Drone Delivery Models for Healthcare

S. NIHAL, S. MUKUNTHA NARASIMHAN, G.PRASHANTH

Panimalar Engineering College

Abstract:

The study examines how drone technology can revolutionize healthcare delivery, particularly in isolated or hard-to-reach areas lacking adequate traditional transportation infrastructure. Drugs and other medical supplies may be delivered without being hampered by impassable roads thanks to delivery drones.

The paper evaluates the top businesses in the field and their various business models, examining the current status of creative drone delivery with an emphasis on healthcare in particular. It also discusses the most recent methods for managing a fleet of drones.

The study recommends two cutting-edge strategiesthat could boost the efficiency, timeliness, and cost-effectiveness of healthcare delivered by drones. The architecture of a drone healthcare delivery network could be considerably improved by these models, potentially saving lives and improving the treatment of patients.

Introduction:

The transportation sector is about to undergo a major change because of the disruptive new technology known as drones. Drones have the potential to replace existing transportation infrastructure in the same way that mobile phones transformed personal communication in underdeveloped countries.

Drones are usually referred to as "unmanned aerial vehicles" (UAVs), while variant terminology includes "unmanned aircraft," "remotely operated aircraft," "remotely piloted vehicles," and "remotely piloted aircraft." With the use of global positioning systems (GPS) and lightweight composite materials, recent developments in hardware, software, and networks have been made specifically for drones, enabling effective flight.

Furthermore, lithium batteries are gradually improving, allowing drones to fly for longer periods of time between charges. Apps for smartphones or tablets can be used in combination with drone software.

Drone package delivery modeling was done prior to developing new drone models for healthcare purposes. The study's final part offers concluding thoughts, and the appendix contains numerical examples.

2. Background on Drone Applications

In addition to carrying cameras, drones can also carrya range of other equipment, including small things.
The military has employed drones in both combat and search & rescue operations. Precision agriculture, wildlife preservation, riot and fire monitoring, scientific investigation, border surveillance, monitoring of sporting and entertainment events, media coverage,
emergency services, and disaster response are just a few of the applications that additional sectors have taken to the use of drones for. Another advantageous use is shark detection at beaches. As the technology

for drones develops, we may anticipate additional cutting-edge uses across a range of industries.

Since human lives are on the line, it may be argued that humanitarian drone uses are the most practical. For instance, drones assisted rescuers in Nepal following the 2015 earthquake by helping them findsurvivors [2]. Commercial drone use is prohibited inthe US without

an exception under Section 333 [9]. Applications for surveillance have received FAA exemptions, for

Drone delivery regulations have presented difficulties for businesses like Amazon, but there are other uses for the technology, such as inspecting BP pipelines.
In the case of Flirtey, the FAA granted them weekend-only permission to carry medicines in the outlying regions of Virginia. However, nations with pressing medical needs, like Rwanda, have been able to get over legal hurdles more swiftly.

3 Drone Applications in Healthcare

Delivering medications, defibrillators, blood samples, and vaccines are all examples of drone uses in the healthcare industry [1, 2, 4, 10, 12, 14, 16, 17, 19, 20, 21].

For instance, like those used by Matternet, autonomous drones use GPS and other sensors to find their way between automated ground stations to distribute medications in distant areas lacking suitable roads [19]. Following the 2010 earthquake, Matternet shipped medications to Haiti and the Dominican Republic [2], as well as to New Guinea and Switzerland [9]. The business collaborates with Doctors Without Borders and UNICEF.

The drones of Matternet can transport objects up to a distance of 10 kilometers (6.2 miles) and at speeds of up to 40 kilometers per hour in as little as 18minutes, including takeoff and landing.

