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Study on the Optimal Number and Position of Drones in Fire Prevention in Victoria

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Abstract: *During the 2019-2020 fire season, every state in Australia had devastating fires, with the worst impact on eastern Victoria. In order to help Victoria's Country Fire Authority (CFA) to monitor and rescue the fire in time, we set up an optimized model of the number of drones combinations, which saves the national cost while monitoring the fire occurrence.*

We first carry on the K-means cluster analysis to the fire dense points according to the fire occurrence situation in Victoria, Australia, which obtains the possible fire area. Then, we calculate the emergency factor to judge the fire grade, according to the area fire occurrence frequency and the fire intensity. By using the improved ant colony algorithm, we find the shortest path through each fire occurrence point. Therefore, the multi-objective optimization model is established with the minimum total cost and the highest safety factor as the optimization target. And we make the signal propagation distance SSA drones, Radio Repeater drones and fireman under different terrain as the constraint conditions. Through the model, we calculate that the Victoria's Country Fire Authority (CFA) needs 23 SSA drones and 20 Radio Repeater drones, as well as the location of the relays and the combination of DRONESs in different positions.

The occurrence of fire is related to climate and season. Through the data of Victorian fire in the past 20 years, we use ARIMA time series to predict the severity and frequency of fire in different areas over the next decade. Then, we determine the annual monitoring range of each area to estimate the probability of fire. In the case of extreme fire events, we update the scale and frequency of volcanic occurrence, using the model of question one, find the optimal number of drones combinations, calculate the increase in equipment costs, and finally get the need to increase the equipment cost price of $500000(AUD).

Considering the different terrain conditions in Victoria, we introduce the altitude correction coefficient to obtain the influence of altitude on radio signal propagation, combing the change of altitude. Then, the influence of terrain on the signal propagation of hovering radio-repeater drones is obtained, and the signal propagation distance under different terrain problem one is changed. The position of the optimized relay is obtained. Finally, we get the number of radio-repeater drones increases to 25.

Finally, we examine the sensitivity and stability of the model and prove that our model is accurate and stable for the problems.

Keywords: *K-means algorithm, Ant colony algorithm, Multi-objective optimization, ARIMA*

1. Introduction

1.1 Background

Australia is sparsely populated, with a wide range of forests and almost annual fires. Fires continued in this area from September 2019 to early 2020. At the end of 2020, fires break out again. The fire in Australia has caused many losses of resources, destroyed our homes and seriously affected human health and life. Because of the rising climate and the increase of carbon emissions, the fire in Australia has reached the that the government has to pay attention to. So the Australian government needs more effective measures to fighting and preventing fires.

As a new remote sensing monitoring method for forest fire, drones have been widely used by governments. The use of drones for aviation monitoring can not only improve the ability of forest fire prevention and prevention system construction, but also improve the command efficiency and comprehensive fire extinguishing ability of forest fire scene. At the same time, it also fills the gap of

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remote sensing monitoring and remote video surveillance in forest fire site.

In recent years, scientists have been trying to apply different instruments to real-time fire monitoring, including the use of thermal measurement to measure fire intensity, and the use of drones, infrared camera and other equipment for monitoring. The data of these devices can be used to monitor fires, provide real-time feedback and be used for prediction.

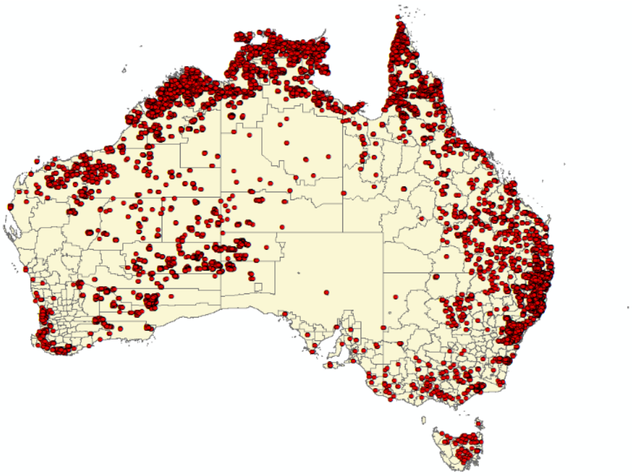

Figure 1: Wildfire Hot Spots in Australia

1.2 Restatement of issues

- Create a drones number optimization model for a new department of the Victoria's Country Fire Authority (CFA) that simultaneously meets the observation and communication needs. The model should consider both economic effects and security. In addition, the requirements and terrain of the task, as well as the size and frequency of fire events, need to be taken into account in the model.
- Predict the fire events in Victoria in the next 10 years and use our own model to adapt to extreme fire events. In the context of constant drones' system costs, how much equipment costs are expected to increase.
- Determine an optimized relay location model to adapt to different terrain and different scale fires.

1.3 Overall analysis

Our mission is to establish and optimize the models of the number and combination of SSA drones and radio-repeater drones, to effectively prevent forest fires and to cope with future extreme fires.

According to the historical fire situation data, we balance the capability, safety and economy, establish the model, plan the optimal path, and determine the flight trajectory and number of drones.

According to the historical fire situation data, we forecast the fire occurrence in the next ten years, determine the key monitoring range of each area every year, calculate the probability of fire occurrence in different areas in the next 10 years, and establish a model to deal with extreme fire. Then calculate the increased cost of equipment.

According to the elevation map of Victoria, considering the influence of fire size and altitude on radio signal, the position of relay on different terrain is optimized.

In summary, the whole modeling process can be shown as follows

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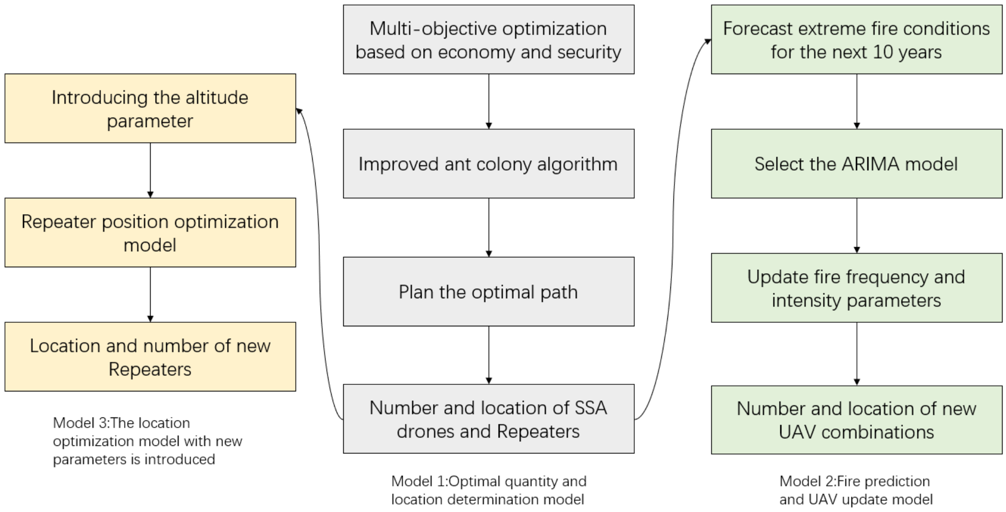

Figure 2: Model Overview

2. Basic assumption

To simplify the problem, we make the following assumptions.

