Original Paper

Models for Drone Go Aerial Disaster Relief Response System

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Received: February 6, 2019      Accepted: March 18, 2019     Online Published: March 20, 2019
doi:10.22158/ibes.v1n1p33                 URL: http://dx.doi.org/10.22158/ibes.v1n1p33

Abstract

According to the requirement, we established a non-linear programming model and a three-dimensional packing model and designed a Drone Go disaster response system meeting the demand of medical supplement and road video reconnaissance. We also determine the optimal location selection, container assembly schemes, as well as the UAV flight routes and flight plans.

First of all, we established a coordinate system to fit the topographic map of Puerto Rico through the digital image processing method and collect the road pixels in the topographic map. Then compared it with the detection range of the UAVs to analyze the exploration area and reconnaissance rate of different flight plans.

Second, we establish a nonlinear programming model with the constraint of the distance between the hospitals and the distribution of the medicine. Using time and exploration area as the target function to determine the optimal location and make a best decision by weighing both factors.

Third, we establish a model of three-dimensional packaging and using the heuristic algorithm to determine the best package solution of two iso container respectively. The constraint is to take enough medicine and drone to make the two highest utilization rates of the volume of the container, trying to reduce the use of buffer material.

Finally, the optimal flight plan is determined with the consideration of the highest flight safety and detection efficiency of UAV. In the stability analysis of our model, we prove the reliability of our model from different perspectives. Then we analyzed the advantages and disadvantages of our model.

Keywords

non-linear programming, Linear programming, 3D packing problem, digital image processing, heuristic algorithm
1. Introduction

1.1 Background

Recently, with the maturity of the UAV technology, UAV-transportation technology has been widely used in series fields of life, such as electric power, military, rescue and so on. In particular, when serious natural disasters occur, like hurricanes, earthquakes, tsunamis and other serious natural disasters, which are usually destructive and possess a wide range of impact, the disasters will cause long term damage to local communities and transportation. As a consequence, it will make it difficult to implement traditional rescue methods. The UAV-transportation technology can greatly reduce the difficulty of disaster relief supplies transportation and road traffic detection in the affected areas because it can transport disaster relief materials to accurate places timely and transmit the real-time disaster situation video to the command center, so as the damaged roads.

1.2 The Restatement of Problem

Problem A. Select a Drone Go disaster response system with A fleet of drones and A medical packages to meet the requirement of Puerto Rico’s hurricane. Design a solution to package up to three iso containers with the cargo to Puerto Rico.

Problem B. determine the optimal location of those up to three cargo containers for the Drone Go disaster response system in Puerto Rico. The places should ensure that the system can supply the medical road network and video reconnaissance simultaneously.

Problem C. Decide a drone delivery routes and schedules to meet emergency medical requirements in Puerto Rico’s hurricane scenario with a drone flight plan for each type of UAV included in the Drone Go disaster response system to enable the Drone Go fleet to supervise major highways and roads.

2. Assumptions

• UAVs are not affected by weather: UAVs are not affected by weather and secondary disaster, as these conditions are impossible to predict.

• Excluding the drone or medicine loss in the secondary disaster: Ignoring the extra power loss when the drone takes off and lands because it is tiny comparing with the whole power using in the flight.

• Ignoring the extra power loss when the drone takes off and lands: Assume that the power supply of the hospital and the container site is stable enough to ensure the charging demand of the drone or the drone will not be a good way to the delivery.

• Assume that the power supply of the hospital and the container site is stable enough to ensure the charging demand of the drone: Assume that the plane must return to iso container every day, and it is too risky and useless to fly at night cause the drone cannot detect at that time.

• Assume that the plane must return to iso container every day, and it is too risky and useless to fly at night cause the drone cannot detect: Ignore the influence of air resistance and other factors about air because they are tiny
• Ignore the influence of air resistance and other factors about air: Drones have the same probability of destruction and it can be assumed to obeys the exponential distribution.

• Drones have the same probability of destruction and it can be assumed to obeys the exponential distribution: UAVs are not affected by terrain as the maximum height of drones is higher than most of the mountains.

