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AN ANALYSIS ON DRONE TECHNOLOGY'S REALISTIC IMPACT ON THE UNITED STATES SUPPLY CHAIN

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ABSTRACT

United States drone technology is not current implemented in commercial scale. Despite public announcements by enterprise corporations in 2013, very few, and arguably no, scaled applications of drone technology operate in the United States today. In this thesis, drone technology and its potential applications are studied. The focus of this study is to examine potential health-related use cases where drone technologies could be deployed to cost effectively address real-world problems and to identify common characteristics that must be in-place for drone deployments to be successful. Ultimately, the goal is to support the acceleration of commercialized drone implementation in the United States. The thesis provides an overview of drone technology, certain aspects of the medical field in the United States, and how both can be combined to affect the lives of Americans. In sum, implementing drone technology to combat the opioid epidemic is a cost-effective, feasible solution that can prevent deaths due to opioid overdose.

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Chapter 1
Introduction to Drones & Supply Chains

1.1 — The Current United States Supply Chain

The United States supply chain is both simplistic and complex. In the simple sense, the United States supply chain leverages people, airplanes, trains and vehicles, and processes to move material from location to location. Each stage performs an important function to the material being transported until it is presented as a final product to the consumer. When you begin to analyze this simplistic model and their inherent cost structures, however, the complexity becomes very apparent. How many employees should we staff for optimal performance? How many trucks should we employ to optimize our transportation cost? Where should we locate our warehouses to optimally account for customer proximity and labor costs? The word "optimality" significantly increases the complexity of supply chains as performing operations optimally can greatly reduce the overall operational expense. In fact, leading global management consulting firm Oliver Wyman claims focused supply chain optimization can reduce organizational costs by up to 25 percent.[1]

Today, the capabilities of global logistics networks enable orders placed to be fulfilled within days. Amazon has revolutionized e-commerce by successfully marketing the abilities of their logistics network with its unrivaled two-day shipping promise. Within a decade, Amazon's two-day shipping transitioned from being groundbreaking to standard practice for any and all e-commerce competitors. Given the fact that our current logistics networks can deliver almost any product anywhere within the United States in a relatively short period of time, the next phase of the U.S. Supply Chain evolution is to

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[1] Lierow, Michael, et al. "Supply-Chain Optimization: Levers for Rapid EBITDA." Oliver Wyman, https://www.oliverwyman.com/our-expertise/insights/2018/may/supply-chain-optimization--levers-for-rapid-ebitda.html.

perform these same operations faster at an overall lower cost. Traditional supply chain operations largely found success leveraging economies of scale by targeting lower cost areas of the country. With the continuing development of advanced autonomous driving and aerial technologies, new autonomous product offerings like the Tesla Semi or Zipline Drones could further optimize operational economics by further lowering the overall labor cost.

1.2 — Drones

A drone, also known as an unmanned aerial vehicle (UAV), is a flying robotic aircraft that operates without a human on-board.[2] Drones consist of three major components: the body, the propulsion, and the payload. The body of the drone is the aeronautical mechanics that enable the drone to fly efficiently through the air. Next, the propulsion is how the drone converts power to air travel. Finally, the payload is what the drone carries during its flight and is usually the purpose of the drone's flight.

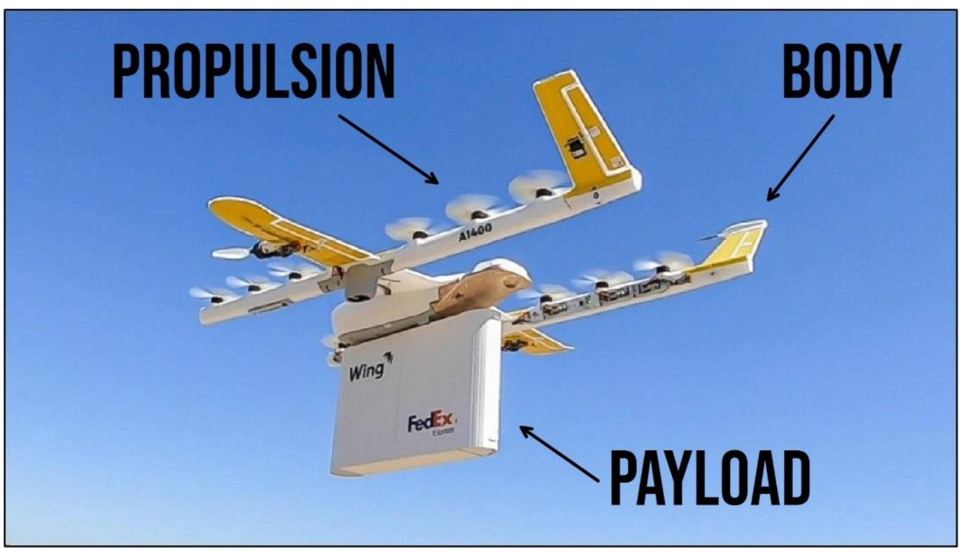

Figure 1: Major Drone Components[3]

[2] "Drone Types." AUAV, 25 Feb. 2022, https://www.auav.com.au/articles/drone-types/.

[3] Murphy, Mike. "Alphabet Is Partnering with FedEx and Walgreens to Bring Drone Delivery to the US." *Quartz*, Quartz, 19 Sept. 2019, https://qz.com/1712200/google-wing-launching-us-drone-deliveries-with-fedex-walgreens/.

Drones can be controlled by humans, utilizing remote control technologies and/or autonomous software to patrol areas or transport goods from location to location. Given the unique capabilities and characteristics of a drone, their usage is often in niche applications, yet can be extremely beneficial in certain scenarios.[4] For instance, the U.S. Military has been investing in drone technology since the 1990s due to a drone's ability to gather important intelligence in potentially dangerous areas of the world without risking the life of a solider.[5] In addition, drones can be leveraged in specific industries that require regular patrolling such as above-ground oil pipelines or monitoring maintenance operations.[6] In this thesis, the analysis will consider and focus on a drone's ability to quickly transport goods and how that capability could impact the current supply chain practice in United States.

Relative to their rapid transportation benefits, drones have many advantages.[7] For example, drones are relatively easy to deploy and control, meaning operators with minimal technical background can operate these aircrafts. Lowering the technical skill levels required, points to a potentially major benefit in labor cost. Unlike traditional aircraft, the labor cost realized with drones is fractional. Also, the ability to quickly deploy a drone is much different than airplanes or helicopters as drone deliveries can be more custom and need-driven versus a planned flight. In addition, the lightweight, battery-powered nature of a drone leaves negligible environmental impact when considering carbon emissions. Furthermore, since drones are aircrafts, they also require relatively little infrastructure to integrate into a supply chain network. Drones can travel upwards of 75 miles-per-hour and are not deterred by common ground transportation characteristics, such as road quality or traffic congestion. Finally, drones by nature are

[4] Chamola, Vinay, et al. A Comprehensive Review of Unmanned Aerial Vehicle Attacks and Neutralization Techniques, vol. 111, 10 Oct. 2020, p. 102324., https://doi.org/10.1016/j.adhoc.2020.102324.

[5] Alkobi, Jackie. "The Evolution of Drones: From Military to Hobby & Commercial." Percepto, 15 Jan. 2019, https://percepto.co/the-evolution-of-drones-from-military-to-hobby-commercial/.

[6] Brown, Jack. "Drone Uses: The Awesome Benefits of Drone Technology." My Drone Lab, 19 Dec. 2021, https://www.mydronelab.com/blog/drone-uses.html.

[7] "10 Major Pros & Cons of Unmanned Aerial Vehicle Drones." Equinox's Drones, https://www.equinoxsdrones.com/blog/10-major-pros-cons-of-unmanned-aerial-vehicle-uav-drones.

fundamentally non-contact devices which could provide additional benefit under social-distancing requirements.

While drone technology exhibits many benefits, drones do have disadvantages that are primarily defined around their limitations. First, a drone's delivery radius is typically only 100 to 150 miles round-trip. The on-board energy for propulsion is typically more than half of the total weight of the drone, which varies from airplanes that can literally carry tons of cargo, ranging from people to products. This also affects the drone's payload as the average drone can carry less than five pounds from place to place. These two technological limitations force drones to be considered in more niche applications.

1.3 — Current State of Drones Technology in the United States

On December 1st, 2013, the CEO of Amazon Jeff Bezos promised that Amazon would utilize drones to deliver packages to consumers.[8] Bezos identified that "last-mile delivery" for Amazon accounted for 28% of total shipping costs and envisioned drones as an opportunity to greatly reduce this portion of the expense.[9] In 2020, Amazon operated 1,137 distribution centers to deliver more than 4 billion packages around the world.[10] Amazon's supply chain infrastructure is impressive, and rivals dedicated logistics companies like UPS or FedEx. When analyzing Amazon's deliveries, over 86% of all delivered packages weigh less than five pounds.[11] The value of these deliveries could have been further enhanced with drone technology throughout the COVID-19 pandemic to promote health and help slow the spread of the virus during package deliveries. With knowledge of Amazon's investment in drone

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[8] Pierce, David. "Delivery Drones Are Coming: Jeff Bezos Promises Half-Hour Shipping with Amazon Prime Air." The Verge, The Verge, 2 Dec. 2013, https://www.theverge.com/2013/12/1/5164340/delivery-drones-are-coming-jeff-bezos-previews-half-hour-shipping.

[9] Scannell, Ed. "Amazon Bets Big on Last Mile Delivery Service Improvements." SearchAWS, TechTarget, 6 Apr. 2020, https://www.techtarget.com/searchaws/feature/Amazon-bets-big-on-last-mile-delivery-service-improvements.

[10] Davis, Don. "Amazon Warehouses Are Located near Big Cities." Digital Commerce 360, 20 Jan. 2022, https://www.digitalcommerce360.com/article/amazon-warehouses/.

[11] Mazareanu, E. "Amazon Logistics: Package Volume in the U.S." Statista, 1 Oct. 2021, https://www.statista.com/statistics/1178979/amazon-logistics-package-volume-united-states/.

technology, their one thousand fulfillment centers around the United States, their package weight distribution characteristics, and the potential COVID-19 benefits, one question remains open: Where does Drone Technology stand in 2022?

