# Drone Distribution Model for Emergency Medicine Distribution to Reduce Delivery Time and Costs: Case of the Peruvian Health Sector

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## Abstract

The lack of adequate infrastructure for most of the roads and routes in Peru has generated a saturation of the roads and longer transport times, which affects the state health sector presenting frequent situations of shortages of medicines for urgent and emergency cases nationwide due to various factors such as the use of ambulances used for the delivery of medicines in a very congested road infrastructure. This research proposes an emergency medicine distribution model to reduce delivery time and costs using drones (remotely piloted unmanned aerial vehicles). The distribution of medicines to thirteen medical posts using 4 ambulances in the northern area of Lima was analyzed and the results were compared with the distribution of medicines using 21 drones, providing care to 313,248 emergency cases, demonstrating the reduction of delivery times and costs. It can be concluded that the use of drones as a substitute in the distribution of emergency medications and medical items is a faster and 22 times less expensive means than traditional distribution using ambulances or distribution trucks, demonstrating that the model is viable to be implemented in the northern area of Lima.

## Keywords
drones, medical supplies, health logistics, the healthcare sector, technological innovations.

## 1. Introduction
In Peru, the state health system is vulnerable due to situations such as the lack of sufficient personnel to provide quality care to patients treated in health centers and medical posts nationwide finding 47% of these centers with inadequate and/or insufficient infrastructure to provide medical services; with 44% facing difficulties of water supply and/or electricity; as well as 39% exposed to environmental pollution (Comptroller General of the Republic 2016). Currently, this sector has frequent shortages of medicines for urgent and emergency cases at the national level in medical posts due to various factors, one of the most important being the use of ambulances as a means of ground transportation used in a very vulnerable road infrastructure due to the size of the vehicle fleet and the consequent road congestion (Baillargeat et al. 2022). In countries such as Malaysia, Sweden, Ghana, and Rwanda, situations similar to the Peruvian reality exist and thanks to the implementation of innovative solutions such as the use of drones for the distribution of emergency medicines, they have managed to improve their delivery times and performance, saving lives. The city of Metropolitan Lima is the urban area with the greatest traffic congestion and also has districts with the highest population concentration and the greatest number of state medical care centers; on the other hand, the supply of medicines using unmanned air transport, by drone, with less investment, reduced logistics costs and more efficient times (De Silvestri et al. 2022, Hiebert et al. 2020). In this regard, the research question is whether the use of drones (unmanned and remotely driven aerial vehicles) for the distribution of urgent and emergency medications in the state health care centers of Metropolitan Lima will reduce delivery times and costs.

### 1.1 Objectives

The general objective of the research is to develop and validate a model for the distribution of emergency and urgent medicines by drones to reduce care time and delivery costs at health posts in the city of Lima.
The specific objectives are:

- Determine the area and scope to apply the drone medicine distribution model.
- Design the model for the distribution of medicines to health care centers in the northern area of the City of Metropolitan Lima.
- Validate the technical and economic feasibility by comparing the current model and the improved model.

## 2. Literature Review

Among the studies currently available on the topic under investigation is a paper that described how in 2016, the Government of Rwanda implemented the use of drones to distribute blood and blood products to several health centers, making 500 deliveries per day without affecting blood quality, resulting in a 67 % reduction in losses due to blood expiration and reducing delivery times from 4 hours to 20 minutes (Lockhart et al. 2021). In Sweden in 2020 between June to September, an investigation was conducted implementing three drones equipped with defibrillators that operated automatically in case of an emergency observing that out of 14 cases that were presented they managed to attend 12 cases resulting in 64% of the cases they were more effective than ground transport (Schierbeck et al. 2019). In Germany, similar research was carried out that evaluated the use of drones in emergencies, facing different weather conditions, for the delivery of defibrillators in the town of Greifswald, Mecklenburg-Vorpommern, incorporating both fixed and mobile bases of operations, reducing response times in a more viable and safe way, identifying challenges related to autonomous flight and continuous operation 24 hours a day for emergency care (Baumgarten et al. 2022).