2.1 The Primary Notations Used in This Paper Are Listed in Figure 1.

2. The Problem Analysis

Since the dynamic performance of the UAV are not given in the question, it can be approximately considered that the weight of the UAV itself is equal to the maximum carrying weight. Moreover, it is assumed that the output power of the UAV is constant, that is, the flight time of the UAV is constant. According to the power theorem:

\[ P = F \times v \]

When the output power P is constant, the flight speed is inversely proportional to the traction F, then the conclusion comes out:

\[ v = \frac{m}{L \times t} \]

So, the distance L is:

\[ L = v \times t \]
According to the information given in the problem, the key to the problem can be listed as follows:
under the condition of meeting the medical transportation requirements of Puerto Rico hurricane, the
transportation time need to be shortened as much as possible and the road detection area should be wild.
The plan is to use as many type B or F UAVs as possible when considering shorter transport times as
the speed is fast, and more type B UAVs when considering a larger road detection area. These two
requirements will also be the primary issues to be considered in the establishment of the models to
ensure the selection of the best location. When thinking about the number of the containers, the
distances can be calculated by the altitudes and longitudes as the first factor. Distance between
Hospitals are listed in Figure 2.

| Sequences Of Hospitals | H1   | H2   | H3   | H4   | H5   |
|------------------------|------|------|------|------|------|
| H1                     | 0    | 41.93km | 45.96km | 54.3725 | 114.99km |
| H2                     | 41.93km | 0    | 24.82km | 10.48km | 69.98km |
| H3                     | 45.96km | 24.82km | 0    | 0    | 60.62km |
| H4                     | 54.3725 | 24.26km | 10.48km | 0    | 0    |
| H5                     | 114.99km | 78.93km | 69.98km | 60.62km | 0    |

**Figure 2. Distance between Hospitals**

It is known from the Figure 2 that the maximum distance between the two hospitals is 114.99km, which
is more than twice the maximum no-load flight distance of any UAV in the selection. Therefore, it is
obvious that one container cannot meet the rescue requirements. According to the data, it can be
estimated that the time T of the affection lasted for hurricane 2017 in Puerto Rico is 360 days. Adding
up the daily demand of five hospitals and $V_d$ of different types of medicine packages, the total volume
Vs of boxed drugs can be calculated as:

$V_S = V_d \times T$

Assuming that the volume of a iso container for $V_0$, it shows that $3V_i \gg V_S$, because requirements
asked to minimize any unused space which needs buffer material, therefore three iso containers can
only stuffed by a large number of UAVs to reduce the cost of container, but in too many planes will
lead to higher costs and waste by the low use rate, so the solution is using two iso containers to meet
the requirements of transport conditions, shorten the transport time and expand road detection area as
much as possible.

In order to meet the requirements of minimizing unused space, we consider using the
Three-dimensional Packing Model and the algorithm to reduce the spare area of iso containers, both
guarantee the daily supplements, and take as many numbers of UAVs as possible, to ensure that the
exploration efficiency and improve the system stability and reliability.

In the model, we combine the low risk (the lowest flight time) with high return (the wildest exploration
area) to make the final decision. First, we work out the optimal solution under two targets Respectively
through the nonlinear programming model. Then giving weight to each result to make the final decision
of location. When arranging the flight plan, we need to meet the supply schedule first and then increase the efficiency of the detection.

We can draw the following conclusions from the analysis of the problems:
1) The location of the two iso containers enables the Drone Go disaster response system to meet the requirements
2) Establish TDP model and algorithm to minimize the empty space in iso containers in order to reduce the volume of buffer materials
3) Establish the nonlinear programming model, work the solution out with the shortest flight time and the widest detection area respectively, and finally determine the optimal location of two iso containers by weighing the flight time and the exploration area.

4. Model

4.1 Drone Model

4.1.1 Usage Time and Backups

The probabilities of all the drones to get destroyed obey the exponential distribution. The mathematical expectation value means the usage time. We use the central limit theorem:

\[
\lim_{n \to \infty} F_n(x) = \lim_{n \to \infty} \left\{ \sum_{i=1}^{n} \frac{X_i - n\mu}{\sqrt{n}} \leq x \right\} = \frac{1}{\sqrt{n}}
\]

M, when alpha is 0.95, the minimum amounts of the drones is \( N \geq \left( \frac{\mu T}{\lambda} \right)^2 \). So, there is a positive correlation between the amounts of everyday running drones and the backup drones.

4.1.2 Best Location Problem

We found the less time the drones run, the less possibly they get destroyed. So the locations must satisfy the following demands:
1) Increasing the reconnaissance area
2) Declining the whole everyday running time of all the drones.

