The Study on Aircraft Search and Rescue Technology for Nuclear Power Plant Accident based on C4ISRE Integrating Ant Colony Algorithm

Yunfeng Ma¹, Yue Shen²*, Bairun Feng³, Fan Yang⁴, Xin Zhen¹, Qiangqiang Li¹, Boying Du¹, Qiongqiong Hu¹, Yushan Bian¹, Hang Yin⁴, Qi Wang¹ and Xiaomin Hu²
¹Shenyang Aerospace University, College of Energy and Environment, 110136 Shenyang, China;
²Northeastern University, College of Resources and Civil Engineering, 110819 Shenyang, China;
³The Air Force Military Agent's Room in Shenyang area, 110016 Shenyang, China;
⁴Shenyang Aerospace University, Technology Department, 110136 Shenyang, China

ABSTRACT

When the nuclear emergency accident occurs, it was very important to search and rescue survivors scientifically and reasonably. So, taking the Hongyanhe Nuclear Power Plant for example, based on C4ISRE, the optimize path for search and rescue was deduced successfully. Experiments showed that the optimize path was 1→2→3→5→4→7→13→15→12→11→9→14→10→8→6→1 and the shortest path length was 4607.6854 m. Evacuation times for adult, child and old man were about 80s, 145s, and 192s respectively in the area (number 1); Evacuation time for adult, child and old man were about 40s, 72s and 96s respectively in the area (number 2); Evacuation time for adult, child and old man were about 95s, 172s and 228s respectively in the area (number 3); Evacuation time for adult, child and old man were about 143s, 260s and 345s respectively in the area (number 4); Evacuation time for adult, child and old man were about 20s, 36s and 48s respectively in the area (number 5); Evacuation time for adult, child and old man were about 20s, 36s and 60s respectively in the area (number 6). About the area 4, it was the most time-consuming area for child and old man evacuation, so professional rescue staff (such as special police or special forces) and special vehicles should be deployed in this area in order to ensure effective evacuation for child and old man. C4ISRE provided a new and effective technical approach for emergency rescue of nuclear accident which could enhance nuclear emergency preparedness response capabilities and organizational efficiency.

INTRODUCTION

On March 11, 2011, the Fukushima Dai-ichi Nuclear Power Plant was struck by the Pacific Ocean Earthquake, which developed into a very serious nuclear accident affecting vast areas. To assess the scope of influence of radioactive substances diffused which spread in a wide area, the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) and U.S. Department of Energy (DOE) conducted joint aerial radiation monitoring (ARM) within an 80 kilometers in radius of the NPP. The widespread distribution of radionuclides can be measured in a short time with less man power; contour maps of the deposition of the radioactive cesium can be depicted.
The radioactivity can be measured in the areas which people cannot come into easily, such as mountains and forests[1]. Air vehicles used by Japan were shown in TABLE I.

In contingency management, aerial vehicles can provide a very important support and the flight trajectory planning was one of key technology for search and rescue, furthermore, the Ant Colony Algorithms (ACA) was one of the method for flight trajectory planning, which can deal with raveling salesman problem (TSP) successfully. In this paper, the search and rescue simulation would be fulfilled by C4ISRE integrated ACA.

C4ISRE — Command, Control, Communications, Computer, Intelligence, Surveillance, Reconnaissance, Environmental Assessment, i.e. Environmental Protection Command Automation System[2-4]. C4ISRE were human-computer discrete event dynamic systems which synthetically utilized modern information network technology and environmental science theory whose core was C4ISR theory in order to realize the relative EA information’s automatic management on collection, transference and analysis. C4ISRE were highly-efficient complicated systems which could fulfill the control, management, simulation and forecast of the related information in EA.

### TABLE I. AIR VEHICLES USED BY JAPAN.

<table>
<thead>
<tr>
<th>Items</th>
<th>Manned helicopter</th>
<th>Unmanned airplane</th>
<th>Unmanned helicopter</th>
<th>Multicopter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of aircraft</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detector</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight Altitude</td>
<td>~ 300m</td>
<td>150m</td>
<td>80m</td>
<td>&lt;10m</td>
</tr>
<tr>
<td>Air Speed</td>
<td>185 km/h</td>
<td>100km/h</td>
<td>30km/h</td>
<td>7km/h</td>
</tr>
<tr>
<td>Flight Time</td>
<td>120 min</td>
<td>360min</td>
<td>90min</td>
<td>20min</td>
</tr>
<tr>
<td>Max. Payload</td>
<td>&gt; 100 kg</td>
<td>10kg</td>
<td>10kg</td>
<td>3kg</td>
</tr>
<tr>
<td>Flight Range</td>
<td>~ 100 km</td>
<td>&gt;10km</td>
<td>&lt;3km</td>
<td>&lt;1km</td>
</tr>
</tbody>
</table>