On the other hand, a quantitative study was conducted in two hospitals located in Malaysia (Sabah Women and Children Hospital [SWACH] and Queen Elizabeth II Hospital [QEH2]), comparing the cost of transporting medical items using ambulances and drones, reducing the delivery time from 34 to 18 minutes using drones; that is, 16 minutes less than when using ambulances, finding that although the cost per minute of air transport is almost double that of ground transport (9,05USD/min vs. 17,74USD/min), the total cost per operation was very similar in both cases due to the time savings (Ground: 9.05USD/min x 34min = 307.70USD vs Air: 17.74USD/min x 18min = 319.32USD) (Zailani et al. 2021). An important study was conducted in the area of Portland, Oregon, United States, explaining the importance of battery capacity in drones to improve efficiency in the delivery of medical supplies, with the researchers concluding that the use of drones for the delivery of urgent medical supplies should be focused on benefiting humanity, beyond economic considerations (Chauhan et al. 2019). At the San Raffaele Hospital in Milan Italy, a pharmaceutical product delivery service was designed using a drone to automate its logistics system, complying with operational and regulatory requirements, demonstrating greater efficiency of the system for the benefit of remote and difficult-to-access populations (De Silvestri et al. 2022).

## 3. Methods

For the design of the proposed model, as a starting point, the geographical area was determined including the northern area with 10 459 inhabitants per km2, the central area with 1 960 inhabitants per km2, and the southern area with 2 851 inhabitants per km2 (Instituto Nacional de Estadística e Informática 2017).; evaluating these alternatives taking as selection criteria the population density to be served in the area, access routes, and traffic congestion during peak hours from 8 a.m. to 6 p.m. (TomTom International BV 2022). With these data, the northern zone was determined as the geographical area to be served considering the 13 categories I-3 medical establishments, called “Health Post with a Doctor”, with a potential for the care of 313 248 emergency cases per year, supplied from the central warehouse nearby Edgardo Rebagliati Martins National Hospital (Salaverry et al. 2009).

As a second step, it was necessary to determine the type of drone to use, search between the two most used alternatives globally, as well as define the method of delivering merchandise to the destination point. Using localization software, the air routes and the land routes were established from the supply point to the destination points (the 13 medical posts selected in the project). The Arena simulation platform version 16.1 was used to carry out the modeling of two different scenarios. This software allowed us to simulate the number of emergency cases attended and the flight time with the aim of optimizing the distribution of medications. Two different simulations were carried out: one using drones as a means of transport and the other using an ambulance as a traditional means of transport, both starting on November 8, 2023 at 8:00. In this way, a comparison of the mentioned variables can be made based on the results obtained.

Applications such as Google Maps, Google Earth, TomTom Geolocation and Microsoft Excel will be used as tools to acquire and record the data necessary to measure time and distance. These data will be entered into the simulation models developed on the Arena platform version 16.1. With the area and its posts selected, the optimal land routes for ambulances are defined using the MyRouteOnline software. While with Google Maps the location coordinates were located to be entered into DistanceFromTo to determine the aerial route for the drones. In both cases, the distances in kilometers and the round-trip time in minutes are noted. Note that in the case of ambulances there are two travel times. One during normal traffic conditions and the other during rush hour.

To execute the proposed simulation models, it is evaluated how many cases an ambulance can handle and how many cases a drone can handle. Additionally, the comparison is made based on the investment required; 1 ambulance can cost up to USD 150 000 while the considered drone costs approximately USD 25 000; Therefore, a simulation is carried out with 21 drones vs 4 ambulances. Once the results were obtained, the different variables were compared to achieve the research objectives.

## 4. Data Collection

### Selection of the area of attention

As the area of attention of the project, the northern zone with 10,459 inhabitants per km2 was selected, considering the 13 basic medical care establishments called "Health Post with Doctor", with a potential of 313,248 emergency cases per year, being supplied from the central warehouse of the Edgardo Rebagliati Martins National Hospital. See Figure 2.

