An adaptive ant colony evacuation model based on CCRP optimization algorithm

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Abstract. With the occurrence of terrorist attacks in tourist attractions, safe and efficient population evacuation scheme becomes very important. Effective evacuation plan can reduce casualties and economic losses, and more reasonable and scientific evacuation plan is of great significance. At present, most of the existing evacuation algorithms are for Single-storey buildings. Even for multi-storey buildings, they can not take into account the types of tourists and some additional interference factors in evacuation, and can not accurately estimate the shortest evacuation time needed, and can not be widely applied to various buildings. To solve these problems, an adaptive ant colony model based on CCRP optimization algorithm is proposed to help Louvre visitors escape from danger effectively in terrorist attacks. In this paper, the shortest escape time is accurately predicted, and the simulation results are basically consistent with the results of the model. Finally, three landmark buildings, Elements Museum in Austria, Student Apartment in Switzerland and Wal-Mart, are solved, which further illustrates the validity and universality of the model.

1. Introduction
Large public occasions such as cinemas, shopping malls, tourist attractions and gymnasiums have the characteristics of high concentration of people and large flow of people. When people need to evacuate in case of accidents, the structure of each group is different, and there are various interference factors when people escape. These are all the factors that need to be taken into account when a large number of people evacuate safely and quickly in public places. This is what we need to consider.

We are committed to providing a more general and practical model for traditional evacuation schemes, and consider as much as possible the impact of tourist types and interference factors on escape time in the process of evacuation. Especially, the idea of optimal path goal planning is added to the estimation of escape time, which makes the evacuation model more scientific.

With the development of urbanization, the density of buildings and population is increasing rapidly. Reasonable and effective evacuation plan is of great significance to reduce casualties and property...
losses. In recent years, countries around the world have increased their investment and Research on evacuation, mainly in mathematical analysis and computer simulation.

However, in the traditional evacuation plan, there are many problems gradually exposed. Up to now, more than 20 successful evacuation models and corresponding calculation software have been developed by foreign scholars. Among them, the more famous ant colony algorithm ASA was first proposed by Dorigo, V. Manizzo, A. Colo RNI et al [1]. This algorithm has strong robustness and has been widely used in the field of combinatorial optimization such as traveling salesman [2-3]. However, the traditional ant colony algorithm has some problems, such as too long search time, premature and easy to stagnate. An adaptive ant colony algorithm based on dynamic pheromone updating [4]. Traditional ant colony algorithm provides a basis for the process of evacuating tourists and has advantages in expressing individual behavior, but it is not fully reflected in the information and subjective will of individuals, which is quite different from the actual situation [5]. The performance evaluation of various network structures shows that CCRP algorithm has very high calculation. At the same time, it has the ability of high efficiency and high quality solutions [6].

Finally, we consider the impact of the type of evacuees, the details of individual behavior and the interaction between individuals on the overall evacuation time, and propose an adaptive evacuation scheme based on CCRP optimization algorithm.

The organizational structure of this paper is as follows: Section 2 first introduces the overall structure and problems of the traditional evacuation model. Section 3 begins to describe the application of CCRP optimization algorithm in evacuation model. The fourth section describes the results of the study and the analysis of adaptability evaluation. The last section summarizes the previous content.

2. Structure of Traditional Evacuation Adaptive Model

Traditional ant colony algorithm was proposed by Marco Dorigo in his doctoral dissertation in 1992. Because the process of dynamic evacuation of tourists to find the optimal path in unexpected escape is very similar to that of ant foraging, the steps are as follows:

The main steps of the ant colony algorithm: Firstly, making $nc \leftarrow 0$ ($nc$ is the number of iterations or searches); Initializing each $t_{ij}$ and $\Delta t_{ij}$; Randomly placing $m$ ants on $n$ vertices; Secondly, the initial starting point of each ant is placed in the current solution set; For each ant $k$, move to the next vertex $j$ according to probability $P_k^{ij}$; Place vertex $j$ in the current solution set; Thirdly, calculating the objective function value $Z_k$ of each ant; Record the current best solution; Then, modifying the track intensity according to the update equation, and setting $\Delta t_{ij} \leftarrow 0$ for each side arc $(i, j)$; After that, if $nc < a$ predetermined number of iterations and no degradation behavior (i.e., all the solutions found are the same), then go to step 2; Finally, output the current best solution.
As more and more factors need to be considered in the actual escape events, the problems of this traditional model are also exposed. The main problems are as follows:

1. Random selection makes evolution slow and prone to stagnation.
2. Personnel classification during escape was not taken into account.
3. The random obstacles and the interference factors between people in the process of escape are not well considered and simulated.
4. Real escape incidents often occur in multi-storey buildings.