With their Parcelcopter, DHL Parcel has been investigating medical drone delivery in Germany for over thirty years. Blood samples were sent from Bonn across the Rhine River using the first generation, which covered a 1 kilometer distance. On Juist, a lonely island in the North Sea, the second generation was tested in 2014. For three months, it delivered much needed supplies. Over 12 km of openwater, the parcelcopter flew. Between two Bavarian Alpine organizations, theorganizationsn of the Parcelcopter transparcelcopterthan 130 important products, including medicine and sporting goods, from January to March 2016. When comparison toIn0-minute journey in the cold, drone deliveries took only 8 minutes. This time difference can be significant in an illness or injury.

In 20 clinics located in remote areas of Rwanda, where malaria, newborn mortality, and maternal deaths are common, UPS and Zipline have worked together to develop a drone network to transport blood and vaccinations [20, 12, 16]. Drones are a viable option for distributing critically needed rabies vaccinations because they are resistant to flooded roadways during the rainy season. Just over a third of Africans live two kilometers or less from a

year-round road. The zipline aircraft released parcels using a paper balloon after being flung from a nest. The drone leaves the nest with a new set of batteries, a SIM card, and the subsequent blood or immunization delivery.

Zipline drones conduct deliveries by dropping products with a paper parachute after being released from a nest. A sim card, fresh batteries, and the blood or vaccinations for the subsequent delivery are placed once the drone has returned to the nest.

Large dog-sized zipline drones have a carrying capacity of three pounds [12]. They have a 30-minute 45-mile flight range. A tablet app allows for the tracking and modification of their path.

An isolated clinic in southwest Virginia that sees about 3,000 patients a year was given permission by the FAA to receive the first drone delivery of medical goods [14, 10]. Flirty drones successfully delivered medical supplies in just three minutes from the Wise County Regional Airport to the clinic that was located at the far-off pavilions. This is a significant development in the use of drones to carry medical supplies to inaccessible locations.

Orders are normally delivered in 90 minutes by the Oakwood pharmacy, 35 miles distant, over a difficult terrain of hills and uneven roads. However, because the Flirtey drone batteries only had a 20-mile maximum Distance, provisions had to be flown from Oakwood to the Wise County airstrip using NASA's experimental staffing drone. In addition to this, Flirtey drones were additionally used to deliver medical supplies in various places, including Nevada, Australia, and New Zealand.

Table 3. Comparison of healthcare delivery drone payload, range and speed

In the Netherlands, prototype drone ambulances have transported cardiac arrest machines [17].

Instead of the typical 10-minute wait for emergency assistance, prototype drone ambulances in the Netherlands can reach patients within 4.6 square miles in just one minute. The drones boost the chance of survival from 8% to 80% at speeds up to 60 mph. For navigation and call monitoring, drones use GPS. With a streaming web camera on the drone, a paramedic can educate a layperson aiding the patient from a control room. It will take five years and $19,000 each to build an emergency drone network, resolve legal concerns, and further enhance helicopter steering. These drones, which are sometimes referred to as "flying medical toolboxes," may deliver additional medical supplies like oxygen masks and insulin injections for diabetics.

Table 1 shows that medications prescribed by a doctor, blood, and vaccinations make up the majority of the medical products shipped by drones.
Defibrillators, oxygen, and insulin could perhaps be transported with the existing design ambulance drone.

According to Table 2, the launch pad is frequently automated and is also referred to as a ground station, Skyport, or nest. The cargo can be dropped using techniques like Zipline's paper parachute or Flirtey's rope. Alternative delivery methods include those used by Matternet and DHL Parcel.

The payload, range, and speed of the various drone delivery systems are compared in Table 3. The payloads of Matternet, DHL, and Flirtey are comparable.

Compared to other drones, Zipline's helicopters has a more compact layout that is quick but has a lesser ability to carry payloads. The range of the drones varies, ranging from 6.5 miles for Matternet to 45 miles for Zipline, however as these numbers are based on data from publications and websites, they could not be current.