### Choice of drone for the project and the mode of medicine delivery

To choose the type of drone to be used, two alternatives were evaluated, the Foxtech Eagle 360 drone of Chinese origin and the Microdrone MD4-3000 of German origin, selected the FoxTech Eagle 360 drone for its cheaper acquisition value of USD 24 099, greater range per trip and flight autonomy compared to USD 45 801 for the Microdrone MD4-3000, and fundamentally for its greater range of care (250 km more than the MD4-3000). See Table 1

Table 1. Characteristics for selection of the drone to be used

| Features by model | MD4-300 | FoxTech Eagle 360 |
|---|---|---|
| Maximum speed | 72 km/h | 115,2 km/h |
| Cruise speed | 57,6 km/h | 72,0 km/h |
| Recommended load | 3 kg | 5 kg |
| Flight autonomy time | up to 45 min | to 5 h |
| Maximum range per trip | 50 km | 300 km |
| Power source | Battery | Fossil fuel |
| Acquisition value | USD 69 900 | USD 24 099 |

The delivery of medicines will be carried out using the "Floating Delivery" method, which consists of loading the medicine inside a box with plastic bubble wrap that maintains the temperature during the trip, together with a parachute, and when the drone reaches the delivery zone with a radius of 3 m it descends to a height of 30 m and releases the package with the parachute over the delivery zone and finally returns to its base (Zipline 2022). To calculate the number of drones needed to attend the 313,248 emergency cases per year, an average of 0,491 hours per case attended and a total of 7 469 hours per year were considered, determining that a total of 21 drones are required.

### Establish restrictions of the drone's flight zone

To operate the drone, it was necessary to establish flight limitations taking into account the flight restriction areas in the northern zone, such as the proximity to Jorge Chavez International Airport - LAP. See Figure 1

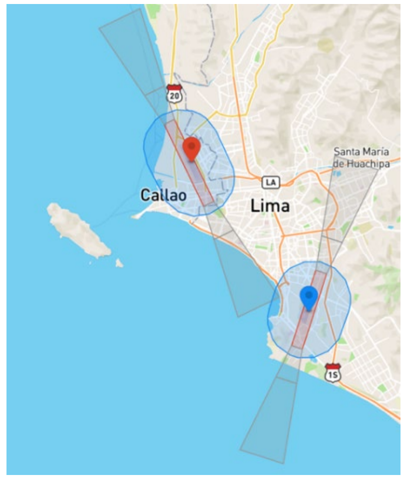
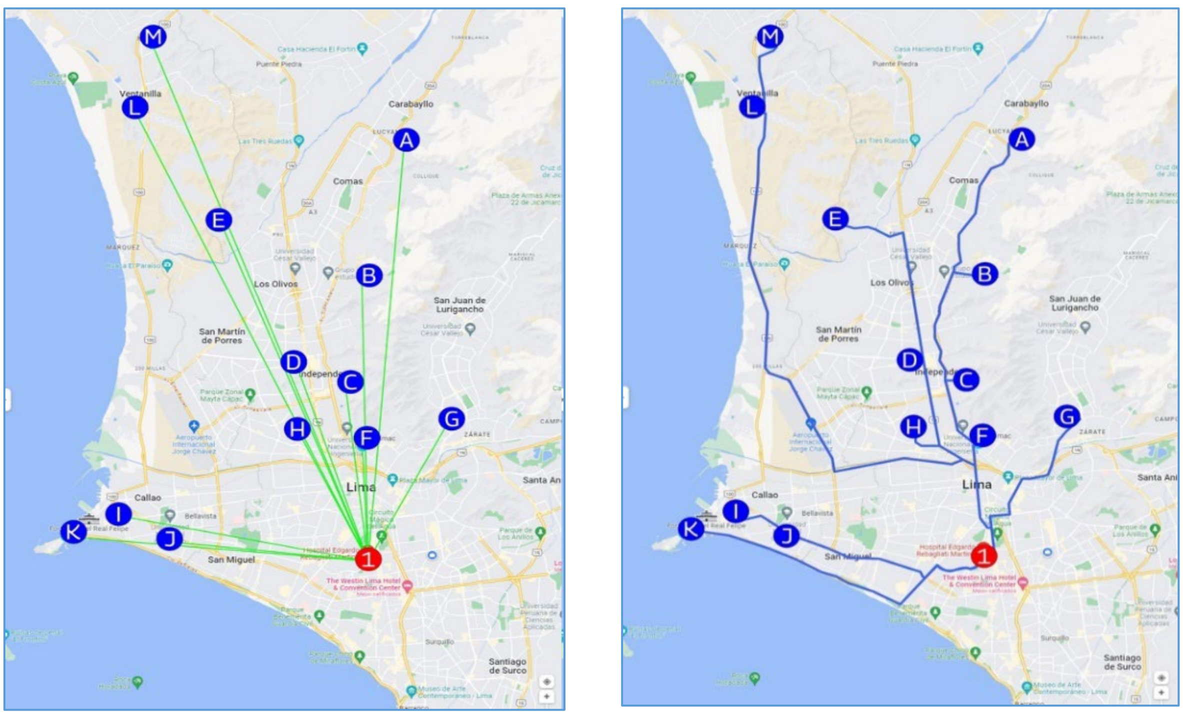