- **Assumption:** The drones has no loss during use.

Justification: The cost loss caused by equipment damage does not belong to the scope of optimal drones deployment, so it is considered that drones equipment and bidirectional radio equipment are not damaged during use.

- **Assumption:** Human resources are adequate

Justification: During the planning process of SSA drones and radio-repeater drones, we think that human resources are sufficient, which means the rescue of fire situation is timely.

- **Assumption:** SSA drones and radio-repeater drones are at the same height.

Justification: To increase the repeater signal propagation effect, we consider the same height of SSA drones and radio-repeater drones.

- **Assumption:** The location and quantity of EOC can depend on the situation.

Justification: Since EOC can move according to the emergency, we can set the number and position of EOC according to the specific situation.

3. Symbols

Important notations used in this paper are listed in Table 1,

Table 1: Notations

Sign	Significance	Unit
u	longitude	°
v	latitude	°
P	cost	$(AUD)
d_{ij}	the distance between the ith position and the jth position	km
h	altitude	km
s_i	the area of the fire in location i	km^2

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4. Data preprocessing

4.1 Data Collection

The data we used mainly include the specific situation of fire in Victoria between 2001 and 2020, the terrain of Victoria, the distribution data of rural cities in Victoria, etc. NASA's two satellite VIIRS and MODIS recorded global fire data, and we chose the MODIS data as the data we analyzed. Data sources are summarized in Table 2.

Table 2: Data source collation

Database Names	Database Websites	Data Type
FME	https://firms.modaps.eosdis.nasa.gov/map/	Geography
NGDC	https://www.ngdc.noaa.gov/	Geography
IEEE	https://www.ieee.org/	Academic paper
Google Scholar	https://scholar.google.com/	Academic paper
VIC	https://liveinmelbourne.vic.gov.au/	Industry Report

4.2 Data Cleaning

4.2.1 Fire data

According to the fire situation in Australia from 2019 to 2020, we screened the location and frequency of fire, and found the area where fire occurred between October 1,2019 and January 11,2020. According to the distribution map of fire occurrence, we can see the distribution of fire in Australia. Catastrophic fires in all states of Australia, with the most severe impacts in New South Wales and Eastern Victoria, can be found more clearly by distribution.

We chose to analyze Victoria in Australia. First of all, we used the ArcGIS to filter out the fire data of Victoria from the overall data.

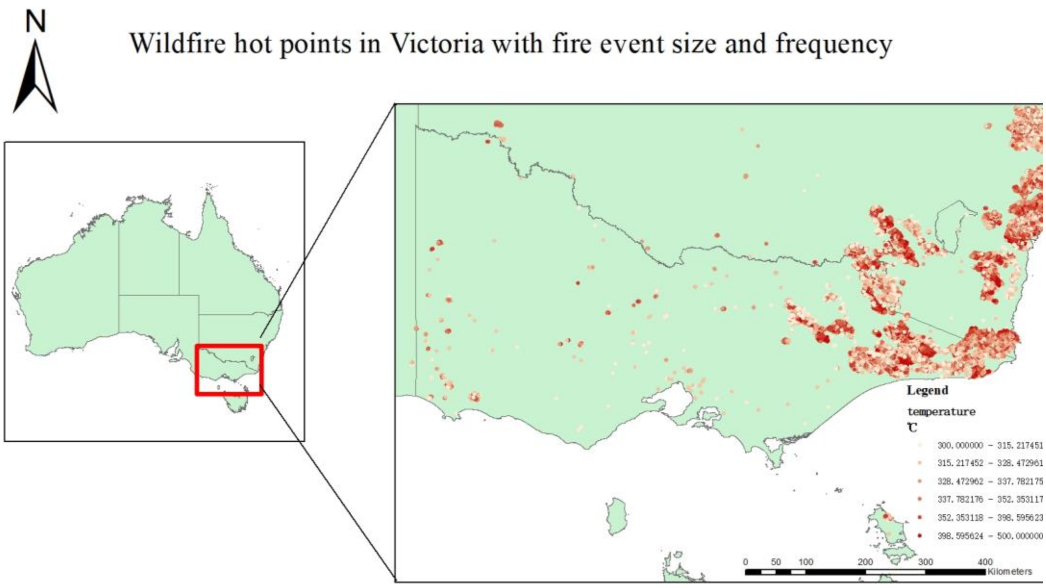

Figure 3: Wildfire hot points in Victoria

Due to the large number of forests in Australia, the rescue situation is difficult, and a fire may last for several days. Therefore, according to the data information, we believe that a fire that continues in the same place and time is a fire, so as to identify individual fires and then count the occurrence and number of fires.

4.2.2 Topographic data

Then we find the height terrain data of Australia, also using the ArcGIS to filter out Victorian terrain data from the overall data.

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5. Problem I The optimal numbers and mix of SSA drones and Radio Repeater drones

5.1 Model Preparation

5.1.1 The division of the territory of Victoria

Due to the scattered locations of fires, we analyzed Victoria by region according to geographical location and the severity of fires. According to the K-means clustering rule, we conducted cluster analysis on the fire data.

The division determined by K-means clustering rule can minimize the square error of classification. The effect is better when the clustering is dense and the difference between classes is obvious. For processing large data sets, this algorithm is relatively scalable and efficient, so it is suitable for data clustering processing of fire distribution.

We use K-means clustering analysis method through R software. First, the data is divided into 50 categories to obtain 50 clustering center domains. Then, the 50 clustering centers are divided into 7 categories, and the state of Victoria is divided into 7 regions, as shown in Figure 4, 6.

Each region scope contains raw data points.