As was already noted, technological developments are advancing quickly, and this includes quicker lithium battery charging times. The distribution of healthcare supplies by drone will be the subject of thenext part, which will focus on a specific model for location decisions.

4. Model Development

Inspired by firms like Google, Amazon, and DHL, multiple researchers have investigated potential drone delivery models, notably for parcel delivery. In this regard, Murray and Chu have suggested two models for drone-based package delivery [13]. They propose using a truck as the main delivery vehicle and launching secondary drones from the truck.

Researchers have looked into various models for drone-based delivery systems, specifically for package delivery, including Murray and Chu. Different mixed integer programming models, such as the traveling salesman-style model, which has been researched for computational issues, have been offered. Other scholars have used meta-heuristic methods to solve the resulting integer programs, including Ponza, Agatz et al., and Ferrandez et al. The key finding of these research is that using both automobiles and drones for transporting goods can result in cost savings. By positioning drone charging facilities and creating delivery paths that avoid obstacles, Hong et al. have also created a drone-based delivery system for urban areas.

By dividing the service the space into numerous demand clusters, which were able, for example, constitute an entire neighbourhood or a collection of villages, our objective is to allocate a drone nest to each demand cluster. A demand cluster would therefore be made up of the demand points for crisis supplies.

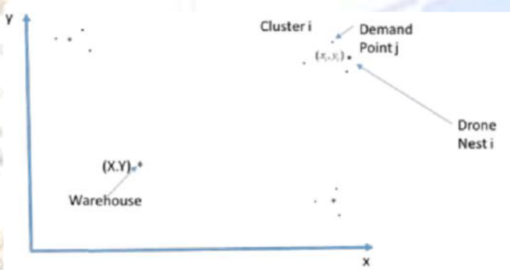

Figure 1. Location of warehouse, drone nests and demand points

4.1 Model 1

$$\sum_i \frac{w_i d_i(X-x_i, Y-y_i)}{v_t} + \sum_i \sum_j \frac{w_{ij} d_{ij}(x_i - a_{ij}, y_i - b_{ij})}{v_d}$$

subject to

$$\sum_i c_t w_i d_i(X-x_i, Y-y_i) + \sum_i \sum_j c_d w_{ij} d_{ij}(x_i - a_{ij}, y_i - b_{ij}) \le B$$

$$d_{ij}\left(x_i - a_{ij}, y_i - b_{ij}\right) \le D \ \forall (i,j)$$

Define $z_{i1} = X - x_i, z_{i2} = Y - y_i$ .The above program is then seen to be convex since d_i and d_{ij} are convex functions.

4.2 Model 2

Optimize the maximum weighted delivery time for trucks and drones while taking into consideration price and distance restrictions on drone trips.

The objective could be stated as

$$\min_{X,x} \max_{i,j} \left[\frac{w_i d_i(X-x_i, Y-y_i)}{v_t} + \frac{w_{ij} d_i(x_{ij} - a_{ij}, y_{ij} - b_{ij})}{v_d} \right]$$

resulting in the following convex program (where we introduce a new variable T)

Min T

subject to

$$\frac{w_i d_i(X-x_i, Y-y_i)}{v_t} + \frac{w_{ij} d_i(x_{ij} - a_{ij}, y_i - b_{ij})}{v_d} \le T \quad \forall i,j$$

$$\sum_i c_t w_i d_i(X-x_i, Y-y_i) + \sum_i \sum_j c_d w_{ij} d_{ij}(x_i - a_{ij}, y_i - b_{ij}) \le B$$

$$d_{ij}\left(x_i - a_{ij}, y_i - b_{ij}\right) \le D \ \forall (i,j)$$

The table below shows the maximum weighted delivery time (T) to any demand location. The use of these two models to position goods (such as cellars and drone nests) and assist budget choices regarding allocation will be covered in the section that follows.

4.3 Numerical Results

We look at a simple situation where there are three desire clusters, each of which serves three desire points.