In short: American consumers have very high expectations of new technology, and autonomous technologies are criticized to an even higher degree. If a new technology isn't executed flawlessly and provides only marginal benefit in today's society, it is often forced into postponement and quickly loses sources of funding. Let's examine autonomous vehicles briefly from that perspective. On November 20th, 2018, Elaine Hezerberg was struck and killed by a self-driving Uber vehicle.[12] The safety driver in the vehicle was distracted and Ms. Hezerberg was jaywalking illegally, but the accident could have been easily avoided by simply changing lanes. The self-driving car, however, was not instructed to autonomously do this. Following the incident, autonomous vehicle testing was banned in multiple states and the publicity around the fatality led to a two-year decline in disclosed funding deals.[13] Driving is a basic aspect of American life and accidents occur daily, but an accident resulting in death by a computer algorithm is often labeled as unjust and unnecessary as an attentive driver could have more safely navigated that situation. Drones are no exception to these expectations, and companies looking to deploy drones in their supply chains must completely foolproof them from the unexpected to minimize the possibility of catastrophic events and their repercussions.

In addition to the high expectations of the American public, new technology often faces legal issues which can stall development and deployment. Specifically for drones, the Federal Aviation Administration (FAA) enforces airspace regulations to ensure aircraft safety for over 16 million flights annually in the United States.[14] The passenger aviation industry is an integral part of American operations, requiring drones to work around current airport and other airspace restrictions. Relative to the

[12] Kopestinsky, Alex. "Self Driving Car Statistics for 2021." PolicyAdvice, 5 Mar. 2022, https://policyadvice.net/insurance/insights/self-driving-car-statistics/.

[13] CB Insights. "Autonomous Driving Startups Raise Record Funding as the Push for Commercialization Begins." CB Insights, 20 Oct. 2021, https://www.cbinsights.com/research/autonomous-vehicle-tech-funding-trends/.

[14] "Air Traffic By The Numbers." FAA, 18 Mar. 2022, https://www.faa.gov/air_traffic/by_the_numbers/.

high expectations addressed in previous paragraph, drone technology needs to prove its value to share the existing airspace in order to be further integrated by the FAA.

1.4 — Zipline’s Successful Drone Implementation

After completing a significant level of research on successful and unsuccessful drone deployment applications, certain characteristics and conditions where drones were effective began to become common in successful drone implementations. Prior to simply explaining these certain characteristics, however, the real-world impact that Zipline made in Rwanda from their drone deployment will help illustrate a successful use case.

Zipline, a San Francisco-based start-up company, is committed to delivering medical supplies in areas with poor or congested infrastructure.[15] Rwanda is a rapidly developing African country that is roughly the size of Maryland. It focuses a significant portion of its government investments in technological infrastructure, healthcare, and education. Over the past two decades, the combination of these investments has increased the life expectancy of Rwandans by 20 years and the percentage of its population living under the poverty line has decreased from 59% to 39%.[16] Ground transportation is very slow as the paved two-lane highways often maneuver around natural barriers and quickly transition to dirt paths once off the highway network.[17] Rwanda has one major airport in Kigali that services an average of 184 flights each week.[18]

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[15] “Instant Logistics.” Zipline, https://flyzipline.com/.

[16] Ackerman, Evan, and Michael Koziol. “In the Air with Zipline's Medical Delivery Drones.” IEEE Spectrum, IEEE Spectrum, 30 Apr. 2019, https://spectrum.ieee.org/in-the-air-with-ziplines-medical-delivery-drones.

[17] Baker, Aryn. “Zipline's Drones Are Delivering Blood to Hospitals in Rwanda.” Time, Time, https://time.com/rwanda-drones-zipline/.

[18] Flightradar24. “Kigali Airport (KGL/HRYR).” Flightradar24, https://www.flightradar24.com/data/airports/kgl.

A study conducted in Rwanda identified that 22.7% of maternal mortality is caused by postpartum hemorrhage.[19] Postpartum hemorrhage (PPH) occurs when the muscles of a mother's uterus do not contract adequately following childbirth. This can result in excessive blood loss and potentially death. Over 100,000 mothers worldwide die from severe bleeding after childbirth and 99% of these deaths occur in low-income countries.[20] If a hospital has excess blood that matches the blood type of the mother, however, the survival rate improves tremendously. The problem Rwanda faced specifically was how to distribute the limited national blood supply to the 26 major hospitals in the country. Prior to drone implementation, the country would leverage health record analytics to make an educated guess on how to distribute the various blood types with minimal waste. Demand for blood type of pregnant mothers, however, is highly unpredictable resulting in unnecessary deaths of Rwandan mothers as well as wasted blood packs that were not used before expiration. While some hospitals could have the required blood in stock, the journey to the hospital-in-need would take upwards of three hours and often result in the mother's death prior to the blood's arrival. In addition, this poor distribution of blood resulted in 7% of all blood packs to be expired before use, costing the Rwandan government over one million dollars (USD) every year.[21]

[19] Sandra, Isano. "Drones Could Save Lives of Mothers around the World." Medium, Medium, 5 Feb. 2019, https://medium.com/@isanosandex/drones-could-save-lives-of-mothers-around-the-world-e282ed2723b6.

[20] Hancock, Angela, et al. "Is Accurate and Reliable Blood Loss Estimation the 'Crucial Step' in Early Detection of Postpartum Haemorrhage: An Integrative Review of the Literature." BMC Pregnancy and Childbirth, vol. 15, no. 1, 2015, https://doi.org/10.1186/s12884-015-0653-6.

[21] Rosen, Jonathan W. "Zipline's Ambitious Medical Drone Delivery in Africa." MIT Technology Review, MIT Technology Review, 8 June 2017, https://www.technologyreview.com/2017/06/08/151339/blood-from-the-sky-ziplines-ambitious-medical-drone-delivery-in-africa/.

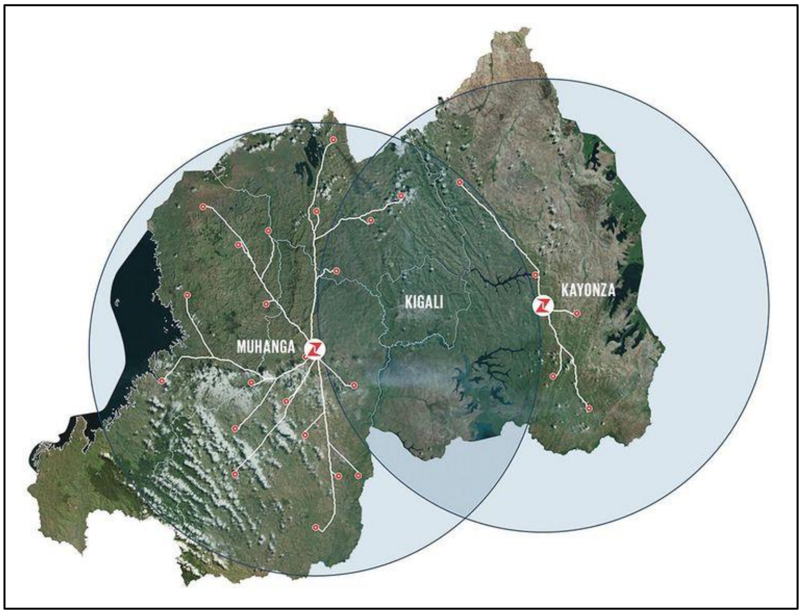

Figure 2: Zipline's Drone Network in Rwanda[16]

When Zipline implemented its technology, however, they determined that a centrally located drone fleet would be able to service many hospitals within 30 minutes of receiving a request from any hospital. Zipline's product design leverages fixed-wing drones that operate similar to traditional airplanes but in a smaller body design. These airplane-like drones travel upwards of 75 miles-per-hour with a roundtrip travel distance of 100 miles. Zipline's drones can be loaded with necessary supplies and launched within 10 minutes of the hospital's request. Another benefit is these drones are constantly connected to GPS, enabling the hospital to track the drone's current positioning and flight path.[22] In this case, the payload of the drone is blood, which is a highly valuable medical supply. Zipline's drones typically carry two 500mL bags of blood, weighing roughly two-and-a-half pounds. Upon arrival at the hospital, the drone simply

[22] van der Meer, Jen. "Connected Things Business Models: Zipline Medical Logistics." Reason Street, 19 Jan. 2021, https://reasonstreet.co/2021/01/19/connected-things-zipline-medical-logistics/.

releases the payload, enabling it to descend to the ground via parachute without requiring the drone to stop.

Figure 3: Zipline's Drone Design[23]

After Zipline successfully proved its ability to deliver blood to hospitals-in-need, Rwanda has removed the majority of blood from its hospitals and now permanently stores blood packs at Zipline launch stations. The rapid transportation these drones provide within the country alleviate the need to speculate how best to distribute the blood across the hospital network. The current system includes two launch stations with a capacity to complete over 500 blood deliveries per day, resulting in Zipline-serviced hospitals wasting zero blood packs in 2018. Zipline's operation is fully integrated with the Kagali International Airport (KGL) to coordinate drone delivery flights and to ensure a positive coexistence with passenger air travel in and around Rwanda.[24]

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[23] Bright, Jake. "Drone Delivery Startup Zipline Launches UAV Medical Program in Ghana." *TechCrunch*, TechCrunch, 24 Apr. 2019, https://techcrunch.com/2019/04/24/drone-delivery-startup-zipline-launches-uav-medical-program-in-ghana/.

[24] Spaeth, Andeas. "African Drones Pave the Way to an Autonomous Future." Airline Ratings, Airline Ratings, 15 May 2019, https://www.airlineratings.com/news/african-drones-pave-way-autonomous-future/.

1.5 — Important Conditions for Successful Drone Implementations

Zipline, as well as other successful commercial drone applications, identified five major characteristics and conditions that need to exist prior to implementation: comparative advantage of infrastructure, immediate response time, centralized inventory, high value payload, and willing leadership.

First, the comparative advantage of infrastructure refers to the best options for ground transportation that exist in the deployment area. In Rwanda, the poor, congested roads led to travel times of upwards of three hours. Even in these conditions, ground transportation was the recommended transport method for these emergency situations as alternative methods, like helicopters, were much more expensive. A drone can not only travel a direct route at 75 miles-per-hour but could also fly for roughly $30 per flight. Next, the Rwandan government and its prominent health officials also recognized the immediate response required for PPH and other medical issues. Given that mothers could die in under an hour and there were no other immediate response options available in the country, drones solved the delivery issue in a cost-effective manner. Third, the value of centralized inventory had the ability to reduce blood bag waste as blood has a specific shelf life and costs to transport it to each location. By capitalizing on the benefits of centralized inventory, drones had the potential to save wasted money to help defray the cost of its implementation. Fourth, drones are expensive technology that have a limited weight capacity for their payload. For the cost per flight to be rationalized, the payload must be of high value and thus medical supplies are traditionally justified, especially in life-threatening situations. Lastly and potentially the most important, the Rwandan government understood the issue of PPH and how it impacted the citizens of the country. Rwanda, who took calculated risks on technology and healthcare, was willing to attempt Zipline’s presented proposal.