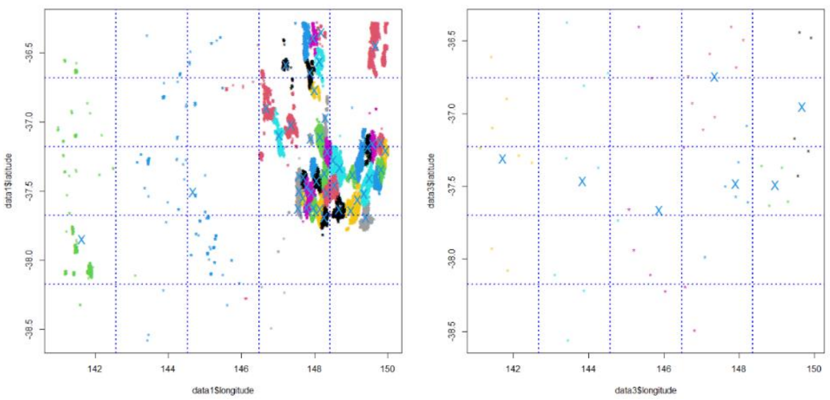
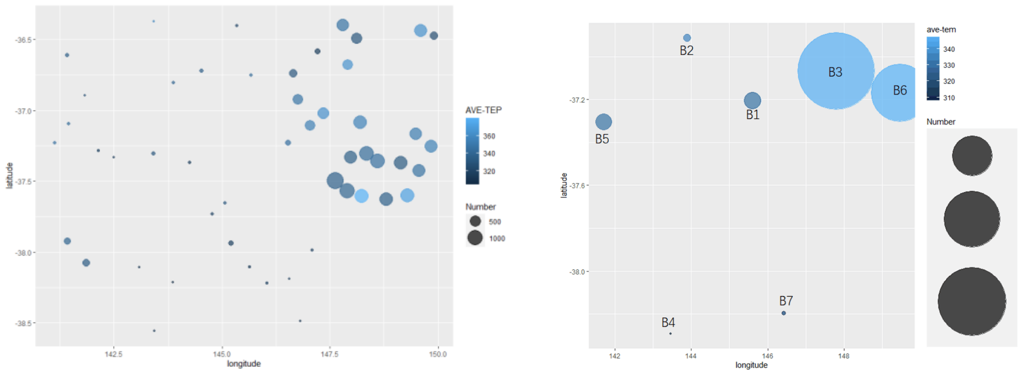


Figure 4: A two-step cluster of fires in Victoria

In addition, the number of all fires in the central domain is counted to get the frequency of fires in the region in one year. Using the temperature as the event size.



(a)Fire range of 50 cluster points (b)Fire range of 7 cluster points

Figure 5: Visualization of the range of two-step clustering

The radius of the circle is the fire frequency and the color is the event size.

The average event size (Ave-term), the number of fires (Number) and the number of points (Number50) in the 7 regions are shown in Table 3.

Table 3: Clustering center condition

District	Number	Ave-tem	Number50

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B_1	396	328.832	7
B_2	63	334.786	5
B_3	9614	346.396	14
B_4	4	307.9	3
B_5	350	330.5	8
B_6	5315	347.25	8
B_7	14	313.83	5

Normalize the fire frequency x_j^i and event size y_j^i of the fire cluster central domain. Set the weight, get the emergency factor of the ith fire cluster central domain of region j

$$E_j^i = \theta x_j^i + \varphi y_j^i \tag{1}$$

Where, θ, φ is the setting of the weight value. Considering the actual fire situation and the importance of these two factors, we define the weight as 0.5 respectively.

According to the number of fires and the size of the event, the seven areas are divided into three levels.

Table 4: Division of regional hierarchy

Level	Not serious	Middle	Serious
Frequency	0-50	50-1000	>1000
Fire intensity	300-320	320-330	330-350
Emergency factor	0.1-0.2	0.2-0.7	0.7-1
Seven areas	B_4, B_7	B_1, B_2, B_5	B_3, B_6

5.1.2 Rules

Rules one We have divided Victoria into seven regions, and we have an Emergency Operations Center (EOC) in each of these regions that is responsible for monitoring and directing fire emergencies in that area. Two types of drones are dispatched from the EOC

- **Rules for the emergency fire rescue system.**

SSA drones are used to enlarge the deployer vision, used for monitoring the changing situation. Then, passing site condition and location of personnel to Repeater drones, Repeater drones transfer the information to the EOC. Firstly, EOC processing data, then through a repeater to fire forwards for signal transmission and charges, as shown in figure 7.

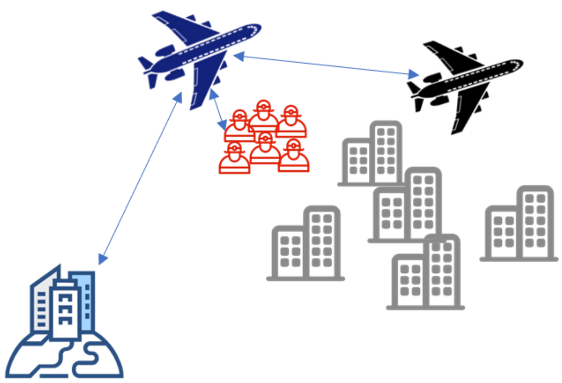

Figure 6: Working mechanism of domains

$B_i (i=1,2...7)$ region contains n_i fire cluster center domains. Considering the overall monitoring, we believe that SSA drones must pass through this cluster central domain in the process of

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navigation detection. In order to enable rescuers and SSA drones to reach the scene of the fire quickly, we use the improved ant colony algorithm to find the shortest path which is the shortest path connecting the central domain of the fire cluster.

- **The longest sailing distance of each SSA drones**

Maximum speed of drones v_m is 20m/s, Maximum flight time t_m is 2.5h,

$$s_m = v_m \times t_m \tag{2}$$

Then, the longest sailing distance of each SSA drones s_m is 180km

- **Distance conversion formula**

According to the longitude and latitude distance formula, the actual distance between any two points $A(u_A, v_A), B(u_B, v_B)$ can be obtained as

$$d_{ij} = R\arccos[\cos(u_A - u_B)\cos v_A \cos v_B + \sin v_A \sin v_B] \tag{3}$$

Where, u is longitude, v is latitude.

5.2 Model Construction

5.2.1 Construction of heuristic factors

The heuristic factor $\eta(i,j)$ represents the priority degree of SSA drones from the i-th cluster center point to the j-th point. We believe that it is inversely proportional to the distance and directly proportional to the emergency factor, namely:

$$\eta(i,j) = \frac{\mathrm{E}_1^{ij}}{d_{ij}} \tag{4}$$

5.2.2 State transition rule

The probability of drones k from the i-th cluster center point to the j-th point adopts the pseudo-random ratio selection rule, that is, if the random number generated $q \leqslant q_0$, q_0 is constant, then the j-th point is selected as

$$j = \arg \max_{u \in allowed_k} \{(\tau_{iu})^{\alpha}.(\eta_{iu})^{\beta}\} \tag{5}$$

If $q > q_0$, the state transition probability is

$$p_{ij}^k = \begin{cases} \dfrac{(\tau_{ij})^{\alpha}.(\eta_{ij})^{\beta}}{\sum\limits_{u \in allowed_k} (\tau_{iu})^{\alpha}.(\eta_{iu})^{\beta}} & j \in allowed_k \\ 0 & j \notin allowed_k \end{cases} \tag{6}$$

Where, τ_{ij} is the pheromone concentration on the path between point i and point j during the state transition of drones k; η_{ij} is the heuristic factor for the state transition of drones k; α and β show the weight of the sanguine and the initiator; $allowed_k$ is the optional and operational assembly of the next step of drones k;

5.2.3 Information update strategy

$$\tau_{c+1}(i,j) = (1-\rho)\tau_c(i,j) + \rho\Delta\tau_c(i,j) \tag{7}$$

Q is constant, $\Delta\tau_c(i,j)$ means

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$$\Delta\tau_c(i,j)=\begin{cases}(Q)^{-1} & (i,j)\in \text{ The optimal edge} \\ 0 & \text{others}\end{cases} \tag{8}$$

5.2.4 Algorithm steps

Table 5: Symbolic interpretation in the algorithm

Symbol	Explaining
Length	Length of the path traveled
BestTour	The optimal path
Pheromone	Pheromone matrix
Delta	A pheromone released at one time
Allowed	Stores the accessible fire cluster central domain
Tabu	Stores the inaccessible fire cluster central domain

Step 1: Initializing

Initialize the control parameters α,β,ρ,q_0,Q, the maximum number of iterations C_{max}, and BestTour is empty. The initial pheromone concentration is the maximum time window of the task set, the Delt matrix is 0, all the central domains of fire clustering in the region are added into the Allowed table, the Tabu table is cleared, set, and the initial iteration counter c = 0.