Because of the above shortcomings, we propose an improved design scheme.

3. Classification of Escape Personnel

In order to simplify the model, we neglect the escape differences caused by the sex of the evacuees. Considering the phenomenon of disability and group of escaped tourists, we can divide them into three categories: normal tourists, group tourists and disadvantaged tourists.

According to Predtechenski and Milinskii’s Research results:

- On the horizontal channel, the average evacuation velocity of the horizontal channel is a function of the flow density:
  \[ V = 112D^2 - 380D^3 + 434D^2 - 217D + 57 \text{(m/min)} \]  
  (1)

  - Downstairs speed:
    \[ V_0 = V[1.17 + 0.13\sin(6.03D - 0.12)] \text{(m/min)} \]  
  (2)

  - Upstairs speed:
    \[ V_1 = V[1.21 + 0.15\sin(4.16D - 0.11)] \text{(m/min)} \]  
  (3)

Flow density \( D \) refers to the ratio of the actual area of the human body to the total area of the human body, that is, the outer contour area, which reflects the crowding degree of the crowd. It can be expressed as follows:

\[ D = \frac{Nf}{WL} \text{(person/m²)} \]  
(4)

When the population density, the flow of people migrates freely; when the population density \( D = 2 \text{person/m²} \), the flow of people migrates slowly. Based on the estimation of the overall volume of the Louvre and the daily flow of people, we can approximately estimate the crowd density of tourists \( D = 1.26 \text{person/m²} \) in the Louvre.

The speed tables of three types of tourists can be obtained by referencing Predtechenski and Milinskii’s analyzing the research results and the above population density.

| Research Group                | Downstairs speed | Horizontal walking speed | Ascending speed of stairs |
|------------------------------|------------------|--------------------------|--------------------------|
| Normal tourist               | 0.90 (m/s)       | 1.25 (m/s)               | 0.85 (m/s)               |
| Group tourists               | 0.74 (m/s)       | 1.05 (m/s)               | 0.64 (m/s)               |
| Disadvantaged tourists       | 0.52 (m/s)       | 0.76 (m/s)               | 0.40 (m/s)               |

4. Application of CCRP optimization algorithm in evacuation model

When the network size and population range of the evacuation model become larger, the model of the above ant colony algorithm will have a tendency to increase the geometrical overhead of the computer. Therefore, although it is suitable for dealing with the planning problems of evacuation routes in the micro-environment, it is difficult to cope with the macroscopic situation of large-scale population evacuation. So we introduced the CCRC (Capacity Constrained Route Planner) algorithm to deal with this problem. The CCRC heuristic algorithm is a route planning algorithm considering capacity
limitation proposed by Q Lu e.t. This algorithm simulates the capacity of the path as a time series. Through a dynamic network model and heuristic solution, the optimal solution of the evacuation planning problem is obtained, rather than the optimal solution. The algorithm flow chart is as follows:

![Algorithm Flow Chart](image)

Figure 2. Schematic diagram of CCRP optimization algorithm

Capacity Constrained Routing Planner Algorithm (CCRP): Firstly, input: The network model of the path includes the initial capacity and transit cost of each point and path. Second, pre-process: Add super source node and super end point. Thirdly, judgment: Is there a path on the source node that has not yet been assigned? If it is No, output: planned path. Otherwise, regular algorithm, short path. Then, allocation: Find the path with the lowest time cost in the path, and assign the number of people that the current path may accommodate. Finally, update: Update the capacity and cost of all nodes and paths within each ti time point, and return to the judgment statement.

Large-scale evacuation plans can usually be considered from three aspects:
1. Minimizing evacuation time TET: The total evacuation time is understood as “the time it takes for people exposed to danger to arrive at a safe place.”
2. Minimize the emptying time CT: The understanding of CT is “the moment when the last person or vehicle leaves the dangerous place”
3. Maximizing the number of evacuated populations: Maximize the number of people leaving the danger zone within a given time interval.

Compared with the traditional way to find the shortest path, the most important difference is that this paper considers the impact of disasters on the capacity of each arc in the evacuation road network. The speed of each arc will increase with the increase of disasters such as poisonous gas and fire caused by terrorist attacks. Therefore, the time required to pass each arc will no longer be constant. In order to couple the factors of disaster expansion into the large-scale evacuation model, we first establish a scalable large-scale evacuation network model with multiple capacity and capacity constraints. Firstly, the minimum evacuation time is taken as the optimization goal, and the basic model of multi-source, multi-destination large-scale evacuation is established.