### EXPERIMENTAL METHOD

**Ant Colony Algorithm**

In some processor, the probability for ant selecting one task was defined as [5-7]:

$$
    p_{ij}^{k} (\text{iter}, \text{iter}) = \left[ \tau_{ij} (\text{iter}) \right]^\alpha \cdot \left[ \eta_{ij} (\text{iter}) \right]^\beta / \sum_{S \in \text{RT}_k} \left[ \tau_{ij} (\text{iter}) \right]^\alpha \cdot \left[ \eta_{ij} (\text{iter}) \right]^\beta
$$

(1)

where
- k was ant number,
- iter represented iteration,
- RT_k represented the list of remaining targets yet which be not searched and rescued by the ant,
- \( \tau_{ij} \) (tau) was the sum of pheromone value,
- \( \eta_{ij} \) (eta) was the heuristic function,
- \( \alpha \) (alpha) were the pheromone trials control parameters,
\( \beta \) (beta) were the heuristic function control parameters.

The kth ant lays down on the edge the pheromone value was defined as:

\[
\Delta \tau_{ij,k}(\text{iter}) = \frac{Q}{LR_k(\text{iter})}
\]

(2)

where

\( R_k(\text{iter}) \) represented the route of the ant k at iteration t,
\( LR_k(\text{iter}) \) represented the length of \( R_k(\text{iter}) \).

Pheromone update formula was defined as:

\[
\tau_{ij}(\text{iter} + 1) = (1 - \rho) \tau_{ij}(\text{iter}) + \sum_{k=1}^{m} \Delta \tau_{ij,k}(\text{iter})
\]

(3)

where

\( \rho \) (rho) represented evaporation coefficient,
\( m \) represented the number of ants.

The major pseudo code coded in MATLAB environment (R2012a) were as follows:

```
...... while iter <= iter_max
    start = zeros(m,1);
    for i = 1:m
        temp = randperm(n);
        start(i) = temp(1);
    end
    Table(:,1) = start;
    targets_index = 1:n;
    for i = 1:m
        for j = 2:n
            tabu = Table(i,1:(j - 1));
            allow_index = ~ismember(targets_index,tabulist);
            allow = targets_index(RTk_index);
            P = RTk;
            for k = 1:length(RTk)
                P(k) = Tau(tabulist(end), RTk(k))^alpha * Eta(tabulist(end),RTk(k))^beta;
            end
            P = P/sum(P);
            Pc = cumsum(P);
            Rescu_targets_index = find(Pc >= rand);
            Rescu_targets = allow(Rescu_targets_index (1));
            Table(i,j) = Rescu_targets;
        end
    end......
```

The Composition of C4isre System

Physical composition of C4ISRE system was shown in Figure 1.

Arma3 was the latest premier award-winning tactical military simulation system developed by Bohemia Interactive. Set in a massive Mediterranean sandbox of over 290 km², featuring 40+ weapons and 20+ vehicles, Arma3 provided an authentic, diverse and open combat experience – supported by a wide variety of single player and multiplayer gameplay [8].
NUCLEAR EMERGENCY PREPAREDNESS EXERCISES SCENARIO DESIGN

Simulated Region

The experiment parameters for scenario were set based on Arma3 (TABLE II).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>StartTime</td>
<td>201706241200</td>
</tr>
<tr>
<td>Civilian</td>
<td>20</td>
</tr>
<tr>
<td>Aircraft</td>
<td>1</td>
</tr>
<tr>
<td>Weather condition1</td>
<td>Sunny day</td>
</tr>
<tr>
<td>Weather condition2</td>
<td>Rainy day</td>
</tr>
<tr>
<td>wind direction1</td>
<td>Southeast wind</td>
</tr>
<tr>
<td>wind direction2</td>
<td>Southeast wind</td>
</tr>
<tr>
<td>wind power1</td>
<td>2m/s</td>
</tr>
<tr>
<td>wind power2</td>
<td>8m/s</td>
</tr>
</tbody>
</table>

Aircraft Search and Rescue

The temporary evacuees placements for emergency planning area of Hongyanhe Nuclear power plant were set on the basis of Regulations on Emergency Measures for Nuclear Accidents at Nuclear Power Plants, Contingency Measures for Unexpected Events, Guideline on Emergency Exercises for Unexpected Events and Regulations on Nuclear Emergency Preparedness Exercises (shown in Figure 2).
The points were as follows: point 1(2765 X,18844 Y), point 2(3097 X,19208 Y), point 3(2874 X,19448 Y), point 5(2903 X,19742 Y), point 6(2903 X,19742 Y), point 7(2333 X,20281 Y), point 8(2109 X,19967 Y), point 10(1813 X,20377 Y), point 11(2057 X,20297 Y), point 12(2199 X,20356 Y), point 13(2369 X,20379 Y), point 14(1927 X,20458 Y), point 15(2276 X,20446 Y).

