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Study on Australian Bushfire Detection Model based on Drones and Unmanned Intelligent Vehicle Swarm

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Abstract

This paper is based on the research background of communication problems in fighting fires in eastern Victoria, Australia. The number, combination and location of SSA drones and Radio Repeater drones involved in fire information transmission are studied. We selected the eastern part of Victoria as the target area for our study, the area is divided into ten zones according to the intensity of the fires. The ten areas are further divided into three different fire risk levels, high-level areas arranged SSA drones patrol more times, whereas low-level areas arranged SSA drones patrol fewer times. In the third part of the article, we looked at the number of two types of drones needed to patrol all areas. It is believed that ten regions can be divided into several regular hexagons, the mathematical programming model is adopted. The constraints of fire size and frequency, inspection range, charging time and rotation times were considered. The method of discussing the side length of regular hexagon is adopted. We obtained that in theory to achieve the goal of minimum cost, the length of side of regular hexagon should be 17.3km. Without considering the charging time and charging demand, both will require 461 drones. When charging time and demand are taken into account, 515 SSA drones and 537 Repeater drones are needed. In Part 4, we looked at the last 50 years of fire data in Australia. And combined with data on climate change, AR prediction algorithm and grey neural network algorithm are combined. Modeling and predicting the size and frequency of fires over the next 10 years. Our conclusions is: with the warming of the climate, the fire density in the target area will increase year by year. According to the new fire density predicted in the target area, the fire risk level is reclassified. Using the models and calculation methods in Part 3, and the prediction is that: A total of 1,073 drones will be needed after three years to meet the fireproof safety requirements. After seven years, a total of 1,162 drones will be needed. In the fifth part, the position optimization of the Radio Repeater drones is studied. We rezoned the target area based on the 2019 fire data. A forward team is responsible for each area. The forward team dispatches front-line personnel to the fire area according to the size of the fire. Unmanned intelligent vehicle that detects terrain automatically then feeds the data back to Emergency Operations Center (EOC). At this time, the number of Radio Repeater drones is composed of the Radio Repeater drones from front personnel to front team and the Radio Repeater drones from forward team to EOC. Front-line personnel are on the perimeter of the fire line. The larger the fire area, the more Front-line personnel will be needed and the more Radio Repeater drones will be needed. In order to minimize the number of Radio Repeater drones between the position of the forward team and the EOC, a planning model was established to make its path shortest. For the completeness of the model, we analyzed that after the forward team position and EOC position were determined, the number of relay drones in between depends on the size of the fire and the terrain. Finally, we change the values of the urban range of the small power radio transceiver in the model several times, our model is stable because the fluctuation of the results is relatively small.

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Keywords

Regular Hexagon Regionalism; Poisson's Distribution; AR Prediction Algorithm; GNN; Immune Optimization Algorithm.

1. Introduction

1.1 Research background

Wildfires raged across several Australian states in 2019-2020. Large areas of land were destroyed, it caused economic losses, human casualties and nearly 3 billion animals died. Wildfires in eastern Victoria and New South Wales have been the worst affected. In the course of this fire fighting,the Australian government has used different types of drones, such as SSA drones and Radio Repeater drones, to help communicate information about the fire in ways that ordinary firefighters cannot.

Monitoring fire information and timely reporting to EOC is one of the key points of fire fighting. Drones are unmanned aircraft operated by radio remote control equipment and self-contained program control devices. It can not only receive signals but also send signals, and it can overcome the harsh environment such as high temperature and smoke, and it can effectively detect fire, making the information transmission safe and effective. To achieve the purpose of cooperating with EOC to adjust action plan in time and arrange front-line personnel to extinguish fire effectively. How to effectively and reasonably configure different types of drones within a certain financial scope has become an issue that relevant government departments of various countries have deeply considered and paid close attention to.

2. Model preparation

2.1 Symbols

Table 1. Symbol description

Symbols	Definition
N_{ssa}	Number of SSA drones
N_{re}	Number of Radio Repeater drones
s_i	Area of region i
m_i	Number of inspections in region i in 4.25 hours
s	Total area
T	The maximum duration of a drone's flight
D	Height of a regular hexagon
b	The length of the side of a regular hexagon
n	The drone detects the distance traveled by a regular hexagon
N_{assa1}	Number of SSA drones to take a tour of area a
N_{assa2}	Number of SSA drones to be rotated to patrol area a
N_{re1}	Number of north-south Radio Repeater drones
N_{re2}	Number of east-west Radio Repeater drones

2.2 Model analysis

In the study of this paper, we believe that there are several information transmission modes between the former fire situation and EOC: First, in normal weather conditions, the SSA drone detects the fire and relayed the fire signal to the EOC; The EOC sends the fire command signal to the SSA drone, which in turn sends the fire command to the front-line firefighters; Second, Boot-to-the-ground front teams communicate directly with EOC to report front-line fire information and make recommendations on fire-fighting plans.

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The communication between the SSA drone and the EOC may require the assistance of a Radio Repeater drone; In the third case, boot-to-the-ground front teams may also be using relay drones to exchange information with EOC.

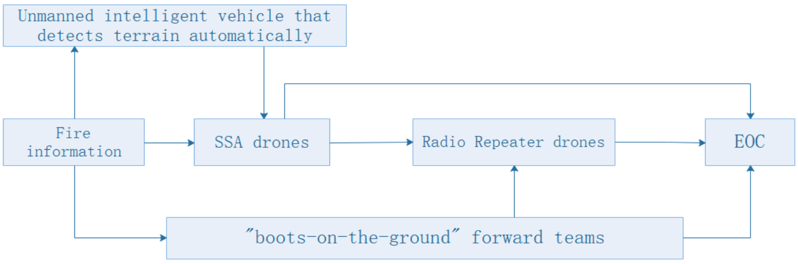

Figure 1. Diagram of fire information transmission mode

Analyzing from the time line, the surveillance phase before a fire and the early stage of fire discovery, we rely more on SSA drones to find the fire and report it to EOC. When EOC gets the fire report and sends "Boot-to-the-ground" front teams to the fire front for fire analysis and plan formulation, we rely more on Radio Repeater drones to keep the information communication between the "Boot-to-the-ground" front teams and EOC.

2.3 Simplifying assumptions

By adequate analysis of the problem, to simplify our model, we make the following well-justified assumptions.

Assumption1: The range of the SSA drones is different from that of the Radio Repeater drones, but the SSA drones will fly at the same speed and time as the Radio Repeater drones.

Assumption2: All drones fly at the same speed and maximum flight time t', maximum flight time equals charging time plus usage time.

Assumption3: All drones have the same maximum flight cycle T, this is the time it takes for a fire to start until the maximum burning rate is reached.

Assumption4: Within the same fire density grade area, the duration of drones inspection is a function of the magnitude and frequency of fire events. The higher the frequency of fire incidents, the shorter the inspection period of drones, which means that more inspections are needed. The number of SSA drones patrolled in each area $m_i = T/T_i$.

Assumption5: We assume that the monitoring range of the drone in fire monitoring is a rectangle, where the length is the drone's travel distance = speed*time=vt, the width is $2r$.

Assumption6: The SSA drone has a range of 4km.

Assumption7: The drone cannot fly while charging, but can set off for missions as soon as it is charged.

Assumption8:The drones have a flight range of 30Km, the maximum speed of 20m/s, and a maximum flight time of 2.5 hours.