Step 2 Selecting the next node for each ant.

Select the next node from Allowed according to the state transition rules, observe whether the total length of the path is less than 180km, if not, return the initial point on the previous node. Multiple routes are added until the limited conditions are met to form multiple ant colony routes.

Step 3 Updating the pheromone matrix.

Update the pheromone matrix according to the information update strategy.

Step 4 Output of the optimal route

Algorithm 1: The process of Improved Ant Colony Algorithm

Input: $d_{j1,j2}$, $A_i(x,y)$), $B_{ij}(x,y)$,

Output: BestLength, BestTour

for i =1 to $C_{\max}$ do

(1) Select the next node for each ant according to the state transition rules
(2) Determine the nodes to make the driving route shortest
(3) Modify Table Tabu, Tabu number of nodes +1
(4) Table Allowed numbers of nodes -1
(5)Length=Length+ d_{ij}, update the node in Table BestTour, determine whether the ending condition is met. If not, the optimal route will be output if it is.

End

5.3 Multi-objective programming

After the shortest path is obtained by using the improved ant colony algorithm, we need to measure the economy and security in the problem, and adopt the multi-objective programming model to deal with it.

The objective function 1

Expended funds P minimum

$$MinP \tag{9}$$

The Wile E-15.2X hybrid drone is known to be equipped with either a radio repeater or video, which mean it can be used as a repeater drone and an SSA drone. Each hybrid drone will cost about \$10,000. Assume that the number of Repeaters is n_a, the number of SSA drones is n_b. Then

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$$P = 10000(n_a + n_b) + C \tag{10}$$

Where C is the cost of charging, personnel transfer and other things.

The objective function 2

We use the ratio of the monitoring range to the area of the fire occurrence area to measure the safety. According to the results of cluster analysis, the monitoring areas of different nodes in the area are determined by taking the fire occurrence frequency and fire event size as parameters and combining with the original fire occurrence area S_i.

$$S_i = \mathrm{E}_i s_i \tag{11}$$

The coverage ratio of the monitoring range of all SSA drones $\overline{S}$ to the main monitoring area $\sum_{i=1}^{n} S_i$ is taken as the security index, that is, the other target is:

$$Max\mathbb{R} = \frac{\overline{S}}{\sum_{i=1}^{n} S_i} \tag{12}$$

SSA drones by patrol found in a certain region forward team and the number of specific disaster situation, and the maximum transmission distance is 5 km. the monitoring scope of SSA drones is associated with driving path. We find the information from drones in the center of the fire clustering domain in the region where scanning, namely the drones inspection scope as a circular area, through the field in the center of the fire clustering in the operation of the scanned, area coverage of the most widely known way to zigzag way to walk.

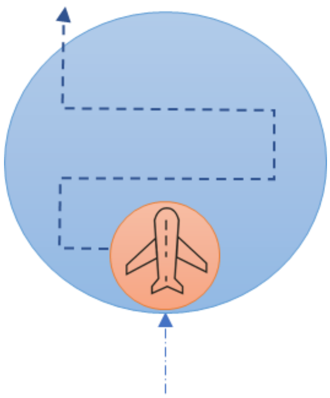

Figure 7: SSA DRONES fire area scanning diagram

As shown in the figure , the walking map of the SSA DRONES passing through the fire site is shown. The dotted line is the walking route, the blue area is the area of the fire area, and the orange area is the scanning coverage area of the DRONES.The monitoring area of the DRONES in the area is related to the walking route, then

$$\overline{S} = sl \tag{13}$$

Where s is the scanning range of the drones and l is the driving distance of the DRONES in the central domain of fire clustering, making the coverage range of the DRONES greater than the fire range.

The conditions

The range of handheld radios is 5 km over flat, unobstructed ground, but drops to 2 km in an urban area. Repeaters can extend to 20km.

Forward teams member x_i The geographical location of the its region is G_A

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$$G_A = \begin{cases} 1 & city \\ 0 & others \end{cases} \tag{14}$$

According to the above relation, the transmission range F of the signal of the advancing party member can be obtained

$$F = 2G_A + 5(1 - G_A) \tag{15}$$

The location of EAC is close to the emergency point of fire. Since the SSA drones have a signal monitoring range. In order to ensure the flight safety and maneuverability of the DRONES, it is advisable to use EOC as the signal center. The SSA drones has a signal within a range of 30km. According to the distance between the disaster centers, the appropriate location of EOC can be selected $G(u_0, v_0)$.

If the distance between the forward teams and EOC is small, the signal can be transmitted directly through the radio. If the distance is large, the signal needs to be transmitted through the repeater. For surveillance purposes, the height of the DRONES with high-definition camera is generally around 100m, and the height of the repeater is up to 2km[]. Since the distance from the ground is short and the actual monitoring range is too big, we can approximate the distance between the repeater and EOC for the repeater signal propagation range.

So within the zone B_1, the set $K = (k_1, k_2, ..., k_{n_a})$ represents the repeater drones, and the set $R = (r_1, r_2, ..., r_{n_b})$ represents the SSA drones. Among them, the number of Repeaters is, and the number of SSA drones is. Correspondingly, the positions of EOC, repeater and SSA DRONES can be represented in the form of a set, and the specific manifestation is shown as follows

$$\begin{cases} k_i = (u_{ik}, v_{ik}) \\ r_j = (u_{jr}, v_{jr}) \end{cases}, \quad \forall i \in n_a, \ \ j \in n_b \tag{16}$$

Condition 1

There is a need for signal transmission between the repeater and EOC. When the distance is within a certain communication range, the communication can be effective. Namely, the following conditions are satisfied

$$d(G, k_i) \le d_0, \quad \forall i \in n_a \tag{17}$$

Condition 2

Where, represents the maximum transmission range of the repeater d_β is 20km. In addition, signal transmission can also be carried out between repeaters at different positions to expand the signal transmission range. In order to improve the utilization rate of repeaters, the distance between Repeaters d_α should not be too close to the minimum of 4km. That is, the following conditions are met

$$d_\alpha \le d(k_i, k_j) \le d_\beta, \forall i \ne j \in n_a \tag{18}$$

Due to the distance, the advancing player passes the information to the EOC via the repeater. At this time, the position of the repeater closest to the forward team member is matched with the position of the forward team member meet

$$\min_{i=1,...n_a} (k_i, G_A) \le F \tag{19}$$

The position relationship between the SSA drones and the repeater meets the following conditions.

$$\min_{j=1,...n_a} d(k_i, r_j) \le d_1, \quad \forall j \in n_b \tag{20}$$

Within the region B_1, the range for node coordinates should be

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$$\begin{cases} \alpha_a \le u_{ik}, u_{jr} \le \beta_a \\ \alpha_b \le v_{ik}, v_{jr} \le \beta_b \end{cases}, \forall i \in n_a, \ \ j \in n_b \tag{21}$$

Where, α_a β_a is the longitude range of the region B_1, α_b β_b represents the latitude range of the region, and the SSA drones move forward through the shortest path. According to the objective function and constraint condition formula (13-21), a multi-objective programming model is established to solve the number and combination of SSA DRONES and Repeaters.