RESULTS AND DISCUSSION

The optimize path was figured out by matlab on basis of ant colony algorithm (shown in Figure 3 and Figure 4) and the situation analysis for personnel evacuation deployment on basis of the optimize path was shown in Figure 5.
As seen in Figure 3 and Figure 4, the optimize path was 1→2→3→5→4→7→13→15→12→11→9→14→10→8→6→1 and the shortest path length was 4607.6854m. Taking 1→2→3 for example, the evacuation situation analysis were shown in Figure 5, there were 3 evacuation areas (Area 1, Area 2 and Area 3).
Area 3) based on the optimize path (1→2→3) and the evacuation plans for these areas were as follows:

The evacuation plans for Area1: Area1 consisted of reception center, hotel, swimming pool and gymnasium, and the hotel was the most important search and rescue targets. The distance was about 160m between hotel (number 1) and the optimize path, the evacuation azimuth was about 72 degree (clockwise) deduced by Arma3. Hypothesis that the moving speed of adults was about 2m/s, the moving speed of child (about 10 years old) was about 1.1m/s and old man's (about 60 years old) speed was 0.83m/s, so the time for adult to evacuate to the optimize path was about 80s, the time for child was about 145s and the time for old man was about 192s.

The evacuation plans for Area2: Area2 consisted of 10 dormitory buildings, where many important personnel (such as employees, old mans and children) lived. The distance was about 80 m between dormitory building area (number 2) and the optimize path, the evacuation azimuth was about 276 degree (clockwise). So, the evacuation time for adult, child and old man were about 40s, 72s and 96s respectively. For the dormitory building area (number 3), the evacuation time for adult, child and old man were about 95s, 172s and 228s respectively because of the distance 190m far away from the optimize path with the evacuation azimuth 270 degree (clockwise). As for dormitory building area (number 4) whose distance was about 283m far away from the optimize path, the evacuation time for adult, child and old man were about 143s, 260s and 345s respectively.

The evacuation plans for Area3: Area3 consisted of 11 dormitory buildings, which were divided into two areas (number 5 and number 6). The distance was about 40 m far away from the optimize path about the buildings (number 5), the evacuation azimuth was about 71 degree (clockwise), so the evacuation time for adult, child and old man were about 20s, 36s and 48s respectively. For the buildings (number 6), the distance was about 60 m far away from the optimize path, the evacuation azimuth was about 257 degree (clockwise), so the evacuation time for adult, child and old man were about 20s, 36s and 60s respectively.

Comprehensive analysis was shown in Figure 6.

![Figure 6. Analysis for evacuation time.](image)

As can be seen from the Figure 6, the area 4 was the most time-consuming area for child and old man evacuation, so, professional rescue staff (such as, special police or special forces) and special vehicles should be deployed in this area in order to ensure effective evacuation for child and old man. Because the aircraft would search and
rescue along the optimize path preferentially instead of along the highway, it was most important that all staffs should evacuate along the optimize path in order to improve the efficiency of being searched and rescued.

CONCLUSIONS

a) Based on C4ISRE, the optimize path for search and rescue was deduced successfully, and then, the actual effect of rescue was simulated by the Arma3 which was the one of components of C4ISRE, so this simulation method provided a new and effective technical approach for emergency rescue of nuclear accident.

b) The optimize path was 1→2→3→5→4→7→13→15→12→11→9→14→10→8→6→1 and the shortest path length was 4607.6854 m. Taking 1→2→3 for example, evacuation times for adult, child and old man were about 80s, 145s, and 192s respectively in the area (number 1), evacuation time for adult, child and old man were about 40s, 72s and 96s respectively in the area (number 2), evacuation time for adult, child and old man were about 95s, 172s and 228s respectively in the area (number 3), evacuation time for adult, child and old man were about 143s, 260s and 345s respectively in the area (number 4), evacuation time for adult, child and old man were about 20s, 36s and 60s respectively in the area (number 5), evacuation time for adult, child and old man were about 20s, 36s and 60s respectively in the area (number 6).

c) About the area 4, it was the most time-consuming area for child and old man evacuation, so, professional rescue staff (such as, special polices or special forces) and special vehicles should be deployed in this area in order to ensure effective evacuation for child and old man.

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