Based on the above assumptions, we will analyze and solve the problem

2.4 Determination of the size and frequency of fire events

2.4.1 Fire topography

In order to study the distribution of fires in the eastern part of Victoria, a topographic map of the eastern part of Victoria was first drawn, in which the colors from light to dark indicate a gradual increase in elevation, as shown in Figure 2:

Next, we collect the longitude and latitude data of the fire site from October 1, 2019 to January 7, 2020[1], and add the data of the fire points according to longitude and latitude to the positions corresponding to the topographic map, this is shown in Figure 3:

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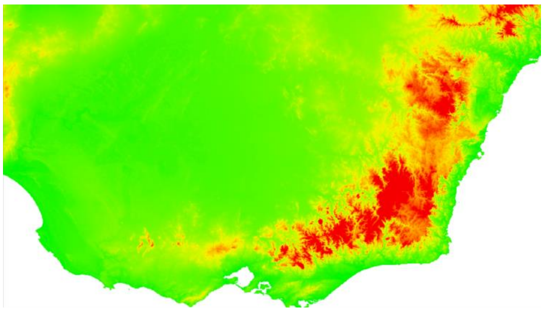

Figure 2. Topographic map of the eastern region of Victoria

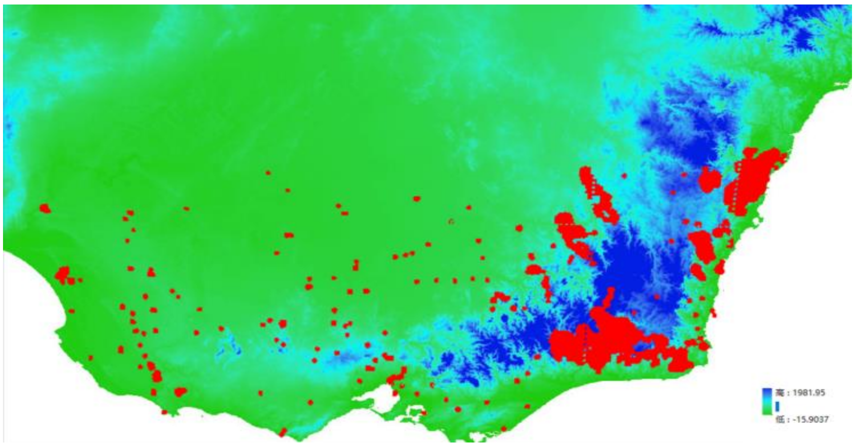

Figure 3. Topographic map of fires in eastern Victoria

2.4.2 Size and frequency of fire events

Divide the fire topographic map into zones. 10 rectangular areas are divided according to the intensity of fire occurrence points. Each area contains a different number of fire occurrence points. The specific areas are divided as follows:

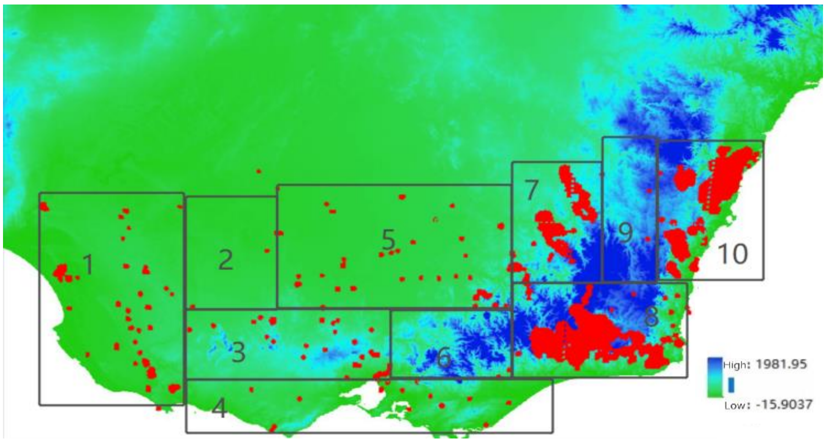

Figure 4. Regional division of fire density in the eastern part of Victoria

The area of each region is:

Table 2. The area of each area

Label	1	2	3	4	5
Area	62109.5	32257	43651	40180.1	68756
Label	6	7	8	9	10
Area	19802.5	24609.37	27003	18281	21504

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The total area is $s = s_1 + s_2 + s_3 + \ldots\ldots = 358153.47$.

The number of fires in each region during this period is defined as the fire frequency, and the fire area in each region is defined as the fire size. The frequency of fires per unit area of an area is defined as fire intensity. According to the intensity of fire in the 10 areas, they are divided into three different fire grades. Areas with high fire levels usually send SSA drones to monitor the fire situation at a higher frequency, whereas areas with low fire levels usually send SSA drones to monitor the fire situation at a lower frequency. See the table below:

Table 3. Hierarchy

Label	1	2	3	4	5	6	7	8	9	10
Grade	B	C	B	C	B	C	A	A	C	A
Number of patrols per unit time	1.25	1	1.25	1	1.25	1	2.5	2.5	1	2.5

Regions with high fire frequency (Category A) include Zone 7,8, and 10, which have had the highest fire intensity in the past year, area $s_A = s_7 + s_8 + s_{10} = 64394km^2$

The fire frequency regions (Category B) includes Zone 1,3 and 5, which have a high fire intensity in the past year, area $s_B = s_1 + s_3 + s_5 = 174515.6km^2$

Regions with low fire frequency (Category C) include Zone 2,4,6, and 9, with the lowest fire intensity in the past year, area $s_C = s_2 + s_4 + s_6 + s_9 = 110520.6km^2$

3. Number and combination model of SSA drones and Radio Repeater drones

3.1 Model analysis

In the stage of fire monitoring, in order to grasp the accurate information of the fire scene, the more SSA drones there are, the more they cover the entire surveillance area. But there is no doubt that this will increase the cost of deploying drones. Therefore, we chose to minimize the number of SSA drones in order to reduce costs while ensuring information security.

At the same time, we also found that SSA drones can move appropriately, so we can choose appropriate movement to expand its monitoring range, thus reducing the number of SSA drones and reducing the cost. In order to make up for the difficulty that the SSA drone's mobile range is too small to contact the EOC, we need to arrange a certain number of relay drones between the SSA drone and the EOC. This requires a trade-off between the number of SSA drones and the number of Radio Repeater drones, so that we can make a decision to communicate fire information effectively while keeping the cost within a reasonable range.

3.2 Build a model

In order to solve this problem, we build a mathematical programming class model, the number of the two types of drones was used as the decision variable. The objective function of the model is to minimize the total purchase cost, and the constraints include cruise surface area requirements, information transmission security requirements, speed and time requirements. We need to ensure the following constraints:

The sum of the monitored areas of SSA drone should not be less than the sum of the areas flown by SSA drone to ensure full coverage as far as possible.

Given the short range of SSA drones, the sum of the monitored areas of all Radio Repeater drones should not be less than the covered area and reduce repeated coverage.

Drones should be flown for less time than their maximum working hours.

At any time, the distance between the SSA drones and the Radio Repeater drones is less than 24km to ensure that the SSA drones can transmit information to the Radio Repeater drones.

At any time, the distance between the Radio Repeater drones is less than 20km to ensure the transmission of information between the Radio Repeater drones.

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3.3 Model solution

3.3.1 Segmentation and patrol mode of rectangular monitoring area

The objective function is to minimize the total number of deployed drones of the two types. What we need to decide is how many of the two types of drones we need to have in order to minimize the total.

The rectangular area was further divided into several regular hexagons, and one or two SSA drones were arranged in one regular hexagon area to inspect the fire situation. The longer the length of the hexagon side, the fewer hexagons in the fixed rectangle, otherwise, the shorter the length of the hexagon side, the more hexagons. If SSA drones can patrol a hexagonal area in a given period of time, it must be because the smaller the side length, the less SSA drones will be used. If the side is too long, an additional SSA drone may be required to assist in the task in order to complete the inspection within the specified time. Therefore, side length can help us quickly find a better initial solution.

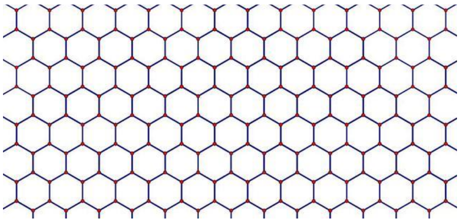

Figure 5. Divide a rectangular area

The SSA UAV starts its patrol from the center of gravity of each regular hexagon, and the patrol route is roughly as follows:

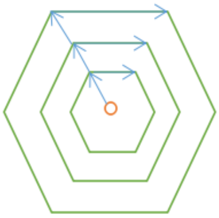

Figure 6 (a). The selection route of a drone

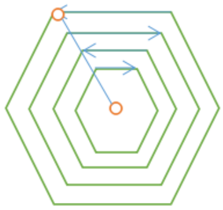

Figure 6 (b). The selection route of two drones

When an SSA drone is assigned to inspect each regular hexagon, all drones move in the same direction and at the same speed during the inspections. In other words, each SSA drone remains relatively stationary relative to other drones during the inspection, and the formation of drones fleet remains unchanged.