Chapter 2
Introduction to American Healthcare and Medical Conditions

2.1 — Prevalent Medical Conditions and Healthcare in the United States

Over 9,000 Americans die every day due to a variety of health conditions.[25] Prevalent conditions such as heart disease, cancer, stroke, and diabetes account for over 46% of all deaths in the United States. Relative to other countries, the United States healthcare system is complex, consisting of a mix of public, private, and non-profit healthcare providers.[26] Similarly, health insurance varies between Medicare, Medicaid, and private insurance typically provided by employers. American healthcare ranks poorly in relation to other 1st world countries and recently scored last in comparison to other high-income countries.[27] This is primarily due to greater use of medical technology and more expensive prices for the patient.[28] There is no denial that U.S. healthcare should continue to research new methods and technologies that could improve overall health for Americans.

2.2 — Emergency Response Opportunities

Drones have the unique opportunity to expand medical capabilities in the United States by quickly delivering readily available medicine to those facing life-threatening conditions. When analyzing which specific medical conditions drones could impact significantly, deaths related to immediate conditions, such as stroke or heart attack, aligned well with drone technology capabilities. Deaths related

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[25] "Deaths and Mortality." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 13 Jan. 2022, https://www.cdc.gov/nchs/fastats/deaths.htm.

[26] Tikkanen, Roosa, et al. "United States." The Commonwealth Fund, 5 June 2020, https://www.commonwealthfund.org/international-health-policy-center/countries/united-states.

[27] Schneider, Eric C., et al. "Mirror, Mirror 2021: Reflecting Poorly." The Commonwealth Fund, 4 Aug. 2021, https://www.commonwealthfund.org/publications/fund-reports/2021/aug/mirror-mirror-2021-reflecting-poorly.

[28] "U.S. Health Care from a Global Perspective, 2019: Higher Spending, Worse Outcomes?" *The Commonwealth Fund*, 30 Jan. 2020, https://www.commonwealthfund.org/publications/issue-briefs/2020/jan/us-health-care-global-perspective-2019.

to gradual conditions, such as cancer growth or Alzheimer's disease, are conventionally covered by traditional healthcare programs.

Diving deeper into the immediate conditions category, a drone's ability to deliver life-saving medicine to those experiencing stroke, diabetes, or heart attack initially felt like the ideal use-case. After researching about stroke, however, there are two types of strokes: ischemic and hemorrhagic.[29] Ischemic stroke accounts for 87% of stroke cases and occurs when blood flow is blocked in arteries connecting to the brain, essentially starving the brain of oxygen. Thrombolytic drugs, such as tissue plasminogen activator (tPA), are commonly leveraged to thin blood and break-up blood clots, enabling oxygen to revive the brain[30]. On the other hand, hemorrhagic stroke occurs when an artery in the brain ruptures. This applies excess pressure to brain cells, eventually damaging or destroying them. Brain surgery or endovascular repair are procedures commonly utilized to release the blood pressure in the brain and repair the ruptured artery. While hemorrhagic stroke accounts for the remaining 13% of stroke victims, a person experiencing hemorrhagic stroke that is incorrectly diagnosed with an ischemic stroke can prove to be immediately fatal. When the ischemic stroke medication enters the body, the blood flowing out of the ruptured blood vessel will become thinner, resulting in more pressure in the brain. To medically treat a stroke, an initial imaging analysis of the patient needs to be conducted for the hospital to proceed in a safe manner. When analyzing diabetes, immediate deaths typically result by hyperglycemia or hypoglycemia, which occurs from irregularities in the blood sugar levels in the body. Similar to stroke, these two diabetic conditions are direct inverses of each other, and incorrect diagnosis would result in faster death.

For the heart attack analysis, initial research seemed promising due the abilities of the Automated External Defibrillator (AED). An AED is a lightweight, portable device that delivers electric stimulant to

[29] "Types of Stroke." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 2 Aug. 2021, https://www.cdc.gov/stroke/types_of_stroke.htm.

[30] Han, Seunggu. "Stroke Treatments: Options for Ischemic or Hemorrhagic Stroke." Healthline, Healthline Media, 7 June 2019, https://www.healthline.com/health/stroke/treatments.

the chest and heart.[31] Resemblant of stroke and diabetes, there are multiple types of heart attack based on the victim's heartbeat, each requiring different procedures after diagnosis.[32] An AED, however, detects the irregularities in the heartbeat and automatically adapts to treat the patient. AEDs can be leveraged by any bystander with little-to-no medical knowledge to help regulate a heart attack victim's heartbeat, potentially saving their life. This technology, however, is so revolutionary and relatively inexpensive that AEDs are widespread in the United States. While drones could technically deliver AEDs to those experiencing a heart attack, the lack of regional heart attack patterns results in suboptimal drone coverage.

After unsuccessfully identifying medical applications which would benefit from drone technology, I shifted to identifying medical cures that would prevent a fatal death but would also not adversely affect the patient if incorrectly diagnosed. This was necessary as drones can only be leveraged as rapid transport vehicles rather than a device suited for diagnosis. This marked the transition to understanding how the opioid epidemic could leverage drones to rapidly deliver Naloxone.

2.3 — United States Opioid Epidemic

Opioids have been an escalating problem within the United States. Between 1999 and 2019, the opioid overdose death rate has quadrupled, resulting in over 500,000 American deaths due to overdose.[33] Today, 136 Americans die daily due to an opioid overdose as opioids account for 72% of all overdose victims. Current opioid crisis programs enable individuals with substance-use disorders to seek help through a variety of prevention, treatment, and counseling services. The U.S. Department of Health and Human Services distributed over $9 billion in grants to states and local communities between 2016 and

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[31] "What Is an Automated External Defibrillator?" American Heart Association, 2017, https://www.heart.org/-/media/files/health-topics/answers-by-heart/what-is-an-aed.pdf.

[32] Roland, James, and Debra Sullivan. "Types of Heart Attacks: Names, Symptoms, and Treatment." Healthline, Healthline Media, 18 Feb. 2020, https://www.healthline.com/health/heart-disease/types-of-heart-attacks.

[33] "Understanding the Epidemic." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 17 Mar. 2021, https://www.cdc.gov/drugoverdose/epidemic/index.html.

2019 to combat the opioid epidemic.[34] Despite the efforts of these government programs to help combat the crisis, the world shifted focus from the opioid epidemic to the COVID-19 pandemic. While funding for scientists and vaccine efforts were justifiably abundant, Americans struggling with opioid addiction and abuse faced declining funding for programs as well as a new "socially-distant" world. In the months prior to the COVID-19 pandemic, opioid overdose deaths hovered around 4,200 per month. In the first three months of the pandemic, the monthly opioid overdose deaths grew rapidly, claiming the lives of over 7,250 Americans in May 2020.[35] Opioids overdoses are regional problems, meaning some sections of the United States struggle severely while others hardly struggle at all. Specifically in West Virginia, the National Center for Drug Abuse Statistics confirmed that drug overdose deaths exceeded homicides by 306.7% in 2021.[36] Comparatively, motor vehicle accidents and suicides combine for only 84.5% of the lives killed annually by drug overdoses in West Virginia. Despite these numbers, however, the United States media tends to sensationalize other topics rather than drug overdoses.

2.4 — Naloxone

Naloxone, also referred to as "Narcan", is an approved medication designed to rapidly reverse opioid overdoses by binding the opioid receptors in the body, thus blocking the ingested opioid's fatal effects temporarily.[37] Naloxone counters overdoses caused by any variety of opioids from prescription painkillers such as OxyContin to street drugs like Heroin.[38] The medication can be administered in

[34] "Opioid Crisis Statistics." U.S. Department of Health and Human Services, HHS.gov, 12 Feb. 2021, https://www.hhs.gov/opioids/about-the-epidemic/opioid-crisis-statistics/index.html.

[35] Baumgartner, Jesse C, and David C Radley. "The Spike in Drug Overdose Deaths during the COVID-19 Pandemic and Policy Options to Move Forward." The Commonwealth Fund, 25 Mar. 2021, https://www.commonwealthfund.org/blog/2021/spike-drug-overdose-deaths-during-covid-19-pandemic-and-policy-options-move-forward.

[36] "Drug Overdose Death Statistics: Opioids, Fentanyl & More." National Center for Drug Abuse Statistics, 2022, www.drugabusestatistics.org/drug-overdose-deaths/#west-virginia.

[37] "Naloxone." Substance Abuse and Mental Health Services Administration, 4 Apr. 2022, https://www.samhsa.gov/medication-assisted-treatment/medications-counseling-related-conditions/naloxone.

[38] "Does Naloxone Reverse Any Overdose?" BJA National Training and Technical Assistance Center, 22 Oct. 2014, https://bjatta.bja.ojp.gov/naloxone/does-naloxone-reverse-any-overdose.

various methods, but is typically delivered via a nasal spray or intravenous injection. When Naloxone is administered to someone suffering from an opioid overdose, the medication's efficacy is estimated between 75 – 100%.[39] Although co-prescribing Naloxone with prescription opioids is gaining traction, less than 1% of Naloxone prescriptions are filled.[40] Due to this, Naloxone is primarily delivered to the patient at the time of need via Emergency Medical Services (EMS). If administered in time, Naloxone is proven to restore stable breathing within minutes to those whose breathe has slowed or even stopped due to an opioid overdose.[41] When Naloxone is administered to someone not suffering from an opioid overdose, however, the effects of the drug are negligible and there is no evidence of significant adverse reactions.[42]

Figure 4: Naloxone Nasal Spray[43]

[39] Rzasa Lynn, Rachael, and JL Galinkin. "Naloxone Dosage for Opioid Reversal: Current Evidence and Clinical Implications." Therapeutic Advances in Drug Safety, SAGE Publications, 13 Dec. 2017, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5753997/.

[40] "Naloxone: The Opioid Reversal Drug That Saves Lives." U.S. Department of Health and Human Services, HHS.gov, https://www.hhs.gov/opioids/sites/default/files/2018-12/naloxone-coprescribing-guidance.pdf.

[41] "Lifesaving Naloxone." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 23 Feb. 2022, https://www.cdc.gov/stopoverdose/naloxone/index.html.

[42] "Naloxone for Opioid Overdose: Life-Saving Science." National Institutes of Health, U.S. Department of Health and Human Services, 23 Jan. 2022, https://nida.nih.gov/publications/naloxone-opioid-overdose-life-saving-science.

[43] Rakola, Matthew. "Nation's Top Doc Wants the Overdose Antidote Widely on Hand. Is This Feasible?" *NBCUniversal News Group*, 18 Apr. 2018, https://www.nbcnews.com/health/health-news/surgeon-general-wants-naloxone-widely-hand-feasible-n866976.