4.1.3 Drone Selection

![Drone Parameters Comparison](image)

Figure 3. Drone Parameters Comparison
Also, the selection of the drones must obey the rules. In Figure 3 compared those drones with the four parts. The results show that Drone B run fastest and can cover a very long distance without cargo, which means it can cover a large reconnaissance area. So we choose Drone B.

4.1.4 Reconnaissance Shape

![Figure 4. Drone B](image)

The drones with cameras can conduct detection tasks in two situations:

1) On the way to hospitals
Because the hospitals and the locations are stationary, so we found the flight path of drones is oval in shape showed in Figure 4. The focal points are the hospitals and the locations.

2) Definite detection tasks
Also we found the flight path of drones which conduct a detection task is circle in shape showed in Figure 4.

4.1.5 Digital Image Processing
According to the coordinates of the hospitals and the container locations and the reconnaissance shapes, we use Matlab to extract the area of the reconnaissance and the road on the image (1). Showing in Figure 5.
4.1.6 Drone Model

Figure 5 Extracted highways. According all the above conditions, we establish the following equations to find the best location where \( n_{ij} \) means whether distribute cargo from container location \( j \) to hospital \( 1 \) if yes; \( 0 \), if not and define \( c_0 \leq 0.1 \):

\[
\begin{align*}
    d_{5,A} &\leq D_2^{(3)} \\
    d_{4,A} &\leq D_2^{(5)} \text{ or } d_{4,B} \leq D_2^{(5)} \\
    d_{1,B} &\leq D_2^{(5)} \\
    d_{2,B} &\leq D_2^{(5)} \\
    d_{3,B} &\leq D_2^{(2)} \text{ or } d_{3,A} \leq D_2^{(2)} \\
    d_{5,A} + d_{4,A} &\geq d_{4,5} \\
    \frac{|V_A - V_B|}{V_A + V_B} &\leq c_0 \\
    \sum n &\geq 1
\end{align*}
\]
Figure 6. The Reconnaissance Area of A1B1

Figure 7. The Reconnaissance Area of A1B2

Figure 8. The Reconnaissance Area of A2B1
The result is plan 2 is the best scheme. The plan that using container A as the producer of H5, H3 or H5 only cannot meet the restraint of $c_0$. and the distance between H1 and H5 and the distance between H2 and H5 is too long, so these pairs of hospitals cannot share one containers. The distance between H3 and H4 is too much shorter than the flight distance of drone b, so we consider them the same position. As a result, the scheme we need to discuss is A for H5, H4 or for H5,H4 and half of H3, and B supplies others. Then take the minimum time and maximum area into account, we draw a conclusion that scheme 2 is the best.

4.1.7 Model Optimization

When considering the emergency, we optimize our model. The demand of medicine differs from hospitals to hospitals, we define the center of gravity is $(x, y)$ (where $x_{ij} = \sum_{k=1}^{n} q_{kj}$, $d_{ij} = \sum_{k=1}^{n} d_{kj}$ means the cargo distributed from $j$ to $i$, $d$ means the distance). We calculate the equations (2) using penalty function, the results are listed in Figure 10. We use SPSS for data normalization and calculate the weighted average:

$$G = c \cdot O_1 + (1-c) \cdot O_2$$

The destruction rate and the reconnaissance have connections with the recovery after disasters. On the analogy of the rate between disaster-relief funding and post-disaster reconstruction funding, $c$ is 0.4.

| Plan | Total Flight Time(min) | Plan | Reconnaissance Rate(%) |
|------|------------------------|------|------------------------|
| A1B1 | 574.382138             | A1B1 | 65.33%                 |
| A1B2 | 562.6283965            | A1B2 | 62.76%                 |
| A2B1 | 527.6075966            | A2B1 | 48.66%                 |
| A2B2 | 515.6983058            | A2B2 | 45.24%                 |
| A3B1 | 552.319495             | A3B2 | 49.23%                 |
| A3B3 | 552.319495             | A3B3 | 59.23%                 |
| A3B4 | 543.7889951            | A3B4 | 54.12%                 |
| A4B1 | 512.8653272            | A4B1 | 59.93%                 |
| A4B4 | 524.305727             | A4B4 | 41.1%                  |

Figure 10. Comparisons between 8 Schemes
The results showed in Figure 11 show plan 2 is the best, and plan 1 and plan 5 can be considered as a backup plans when c changes.