3.3.2 Segmentation and patrol mode of rectangular monitoring area

The following is to determine the length of a regular hexagon after the area is divided, so as to determine the size of the regular hexagon that the SSA drones is patrolling. The monitoring range of SSA drone is $2r = 8km$, and it can fly $x_{max} = 180km$ at the maximum speed. A represents the area of the regular hexagon. The distance traveled in the detection process is $n = S^{'}/2r$, the number of drones needed to patrol a regular hexagon is $k = n/x_{max}$. Considering that it takes 1.75 hours for the drones to charge, we used two batches of SSA drones for monitoring in rotation. After patrolling all areas, the number of SSA drones is:

$$N_{ssa} = \frac{\sum s_i \cdot k \cdot m_i}{S^{'}} \cdot 2 \quad (1)$$

Due to the short range of SSA drone, in order to timely transmit the fire information to EOC, we equipped each SSA drone with a Radio Repeater drone to follow and receive the information delivered by SSA drone at any time. The transmission of information between the Radio Repeater

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drones depends on the size of the regular hexagon we are dividing. When the length of the hexagon side is b, the area of the hexagon is:

$$S' = \frac{3\sqrt{3}}{2} \cdot b \tag{2}$$

Because the SSA has a range of only 4km and can fly a maximum distance of 30km, the maximum length of a regular hexagon is only 34km.

To ensure that the information collected by the Radio Repeater drones can be passed on, we set a hovering Radio Repeater drone at the center of each triangle. At this point, its farthest point from the triangle is 20km, which can ensure the maximum coverage of information between Radio Repeater drones. Therefore, the number of Radio Repeater drones is:

$$N_{re} = \frac{\sum s_i}{S'} \cdot 6 + N_{ssa} \tag{3}$$

Into the data: $N_{ssa} = 690, N_{re} = 1410$ That's 690 SSA drones and 1,410 Radio Repeater drones.

The positions of the two types of drones are shown in the figure, where the dotted blue line represents the position of the SSA drone, and the dotted blue line and yellow circle represent the position of the Radio Repeater drones.

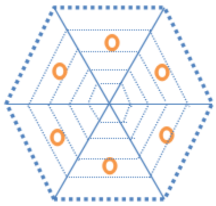

Figure 7. Location distribution of two types of drones at b=34km

When the length of the regular hexagon is reduced to 10km, it is not necessary to place the Radio Repeater drones in the center of each regular triangle forming the regular hexagon. As long as the Radio Repeater drone is placed at the center of the regular hexagon, the distance between the two adjacent Radio Repeater drones at the center of the regular hexagon is 17.32km, which is less than the range of the Radio Repeater drone and can meet the full coverage of the signal.

Therefore, the number of Radio Repeater drone is:

$$x_{re} = \frac{\sum s_i}{S'} \cdot 6 + x_{ssa} \tag{4}$$

Into the data: $N_{ssa} = 712, N_{re} = 1379$. That's 712 SSA drones and 1379 Radio Repeater drones.

The two drones positions are shown in the figure, where the dotted blue line represents the position of the SSA drone, and the dotted blue line and yellow circle represent the position of the Radio Repeater drone.

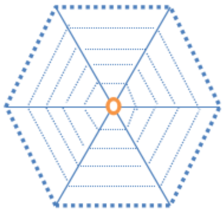

Figure 8. Location distribution of two types of drones at b=10km

When the length of the regular hexagon is reduced to 17.3km and the height of the regular hexagon is 30KM, it is not necessary to place the Radio Repeater drone at the center of each triangle, but only needs to place the Radio Repeater drone at 10km (D1 distance) due south of the SSA UAV (as shown in the figure):

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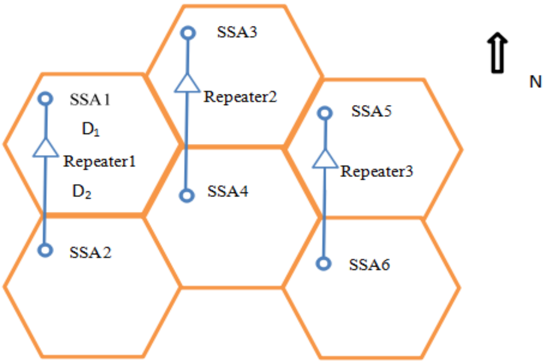

Figure 9. Location distribution of two types of drones at b=17.3km

At this time, the Radio Repeater drone is 10KM away from the SSA drone to the north and 20KM away from the drone to the south. At this time, the signal can be transmitted from the most north all the way to the most south at the same latitude. Therefore:

$$N_{ssa} = \frac{\sum s_i}{S'}, N_{ssa} = N_{re1} \tag{5}$$

Into the data: $S' = 777.58km^2, N_{ssa} = 461, N_{re} = 461$. That's 461 SSA drones and 461 Radio Repeater drones.

At this point, data can be transmitted from the far north to the far south, and the position of a Radio Repeater drone can be viewed as a third equal between its two northern and southern drones. When the Radio Repeater drone is in the third equinox of the north, the data can be sent from the north to the south. Obviously, when we put the Radio Repeater drone in the third equinox of the south, the information can be sent from the south to the north.

But our goal is to get the data to the EOC, and we look at the EOC as a point, and in order to get the data to a point, we also need to have the ability to send the data in the east-west direction. Since all the data listed in the north-south direction have been transmitted to the same latitude, we only need a east-west Radio Repeater chain to gather the data to a point at this time, as shown in the figure below:

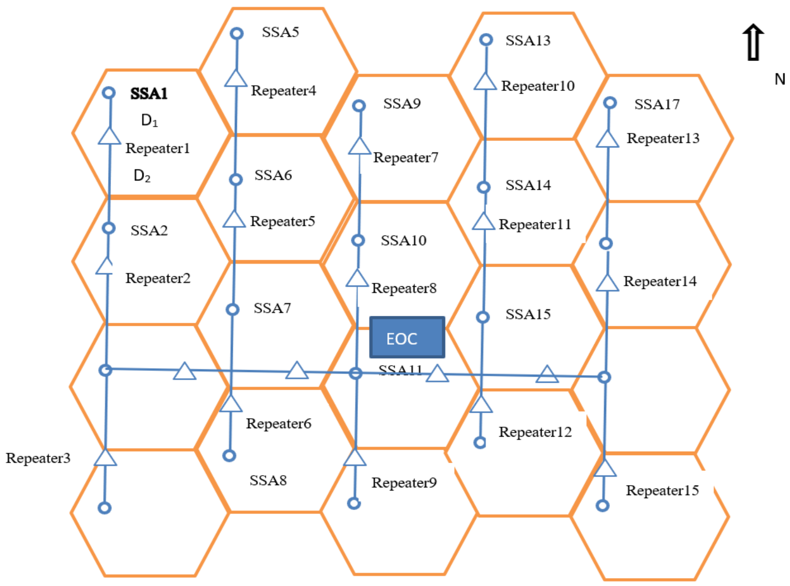

Figure 10. Location distribution of 2-dimensional Radio Repeater drone at b=17.3km

Assuming the map is square, the number of drones needed in the east-west direction is: $N_{re2} = \sqrt{461} \approx 22$

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We present the above three cases in table form:

Table 4. The number of drones in different situations

b	34	10	17.3
N_{ssa}	690	712	461
N_{re}	1410	1379	461

3.3.3 Model solution considering charging time and charging demand

When the length of the regular hexagon marking the cruising range was 17.3hr, each drone took 1.35 hours to complete a round of the hexagon and consumed 54% of the power. Assuming uniform charging speed, charged again need 0.945 hours. Comprehensive consideration of economy and safety. In the high fire have been patrolling SSA, cycle report for 1.35 hours. In the frequency region B, each SSA drones to patrol the again after charging 0.945 hours after touring again, report period of 2.295 hours. In the low frequency region fire C, after charging, the drone waits 0.705 hours before patrolling, and the reporting period is 3 hours.