The price per dose of Naloxone is roughly $25 and the package weight is less than one pound per dose.[44] Between 1996 and 2014, Naloxone enabled more than 26,000 opioid overdoses to be reversed by non-medical bystanders in the United States, further proving its ability to single-handled counter opioid overdoses.[45]

[44] Abrams, Abigail. "Where to Get Naloxone and How Much It Costs." Time, Time, 5 Apr. 2018, www.time.com/5229870/naloxone-surgeon-general-cost-where-buy.

[45] "The History of Naloxone." Cordant Health Solutions, 5 July 2017, www.cordantsolutions.com/the-history-of-naloxone.

Chapter 3
Business Analysis of West Virginia's Opioid Overdose Epidemic

3.1 — Chapter Introduction

Supply chains in United States have evolved to a position that are fully capable. The next evolution is to perform operations faster at an overall lower cost. While drone technology can currently only be leveraged in niche scenarios, their ability to rapidly transport goods autonomously will be leveraged in the next phase of supply chain. As companies continue to work with the FAA and foolproof their product offerings, drones can begin to target areas to quickly deliver high value payloads in areas with poor infrastructure. While willing leadership is necessary for approval, the benefits of immediate response time and centralized inventory could justify drone implementation.

With respect to healthcare, the U.S. system lacks in many outcomes, such as infant mortality rates, access to care, and patients costs, when compared with similar high-income countries. The ability to integrate technology into healthcare could vastly improve the healthcare offering for citizens of the United States. Given the current capabilities of drones, medical diagnosis via drone is currently infeasible. Therefore, scenarios that require immediate delivery of medical supplies are feasible for drone integration. While various health conditions could possibly be explored, the rapid delivery of Naloxone to help the opioid epidemic in West Virginia will be the target of this research analysis.

3.2 — Business Analysis

3.2.1 — Introduction to Problem

West Virginia is a landlocked state in the central-eastern United States. It is home to 1.79 million Americans and covers 24,038 square miles.[46] Prior to the COVID-19 pandemic, West Virginia experienced solid economic growth as median household income increased by 10.8% to $48,850.[47] Additionally, 73.4% of housing units in the state were occupied by their owner which is 9.3% higher than the national average and higher than all its neighboring states. Medically, 93.3% of the West Virginia population have health coverage.[48]

In 2021, however, an extensive study completed by U.S. News compiled 24 reputable data sources to analyze and rank U.S. states in a variety of categories. Eight major categories, including health care, education, and infrastructure, were further divided into subcategories. These subcategories were then weighted based on their importance in the United States. West Virginia ranked 47th out of 50 states after receiving scores of 45th or higher in half of the eight major categories.[49] After reviewing the subcategories as well, West Virginia ranks 49th in transportation infrastructure[50] and last in public health[51]. In addition, the 2022 median income of West Virginia has declined to $46,711, which is 49th out of the 50 U.S. States.[52]

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[46] "U.S. Census Bureau QuickFacts: West Virginia." United States Census Bureau, 1 Apr. 2020, https://www.census.gov/quickfacts/WV.

[47] Semega, Jessica, et al. "Income and Poverty in the United States: 2019." United States Census Bureau, 15 Sept. 2020, https://www.census.gov/library/publications/2020/demo/p60-270.html.

[48] "West Virginia." Data USA, https://datausa.io/profile/geo/west-virginia.

[49] "Overall Best States Rankings | US News Best States." U.S. News, https://www.usnews.com/news/best-states/rankings.

[50] "Best States for Infrastructure | US News Best States." U.S. News, https://www.usnews.com/news/best-states/rankings/infrastructure.

[51] "Best States for Healthcare | US News Best States." U.S. News, https://www.usnews.com/news/best-states/rankings/health-care.

[52] "Best States for Economy | US News Best States." U.S. News, https://www.usnews.com/news/best-states/rankings/economy.

West Virginia is the current epicenter of the opioid epidemic. The state's age-adjusted opioid overdose death rate is 81.4 per 100,000 people, nearly four times higher than the national average.[53] Despite this average, there is still a large variation across the counties of West Virginia as some counties have reported 26 opioid overdoses in a single day[54] while others have reported zero opioid overdose deaths for the entire year. In a vulnerability study completed by the West Virginia Department of Human & Health Resources, drug overdose mortality varies greatly in different locations in the state.[55] Cabell County, the home of Huntington, West Virginia, has the highest age-adjusted drug overdose rate in the country, with 189.8 deaths per 100,000 people. Moreover, almost 91% of these deaths involved opioid consumption.[56] When analyzing the vulnerability map, it is evident that a majority of opioid issues occur in the southwestern portion of the state as well as the northern and eastern panhandles.

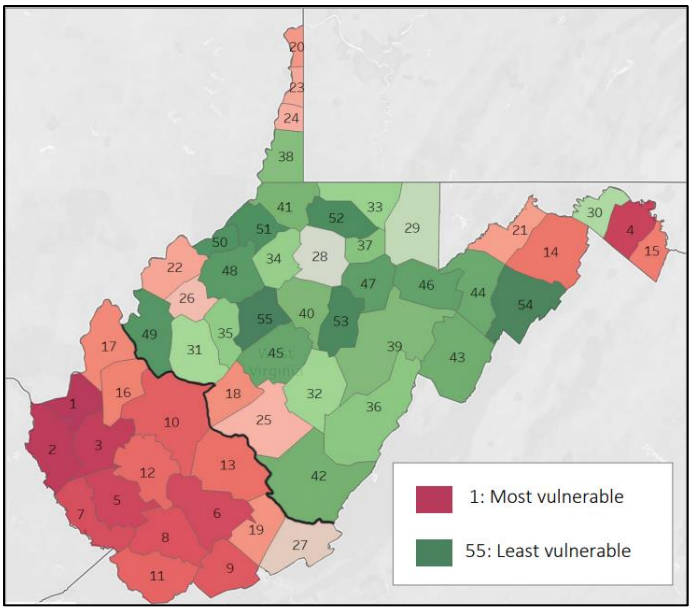

Figure 5: West Virginia Opioid Overdose Vulnerability Study[55]

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[53] "Drug Overdose Mortality by State." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 1 Mar. 2022, www.cdc.gov/nchs/pressroom/sosmap/drug_poisoning_mortality/drug_poisoning.htm.

[54] Joseph, Andrew. "26 Overdoses in Just Hours: Inside a Community on the Front Lines of the Opioid Epidemic." STAT, 22 Aug. 2016, https://www.statnews.com/2016/08/22/heroin-huntington-west-virginia-overdoses/.

[55] Batdorf, Samantha. "County-Level Vulnerability to Overdose Deaths in West Virginia." West Virginia Department of Human & Health Resources, https://oeps.wv.gov/HCV/documents/data/WV_OD_Vulnerability_Assessment.pdf.

[56] "Understanding the Opioid Crisis in Appalachia." Drug Overdose Deaths in Appalachia, NORC at the University of Chicago, https://overdosemappingtool.norc.org/.

The sixteen Southwestern counties account for ~29% of the total counties in West Virginia as well as 33% of the land area and 36% of the West Virginia population. More importantly, medical drone services in this area would cover for ~414 opioid-related deaths per year, accounting for ~60% of the total opioid-related deaths in West Virginia.[56] Specifically, the counties included, and their vulnerability ranks are as follows: Cabell (1), Wayne (2), Lincoln (3), Logan (5), Raleigh (6), Mingo (7), Wyoming (8), Mercer (9), Kanawha (10), McDowell (11), Boone (12), Fayette (13), Putnam (16), Mason (17), Summers (19) and Monroe (27).[55]

Within these counties, there are three prominent airspace restrictions that must be considered. First, West Virginia International Yeager Airport (CRW) is located three miles east of Charleston, WV in Kanawha County. This airport serves 62 flights per week, primarily to Atlanta, Charlotte, and Chicago.[57] Second, Huntington Tri-State Airport (HTS) is located three miles south of Huntington, WV in Cabell County. This airport serves 28 flights per week, offering passenger flights to Charlotte and air cargo flights to various regional airports.[58] Lastly, Beckley Raleigh County Memorial Airport (BKW) is located three miles east of Beckley, WV in Raleigh County. This airport serves 26 flights per week, providing air cargo services to and from various regional airports.[59] In this case, a flight is defined as an inbound landing and an outbound takeoff, meaning each flight results in 2 interactions with an air traffic controller. In total, these three airports service 106 weekly flights, or 212 total air traffic controller interactions. Given drones fly at low elevation relative to passenger airplanes, it is only necessary to consider landing and takeoff operations. Although establishing a seamless communication mechanism to connect with these air traffic controllers will require integration with their existing system, I will assume

[57] Flightradar24. "Charleston Yeager Airport (CRW/KCRW)." Flightradar24, https://www.flightradar24.com/data/airports/crw.

[58] Flightradar24. "Huntington Tri State Airport (HTS/KHTS)." Flightradar24, https://www.flightradar24.com/data/airports/hts.

[59] Flightradar24. "Beckley Raleigh County Memorial Airport (BKW/KBKW)." Flightradar24, https://www.flightradar24.com/data/airports/bkw.

that is to simplify the analysis. My assumption stems from Rwanda's Kagali Airport (KGL) integration with Zipline as that airport services 184 weekly flights, or 368 total interactions, that fly larger aircraft to over 25 international destinations.[18]

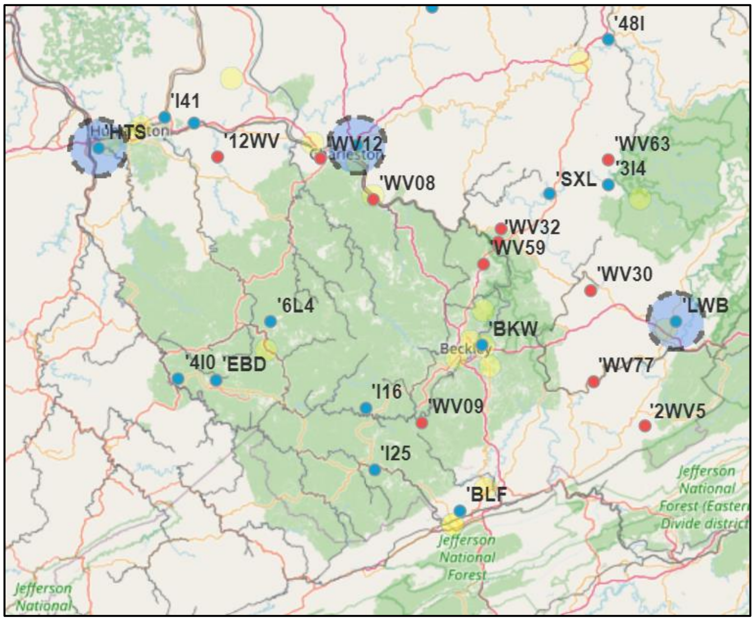

Figure 6: West Virginia Restricted Airspace Map[60]

Despite the high age-adjusted mortality rate in the northern and eastern panhandles, this analysis will focus on the southwestern portion of the state due to the higher vulnerability in these areas and the ability for drones to better serve the area. By rapidly delivering Naloxone in these areas, investment in Zipline drone technology could help prevent deaths of opioid overdose victims.