Figure 1. Flight restriction zones in the northern zone

Using the MyRouteOnline web application, Figure 2 shows the routes traveled using air care compared to those using ground transportation.




Aerial Attention

Land Attention

Figure 2. Comparison of distance traveled in air vs. ground care

## 5. Results and Discussion

### 5.1 Numerical Results

As a result of this evaluation, it can be seen that the length of the air route is less than that of the ground route, and the time spent on distribution during the flight is less than during the ground route compared to the best case, which is without traffic. The peak time is taken based on 18:30 hours on November 8, 2023, during the outbound leg. For the air flight time, a cruising speed of 72,0 km/h is considered and 5 minutes are added for take-off. See Table 2.

Table 2. Comparison of air distances and ground distances

| Destination zone | Aerial distance (km) | Land distance (km) | Land time (minutes) | | Aerial time (minutes) |
|---|---|---|---|---|---|
| | | | Peak hour | No traffic | |
| A | 25,1 | 19,96 | 35 | 150 | 21,6 |
| B | 17,4 | 13,39 | 24 | 110 | 16,2 |
| C | 9,6 | 8,62 | 16 | 85 | 12,2 |
| D | 11,7 | 9,8 | 17 | 90 | 13,2 |
| E | 20,0 | 17,22 | 27 | 130 | 19,4 |
| F | 5,5 | 4,9 | 9 | 55 | 9,1 |
| G | 11,7 | 7,46 | 16 | 85 | 11,2 |
| H | 8,8 | 6,74 | 14 | 70 | 10,6 |
| I | 12,2 | 10,72 | 20 | 85 | 13,9 |
| J | 13,2 | 8,48 | 18 | 70 | 12,1 |
| K | 16,4 | 12,91 | 22 | 75 | 15,8 |
| L | 29,9 | 23,69 | 45 | 140 | 24,7 |
| M | 34,2 | 25,68 | 35 | 150 | 26,4 |

## 5.2 Graphical Results

In order to technically validate the proposal, a simulation was carried out using Arena software, comparing the number of annual attendances with the following configuration: one drone, one ambulance, 21 drones, four ambulances, 74 ambulances using seven replicas. As shown in Figure 3, implementing a drone is more efficient than using an ambulance. Figure 3 shows that in order to attend 313 166 cases per year, 21 drones would be used with an investment of USD 525 000, while 74 ambulances would be used with a much higher investment, so that in economic terms, the model with drones is viable.