Since high-frequency fire areas A are constantly being patrolled, the issue of drone rotation needs to be considered. The ratio of charging flight duration is defined as K= 2.5:1.75 =1.429. The number of SSA drones patrolling in areas A with high fire frequency at a certain time is N_{assa1}

$$N_{assa1} = \frac{S_A}{S} * N_{ssa} \tag{6}$$

Into the data: $N_{\text{assa1}} = 76$

In order to ensure reliable rotation, from an energy point of view, the number of alternate rotating SSA drones with ground charging drones should be greater than or equal to the energy consumed by airborne SSA drones, $N_{assa1} \leq N_{assa2} * 1.429$. In order to keep the number of SSA drones to a minimum, set equal here: $N_{\text{assa1}} = N_{\text{assa2}} * 1.429$

Into the data: $N_{\text{assa2}} = 54$

High fire frequency area A Radio Repeater drones are rotated with SSA drones, $N_{re3} = N_{\text{assa2}} = 54$

The total number of SSA drones needed in areas with high fire frequency is N_{assa3}

The total number of drones needed is $N = N_{ssa} + N_{re1} + N_{re2} + N_{re3} + N_{\text{assa2}} = 1052$

3.4 Conclusion

Through the above calculation, we find that:

(1) When the length of the regular hexagon is 34km, a total of 2,100 drones will be needed; When the length of the regular hexagon is 10km, a total of 2,091 drones are needed; When the length of the Hexagon is 17.3km, a total of 944 aircraft will be needed. Given that the cost of the two drones is the same, in order to achieve the lowest cost, we chose the division method of scenario three, dividing each region into regular hexagons with a side length of 17.3km to meet the economic requirements.

(2) The optimal combination of the two types of drones is 515 for the SSA drones and 483 for the Radio Repeater drones. In the regular hexagon, each Radio Repeater drones follows the SSA drones and establishes an east-west data transmission chain for the data repeater at a certain latitude.

(3) When we consider the impact of charging on quantity demand, the number of SSA drones is 515, the number of Radio Repeater drones is 537.

4. A study of the number and composition of drones under changing fire events

4.1 Fire event prediction

Under the trend of global warming, areas with low fire frequency may become areas with medium fire frequency and areas with high fire frequency in the future. We use AR prediction model and GNNM to forecast the number of fires in the next ten years.

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4.1.1 Build a model

Let the original data sequence be:

$$X^{(0)} = (x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), x^{(0)}(4)...... x^{(0)}(n))$$

Among them: $x^{(0)}(k) >= 0, k = 1,2,3...n$

Build GM(1,1) Model [3]:

$$x^{(0)}(k) + az^{(1)}(k) = b$$

Among them: $z^{(1)}(k)$ Represents the background value of the gray model. Estimated values of a and b were obtained by regression analysis, so the bleaching model is

$$x^{(1)}(t) = (x^{(1)}(1) - b/a)e^{-at} + b/a$$

Thus, the summation of the predicted values of the original sequence is obtained:

$$x^{(1)}(k+1) = (x^{(0)}(1) - b/a)e^{-ak} + b/a, k = 1,2,3...n$$

First order reduction of the above formula is carried out to get the predicted value: $x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k)$

TMPG (1,1) model is used to optimize the traditional grey prediction model, In the formula, a, b and c are parameters. $x^{(0)}(k) + az^{(1)}(k) = 0.5(2k-1)b + c$

$$x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1)$$

$$z^{(1)}(k) = 0.5(x^{(1)}(k) - x^{(1)}(k-1))$$

The results are as follows:

$x^{(1)}(k) = \frac{(1-0.5a)x^{(1)}(k-1) + bk - 0.5b + c}{1+0.5a}$, In the formula, a, b and c are estimated values of the three parameters, Predictive value is $x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k)$

MATLAB is used to predict the probability of fire occurrence in the eastern region of New South Wales and Victoria during 2021-2030.

In the model building of the first research, we divided the southeast corner of Australia into 10 areas according to the frequency and size of fire. Over the next 10 years, the likelihood of extreme fire events is changing. In order to better adapt to this change, we collect data on the area of fire in Australia from 1970 to 2019 [2].

Combined with climate change, AR prediction model and GNNM are used to predict the fire frequency and size in the next ten years. The frequency and size are quantified as the area burned by fires each year.

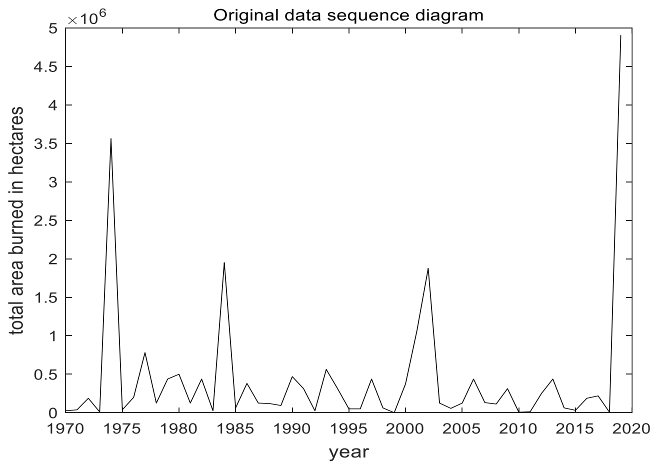

Figure 11. Australia fire area 1970-2019

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First of all, we make two differences for the overshot area data, and then compare the sequence diagram of the two differences with the original data.

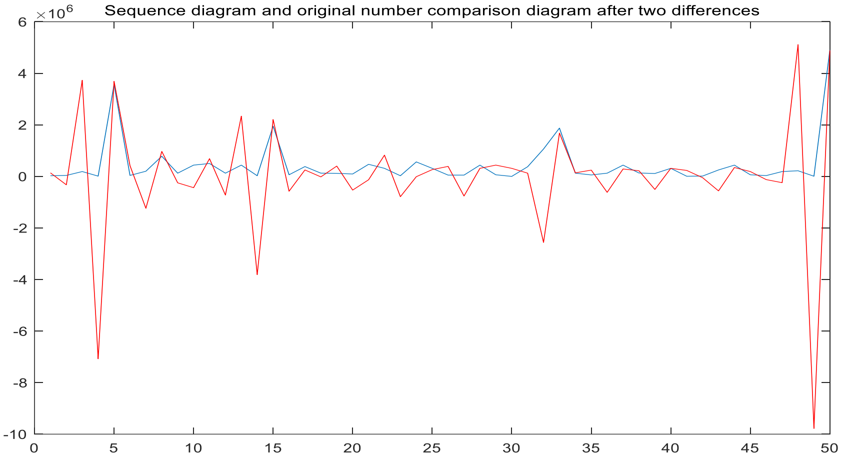

Figure 12. Area chart

Then we analyzed the data for analyzing coefficient of autocorrelation and partial correlation function, and the results of the two analyses are shown in the figure 13, 14:

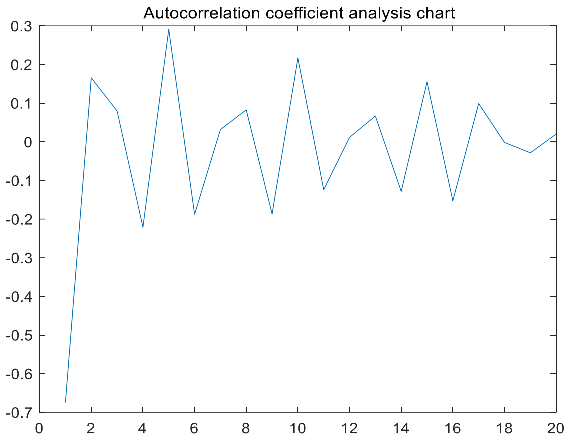

Figure 13. Coefficient of autocorrelation

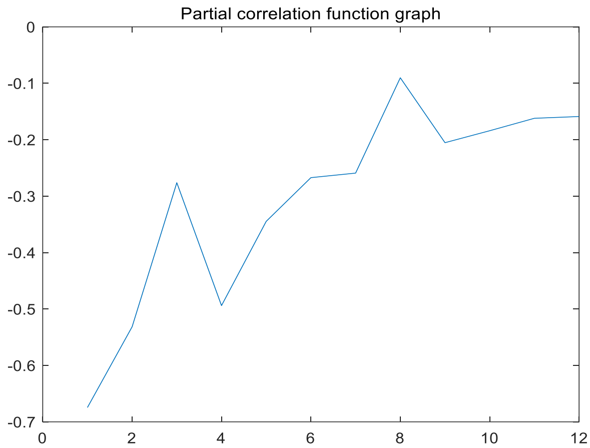

Figure 14. partial correlation function

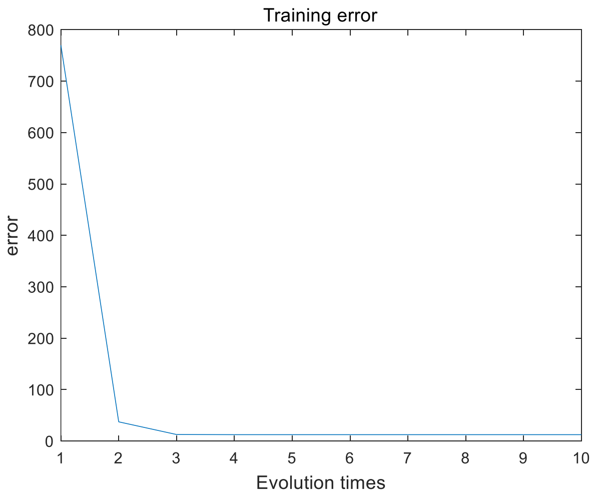

Figure 15. Evolution times and errors

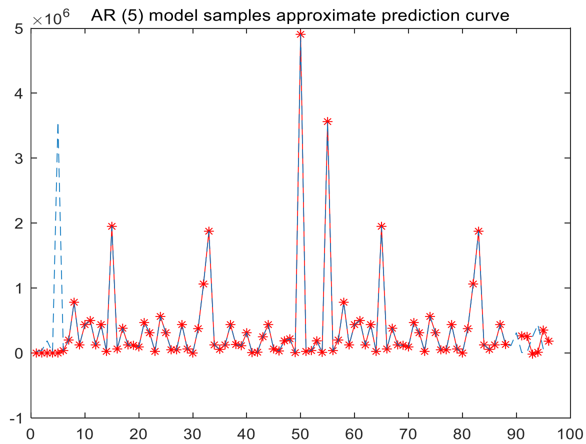

Figure 16. The AR(5) model sample approximates the prediction model

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Finally, combined with the grey neural network algorithm, after training the model for 10 times, the AR(5) model sample was obtained to approximate the prediction curve.

4.1.2 Model solution

We used the model to predict the annual area of wildfires in Australia over the next ten years, and concluded as follows:

Table 5. The number of drones in different situations

Particular year	2021	2022	2023	2024	2025
Total area burned in hectares	12200	32500	183200	304160	264480
Particular year	2026	2027	2028	2029	2030
Total area burned in hectares	90580	189850	16350	82150	65840

The result is a forecast chart of fire conditions from 2021 to 2030,and compared it to fires in the previous 50 years.

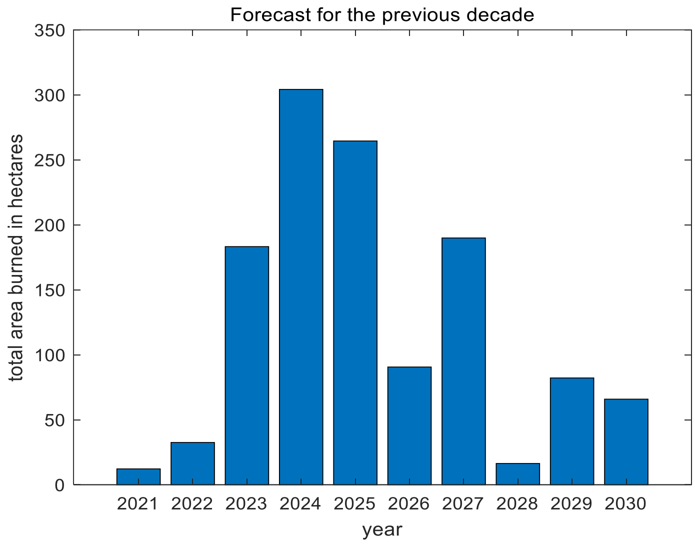

Figure 17. Fire prediction

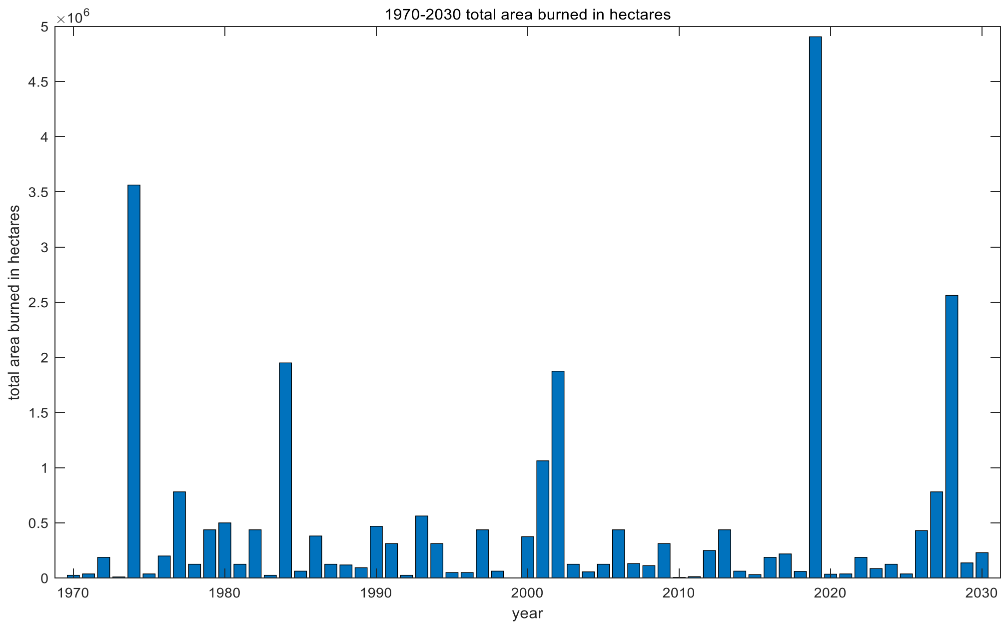

Figure 18. Area chart

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By looking at the size of fires in previous years, we found that the size of fires can be affected by a single fire. Assuming that the frequency of natural disasters such as fires obeys the Poisson distribution, the occurrence of such fires in 2019 is an accidental event. The data of nearly 50 years were put into the grey neural network algorithm, and the probability of a fire with an annual area larger than 2,019 fires in the next decade was 6.32%. Since the model established in the first research is based on the fire data in 2019, our model has been able to guarantee safety to a certain extent if more intense fires do not occur. But the forecast result is a 6.32 percent chance of more intense fires than in 2019.

The probability of a larger fire than that in 2019 is defined as a binomial distribution. The probability of a larger fire than that in 2019 is p=6.32%, and the probability of no larger fire than that in 2019 is q=1-p=93.68%.

In the binomial distribution, the probability of events occurring k times in n experiments is: $P\{X=k\}=C_n^k p^k q^{n-k}$

It is concluded that the probability of at least one fire occurring in the next one to ten years larger than that of 2019 is respectively

Table 6. Probability

nth year in the future	1	2	3	4	5
Probability of at least 1 major fire	0.0632	0.122406	0.17787	0.229828	0.278503
nth year in the future	6	7	8	9	10
Probability of at least 1 major fire	0.324102	0.366819	0.406836	0.444324	0.479442

4.2 Number and combination of drones in the future

Considering both safety and economy, we propose to increase the number of SSA drones for patrol in the third year for the first time, and increase the number of SSA drones in the seventh year. Three years later, the inspection period in areas with high fire frequency in the first research is reduced to one hour, to two hours in areas with high fire frequency, and to 2.7 hours in areas with low fire frequency. When the period is reduced to one hour, the analysis is made according to the model of the first research:

The area that drones can patrol in an hour is $s=2rvt=576km^2$, The length of the hexagon is $14.89km$, the number of SSA drones required for one patrol in areas with high fire frequency is 112.