Drones can fly at 50 mph, whereas trucks can only travel at 40 mph. Costs are especially challenging to assess.

Welch asserts that the costs of Amazon Prime Air have been examined [24], but it seems unlikely that these forecasts would hold true in a developing country. According to Matternet's estimation [2], a six-mile drone trip would cost $24 and take 15 minutes. Due to the fact that vehicles typically carry numerous items but drones typically carry just one, we base our base model on the assumption that the unit cost per mile for drone transportation is twice as high. Since drones can only travel 100 miles per delivery trip, we also presume the delivery point must be 50 miles or less from the nest. Because drones are now unable to do this, we believe that battery life will greatly increase and journey lengths will lengthen.

In any event, the models are broad, and if improved estimates become available, they may be applied. The total budget will be determined to allow for manageable delivery schedules. The models also incorporate weights (estimated demand levels). The Appendix has detailed values.

AMPL/MINOS is currently used to solve the models [8]. All models are convex, hence global optima are a given. Below, we examine a few case studies. Model 1: Budget=$9,000

After resolving Model 1, we find that the warehouse is situated at X = 204, Y = 148, and that the drone nests are situated to serve Clusters 1, 2, and 3 at (46, 207), (228, 197), and (282, 55, separately). By way of illustration, a vehicle could travel from (204, 148) to (46, 207), pick up a drone, and send it flying to demand cluster 1. According to the computer output, drone nest 3 (which serves cluster 3) is the drone nest that is most remote from the other drone nests. We also examine the impact of budget adjustments on the maximum weighted delivery period.

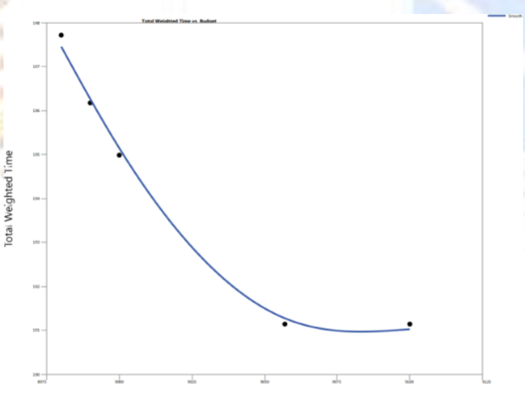

Figure 2. Total weighted time versus budget

The total weighted time will be reduced if the budget is increased up to roughly $9057, but additional increases are ineffective because the drone distance limitation is now in effect. Therefore, in this case, a budget allocation of more than $9057 is not required. On the other hand, any budgetary allotment less than $8980 will fall short of meeting service requirements.

It is obvious that the distance a drone can go from its nest will grow as drone technology develops. The table that follows shows how the maximum drone distance varies depending on the location of the warehouse and drone nest. We boosted the budget by $1,000 in order to achieve a more comprehensive setof findings.

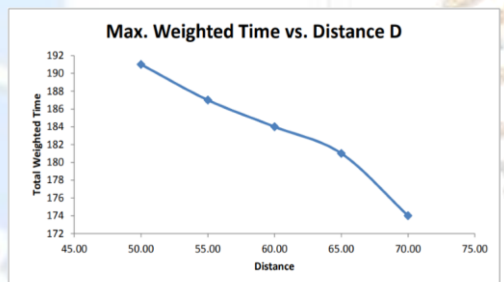

Figure 3 shows that when a drone's range D grows, the total weighted time falls since quicker drones cancover more distance than slower trucks.

D	(X,Y)	(x_1,y_1)	(x_2,y_2)	(x_3,y_3)
50	(200,151)	(48,205)	(267,191)	(283,56)
55	(200,151)	(52,203)	(262,189)	(279,60)
60	(199,151)	(57,201)	(258,186)	(275,63)
65	(198,150)	(62,199)	(253,184)	(271,67)
70	(198,150)	(66,197)	(149,181)	(266,69)

Table 4 shows that the warehouse's position only slightly changes from (200,151) to (198,150). However, drone nests have the potential to Nest "1" saw a major shift in position, going from (48,205) to

(66,197). However, this should not have any practical implications because all the components of a drone nest can be transported in a container.