3.2.2 — Coverage Analysis

The proposed solution would include two Zipline launch stations that would be placed optimally within the state of West Virginia to service the required areas. The optimization analysis included the following constraints.

[60] "Drone No-Fly Zones of West Virginia." *Arcgis.com*, https://www.arcgis.com/apps/InteractiveFilter/index.html?appid=30799913faf349e785026fb288da170c.

First, the Zipline launch station must be placed outside of restricted airspace of the airports. Although daily service to these airports is minimal, a Zipline launch station placed directly within the restricted airspace of an airport is suboptimal due to potential interference. In the worst-case scenario, when a plane is arriving or departing, placement outside of an airport's airspaces still allows the drone to launch if necessary as it would avoid the restricted airspace by flying around it. Second, the Zipline launch station must be stationed at a public facility that is operated 24 hours per day. While a true optimization analysis would optimally and precisely place the launch stations, my lack of familiarity with West Virginia in general drove a more conservative placement approach. Finally, the selected location would need to be multi-faceted in terms of its service times. Areas with alarmingly high age-adjusted mortality due to opioid overdose would be near the launch station to ensure rapid delivery while areas that have medium to high age-adjusted mortality would be included in the drone's extended delivery radius. In this analysis, "rapid delivery" is defined as locations within a 25-mile radius of the launch station, or equivalently within 20 minutes of flight time.

While the first constraint is essential, the restriction of three areas are very minor portions of the total area and had little impact on the possible locations for the launch stations. For the second constraint, however, I propose the utilization of fire departments within the selected counties. Note that ~96% of fire departments in West Virginia are volunteer or mostly volunteer.[61] Given this, I targeted the remaining ~4% of fire departments in West Virginia. When considering the remaining options, I leveraged my third constraint to target urban areas that require rapid delivery. Due to the overlap between urban areas and non-volunteer fire departments, many of the remaining locations were confirmed as viable for a Zipline launch station. When analyzing my final potential locations, I selected the two fire departments that provided the most coverage to the included counties while targeting areas with the most need.

[61] "National Fire Department Registry Quick Facts." U.S. Fire Administration, 7 Apr. 2022, https://apps.usfa.fema.gov/registry/summary.

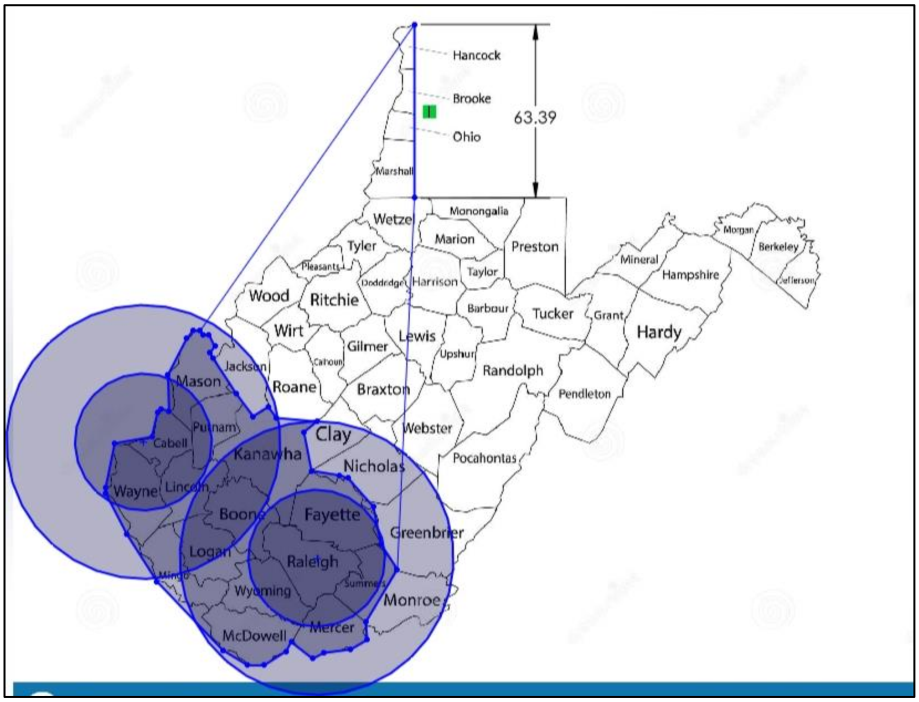

Figure 7: Proposed Launch Stations and Coverage

As shown in the figure above, the selected locations for my launch stations are the Huntington Fire Department in Cabell County and the Beckley Fire Department in Raleigh County. While each location is near one of these airports previously mentioned, the relatively low number of weekly flights bolsters confidence that drone flight would be rarely impacted. In addition, these locations would provide rapid delivery to the entirety of Cabell and Raleigh Counties as well as provide rapid delivery to a majority of Wayne and Lincoln Counties. These four counties all rank within the top five of the selected counties in the vulnerability rankings.

3.2.3 — Incremental Benefit

To understand the additional benefit that Zipline's drone implementation would have on the opioid epidemic in West Virginia, one must consider the current opioid overdose response times. Due to lack of information around the true West Virginia response times, my analysis leveraged EMS response times in Indiana. Based on the similar rural/ urban mix, I assumed that West Virginia's EMS response times were identical to Indiana's EMS response times due to their similarities in healthcare and population distribution. The study leveraged is called Quantifying the Impact of Acute Stroke System of Care Transfer Protocols on Patient Outcomes.[62] While the study primarily examines stroke and its various outcomes, data involving EMS dispatch time, chute time, and rate of travel were instrumental to this analysis.

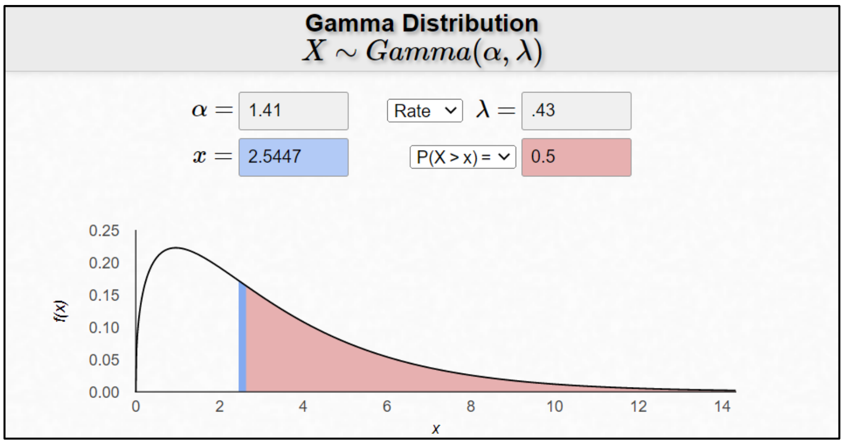

Figure 8: EMS Dispatch Time Gamma Distribution[63]

The EMS dispatch time is defined as the time interval from the initial 911 phone call to the moment the EMS unit is notified of the incident. After leveraging data from the National Emergency Medical Services Information System (NEMSIS), the study concluded the EMS dispatch time is best represented with a Gamma distribution that has an alpha (α) value of 1.41 and a lambda (λ) value of 0.43. These values result in the dispatch time distribution to have a mean of 3.2791 minutes and a standard deviation of 2.7615 minutes.

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[62] Lee, Min K., et al. "Quantifying the Impact of Acute Stroke System of Care Transfer Protocols on Patient Outcomes." Medical Decision Making, vol. 40, no. 7, 2020, pp. 873–884., https://doi.org/10.1177/0272989x20946694.

[63] "Mathematical Sciences Home Pages." *The University of Iowa College of Liberal Arts & Sciences*, https://homepage.divms.uiowa.edu/.

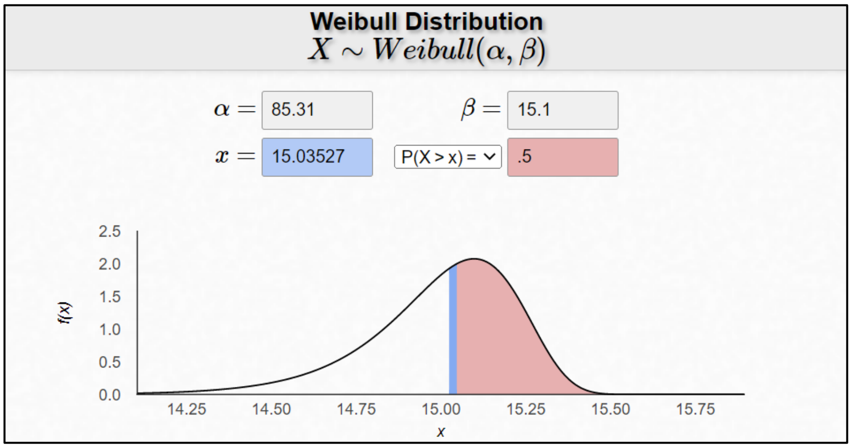

Figure 9: EMS Chute Time Weibull Distribution[63]

The EMS chute time is defined as the time interval between the EMS unit notification and the moment the EMS unit begins traveling toward the necessary location. Once again, by utilizing the data from NEMSIS, the study concluded the EMS chute time is best represented with a Weibull distribution of alpha (α) value of 85.31 and beta (β) value of 15.1. This distribution results in a mean chute time of 15 minutes and standard deviation of 0.2227 minutes.

Rates of travel	Urban: 1.27, suburban: 1.23, rural/wilderness: 0.90	Bliss et al. (2012)[57]
EMS dispatch time (min)	Gamma (1.41, 0.43) Mean = 3.2791 SD = 2.7615	NEMSIS (2017)[30]
EMS chute time (min)	Weibull (85.31, 15.10) Mean = 15.00 SD = 0.2227	NEMSIS (2017)[30]

Figure 10: EMS Rate of Travel Values[62]

The EMS rate of travel is defined as the number of minutes it takes to travel one mile. After leveraging a study completed by Bliss et al., the rates of travel were divided into subcategories for each area type. Given that my analysis further divides the counties into urban and rural, the urban value of 1.27 minutes per mile and the rural value of 0.90 minutes per mile were utilized in my analysis.

