Supply-Demand Allocation and Distribution Path Planning of Emergency Food Materials under Flood Scenarios: A Case Study in Fengxian District, Shanghai, China

Appendix A: The optimal supply–demand allocation model
The main equations of the optimal supply–demand allocation model are as follows:

$$Min \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}\, X_{ij} \tag{A.1}$$

$$\sum_{i=1}^{m} X_{ij} = D_j \qquad \forall j \in n \tag{A.2}$$

$$\sum_{j=1}^{n} X_{ij} \leq W_i \qquad \forall i \in m \tag{A.3}$$

$$X_{ij} = \{0,1,2,\dots\} \qquad \forall \mathrm{j} \in n; i \in m \tag{A.4}$$

where *i* is the sequence number of an MSD, i=1,2,3..., m; *j* is the sequence number of a demand point, $j = 1,2,3 \dots, n$; C_{ij} is the distance from the MSD *i* to the demand point *j*; D_j is the total amount demand of a type of material of the demand point *j*; W_i is the total amount of a type of material of the MSD *i*; X_{ij} is the decision variable which represents the material amount provided by the MSD *i* for the demand point *j*. The Equation A.1 is the objective function that minimizes the total distance of material distribution, which can satisfy the demands of all the demand points.

Appendix B: "Road design daily traffic volume", "Degree", and "Squares clustering coefficient"
(1) "Road design daily traffic volume" is the maximum design number of vehicles passing through a road section in a day. The design of daily traffic volume in roads can be used as a quantitative expression of the grade of road facilities. Compared with the division of the grades 1 to 5 of road facilities, it can better reflect the functional differences between different grades of roads. The higher value of the road design daily traffic volume, the higher the road grade and the road reliability (Ministry of Transport of China, 2014).
(2) "Degree" refers to the number of neighbor nodes that are connected to a node (a road section), which can be used to quantify the flexibility of road sections. The more road sections adjacent to a road section, the more sections can be selected for temporary path change of emergency material distribution vehicles in case of emergencies, and the higher the reliability of the road section. Hagberg et al. (2008) provided the detailed calculation method.
(3) "Squares clustering coefficient" indicates the probability that two neighbor nodes of the node v share a public neighbor node except the node v. The higher the value of the squares clustering coefficient, the higher the reliability of the road section. Zhang et al. (2008) provided the detailed calculation method.

Appendix C: The reason for choosing the maximum inundation area and depth as the flood scenarios in this study

The reason for choosing the maximum inundation area and depth as the flood scenarios in this study mainly consists of two aspects: (1) Considering the maximum inundation area and depth can directly reveal the most severe flood situation and ensure the safety of the selected shelters to the greatest extent. (2) The adoption of the maximum inundation area and depth enables a more explicit estimation of traffic interruption and traffic capacity reduction, ensuring the reliability and safety of the paths to the greatest extent when planning the distribution paths of emergency supplies. For instance, the maximum extent of inundation and water depth in the most severe flood scenarios can help determine which road sections require temporary closure measures under extreme flood conditions. These measures for road closures are often implemented in advance and lifted later rather than changing instantly with the flood evolution. Additionally, flood disasters are often accompanied by secondary disasters such as road damage, bridge collapses, and geological disasters (such as landslides). Based on the maximum inundation area of floods, these potentially dangerous areas can be avoided, reducing secondary disasters caused by emergency transportation and ensuring the continuity of rescue efforts.

Appendix D: The basic daily demands of three types of emergency food materials for persons of different age groups

The amounts of rice required by people of different ages and genders every day were estimated based on the “Recommended intake of dietary nutrients for Chinese residents” (Chinese Nutrition Society, 2013). The amounts of infant milk powder required by infants were estimated based on the feeding guide of a commercially available infant milk powder. As to water, “Dietary guidelines for Chinese residents” (Chinese Nutrition Society, 2016) and the local emergency bottled-water supply standard of Shanghai were referred to estimate the daily basic water demand of each person. The detailed basic daily needs of three types of emergency food materials for persons of different age groups are shown in Table D.1 (Jiang, 2018).

Table D.1 Detailed basic daily demands of three types of emergency food materials for persons of different age groups

Age/Years old	0-4	5-9	10-14	15-19	20-44	45-59	60-69	70-79	⩾80
Water/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Rice/kg		0.4468	0.61485	0.6422	0.76585	0.6433	0.5647	0.4919	0.50215
Milk/kg	0.18								

Appendix E: The comparison of the solution qualities (distribution times) of four algorithms: simulated annealing algorithm, Christofides algorithm, ant colony algorithm, genetic algorithm.