Model 2: $9,000 in spending in the warehouse can be found at coordinates X=177, Y=157, while drone nests can be found at (44, 209), (293, 202), and (287, 42). The position of the drone nests is not very dissimilar from Model 1, which reduces the overall weighted time. The computer output in this situation reveals that demand point 1 in cluster 1 has the poorest weighted service time. Below, we compare the overall weighted timings to service each demand point j from drone nest i to compare the outcomes from both models.

Table 5. Total weighted time comparison

Drone Nest/Demand Point	Total Weighted Time Model 1	Total Weighted Time Model 2
1,1	99	85
1,2	95	81
1,3	95	80
2,1	29	36
2,2	28	36
2,3	29	35
3,1	58	74
3,2	58	74
3,3	55	71

We see that using approach 2 (a more equitable approach), cluster 1, which is supplied by drone nest 1, receives better service than clusters 2 and 3, which receive marginally lower service.

The overall weighted service time for the worst-served demand point (point 1 in cluster 1) has decreased from 99 to 85.

Given that this is how medical supplies reach a developing country, it might make sense to locate the warehouse there. To do this, choose a site for the warehouse, such as close to the airport. Let's thus assume that X and Y are constants and that the warehouse position is constant at the origin. In this case, we learn that the drone nests are located for Model 1 with a Budget of twelve thousand dollars at (21, 175), (283, 142), and (283, 24), and for Model 2 with a Budget of $15,000 at (26, 192), (297, 200), and (281, 31). Trucks need to spend more money because it takes them longer to travel from the airportto a drone nest

With the use of mobile technologies and drones, developing nations may advance healthcare delivery to remote areas even with an unstable transportation network. Only a third of Africans, as was previously said, reside within two km of a year-round road [12]. Disasters like earthquakes and fires may make roadways impassable, even in wealthy nations.
Furthermore, the delivery of emergency medical care may be complicated by severe weather and urban congestion.

Drone technology and its parts, such GPS and lithium batteries, are readily available and advancing quickly. Despite concerns about privacy, security, safety, and regulation, drones have useful and humanitarian uses, particularly in the field of healthcare. As a result, it is anticipated that in the near future, drone healthcare delivery to difficult places will become more commonplace.

This essay explores various ground-breaking uses of drones in the medical field. Our two methods, which employ a tandem technique of conventional ground transportation followed by drone delivery, will enable more prompt, effective, and affordable healthcare delivery. Costs associated with healthcare are a significant issue in both developed and developing nations. The models provide site choices for warehouses and drone nests that enable prompt delivery while using a budget limitation. In an emergency, time is of the essence, thus a quicker reaction might possibly save lives by preventing medical trauma.

Our models might be utilized by governments, delivery services, healthcare facilities, and humanitarian organizations. Governments and drone manufacturers may occasionally work together as Rwanda did with Zipline.

These models are currently being expanded in many ways. Here, we've utilized a distance metric for truck delivery that was empirically determined. The real road network might be precisely modeled for a better depiction. Future studies can look at things like how many drones are required at a certain drone nest and how well a network covers an area. Another challenge is how to include it in the location model and take into consideration the impact of impediments like a high mountain on a drone path. Paths must be designed to avoid large structures and airports, for example, in order to use drone delivery in an urban region. Future study in the emerging subject of drone healthcare delivery has a lot of potentials to have a significant influence.

6. Appendix

Here, we present the data that were utilized in the two models' numerical analysis.

Table 6. Weights associated with travel from drone nest *i* to demand point *j*.

w	1	2	3
1	5	3	6
2	4	2	1
3	5	4	2

For example, $w_{11} = 5$ is the weight associated with travel from drone nest 1 to demand point 1 in cluster 1.