In a study conducted by Pew Research Center, the average distance Americans live from a hospital was determined relative to urban and rural communities.[64] In urban communities, patients live an average of 4.4 miles away from a hospital, meaning the mean arrival time for an EMS unit would be 5.59 minutes. In rural communities, patients live an average of 10.9 miles away from a hospital, meaning the mean arrival time for an EMS unit would be 9.45 minutes. The study provided additional gave data that allowed allowing for an accurate calculation of the interquartile range for my analysis. This was completed by dividing the average speed leveraged in the Pew Research Center analysis and multiplying in the EMS rate of travel outlined above. For urban areas, the interquartile range spanned from 3.11 minutes to 12.55 minutes. Similarly, the interquartile range spanned from 3.22 minutes to 18.9 minutes in rural areas.

Due to the lack of information regarding EMS travel times or distances, I extrapolated the data to fit a normal distribution for both urban and rural areas. For urban communities, the 90th, 95th, and 99th percentile of EMS travel times were 13.74 minutes, 16.05 minutes, and 20.39 minutes, respectively. For rural communities, the 90th, 95th, and 99th percentile of EMS travel times were 27.41 minutes, 32.45 minutes, and 42.04 minutes, respectively. Given the four distributions have been accounted for, the following table was created to compile the results.

Table 1: EMS Response Time Analysis

Total EMS Time (minutes)	25%	50%	75%	90%	95%	99%
Dispatch Time	1.27	2.54	4.50	6.94	8.72	12.77
Chute Time	14.88	15.04	15.16	15.25	15.30	15.37
Travel Time in Urban Areas	2.41	5.59	9.88	13.74	16.05	20.39
Travel Time in Rural Areas	3.22	9.45	18.90	27.41	32.45	42.04
Total EMS Response Time in Urban Areas	18.56	23.17	29.54	35.93	40.07	48.53
Total EMS Response Time in Rural Areas	19.37	27.03	38.56	49.59	56.47	70.18

[64] Lam, Onyi, et al. "How Far Americans Live from the Closest Hospital Differs by Community Type." Pew Research Center, 12 Dec. 2018, https://www.pewresearch.org/fact-tank/2018/12/12/how-far-americans-live-from-the-closest-hospital-differs-by-community-type/.

The table above highlights several key values for the analysis. First, the Total EMS Response Time in Urban Areas is greater than 30 minutes in 25% or more of cases. Additionally, the Total EMS Response Time in Rural Areas is greater than 50 minutes in 10% of cases.

When considering the transportation times of Zipline's drone, linear distributions were utilized as I assumed a constant drone speed. For urban populations, the drones would be able to deliver Naloxone within the 25-mile radius, resulting in a 20-minute maximum one-way flight length. For rural populations, the drones would be able to deliver Naloxone within a 50-mile radius, resulting in a 40-minute maximum one-way flight length. Given that Zipline drones require on average 5 minutes of dispatched time and 5 minutes of preparation time[15], urban populations would experience a minimum delivery time of 10 minutes and a maximum delivery time of 30 minutes. Additionally, rural populations would experience a minimum delivery of 30 minutes and a maximum delivery time of 50 minutes.

When comparing the incremental benefit of the drone technology relative to the current EMS response times, it is evident that the autonomous nature of drones provides a robust, stable platform to supplement the current response scenario. Although variations in humans significantly help opioid overdose victims when they variate under the mean, the variations at the upper end of the distribution result in unnecessary deaths due to poor response time. The consistency of drone deliveries supplement traditional EMS response services in the opposite direction. While drone delivery is relatively on par with human response times, it is evident that the lack of variation seen in the drone response times dominate human response times toward the upper end of the distribution. For instance, a drone can deliver Naloxone to urban patients faster than an EMS response 25% of the time. Additionally, a drone can deliver Naloxone to rural patients faster than an EMS response 10% of the time. Due to true data limitations, these values were manually calculated and could be tested with further precision with additional information. Given that seven of the counties are considered urban and the remaining nine are classified as rural, however, drones can more quickly deliver medical supplies in ~17% of the total opioid overdose accidents, proving their incremental benefit to the counties served.

3.2.4 — Implementation Cost and Justification

As addressed earlier in the paper, the drone deployment footprint will cover ~414 opioid-related deaths per year. Any cost justification based solely on the value of a human life is delicate, therefore I decided to enact a multi-faceted approach to my justification.

First, I would like to focus on cost. To simplify the many details of drone implementation cost over multiple years, my proposed solution will include 2 Zipline launch stations with 15 total drones. Similar to the Rwandan implementation of Zipline drones, Ghana has recently agreed to a four-year deal that includes 4 Zipline launch stations with 30 total drones. The Ghana arrangement will pay Zipline $12.5 million to establish and operate 150 flights per station per day.[65] Additional details on the contract confirm an operating cost of ~$88,000 per day. Multiplying this figure by the total number of operating days results in an operating cost of ~$4,224,000, with the remaining ~$8,276,000 allocated to facility set-up, drone hardware, and overhead costs. Using this proportional cost arrangement for West Virginia's 2-station, 15-drone network over four years, leads to an implementation cost of ~$6.25 million with ~34% allocated to operating costs and ~66% allocated to facility set-up, drone hardware, and overhead costs. Although this allocation approach is mathematically logical, in practice the West Virginia drone network will rarely operate 300 medical deliveries per day for opioid overdose victims. Given the lack of publicly available cost details around full-scale operation, I will conservatively assume the estimated cost at $8 million to account for other contract and hidden costs associated with the deal.

My first investment analysis will be based on the value of a life and to estimate the number of saved lives required for the justification. In a 2008 study by Scott Grouse, an analysis of the value of a life was completed and was determined to be $50,000 per life-year.[66] This directly translates to $50,000 in

[65] Mortimer, Gary. "Zipline Medical Deliveries for Ghana Meet Resistance." SUAS News - The Business of Drones, 14 Dec. 2018, https://www.suasnews.com/2018/12/zipline-medical-deliveries-for-ghana-meet-resistance/.

[66] Grosse, Scott D. "Assessing Cost-Effectiveness in Healthcare: History of the $50,000 per Qaly Threshold." Expert Review of Pharmacoeconomics & Outcomes Research, vol. 8, no. 2, 2008, pp. 165–178., https://doi.org/10.1586/14737167.8.2.165.

contributed value to society for each additional year a person lives and is leveraged to justify expensive medical procedures. In 2020, however, the Institute of Clinical and Economic Review valued a life-year of United States residents between $50,000 and $150,000. For simplicity, I will utilize $100,000 per additional year a patient lives after receiving treatment.[67] In West Virginia, the average life expectancy is ~72 years for males and ~77 years for females.[68] In the 2016 West Virginia Overdose Fatality Analysis, research found that "males were twice as likely as females to die from a drug overdose".[69] Additionally, the National Safety Council determined that preventable opioid overdoses accounted for 64,183 deaths where ~72% of those deaths were male.[70] Given these two facts, I will assume a 70% / 30% male-to-female ratio for opioid overdose victims in West Virginia. In the Opioid Overdose Deaths by Age Group data, The Kaiser Family Foundation confirmed that the median age of a West Virginia overdose victim was between 35 and 44 years old.[71] Given this data, I will assume the median age to be 44 in order to conservatively estimate the value of the program. To continue my conservative estimation, I will assume these overdose victims will have an expected lifespan of 80% the traditional lifespan in West Virginia, resulting in ~58 years for males and ~62 years for females. With these data elements and assumptions, the following estimations are offered for consideration:

$$13.52\ Additional\ Years\ Lived\ per\ Male \times \frac{\$100{,}000}{1\ Year} = \$1.352\ million\ per\ male\ life\ saved$$

Figure 11: Male Equation

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[67] "2020-2023 Value Assessment Framework." *Institute for Clinical and Economic Review*, 13 Oct. 2020, https://icer.org/wp-content/uploads/2020/10/ICER_2020_2023_VAF_102220.pdf.

[68] "National Vital Statistics Reports." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 10 Feb. 2022, https://www.cdc.gov/nchs/data/nvsr/nvsr70/nvsr70-18.pdf.

[69] Sanders, Sarah, et al. "2016 West Virginia Overdose Fatality Analysis." *West Virginia Department of Health and Human Resources*, 20 Dec. 2017, https://dhhr.wv.gov/bph/Documents/ODCP%20Reports%202017/2016%20West%20Virginia%20Overdose%20Fatality%20Analysis_004302018.pdf.

[70] "Drug Overdoses." *National Safety Council*, https://injuryfacts.nsc.org/home-and-community/safety-topics/drugoverdoses/.

[71] "Opioid Overdose Deaths by Age Group." *Kaiser Family Foundation*, https://www.kff.org/other/state-indicator/opioid-overdose-deaths-by-age-group/?currentTimeframe=0&sortModel=%7B%22colId%22%3A%22Location%22%2C%22sort%22%3A%22asc%22%7D.

$$17.84\ Additional\ Years\ Lived\ per\ Female \times \frac{\$100{,}000}{1\ Year} = \$1.784\ million\ per\ female\ life\ saved$$

Figure 12: Female Equation

Finally, by employing the 70% / 30% male-to-female ratio assumed earlier, the average saved life, regardless of biological sex, at ~$1.482 million in West Virginia.

This conservatively estimated value is important in many ways. Primarily, it defines the expected yearly contribution in value to society of a saved opioid overdose victim. In relation to the analysis, it defines a theoretical break-even figure on how much each life-saving operation could cost prior to being classified as "not worth it". In short, the average West Virginian opioid overdose victim could receive up to ~$1.482 million in treatment to save their life and the return on investment would still be justified. Between 2015 and 2019, an average of ~414 West Virginians died per year due to opioid overdose in the covered region. Mathematically, the $8 million in operating costs would be justified if the program saved ~5.4 total lives across the 4 years. In reality, the expedited delivery of Naloxone has the potential to save at least 15% of all opioid overdose victims, proving the true value of the implementation to ~$92 billion.

