venom, and antibiotics to out-of-stock clinics; comparison of the speed of drone delivery to that of road delivery; interviews of community members to determine the everyday reliability of road delivery; interviews of community members to determine attitudes toward a drone system; employment of experts in air traffic control to ensure the safety of the test system in the absence of time-tested policies; rough estimates for the cost of a drone-system of various scales, based on data collected in this test and data taken from drone systems in use elsewhere. It will be difficult to determine with much precision the cost of a large-scale system on the basis of a small-scale test because economies of scale can only be estimated. However, the feasibility of urgent, high-value delivery can and should be determined with reasonably high confidence.

5. CONCLUSION.

Although it is in the early days of drone usage in healthcare delivery, there is already a substantial corpus of research on existing drone programs, especially in Vanuatu, Malawi,

Rwanda, and Ghana. Much of the groundbreaking has already been done, and Mexico can copy and paste many elements from currently operational drone systems. Of course, there will still need to be much care taken to tailor a drone system to Mexico's current healthcare infrastructure and needs, especially since Mexico is larger, with more roads and airports and a larger budget than the countries that have heretofore built drone systems. Nonetheless, the work to design and test a drone system is clearly worthwhile. Drones are a uniquely charismatic and promising technology to improve Mexico's rural health coverage.

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