5.4 Result analysis

The road map style obtained by using the improved ant colony algorithm is shown in the following two situations: one is that a DRONES completes the route alone, and the other is that multiple DRONESs complete the route together.

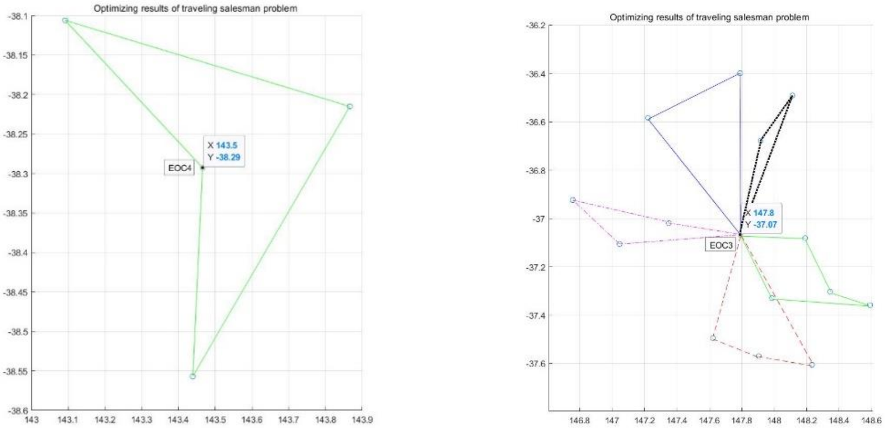

Figure 8: SSA DRONES flight map

The location of the Repeaters in one of the areas is shown.

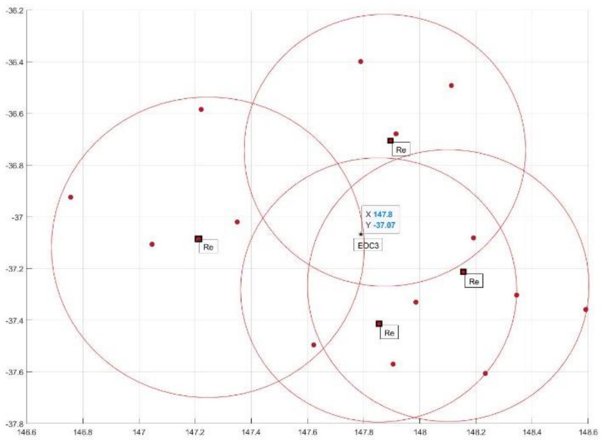

Figure 9: Diagram of repeater position

The number of SSA DRONESs and Repeaters in each region calculated by the model is shown in the following table.

Table 6: Number and location of SSA and Repeaters in different areas

EOC	The fire point	SSA	repeater	repeater location
1	7	3	3	(146.325, -37.014)(145.414, -36.791) (145.325, -37.582)
2	5	3	3	(143.925, -37.355)(143.714, -36.656) (144.414, -37.028)

3	14	5	4	(147.212, -37.084)(147.854, -37.412) (148.155, -37.214)(147.894, -36.705)
4	3	1	1	(143.612, -38.251)
5	8	4	3	(141.625, -37.028)(142.124, -37.525) (141.725, -37.612)
6	8	4	3	(149.634, -36.738)(149.111, -37.356) (149.585, -37.423)
7	5	3	3	(146.655, -38.374)(146.135, -38.174) (146.805, -38.095)
total	50	23	20	

According to the optimization model of problem 1, we can get that the number of SSA drones that need to be purchased is 23 and the number of radio-repeater drones is 20, under the premise of ensuring economic benefit and safety. The cost of getting the drone was $430,000(AUD). Considering the labor call cost, battery replacement and charge consumption, we estimate the total cost is $500,000(AUD).

6. Problem II Adapt to fire extremes in the next 10 years

6.1 Problem analysis

Australia has a high proportion of natural forests, and fires occur almost every year. According to the analysis of the past news, the main causes of frequent fires in Australia include climate change and seasonal influence, the increase of carbon emissions and global warming, which lead to the increase in the frequency and intensity of heat waves and droughts in Australia. In addition, fires in Australia can occur throughout the year, and the severity varies from region to region, with bushland fire occurrence and severity often higher. Each year's situation is closely related to previous years' data, so it often has a seasonal effect.

The occurrence of fires can be predicted and illustrated by historical data, and the fire occurrence of Victoria State can be analyzed and predicted by using the 20-year data between 2001 and 2020.In the first question, the determined scope of 50 fire cluster center domains has been obtained. According to the historical data, it can be concluded that the occurrence of fires in other regions is accidental. Therefore, it is of practical significance to analyze the occurrence of historical fires in the 50 regions.

We selected the ARIMA model to predict the fire frequency and intensity in the next 10 years, and selected the extreme cases in the next 10 years for analysis. Since we focus on the analysis of 50 regional points in Victoria, we will only forecast and analyze these 50 regional points. Due to too much data, we will only select one of them for analysis, and the rest of them will be treated in the same way.

6.2 Model preparation

6.2.1 Prediction of fire frequency

First, fires in Victoria over the past 20 years were used to forecast fires for the next 10 years.

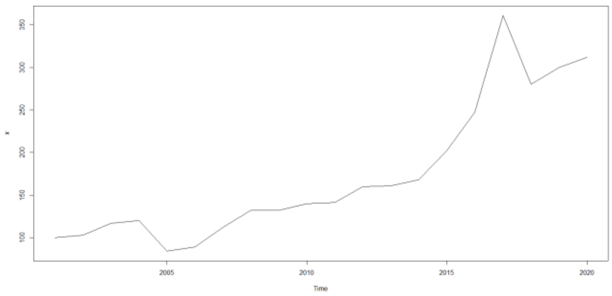

Figure 10: Schematic diagram of fires in the past

The sequence diagram shows that the sequence has obvious tendency, so the sequence is not stationary. The time sequence diagram shows an obvious trend, so differential processing is carried out. After the first-order difference, it did not pass the significance test, and the second-order difference was finally selected according to the test results. After the second-order difference, it shows the stable fluctuation of the sequence diagram near the mean value.