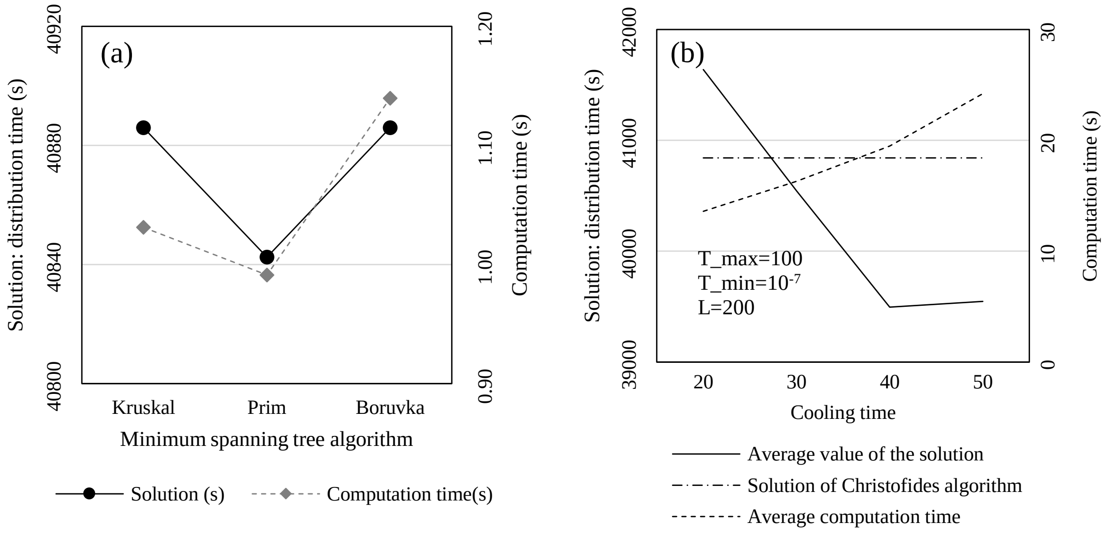
To prove the performance of the simulated annealing (SA) algorithm, several heuristic algorithms: Christofides algorithm, ant colony algorithm, and genetic algorithm were utilized to convince the solution quality and performance of the SA algorithm. The desktop computers with Intel Core i3-530 CPU@2.93GHz processor, 4GB RAM, 64-bit operating system, and Windows 7 operating system were used. The 143 shelters and the Fengxian Sports Center were taken as the experimental data. Kruskal, Prim, and Boruvka algorithms were utilized to build the minimum spanning tree for Christofides algorithm. In this case study, the solution calculated by the Christofides algorithm based on the Prim algorithm had the best optimal solution and the shortest computation time (Figure E.1a). The Christofides algorithm based on the Prim algorithm can generate the solution within a very short time. Therefore, its solution was used as the baseline for the parameter adjustment of the other three heuristic algorithms.

For the SA algorithm (Figure E.1b), the starting temperature (T_max) was 100, the stopping temperature (T_min) was 10-7, and the Markov chain length (number of inner cycles L) was 200. Under the above parameter combination, when the iteration was 40 times, the quality of the solution is no longer significantly improved, and the average solution time was 20s, which is acceptable in real-time applications.

As to the genetic algorithm, in this case study (Figure E.1c), when the population size (size_pop) of the genetic algorithm was 50, a solution better than that of the Christofides algorithm could be obtained with a mutation rate (prob_mut) between 0.4 and 0.8. The final parameter combination for the genetic algorithm was determined to be: size_pop = 50, prob_mut = 0.7, and the maximum number of iterations was 2000. Under this parameter combination, the average computation time of the genetic algorithm was 52s.

For the ant colony algorithm, based on multiple experimental comparisons, the parameters were determined as follows: maximum number of iterations was 300, size_pop = 50, pheromone importance (alpha) = 1, heuristic importance (beta) = 4, and pheromone evaporation rate (rho) = 0.2 (Figure E.1d). Under this parameter combination, the average computation time was 356s.