In the case of a fire, area B with high fire frequency still maintains a 17.3km hexagon formation, requiring 225 SSA drones, the number of SSA drones needed in area C with low fire frequency is 143. These SSA drones need to be equipped with 368 Radio Repeater drones. In order to rotate the SSA drones in frequency area B of the fire, the first research has a model $225\times 1.35=225\times 0.65\times\frac{2.5}{1.75}+2\times\frac{2.5}{1.75}\times c$, where C is the number of drones to be rotated. The total number of drones needed is 112+112+79+225+143+368+34=1073.

Table 7. The summary table

	Region A	Region A	Region A	Summary
SSA drones	112	225	143	480
Radio Repeater drones	112	225	143	480
SSA for rotation	79	34	0	113
Summary	303	484	286	1073

Seven years later, we reduce the inspection period of high-frequency areas A in the first survey to 0.8 hours. Reduce the patrol period of frequency area B in fire to 1.7 hours. Reduce the patrol period in areas C with low fire frequency to 2.5 hours. The analysis process is consistent with the analysis process three years later, and is brought into the model.

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Table 8. The summary table

	Region A	Region A	Region A	Summary
SSA drones	112	225	143	480
Radio Repeater drones	112	225	143	480
SSA for rotation	79	34	0	113
Summary	303	484	286	1073

5. Optimize the location of VHF/UHF radio-repeater drones

5.1 Model analysis

In order to obtain the optimal location of the Radio Repeater drones for different fires of different sizes in different terrains, the planning goal is to minimize the number of drones. We use tree structure to establish information transmission route to optimize the path, as shown in the figure below:

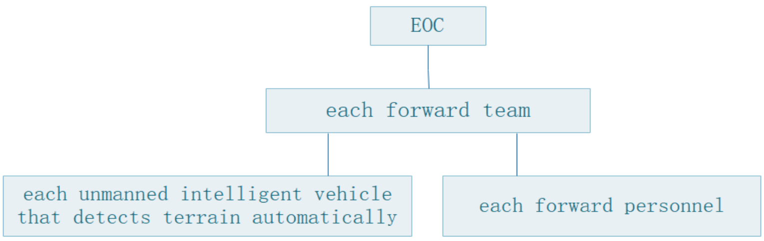

Figure 19. Message route

Between the forward team and the front line personnel, it can be converted into a relay drone to cover the longest line of fire. On the information route from EOC to the forward team, the position of the forward team is relatively scattered, which can be converted into the problem of the shortest information transmission path.

5.2 Build a model

Where there is a fire, the larger the area of the fire, the more front-line personnel are needed, and the more relay drones are needed between the front-line personnel and the forward team. Assuming that the fire area is circular, each front line personnel can detect the fire-line is $L(L << 2km)$, measure the size of a fire by the size of its area. When the fire area is S_h, the length of the wire is $L_t = S_h/\pi$. Let the proportion of mountain area in the fire area be W. Let the fire area be R, the distance between the Radio Repeater drones and the fire edge be d, and the coverage range of the handheld two-way radios communication of front-line personnel be r. r is a function of W r=(W)

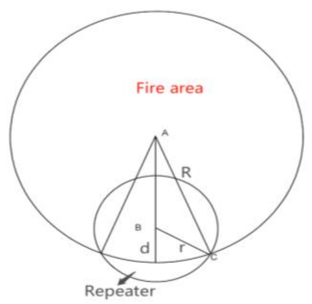

Figure 20. Dynamic figure

First of all, it is clear that the drones should be tested in the circular disaster area. Based on this analysis, in the mountainous area, when the fire radius is less than r, the Radio Repeater drones should

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be in the center of the fire. When the fire radius is greater than r, in triangle ABC, $A = arccos(\frac{R^2+(R-d)^2-r^2}{2R(R-d)})$.

In a fire, the r at a point is determined by the topography. When R, S_h is constant and A reaches the maximum, the relay drone can radiate the longest fire line. The number of relay drones is minimal at this point, we get the target function:

$$max\ F\ (R, r, d) = arccos(\frac{R^2+(R-d)^2-r^2}{2R(R-d)}) \tag{7}$$

The number of Radio Repeater drones is:

$$N_{re5} = \frac{2\pi}{max\ F(R,r,d)} \tag{8}$$

A particle swarm optimization algorithm was established to solve the objective function.

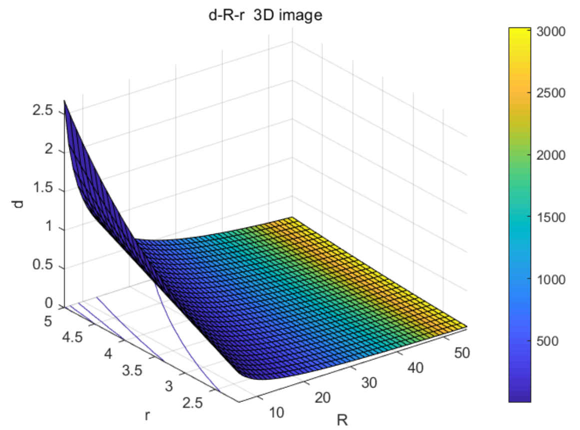

Figure 21. d-R-r 3D image

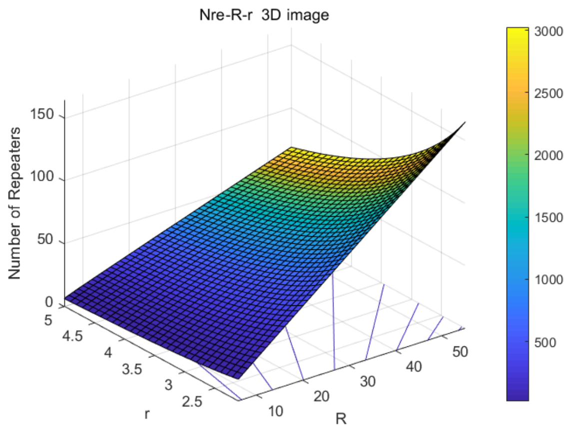

Figure 22. Nre-R-r 3D image

In order to facilitate observation, the three-dimensional image is decomposed into two-dimensional observation.

When r=2: the optimal position of Radio Repeater drones changes with the fire area as shown in the figure:

The number of drones needed at this time is shown in the figure below:

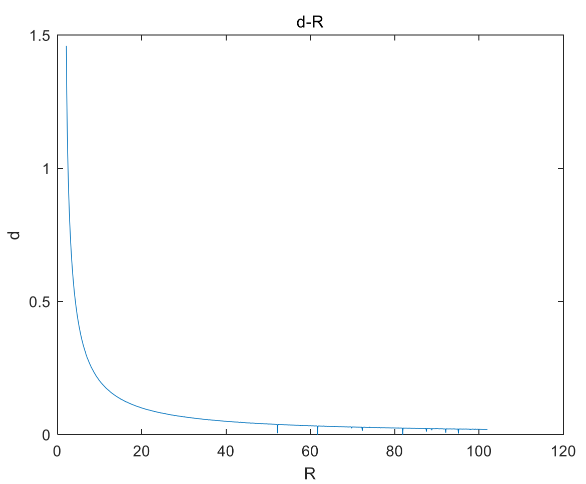

Figure 23. Location varies with fire area

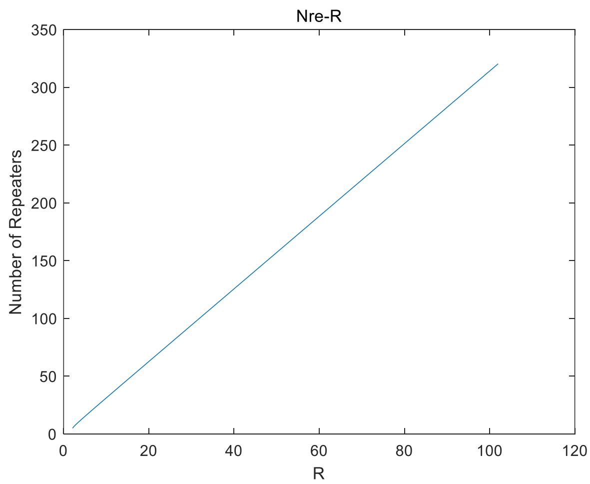

Figure 24. The number of drones

The three-dimensional image is shown below:

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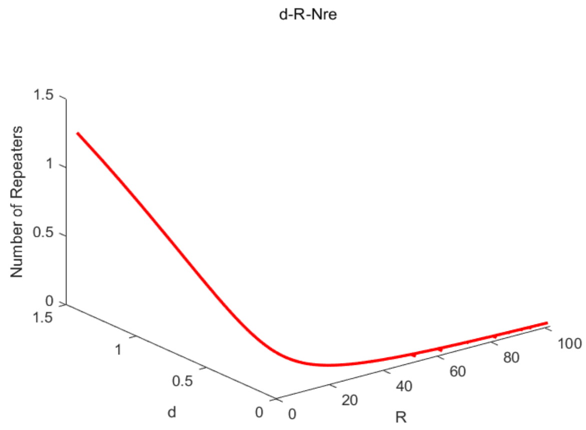

Figure 25. Number of Repeaters

When r=20: the optimal position of Radio Repeater drones changes with the fire area as shown in the figure:

The number of drones needed at this time is shown in the figure 26, 27:

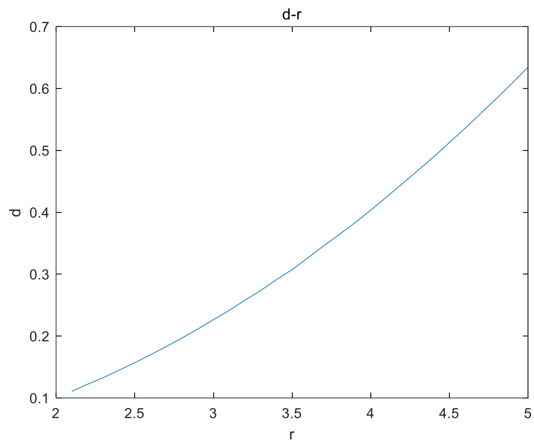

Figure 26. Location varies with fire area

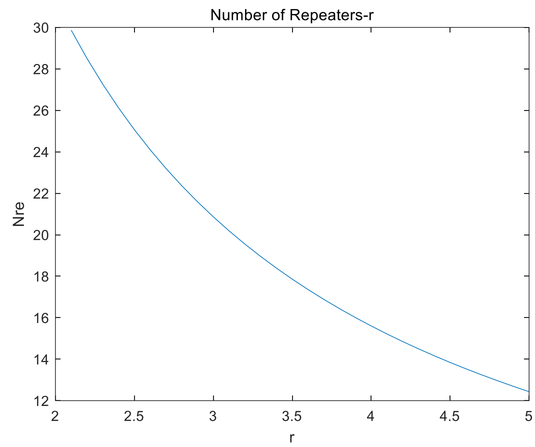

Figure 27. The number of drones

The three-dimensional image is shown below:

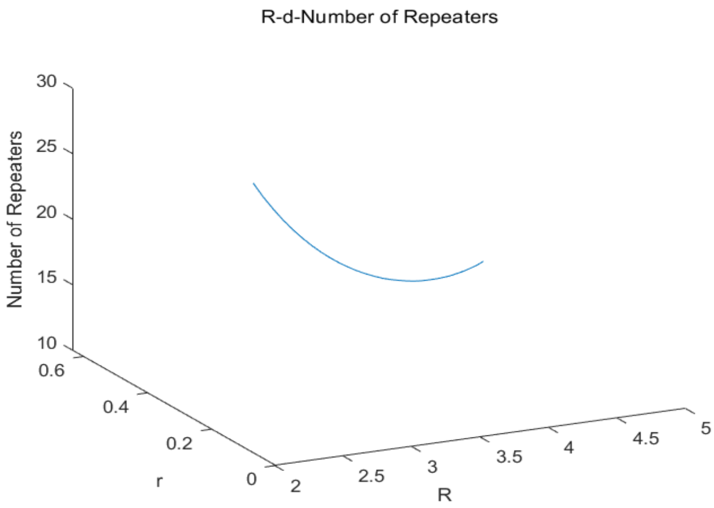

Figure 28. Number of Repeaters

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5.3 Route of EOC to Forward Team Repeater

Since the map of the state is roughly rectangular, long from east to west and narrow from north to south, we set up an EOC in the east and west to manage the forward teams in the east and west respectively.

The first consideration is to establish the shortest path between the forward team and the EOC, combined with the data of fires in previous years. We selected 31 forward team positions to be responsible for the control of 31 areas. The number of front line personnel under each forward team was determined by the size of the fire and the terrain where the fire occurred. After the forward team position is determined, the immune optimization algorithm can be used, determine the optimal route of EOC- forward team information transmission. The forward team-front personnel communication route is determined by the size of the fire and the terrain in which the fire occurred. We can get the total number of relay drones.

5.4 Model solution

This model is a site selection model that needs to find the shortest path for EOC from n points of demand and send information to each forward team.

Establish the coordinate system according to the scale of (1:23.25), as shown in the figure:

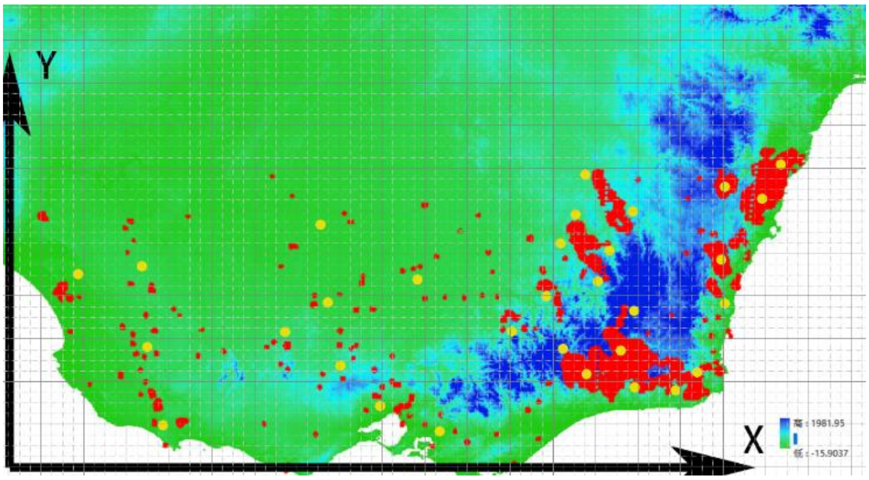

Figure 29. Forward team position

The yellow point is the position of the selected forward team, and its coordinate is:

Table 9. The position of the selected forward team

Number	2	3	4	5	6	7	8
X coordinate	13.67	14.33	15.33	27.00	30.67	31.33	32.17
Y coordinate	20.33	13.00	5.33	13.83	23.67	17.00	11.33
Number	10	11	12	13	14	15	16
X coordinate	38.67	41.33	48.17	51.00	52.17	53.00	53.33
Y coordinate	19.00	4.67	13.83	17.17	22.50	13.00	26.33
Number	18	19	20	21	22	23	24
X coordinate	55.00	55.67	57.00	58.00	58.67	59.33	59.67
Y coordinate	11.33	19.00	21.67	13.00	25.67	14.67	9.33
Number	26	27	28	29	30	31	
X coordinate	65.33	67.33	67.33	68.00	70.67	73.50	
Y coordinate	10.33	21.33	28.00	16.33	26.33	29.33	

Through the immune optimization algorithm, the selection position of EOC was obtained as follows:

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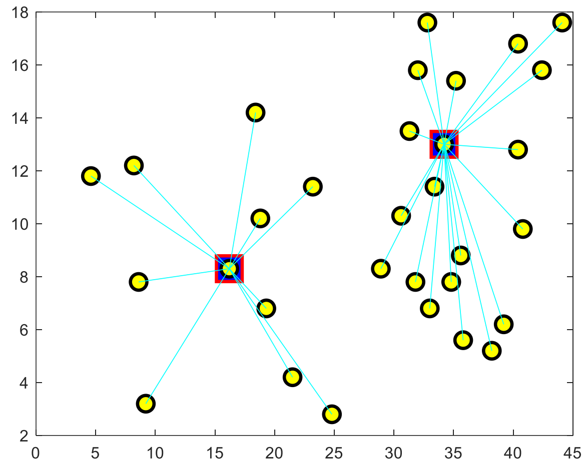