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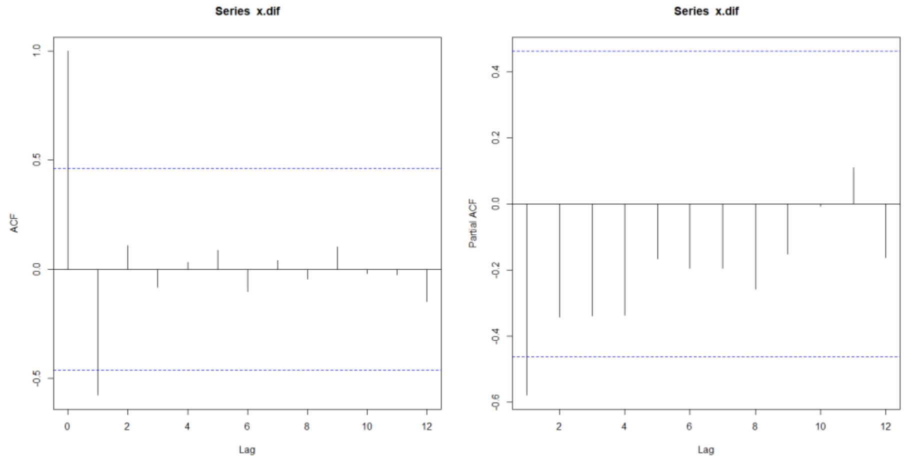

Figure 11: Autocorrelation coefficient and partial autocorrelation coefficient graphs

After comprehensive investigation of the properties of the post-difference autocorrelation graph and partial autocorrelation graph, it can be considered that the first-order truncation of the autocorrelation and the trailing of the partial autocorrelation coefficient are obtained. Therefore, the original sequence is fitted to the ARIMA (0,2,1) model, and the fitting model is as follows:

$$x_t - 2x_{t-1} + x_{t-2} = \varepsilon_t - \varepsilon_{t-1} \quad (22)$$

It passed the test of the model.

6.2.2 Prediction of fire intensity

The same treatment method is used to predict the fire intensity, and the ARIMA (0,2,3) degree is the best. The fitting model obtained is:

$$x_t - 2x_{t-1} + x_{t-2} = \varepsilon_t + 0.771\varepsilon_{t-3} \quad (23)$$

Including $\varepsilon_t \sim N(0,4.577)$

Then, the above model is used to predict the fire frequency and fire intensity data in the next 10 years and the 95% confidence interval is:

Table 7: Table of fire frequency and fire intensity for the next 10 years

Year	fire frequency			fire intensity		
	Point Forecast	**Lo 95**	**Hi 95**	**Point Forecast**	**Lo 95**	**Hi 95**
2021	323.1579	249.9507	396.3651	340.6367	336.4206	344.8528
2022	334.3158	228.2286	440.4031	351.0147	341.5872	360.4423
2023	345.4737	212.4863	478.4611	362.4061	346.6308	378.1814
2024	356.6316	199.6198	513.6435	373.7975	348.2634	399.3316
2025	367.7895	188.4693	547.1097	385.1889	347.6580	422.7197
2026	378.9474	178.4614	579.4335	396.5803	345.3076	447.8530
2027	390.1054	169.2671	610.9436	407.9717	341.4640	474.4793
2028	401.2633	160.6800	641.8466	419.3631	336.2848	502.4413
2029	412.4212	152.5615	672.2808	430.7544	329.8814	531.6275
2030	423.5791	144.8145	702.3436	442.1458	322.3388	561.9528

Visualized forecast results for the next 10 years:

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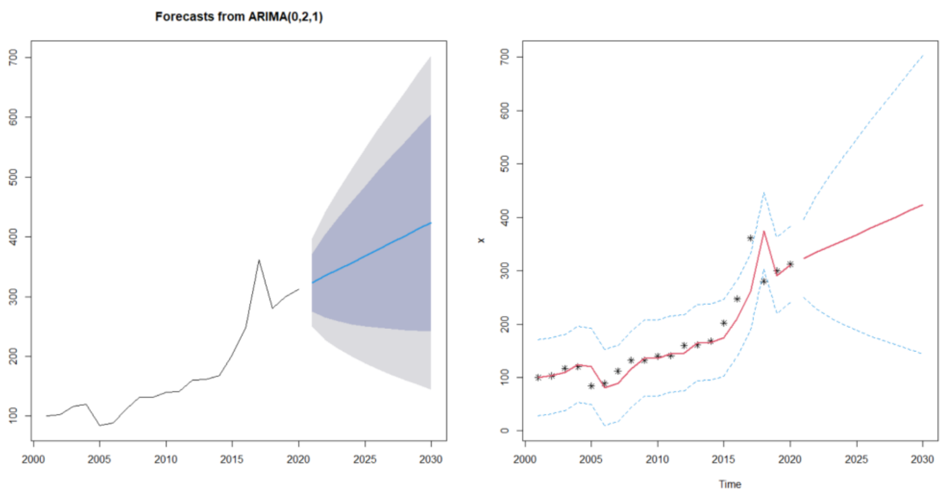

Figure 12: Visualized forecast results for the next 10 years

6.3 Occurrence and prevention of extreme fire events

Let's assume that the cost of DRONESs doesn't change, which means that the price of DRONESs doesn't change over the next 10 years. The ARIMA model has been used to forecast the annual fire frequency and fire intensity of 50 cluster centers in the next 10 years. According to the annual fire frequency and the intensity of fire events, we determine the annual key monitoring scope of each cluster center point, judge the probability of fire occurrence, and take extreme fire situation into consideration, and then make timely prevention.

We have calculated that when the emergency value is higher than 0.7, the region is in a serious situation. Therefore, we may consider the number of years in which the emergency factor index of the region is higher than 0.7 in the next 10 years, ζ_j^i, as the ratio of 10 years, as the probability p_j^i of the fire occurrence in the center domain of the ith fire cluster in the jth region.

$$p_j^i = \frac{\zeta_j^i}{10} \tag{24}$$

Thus, the probability of fire occurrence in the whole Victoria in the future can be calculated, as shown in the figure below.

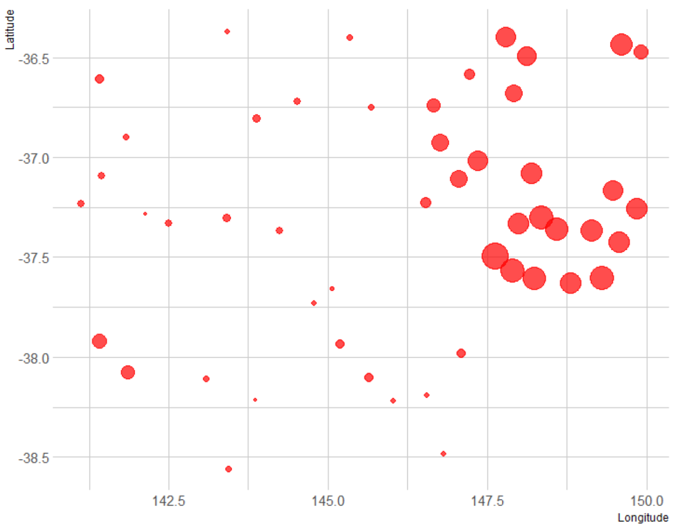

Figure 13: Diagram of fire probability in Victoria

The most extreme scenario for a fire event is when all areas burn in a single year in the next 10 years. The deployment of SSA drones and Repeaters will be changed in areas where fire conditions are

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likely to be high or severe. As the situation is more critical, the probability of fire is higher in areas with higher probability, so more attention should be paid to safety, and the patrol of SSA DRONES should be considered more comprehensively. Based on the safety problem, we choose to increase the number of SSA drones to replace the charging time of the previous drones in the patrol process of SSA drones, so as to carry out all-round monitoring of high-danger areas.