Table 7. *x* Coordinates of demand points

a	1	2	3
1	0	30	41.2
2	306	300	306
3	306	330	282

Table 8. *y* Coordinates of demand points

b	1	2	3
1	220	200	212
2	200	220	222
3	12	40	24

For instance, cluster 1's demand point 1 is located at (0,220).

7. Reference

[1] N. Agatz, P. Bouman and M. Schmidt, Optimization Approaches for the Traveling Salesman Problem with Drone, ERIM Report Series Research in Management, Erasmus Research Institute of Management, Erasmus University Rotterdam, 2015.

[2] A. Choi-Fitzpatrick, D. Chavarria, E. Cychosz, J. P. Dingens, M. Duffey, K. Koebel, S. Siriphanh, M. Yurika Tulen, H. Watanabe, T. Juskauskas, J. Holland and L. Almquist, Up inthe Air: A Global Estimate of Non-Violent Drone Use 2009-2015, Joan B. Kroc School of Peace Studies at Digital@USanDiego, University of SanDiego, 2016.

[3] R. Clarke, "Understanding the drone epidemic", Computer Law & Security Review, 30 (2014), pp. 230-246.

[4] DHL, Successful Trial Integration of DHL Parcelcopter into Logistics Chain, 2016.

[5] Z. Drezner and H. Hamacher, eds., Facility Location: Applications and Theory, Springer,2004.

[6] D. Esler, Drone Revolution, Business & Commercial Aviation, 2015.

[7] S. M. Ferrandez, T. Harbison, T. Weber, R.Sturges and R. Rich, "Optimization of a Truck-drone in Tandem Delivery Network Using K-means and Genetic Algorithm",Journalof Industrial Engineering and Management, 9 (2016), pp. 374-388.

[8] R. Fourer, D. M. Gay and B. W. Kernigham, AMPL: A Modeling Language for Mathematical Programming, Cengage Learning, 2002.

[9] S. French, Drone delivery is already here — andit works, Marketwatch, 2015.

[10] M. Hackman and J. Nicas, Drone Delivers Medicine to Rural Virginia Clinic, Wall Street Journal, 2015.

[11] I. Hong, M. Kuby and A. Murray, Deviation flow refueling location model for continuous space: commercial drone delivery system for urban area, 13th International Conference on GeoComputation, The University of Texas at Dallas, Richardson, Texas, 2015.

[12] O. Khazan, A Drone to Save the World, The Atlantic, 2016.

[13] C. C. Murray and A. G. Chu, "The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery", Transportation Research Part C: Emerging Technologies, 54 (2015), pp. 86–109.

[14] J. Pepitone, First FAA-Approved Drone Delivery Drops Medicine in Virginia, NBC News, 2015.

[15] A. Ponza, "Optimization of Drone-Assisted Parcel Delivery", (2015).

[16] C. Preimesberger, Drones Will Soon Be Dropping Medicines to Save Lives in Rwanda, eWeek, 2016.

[17] M. Prigg, The ambulance drone that could saveyour life, Daily Mail, 2014.

[18] D. A. Raffaello, "Guest Editorial Can Drones Deliver?", IEEE Transactions on Automation Science and Engineering, 11 (2014).

[19] A. Raptopoulos, No roads? There's a drone for that, TEDGlobal 2013, 2013.

[20] A. Tilley, UPS Experiments With Drone Delivery In Partnership With Zipline, Forbes, 2016.

[21] H. Varnholt, DHL’s Drone Demonstration Failsto Deliver, Wall Street Journal, 2016.

[22] J. Villasenor, What Is a Drone, Anyway?, Scientific American, 2012.

[23] X. Wang, S. Poikonen and B. Golden, "The vehicle routing problem with drones: Several worst-case results", Optim Lett (2016), pp. 1–19.