Figure 30. The selection position of EOC

In the figure, the red box points are the two EOC positions, and the blue thin line represents the line between the forward team and EOC. The data records in the iteration process are as follows:

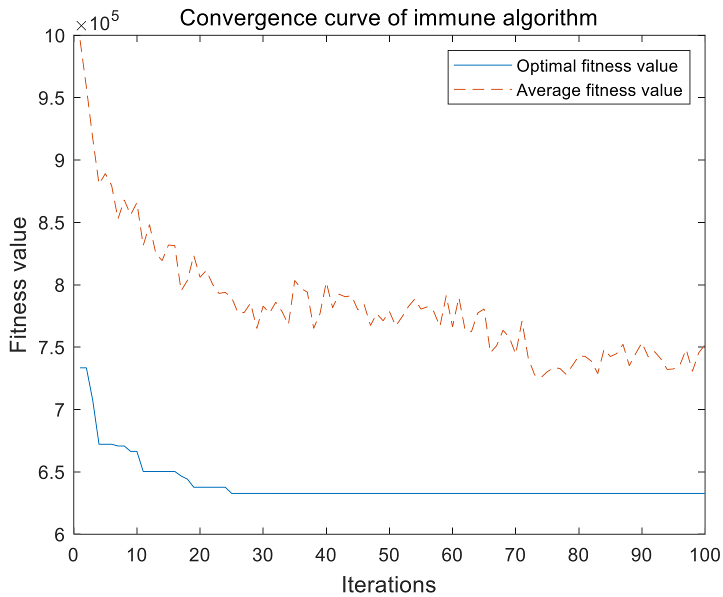

Figure 31. Data records in the iteration process

Table 10. The distance from each point to EOC

Forward team number	1	2	3	4	5	6	7	8
Distance	281.71	206.93	177.08	201.36	0.00	146.40	74.87	80.07
Forward team number	9	10	11	12	13	14	15	16
Distance	155.79	178.00	237.34	164.70	104.63	68.42	133.16	82.79
Forward team number	17	18	19	20	21	22	23	24
Distance	111.79	146.83	41.59	0.00	121.70	60.45	102.93	176.03
Forward team number	25	26	27	28	29	30	31	
Distance	203.81	196.24	144.22	169.07	170.54	201.46	253.81	

Once again, the immune optimization algorithm is used to obtain the repeater network diagram as follows: (The circle in the image is EOC) (see figure 32)

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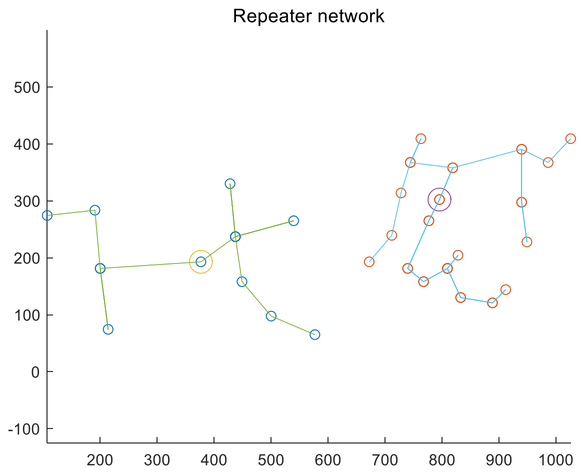

Figure 32. Repeater network diagram

There are 29 routes of the Radio Repeater drones in the figure, and the distance of each route is calculated as follows:

Table 11. The distance of each route

Number of the line segment	1	2	3	4	5
Distance	84.22	102.72	107.86	177.08	74.87
Remove the forward team's own communication range	74.22	92.72	97.86	167.08	64.87
Number of the line segment	4	5	5	9	4
Distance	6	7	8	9	10
Remove the forward team's own communication range	93.46	106.04	79.90	79.19	83.34
Number of the line segment	83.46	96.04	69.90	69.19	73.34
Distance	5	5	4	4	4
Remove the forward team's own communication range	11	12	13	14	15
Number of the line segment	61.03	76.16	55.90	45.80	74.98
Distance	51.03	66.16	45.90	35.80	64.98
Remove the forward team's own communication range	3	4	3	2	4
Number of the line segment	16	17	18	19	20
Distance	60.45	41.59	91.59	36.32	47.87
Remove the forward team's own communication range	50.45	31.59	81.59	26.32	37.87
Number of the line segment	3	2	5	2	2
Distance	25	21	22	23	24
Remove the forward team's own communication range	125.21	29.77	56.19	56.57	32.88
Number of the line segment	115.21	19.77	46.19	46.57	22.88
Distance	6	1	3	3	2
Remove the forward team's own communication range	26	27	28	29	
Number of the line segment	93.00	70.37	51.99	57.56	
Distance	83.00	60.37	41.99	47.56	
Remove the forward team's own communication range	5	4	3	3	

A total of 109 Radio Repeater drones will be needed.

6. Sensitivity Analysis

The third research is that the range of the hand-held two-way radio will affect the conclusion of the question. We might as well change its sending and receiving range in the urban area to 1km, 3km, 4km, and analyze the variation of the results. As the transceiver range increases, the number of Radio Repeater needed will slowly decrease; With a smaller range, the number of Radio Repeater needed will increase dramatically.

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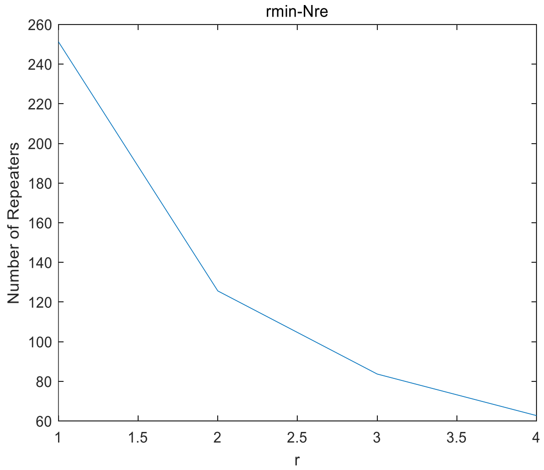

Figure 33. Number of repeaters

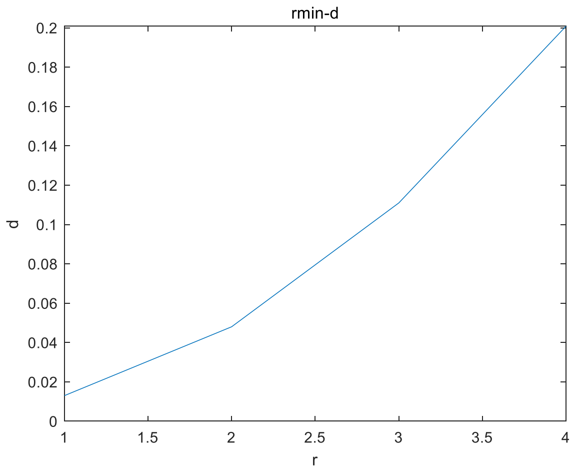

Figure 34. Min-d

7. Advantages and Disadvantages

7.1 Advantages

1. The property that regular hexagon can be densely spread on the plane can be skillfully used, which can not only guarantee the continuity of information transmission of drones, but also avoid the waste of drones resources;

2. Using more intelligent algorithms, the solutions are innovative

7.2 Disadvantages

1. In the second research, there are too few reference data and the prediction is not accurate enough

2. The algorithm idea of the model established in research three is too complicated, and multiple algorithms need to be combined to get the calculation result, which will lead to a long calculation process

8. Conclusion

This paper examines the number, composition and location of SSA and Radio Repeater drones involved in the transmission of fire information in the context of communication problems in fighting fires in eastern Victoria. The information transmission network is laid by the regular hexagon which can be densely spread on the plane. AR prediction model and grey neural network model are used to predict the number of fires in the next ten years. The immune algorithm is used to optimize the location of VHF/UHF radio-repeater drones to effectively realize the transmission of forest fire information.

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[3] Lin Deng, Qiuzhu Chen, Chao Chen, Application of improved hybrid immune algorithm in location of logistics distribution center[J].Neijiang technology, 2020,41(12):49-51+113.