This paper considers that almost no unmanned aerial vehicle is idle in the process of DRONES driving. h_{r_i} said Numbers for r_i the departure time of DRONESs, since DRONES need to be recharged, and charging time is 1.75 h, DRONES flight time and charging time lag, consider the utilization, required Numbers for r_i the SSA of DRONES returns the charging period otherwise SSA drones to take his job, to monitor area. It is assumed that there are a total of ψ SSA DRONESs for real-time monitoring. At this time, the take-off time of the last DRONESs and the charging end time of the first DRONESs should be as small as possible, so as to save the time of the second DRONESs returning to EOC and taking off after charging. At the same time, the travel time gap with the previous DRONES is as large as possible, the scanning area of the DRONES is overlapped and the cost is saved, that is, the constraint conditions are increased.

$$\begin{cases} \max h_{r_\psi} - h_{r_{\psi-1}} \\ \min h_{r_1} + t_a - h_{r_\psi} \end{cases} \tag{25}$$

In order to facilitate calculation and processing, we consider a special case, that is, unmanned aerial vehicle r_i can only return to EOC for charging after traveling for 2.5h, and the charging time is 1.75h. Then, the time interval between the traveling time of the next unmanned aerial vehicle r_{i+1} and the traveling time of r_i is 0.75h, that is, the unmanned aerial vehicle is idle for 0.75h. In order to make full use of DRONES efficiency, cycle inspection for DRONES and take the optimization model, considering safety and economic benefit, we choose four DRONES for this journey of reconnaissance, the time interval and DRONES is near to 0.625 h, can maximum limit at this time of the monitoring of dangerous region, improve the safety index. Add the above restrictions and requirements to decorate model of a DRONES model, according to the known Victoria fire area in the past ten years and each year the number of fire, can predict the future 10 years of Victoria fire situation, according to the severity and frequency of fire prediction set weights only to update the parameters of the model a, due to increased security requirements, the number of DRONES will increase.

6.4 Result analysis

The number and location distribution of SSA and Repeaters in different areas throughout Victoria is shown in the table below.

Table 8: Number and location of SSA and Repeaters in different areas

EOC	**The fire point**	**SSA**	**replace SSA**	**repeater**	**repeater location**
1	7	5	2	4	(145.445, -36.782)(146.285, -36.975) (145.486, -37.584)(145.255, -37.428)
2	5	4	1	3	(143.658, -37.185)(144.156, -37.154) (144.088, -36.625)
3	14	9	4	5	(147.638, -36.705)(147.934, -36.785) (147.214, -37.105)(147.924, -37.428) (148.155, -37.205)
4	3	3	1	2	(143.502, -38.247)(143.555, -38.423)
5	8	5	2	4	(141.825, -37.813)(142.222, -37.401) (141.874, -37.196)(141.386, -37.031)
6	8	5	2	4	(149.502, -36.981)(149.174, -37.321) (149.411, -37.432)(149.605, -37.385)
7	5	4	1	3	(146.074, -38.216)(146.795, -38.132) (146.636, -38.307)
total	50	35	13	25	

According to the results above, we can know that in the context of extreme fire events in the next 10 years, the number of SSA drones will change to 48, increase by 25, and the number of radio-repeater drones will change to 25, increase by 5. Assuming that drones costs remain unchanged, equipment costs are expected to increase by $300000(AUD).

7. Problem III Optimize the location of the repeater

7.1 Model preparation -- The determination of altitude

After collecting the elevation data of Victoria, the topography of Victoria was visualized to obtain the following figure.

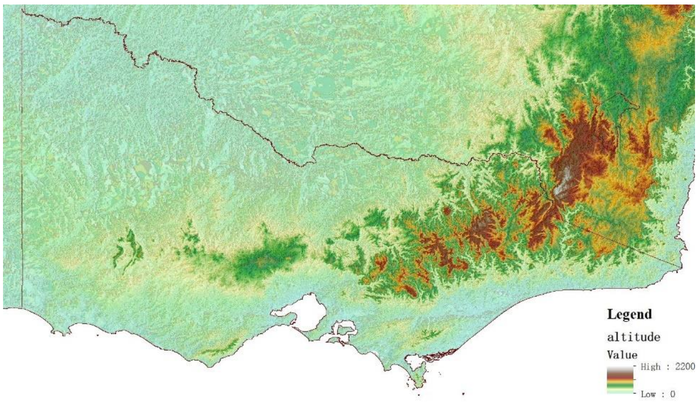

Figure 14: Visualization of elevations in Victoria

7.2 Model establishing and solving

The altitude directly affects the rarefied degree of air, and the signal propagation intensity is affected by the concentration of air in the atmosphere. Therefore, the altitude is directly related to the signal propagation range. We looked up the data and found the definition formula for the elevation correction factor.

$$k = 40(1 - \frac{\sigma}{\sigma_0}) \tag{26}$$

Where σ represents the air density at high altitude where radio interference needs to be corrected, and σ_0 represents the relative air density at standard atmospheric pressure. By substituting the actual value, the radio interference altitude correction coefficient of 1dB/300m can be obtained, which is effective. Where, 1dB/300m represents the radio interference correction of 1dB for every 300m increase in altitude. DB is a ratio, it's a number, it's a pure counting method, it doesn't have any unit notation.

In the rate radiation loss, the conversion formula of power unit P and W (watt) is[4]:

$$\text{d}Bm = 30 + 10\lg W \tag{27}$$

The power of the repeater is 10 watts, while the power of the hand-held intercom is 5 watts. According to the above conversion formula, the power of the repeater can be calculated as 40dBm, and the maximum signal propagation distance is 20km. The power of the hand-held intercom is approximately 37dBm, and the transmission distance in the city is 2km, and the transmission distance in the countryside is 5km. In the field of signal processing 1dBm-0dBm=1dB. From the relationship between dBm and dB, it can be concluded that power decreases by 1 dBm for every 300m elevation increase.

The elevation of each location can be obtained from the topographic map of Victoria. Assuming that the altitude of the repeater is h according to the sea level, the power is P , and the maximum signal propagation distance is $\hat{d}$, then the relationship between the signal propagation distance $\hat{s}$ and the altitude h is

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$$\hat{s} = \frac{P - h/300}{P\hat{d}} \tag{28}$$

Thus, the influence of the height from the sea level on the signal propagation distance can be calculated according to the altitude. According to the terrain of the selected region, the altitude of each point in the region is judged and weighted. Because the difference of terrain height in each region is not big, the signal propagation distance in the same region is almost no influence. We can calculate the average altitude of the whole area, so as to replace the altitude of the repeater and the firemen to calculate the signal propagation distance in this area. The same treatment was done for all seven regions.