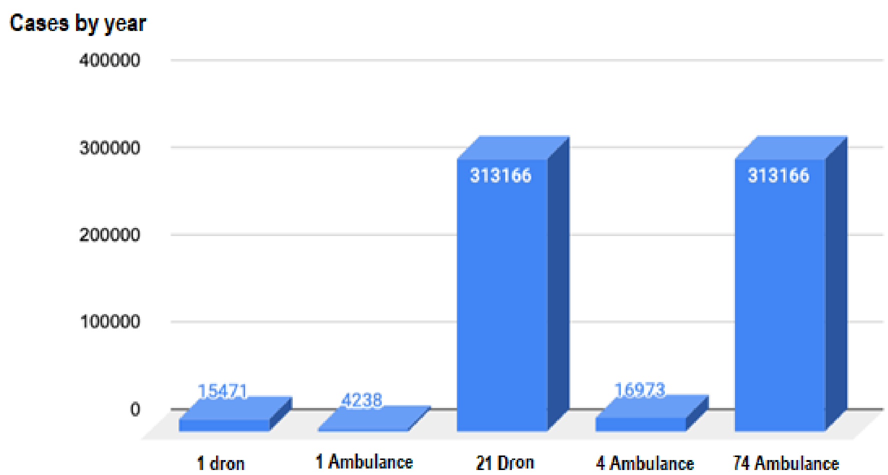



Figure 3. Comparison of the number of emergency cases attended to per year

## 5.3 Validation

To attend to the required cases annually, according to Table 3, it is estimated that ambulances must travel 9 395 163 km at an operating cost of 0,518 USD per km; and using drones it would be necessary to travel 7 449 253 km at an operating cost of 0,1302 USD per km, obtaining a cost of 4,866 thousand dollars for the model using ambulances and a cost of 969 892 thousand dollars for the model using drones. which shows that the proposed model is much more economical.

Table 3. Operating costs per unit (USD/km)

| Ítem | Descripción | Ambulancia | Dron |
|---|---|---|---|
| 1. | Depreciation | 0,0025 | 0,0001 |
| 2. | Fuel | 0,1004 | 0,0175 |
| 3. | Maintenance | 0,3730 | 0,0705 |
| 4. | Permission | 0,0421 | 0,0421 |
| | Total | 0,5180 | 0,1302 |

### 5.4 Discussion

Comparing the results of the research with other experiences, the case of Sweden stands out, which according to the study by Schierbeck et al (2019) the area in square kilometers covered is four times larger but they only manage to serve a population of 80,000 inhabitants, almost a 25.55% less than the proposed project. However, the Swedes used three drones, handling 14 real-life cases within 3 months compared to this study's 313,166 virtual cases from 21 drones, within a year with seven iterations. Contrary to that of Rwanda, where reductions between 79 and 98 minutes were seen in deliveries; Thus, the Arena model, used in the northern area of Lima, showed results of 0 to 150 minutes saved, depending on the route and location served. In that sense, even though in some cases the savings are 50% for Rwanda, in emergency situations every minute is valuable and means a big difference in the result of the care provided. When comparing that in Peru there are 26 airports for an area of 1 285 215,60 km² compared to 38 airports that Germany has to serve 357 588 km², it is highlighted that there are rural areas that, being very far from the cities, are an excellent opportunity for medical care in remote areas to have a medicine distribution system through the use of drones.

## 6. Conclusion

The study has addressed the problem of an inadequate medicine supply system in the northern region of Metropolitan Lima, proposing a medicine distribution system in state medical care centers in the northern area of Metropolitan Lima, using drones which would achieve lower distribution times and costs than the current level.

The study carried out four simulations in the same scenario, the first two made a quantitative comparison between a drone and an ambulance; and the last two making an economic comparison, based on the same investment for a system using 21 drones versus an alternative of using 4 ambulances for the distribution of medicine, finding that one drone could attend a total of 15 471 cases, while the ambulance could only attend to 4 238 cases. With 21 drones it is feasible to attend to 313 166 cases, unlike with 4 ambulances it is only possible to attend to only 5,41% of the cases and in this way the distribution of medicines using drones would reduce response times, especially in critical situations providing faster and more effective care.

The evaluation of operating costs, including depreciation, fuel, maintenance and permits, showed that the deployment of drones is more cost-effective compared to the use of ambulances. Additionally, the careful selection of the FoxTech Eagle 360 drone, with a lower acquisition cost and greater operating range, contributes significantly to the financial efficiency of the project. Likewise, the cost reduction is evident. In economic terms, serving the target population is viable if drones are used as a means of distribution. In order to meet that objective, 74 ambulances would be required. Consequently, the result was a saving of USD 10 593 921. The operating cost per distance is lower for a drone, obtaining a total of 13,02 USD cents per km compared to the figure of 51,80 USD cents per kilometer that the ambulance presented; That is, there is a difference of 38,78 USD cents per km, which shows that the innovative proposal is more economical.

Consequently, the use of drones as a substitute in the distribution of emergency medications and medical items is a faster and 22 times less expensive means than traditional distribution using ambulances or distribution trucks. This demonstrated that the model has viability to be implemented in the northern area of Lima, with a service of thirteen medical posts to a greater expansion, without logistical complexities.

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