5. Research of results
Based on the various interfering factors considered in the above model, such as the interaction of the crowd, and the possible bottlenecks that limit the risk of tourists fleeing to export as considered in the above model, we simulated the entire population evacuation plan. During the simulation, we randomly added several obstacles in the network map of the map.
At the same time, in order to simulate the entry of emergency workers into the museum, in the case of orderly guidance, the use of additional emergency escape exits, we randomly added several new outlets in the network diagram of the model, open to people who escape under restricted conditions. For example, when emulating here, we set it to be open only to tourists, such as the old, the weak, and the sick. In setting the number of evacuated visitors, we dynamically change the initial number of visitors in the previously estimated random number of people, and plan the approximate population capacity between the various exits of each floor in the macroscopic planning of the CCRP algorithm.
model. Finally, we get a simulation of the network video model. Among them, the classification of people, the location of obstacles, and the emergency escape exit are shown in the following examples:

![Simulation example](image)

**Figure 3. Result diagram of evacuation algorithms based on CCRP**

At the end of the simulation results, we statistic the results of the above models and obtain the results of the following three data:

|       | Figure 3-1 | Figure 3-2 |
|-------|------------|------------|
| TET   | 28.3min    | 23.7min    |
| CT    | 11.5min    | 9.2min     |
| Max Number | 632.0 people/minute | 297.4 people/minute |

1. Minimizing evacuation time TET: The total evacuation time is understood as “the time it takes for people exposed to danger to arrive at a safe place.”

2. Minimize the emptying time CT: The understanding of CT is “the moment when the last person or vehicle leaves the dangerous place.”

3. Maximize the number of people in the population: Maximize the number of people leaving the danger zone in a given time interval. The unit we use in the simulation is person/minute.

It can be seen from the above results that the adaptive ant colony model that we added to the CCRP optimization algorithm can handle the bottleneck on the flight path of tourists under various constraints. This result positively proves our model.

Then we use the Pathfinder software to simulate the Louvre tourist escape scene. We can use it to verify the rationality of our model when we can set the relevant parameters similar to our model. In our above Figures, we finally get the final TET results for all visitors to the Louvre to escape to the exit: about 27.97min. This is very close to the results obtained by our adaptive ant colony algorithm based on CCRP optimization algorithm, which further verifies the reliability of the model.

![Simulation result](image)

**Figure 4. Result diagram of evacuation algorithms based on CCRP**

6. Adaptability evaluation analysis

In order to further test our crowd evacuation model in more complex and changeable situation can have universality, we chose a representative 007 Elements museum in Austria and Switzerland three buildings, student apartments and wal-mart and setting and the buildings corresponding to various parameters such as flow type, the final results figure is as follows:
7. Conclusion

The evacuation model of multi-storey buildings is considered in this paper. Firstly, the CCRP optimization algorithm is combined with the traditional adaptive ant colony algorithm model. At the same time, the type of evacuation personnel, random obstacles encountered in the evacuation process and the interference factors between Evacuators are considered. According to the iteration principle of CCRP algorithm, the evacuation time of each floor is calculated, and then the total evacuation time of each floor is accurately estimated by goal programming method, and the final evacuation plan is determined. Finally, three other landmark buildings are solved, which further illustrates the validity and universality of the model.

Reference

[1] Colori A, Dorigo M, Maniezzo V, et al. Ant system for job-shop scheduling [J]. Belgian Journal of Operations Research and Statistic Computing science, 1994, 34(1):39 -53.
[2] Dorigo M, Gianni D C, Luca M G. Ant algorithms for discrete optimization, artificial life [M]. New York: MIT Press, 1999.
[3] Luca M G, Marco D. An ant colony system hybridized with a new local search for the sequential ordering problem [J]. Inform Journal on Computing, 2000, 12(3):237 -256.
[4] Shenjie, Qinling. Adaptive ant colony algorithm based on uniformity of distribution [J]. Journal of Software, 2003, 14 (08): 1379-1387.
[5] Zhibin Mei, Wenhui Dong, Pan Gang, Zhang Peihong, Zhang Yunli. An Adaptive Ant Colony Algorithm for Personnel Evacuation Path Optimization in Building Fires [J]. Journal of Shenyang Jianzhu University: Natural Science Edition, 2008(04): 671-674.
[6] Lu Q, George B, Shekhar S. Capacity Constrained Routing Algorithms for Evacuation Planning: A Summary of Results [J]. Lecture Notes in Computer Science, 2005, 3633: 291-307.