Therefore, the signal propagation distance between repeater and repeater, between repeater and EOC, and between firefighter and repeater in Model 1 can be replaced, and the model parameters can be modified to solve the problem. Optimize the position of the hovering repeater DRONES over different terrain.

7.3 Result analysis

Table 9: Number and location of SSA and Repeaters in different areas

EOC	the fire point	SSA	repeater	repeater location
1	7	3	4	(145.414, -36.785)(146.235, -36.974) (146.111, -37.224)(145.321, -37.601)
2	5	3	3	(143.934, -37.485)(143.804, -36.726) (144.494, -37.869)
3	14	5	5	(147.701, -36.695)(147.863, -36.745) (147.308, -37.845)(147.745, -37.612) (148.255, -37.342)
4	3	1	1	(143.542, -38.341)
5	8	4	4	(141.755, -37.875)(142.342, -37.541) (141.974, -37.201)(141.458, -37.425)
6	8	4	4	(149.702, -36.882)(149.244, -37.281) (149.271, -37.972)(149.545, -37.245)
7	5	3	3	(146.704, -38.401)(146.248, -38.298) (146.915, -38.187)
total	50	23	24	

In order to be able to adapt to different scale fires on different terrain, we optimized the location and number of radio-repeater drones on the basis of problem one. In this case, the number of radio-repeater drones is 24, and its position has changed.

A schematic diagram of the hovering position of the repeater drone is shown below.

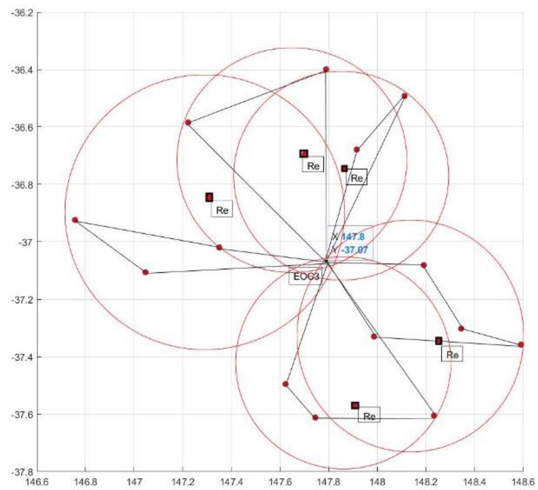

Figure 15: Comprehensive schematic diagram of the hover position of the repeater and the SSA walking path

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The range of the circle indicates the size of the repeater signal transmission, and the size of the circle is different due to the different signals caused by the terrain.

8. Test the Model

8.1 Sensitivity Analysis

In the process of solving problem one, we adopt the improved ant colony algorithm. However, ant colony algorithm is a pioneering biological simulation method, in which the parameters are uncertain, we need to select those parameters with large uncertainty for sensitivity analysis. Here, we choose α , β and ρ as the parameters of the sensitivity test. Take the EOC1 as an example: when β and ρ is unchanged, the change of α will be assigned in 0.3,0.5, and 1. Finally, we found the planning routes are the same. The results are as follows:

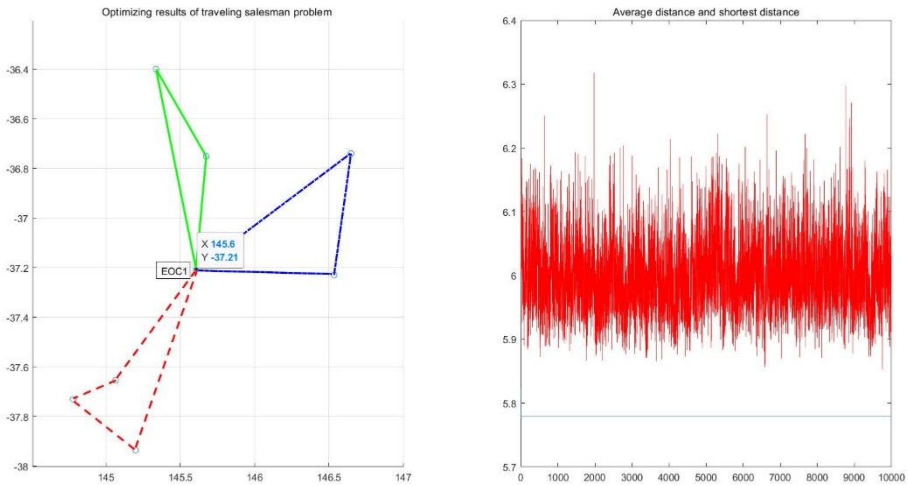

Figure 16: Roadmap for sensitivity analysis

When α and ρ is unchanged, or When α and β is unchanged, the route is exactly the same as above

8.2 Robustness Analysis

When we fit the ARIMA model in problem two, in order to further verify the stability of the sequence, we use the PP test method to test it.

ADF test is mainly used in the case of homogeneity of variance, Its test of the stationarity of heteroscedasticity sequences may be biased. Phillips and Perron modified the ADF test in 1988, Proposed Phillips-Perron test (abbreviated as PP test), Based on the function of PP. test, we obtained:

Table 10: PP inspection table

Phillips-Perron Unit Root Test	
Dickey-Fu1ler	-2.1881
Truncation lag parameter	2
p-value	0.5007

When the significant level is 0.05, the P value is 0.5007, which is greater than 0.05, we can consider that the sequence $\{x_t\}$ is considered to be nonstationary.

We test the fitting effect of the fire occurrence frequency model and fire occurrence intensity model in problem two, and the test results show that both the models are remarkably valid, the fitting degree is good, and the prediction is more accurate.

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Table 11: Box-Pierce test

Parameter	Box-Pierce test(one)	Box-Pierce test(two)
X-squared	3.4716	4.4225
df	12	12
p-value	0.9912	0.9746

9. Conclusion

9.1 Result of Problem 1

By calculation in model, the number of SSA drones and radio-repeater drones in each region is known.

We can get that the number of SSA drones that need to be purchased is 23 and the number of radio-repeater drones is 20, under the premise of ensuring economic benefit and safety. The cost of getting the drone was $430,000(AUD). Considering the labor call cost, battery replacement and charge consumption, we estimate the total cost is $500,000(AUD).

9.2 Result of Problem 2

The number of SSA drones and radio-repeater drones in each region is known.

According to the results above, we can know that in the context of extreme fire events in the next 10 years, the number of SSA drones will change to 48, increase by 25, and the number of radio-repeater drones will change to 25, increase by 5. Assuming that drones costs remain unchanged, equipment costs are expected to increase by $300000(AUD).

9.3 Result of Problem 3

In order to be able to adapt to different scale fires on different terrain, we optimized the location and number of radio-repeater drones on the basis of problem one. In this case, the number of radio-repeater drones is 24, and its position has changed.

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