After determining the parameters of each algorithm, the solutions of the four algorithms were compared. In terms of the computation time, the Christofides algorithm was the fastest, followed by the SA algorithm, genetic algorithm, and ant colony optimization algorithm, respectively. In terms of solution quality, the SA algorithm had the lowest average distribution time, the lowest best distribution time, and the lowest worst distribution time (Figure E.2). Therefore, the SA algorithm was chosen as the solution algorithm for emergency material path planning in this study.



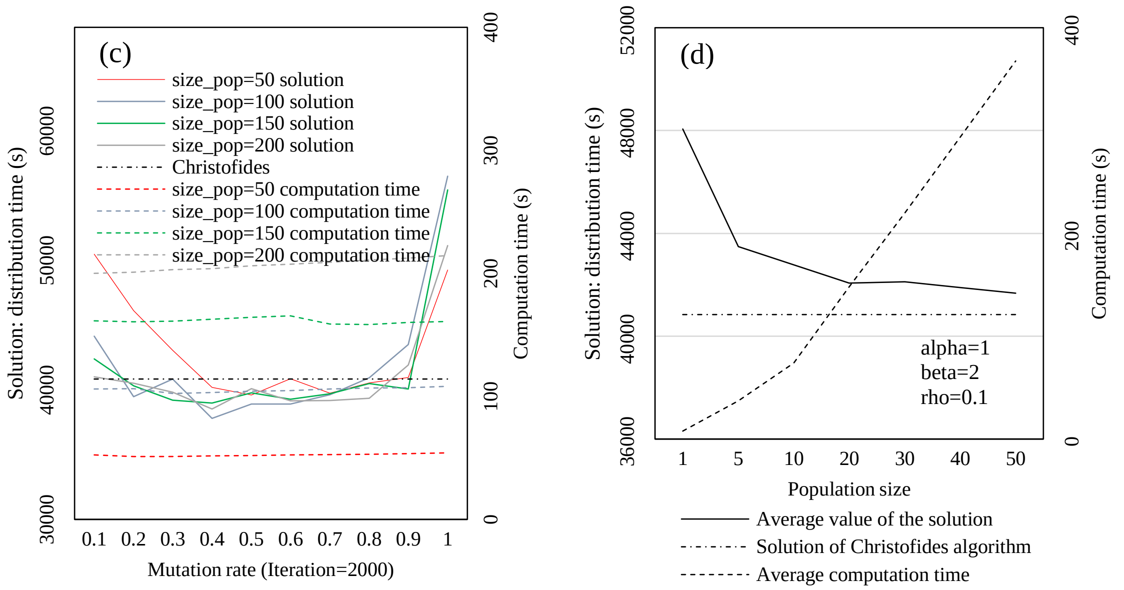


Fig. E.1 The comparisons of the solutions (emergency food material distribution times) and the computation times with different parameter combinations of four algorithms: (a) Christofides algorithm; (b) simulated annealing (SA) algorithm; (c) genetic algorithm; and (d) ant colony algorithm.

*T_max: starting temperature; T_min: stopping temperature; L: number of inner cycles; size_pop: population size; alpha: heuristic importance; beta: heuristic importance; rho: pheromone evaporation rate.

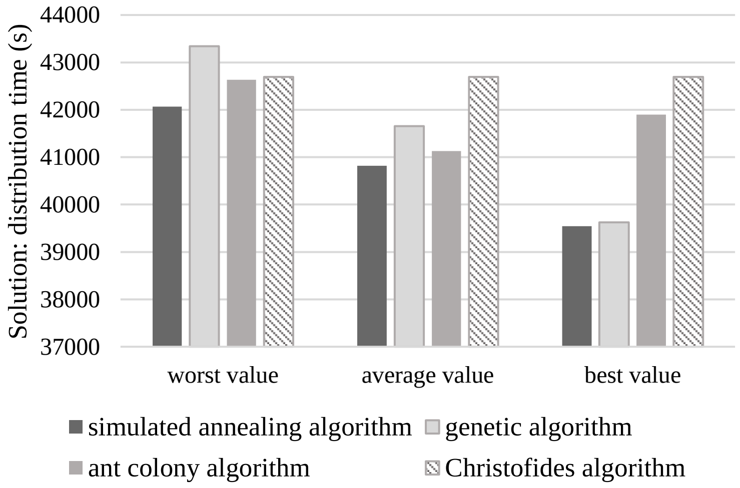


Figure E.2 The comparison of the solution qualities (distribution times) of four algorithms.