4.2 Schedule Model

During the delivery and return of drones, the schedule should conform to the following reality constraints:

1) Each aircraft should minimum the detecting time.
2) Detection aircrafts cannot take off at the same time.
3) Each aircraft can fly most three times a day, because of the charging time. We establish the following 0-1 equations:

Using Lingo, we can find sets of optimal solutions, and consider the shortest usage time:
Each place should keep their path 2 km away from each other to minimum the detecting time. The result means the detection schedule and time Table is four days as a period with the Drone Go of 123 124 234 134 to permit every Drone Go is used as the same frequency.
We assumed that the detection radius is 1 km,

\[
\frac{(y_2 - y_1)x - y + \frac{x_2y_1 - x_1y_2}{x_2 - x_1}}{a^2} + \frac{(x_2 - x_1)x - y + \frac{x_2y_1 - x_1y_2}{y_2 - y_1}}{a^2 - (x_2 - x_1)}
\]

The detection time is \( C/(n \ast r) \), and the longest time to explore the full graphics is 84 days, which can meet the requirements, so the conclusion is reasonable. It also shows the Time Table and the test flight route:

| Time       | Container A                  | Container B                  |
|------------|-----------------------------|------------------------------|
| 7:00-8:00  | Drone B(MED1) To H3         | Drone B(MED1+MED3) To H1     |
|            | Drone B(MED1+MED3) To H4    | Drone B(MED1+MED2) To H3     |
| 8:00-9:00  | Drone B(MED1+MED3) To H4    | Drone B(MED1+MED3) To H2     |
| 9:00-10:00 | Drone B(MED1+MED1) To H4    | Drone B(MED1) To H2          |

Figure 18. Time Table

Figure 19. The Best Flight Route

4.3 Three-Dimensional Packing Model

Figure 20. Loading Vector Schematic Diagram
We pack the container along the loading vector showed in Figure 20. Using the layer method and the packing rules in. We use the heuristic algorithm to calculate the filled space rate. The highest rate is 99.85%, and only 401 pieces of MED1 are loaded at this time. This result is meaningless. Therefore, considering the addition of new constraints which are as follows:

![Figure 21. Packing Rate 99.85%](image)

These equations conform to stability, fleet design, place of delivery and days of medication. The number of left-box aircraft is larger so the running time is longer, we can consider reducing B and adding medicine, that is, increasing the ratio $c_0$ to maximum the filled space. Then the left optimal solution is the volume ratio %. The excess drug can be used as an emergency, so it can still be considered that the condition is met, and finally the optimal solution for packing is considered as:

![Figure 22. Optimal Solution for Packing](image)
In Figure 24, Shipping Container B-3D-P is the solution to 3D-P and Shipping Container B-emergency is the solution to emergency, so the shipping container emergency has large packing rate.

4.4 Model Optimization

As the number of daily running aircraft is positively correlated with the number of aircraft backups, we come up with an optimized model on the basis of 2, comparing the max payload capability and flight distance we choose Drone F to distribute 4a which greatly reduces the whole daily delivery time and reduces the aircraft destruction. However, since there are no cameras on Drone F and the flight distance is shorter, the detection area will be reduced.
It can be seen in Figure 29 that this is a better solution in this situation. The reason is mainly because the flight time is greatly shortened, but the reconnaissance area is also reduced. Therefore, it can only
be used as an emergency solution, that is, an alternative solution when the amount of drone b is
declined than the main option.

5. Strengths and Weaknesses

5.1 Strengths

• The model is stable even under emergency, which means the model fits the reality well;
• We consider that the distance back to the container is longer, so the reconnaissance area could be
wilder;
• We think about the detection of road, because the wilder area of reconnaissance is not equal to the
expansion to the area of roads;

5.2 Weaknesses

• We assume that the running time of drone is a constant which is not quite reasonable;
• The weight in the scoring is based on countries and disasters. So, it is changeable in different
circumstance;

References

Ho, Y. J., Lee, Seokcheon, & Song, B. D. (2019). Truck-Drone Hybrid Delivery Routing: Payload-Energy
dependency and No-Fly Zones. International Journal of Production Economics.

Li, Y. Z., Yuan, C. S., & Zhang, L. (2011). Analyze the C.G of a UAV Based on Load Task. Science
technology and Engineering.

Retrieved from http://ontheworldmap.com/puerto-rico/topographic-map-of-puerto-rico.html

Gao, L. N. (2017). Lina. Optimal allocation model of disaster relief resources for material relief and
financial appropriation.

Jens, E., & David, P. (2009). Heuristic approaches for the two and three-dimensional knapsack
packing problem, Computers Operations Research, 36(4).