My second investment analysis will consider the current and future funding expected in West Virginia to specifically combat the opioid overdose crisis and understand what percentage of total funding would be necessary to implement the program. In 2020, the West Virginia Department of Health and Human Resources allotted $43.7 million to specifically combat the opioid crisis.[72] These funds were the first distribution of a two-year State Opioid Response grant that enables states to "develop tailored approaches to prevention, treatment, and recovery from opioid use disorders." In total, $87.4 million will be distributed over the two-year period. In addition, many states have filed extensive lawsuits against

[72] "DHHR Awarded $43.7 Million to Combat Opioids." *West Virginia Department of Health and Human Resources*, 28 Aug. 2020, https://dhhr.wv.gov/News/2020/Pages/DHHR-Awarded-$43.7-Million-to-Combat-Opioids.aspx.

major opioid makers and distributors that have been successful. Specifically, West Virginia communities were recently granted $1.25 billion in funding from the drug industry to help combat the opioid crisis.[73] After several rounds of lawsuits, it was determined that opioid manufacturers misrepresented the risk and benefits of the drug, resulting in contribution to the opioid epidemic.[74] These funds will be distributed based on population (85%) and severity of the crisis (15%). Today, West Virginia continues to file lawsuits against drug manufacturers in hopes to secure additional funding to eventually solve the crisis. As addressed previously in the paper, the proposed solution will cover sixteen West Virginia counties that account for ~36% of the population and ~60% of opioid-related overdoses in the state. Given these estimates and the $1.25 billion in funding, the covered counties will receive ~$494.3 million to devise unique solutions to address the problem. When also factoring in federal and state funding, these sixteen southwestern West Virginian counties will have over $500 million to effectively combat the opioid crisis. The proposed four-year plan to implement Zipline drone technology will cost $8 million. For 1.6% of the total opioid budget among these counties, Zipline can rapidly transport Naloxone and save hundreds lives to those experiencing opioid overdose.

3.3 — Additional Benefits

In addition to the proven benefits from the earlier thesis analysis, I believe implementing drones in West Virginia will have additional benefits worth considering. These benefits include self-administered service, potential Medicare coverage, centralized inventory, and partial support to neighboring counties.

[73] Izaguirre, Anthony, and Geoff Mulvihill. “West Virginia Plan: Companies Pay $1.25B to End Opioid Suits.” *ABC News*, ABC News Network, 2 Mar. 2020, https://abcnews.go.com/Health/wireStory/west-virginia-plan-companies-pay-125b-end-opioid-69345795.

[74] Raby, John. “Trial Begins in West Virginia Lawsuit against Opioid Manufacturers.” *PBS*, Public Broadcasting Service, 4 Apr. 2022, https://www.pbs.org/newshour/nation/trial-begins-in-west-virginia-lawsuit-against-opioid-manufacturers.

Just for clarity, these benefits were not included in the investment analysis scenarios, but are worth considering if implementation is approved.

First, the current drone network covers sixteen counties in West Virginia and has been the core footprint considered in this thesis analysis. Since the delivery footprint of drones is radial, the actual drone delivery coverage partially includes additional counties in West Virginia and portions of Ohio, Kentucky, and Virginia. From a practical perspective and ignoring state borders, these counties are struggling in similar ways as the core West Virginian counties modeled in this thesis.

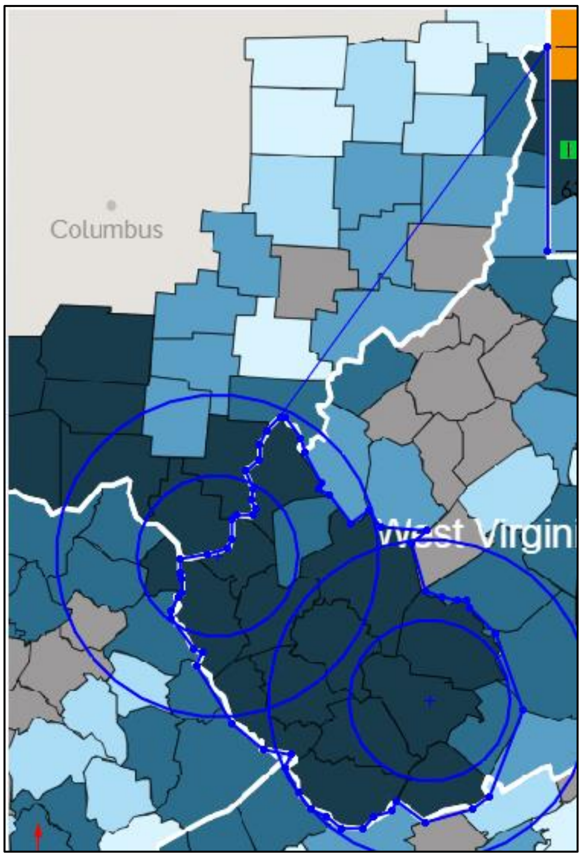

Figure 13: Proposed Solution'Additional County Coverage

As shown in the figure above, the proposed drone station locations have a 50 square mile radius of coverage for potential deliveries. This footprint entirely covers five additional counties and partially covers dozens more. While the added benefits that could be provided to the additional counties were not considered in the thesis analysis, the Zipline drones are fully capable of servicing these areas as well, further justifying the value of the deployment and operation.

Second, I believe that implementing a drone network to deliver Naloxone to overdosing patients would increase the number of 911 calls received as well as decrease the time to place a 911 call. Consumption of opioid is illegal and many opioids, such as fentanyl or heroin, are classified as Schedule I drugs. Sentences associated with Schedule I drugs range in criminal sentencing from one to fifteen years in prison and could incur fines of up to $25,000.[75] While Good Samaritan laws have reduced the stigma around calling 911, I believe that opioid overdose victims and bystanders would more quickly call 911 if they knew an unmanned drone would bring the Naloxone. Once in possession of the drug, the bystander would be able to simply administer it to the opioid overdose victim. Upon arrival of the EMS and police, a successful administration of Naloxone would stabilize the situation and result in a less stressful situation for all involved.

Third, centralized inventory of Naloxone could reduce overall inventory costs in medical facilities. Similar to the successful centralized inventory in Rwanda for blood packs, the procurement and storage of Naloxone is costly to hospitals and medical service organizations. This cost is eventually passed on to the consumer. Naloxone's expiration is roughly 12 to 24 months.[76] Following this initial period, the Naloxone begins to degrade and lose it strength.[77] Today, Naloxone is typically given to individuals, resulting in a majority of the doses to go unused.While this drug expiration process is relatively slow, a centralized inventory with proper first-in-first-out (FIFO) inventory management processes of the Naloxone would ensure that all patients received a full-strength dosage.

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[75] "§60A-4-401. Prohibited Acts A; Penalties." West Virginia Legislature, http://www.wvlegislature.gov/wvcode/code.cfm?chap=60a&art=4.

[76] McMullan, Jason T. "Your Patient's Expired Naloxone Might Still Be Good." *NEJM Journal WatchYour Patient's Expired Naloxone Might Still Be Good*, 24 Jan. 2019, https://www.jwatch.org/na48388/2019/01/24/your-patients-expired-naloxone-might-still-be-good.

[77] "About Expired Naloxone." *NEXT Distro*, https://nextdistro.org/mightynaloxone.

Lastly, Naloxone costs ~$25 per dose and drone flight costs are estimated to be between $20 and $40 per flight. Assuming the average opioid overdose victim only needs one dose, the cost per flight delivery would be ~$55. While there is currently an abundance of short-term funding available from lawsuits and federal contributions, coverage for a free delivery service for those experiencing an opioid overdose could eventually be considered in federal or state health programs.

3.4 — Acceleration of Drone Implementation in the United States

The Gartner Hype Cycle is methodology that allows you to interpret technology hype and further understand whether new technology is truly viable. It consists of five major portions that follow a graph plotted on Expectations vs Time axes.[78]

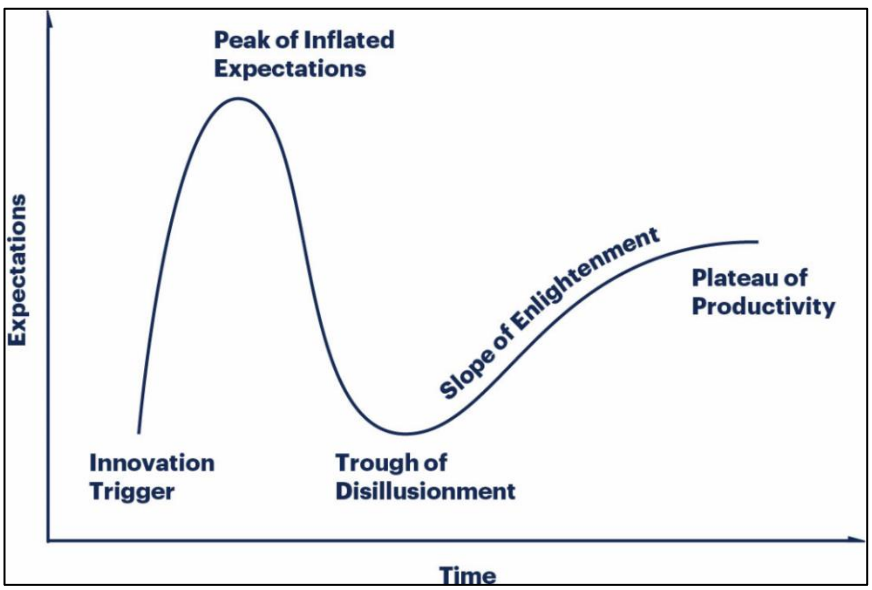

Figure 14: Gartner Hype Cycle[79]

The first phase is the Innovation Trigger. This portion of the graph begins when a new technology discovery results in early proof-of-concept stories. These stories are often picked up by the media and

[78] "Gartner Hype Cycle Research Methodology." *Gartner*, https://www.gartner.com/en/research/methodologies/gartner-hype-cycle.

[79] Raza, Muhammad. "Introduction to the Gartner Hype Cycle." *BMC Blogs*, 5 May 2020, https://www.bmc.com/blogs/gartner-hype-cycle/.

overinflated as there still is no commercial viability in the industry yet. The second phase is the Peak of Inflated Expectations. When Amazon announced drone delivery to their customers, the aftermath of the announcement was in the Peak of Inflated Expectation phase. Media publications continue to be produced in record numbers, educating the public on the potential of this product. This phase traditionally brings in peak investments from risk-taking individuals that are looking to cash in on early adoption. The third phase is Trough of Disillusionment. Following the brief, intense break experienced during the Peak of Inflated Expectations, reality sets in. Companies release realistic, but unattractive timelines that are often further delayed due to legalities and testing issues, resulting in funding for the technology to exponentially decline. The fourth phase is the Slope of Enlightenment. The once-emerging technology becomes further researched and understood. This research leads to the evolution of products that meet enterprise demands in specific use cases. Finally, the last phase is the Plateau of Productivity. The reemerging technology becomes mainstream as average consumers begin seeing and/or interacting with it on a more frequently basis.

Drone technology in the United States is currently in Trough of Disillusionment phase. Amazon's announcement occurred almost a decade ago and there are very few use cases within the United States. This continues to leave investors skeptical, stalling the technologies development. While the initial purpose of my thesis was to help solve the opioid epidemic in the United States, my research and analysis proved that there is no enterprise-level operation that utilizes drones effectively. I believe that implementing my solution in West Virginia will not only provide substantial impact to the region, but also progress drone technology out of the Trough of Disillusionment. A recent song lyric in Kayne West's Donda album reads "you might not have been the only one that could have did that, but you were the one that did do that". While I am aware this is not the only potential use case in the United States, an implementation of this level would prove the worth of drones in our society, bolstering investments and reamplifying the excitement around the technology. A successful implementation of Zipline's drone would pave the way for future drone initiatives of any variety to become reality more quickly.

Chapter 4
Conclusion & Future Areas of Research

4.1 — Conclusion

The completed analysis proves that drone technology has the potential to impact the live of Americans in West Virginia. As the battle against the opioid epidemic ensues across portions of the United States, it is essential to strategically leverage federal and state funding to help solve the issue quickly. The ability for drones to rapidly delivery Naloxone is an opportunity to save lives while understanding the best way to eliminate opioids from communities struggling with opioid addiction. Under various assumptions due to data availability, the analysis above proves that drone implementation in Southwestern West Virginia will expand the current EMS response scenario, creating a more robust system to handle opioid overdoses. The approximated benefit will enable ~17% of opioid overdose victims to receive Naloxone more quickly in emergency scenarios in covered West Virginia counties. This has the potential to save countless lives, reenabling them to contribute to the great good of society.

4.2 — Future Areas of Research

The opportunities to further contribute to drone technology's implementation in the United States is two-fold. Due to data access limitations, I made several assumptions that were highlighted throughout the thesis. While the analysis is still complete, more precise data will further ensure accuracy for the complete analysis. In addition, the completed research dove deeply into Zipline's drone technology and the opioid epidemic in West Virginia. Even though this topic is critically relevant in the United States, drone technology of any type has the potential to impact local communities in prominent ways. Expansionary ideas that highlight additional potential solutions are equally as important as further analysis of the West Virginia opioid epidemic use case.

Appendix
Excel Analysis

2017 Vulnerability Rankin	Counties	2015-2019 Average Age-Adjusted Opioid Overdose Deaths (per 100,000 people)	2015-2019 Average Opioid Overdose Death	Size (mi^2)	Population
1	Cabell	172.5	167.02	281.02	96,826
2	Wayne	116.9	48.79	505.98	41,735
3	Lincoln	79.4	17.15	437.04	21,599
5	Logan	94.5	34.18	453.74	36,169
6	Raleigh	103.9	81.90	605.35	78,827
7	Mingo	74.9	19.65	423.11	26,229
8	Wyoming	87.1	20.21	499.45	23,203
9	Mercer	77.3	48.05	418.99	62,161
10	Kanawha	79.5	152.48	901.59	191,795
11	McDowell	102.9	21.90	533.46	21,281
12	Boone	79.5	19.28	501.56	24,257
13	Fayette	64.1	29.30	661.55	45,709
16	Putnam	54.0	30.43	345.67	56,356
17	Mason	71.2	19.37	430.75	27,207
19	Summers	55.8	7.64	360.46	13,699
27	Monroe	30.3	4.10	472.75	13,524
		1,343.8	721.45	7,832.47	780,577
State	Additional Counties	2015-2019 Age-Adjusted Opioid Overdose Deaths		Size	Population
Ohio	Gallia	78.5	24.15	466.53	30,763
	Jackson	34.7	11.43	420.30	32,952
	Lawernce	68.8	42.72	453.37	62,100
Kentucky	Boyd	78.0	38.41	159.86	49,242
	Lawernce	36.5	5.79	415.59	15,850
	Greenup	56.7	20.78	344.40	36,656
	Carter	51.0	13.99	409.50	27,439
	Martin	45.4	5.79	229.60	12,750
ADDITIONAL SUM		449.6	163.07	2,899.15	267,752
TOTAL SUM		1,793.4	884.52	10,731.62	1,048,329.00

Appendix 1: Raw Data for All Included Counties

County	Total Deaths between 2015-2019	2015-2019 Average Age-Adjusted Opioid Overdose Deaths (per 100,000 people)	Population	Size (mi^2)	Rural or Urban	Covered?
Barbour	14	26.4	16,633	341.06	R	N
Berkeley	311	82.8	115,329	321.14	U	N
Boone	55	79.5	22,368	501.54	U	Y
Braxton	10	22.8	14,190	510.81	R	N
Brooke	41	63.1	22,459	89.20	U	N
Cabell	474	172.5	94,339	281.02	U	Y
Calhoun	-	-	7,295	279.25	R	N
Clay	-	-	8,709	341.90	U	N
Doddridge	-	-	8,560	319.72	R	N
Fayette	83	64.1	43,576	661.55	U	Y
Gilmer	-	-	8,041	338.50	R	N
Grant	12	34.1	11,616	477.37	R	N
Greenbrier	37	38.1	35,155	1,019.57	R	N
Hampshire	62	96	23,309	640.25	U	N
Hancock	58	73.2	29,383	82.61	U	N
Hardy	13	30.5	13,805	582.31	R	N
Harrison	80	39	67,908	416.01	R	N
Jackson	23	28.3	28,907	464.35	R	N
Jefferson	107	60	56,606	209.63	U	N
Kanawha	439	79.5	183,279	901.59	U	Y
Lewis	15	29.8	16,166	384.90	R	N
Lincoln	52	79.4	20,850	437.04	U	Y
Logan	97	94.5	33,154	453.74	R	Y
Marion	42	24.8	56,355	308.74	R	N
Marshall	27	28.7	31,308	305.43	U	N
Mason	55	71.2	26,820	430.75	R	Y
McDowell	57	102.9	18,661	533.46	R	Y
Mercer	136	77.3	59,919	418.99	R	Y
Mineral	44	56.6	27,167	327.83	U	N
Mingo	57	74.9	24,290	423.11	R	Y
Monongalia	107	30.4	105,474	360.06	U	N
Monroe	12	30.3	13,401	472.75	R	Y
Morgan	38	78.3	17,709	229.07	R	N
Nicholas	32	41.6	25,078	646.82	R	N
Ohio	63	53.5	42,143	105.82	U	N
Pendleton	-	-	7,001	696.05	R	N
Pleasants	-	-	7,482	130.10	R	N
Pocahontas	-	-	8,450	940.28	R	N
Preston	26	24.4	33,683	648.80	U	N
Putnam	93	54	56,610	345.67	U	Y
Raleigh	236	103.9	75,252	605.35	U	Y
Randolph	17	18.7	28,390	1,039.68	R	N
Ritchie	-	-	9,844	451.99	R	N
Roane	13	30	14,020	483.56	R	N
Summers	21	55.8	12,848	360.46	R	Y
Taylor	11	20.5	16,864	172.77	R	N
Tucker	-	-	6,982	418.92	R	N
Tyler	-	-	8,811	256.29	R	N
Upshur	12	15.6	24,502	354.64	R	N
Wayne	141	116.9	40,303	505.98	U	Y
Webster	13	50.8	8,386	553.47	R	N
Wetzel	21	45.7	15,436	358.06	R	N
Wirt	-	-	5,798	232.51	U	N
Wood	121	49	84,960	366.26	U	N
Wyoming	60	87.1	21,281	499.45	R	Y
West Virginia	3438	63.6	1,816,865	24,038.18	61.82%	29.09%
	WV Deaths per Year	687.6				
	Death Coverage	60.15%				
	Population Covered	652612				
	Population Coverage	35.92%				
	Urban Coverage	43.75%				
	Rural Coverage	56.25%				
	Area Coverage	32.58%				

Appendix 2: Raw Data for All WV Counties

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ACADEMIC VITA

Matthew P. Wozniak

EDUCATION

The Pennsylvania State University, University Park, PA — August 2018 – May 2022
Schreyer Honors College (SHC) | College of Engineering | Smeal College of Business
Bachelor of Science, Industrial Engineering | Business Fundamentals Certificate

University of Limerick, Limerick, Ireland — January 2020 – May 2020
Semester-long Study Abroad Academic & Cultural Immersion Program

WORK EXPERIENCE

Deloitte. — **Strategy Analyst** — June 2022 – Present, Philadelphia, PA

- Excited to start my full-time career with the Strategy & Analytics division of Deloitte Consulting in Summer 2022

CONNORS GROUP — **Analyst Intern – Consultancy Practice** — May 2021 – August 2021; May 2020 – August 2020

Connors Group is a management consultancy, specializing in operational improvement and productivity enhancement

- Uncovered, quantified, and presented a series of creative, tiered solutions that will generate $13.4M in annual savings for an on-demand, specialty beverage retailer. Developed a retail field study and performed data analysis to reduce cost-per-order by 30%. Established and fostered client relationships with C-level executives
- Identified process improvement opportunities in daily stocking operations of convenience stores for a Fortune 10, multinational oil & gas company, reducing expenses by €600K annually. Engaged in client calls with international field experts to write operational standards utilizing MOST techniques and Lean business practices
- Designed optimal backroom store layout by dissecting pick-up and delivery operations for a prominent, west-coast supermarket chain. Leveraged retail field studies to identify process improvement opportunities and creative solutions. Engaged in weekly, transcontinental travel to meet with clients at various sites

LEADERSHIP

President, Tau Beta Pi, National Engineering Honor Society — January 2021 – Present
- Spearheaded Spring 2022 recruitment efforts, resulting in a 150% increase in year-over-year membership
- Individually devised $1,000 branding campaign to greatly enhance campus presence and organization prestige
- Lead 100-member chapter, organizing board meetings and COVID-19 safe events to engage all members
- Manage and support 12 Executive members individual goals, ultimately accomplishing organizational milestones

Corporate & Alumni Relations Chair, Schreyer Consulting Group — December 2019 – Present
- Active leader in Group with objective to prepare and educate Scholars for future careers in consulting
- Revamped LinkedIn Group page to enhance brand appeal and foster student-alumni connections

Dean's Student Advisory Board Representative, SHC — March 2019 – Present
- Collaborate directly with Dean and Scholars to solve pressing challenges and formulate pioneering initiatives
- Interviewed five new Dean candidates, providing a valued recommendation for the final Dean selection

Vice President, External Relations, Delta Upsilon Fraternity — November 2020 – November 2021
- Recognized Executive Board leader of a 105-member chapter committed to "Building Better Men"
- Lead multiple community service fundraising events. Increased relations with alumni brotherhood

INVOLVEMENT

Activities & Community Service: Education Abroad Peer Advisor, GLOBAL Penn State | Consultant, Engineering-Consulting Collaborative | American Red Cross | SHO TIME Team Mentor, SHC | THON | GLOBE Living Environment

Honors: Harold and Inge Marcus Scholar | Alpha Pi Mu, Industrial Engineering Honor Society | Deposco MVP Award | Golden Key International Honour Society | Sigma Alpha Pi Honor Society | President's Freshman Award

SKILLS

Obtained advanced Excel certification | Proficient in Microsoft Office | SolidWorks | MATLAB | Salesforce