Chapter 45
Emergency Logistics Distribution Optimization Model and Algorithm in Disaster Chain

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Abstract  Emergency logistics distribution of disasters and accidents is an effective means to reduce the loss of lives and property. On the condition of meeting the timeliness requirement of emergency logistics, the study of emergency logistics distribution can rationally schedule vehicle, substantially reduce the vehicle allocation time and the logistical cost. Through the analysis of the characteristics of rescue emergency logistics, the system structure of emergency logistics distribution is proposed. After the material distribution optimization model for emergency logistics is established, an improved genetic algorithm is designed to solve this problem. In improved genetic algorithm, the best individual reservations, roulette selection, blend crossover, and blend mutation have been adopted to avoid premature convergence and enhance the process efficiency. A numeric example is presented to validate the feasibility and effectiveness of the model and its algorithm.

Keywords: Emergency logistics · Logistics distribution · Optimization model · Genetic algorithm · Disaster

45.1 Introduction

In recent years, a lot of large-scale public emergencies frequently occurred in China, such as the crises of SARS in 2003, the poison gas leak of Chongqing and the water pollution of Songhua River in 2005, the Avian Influenza, the south snow disaster in the beginning of 2008 [1], the Wenchuan Earthquake, the influenza A

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virus subtype H1N1 in 2008, and so on, which resulted in gigantic loses. The emergency logistics system is a special logistic action to provide the emergency supplies to the incidents.

Kem ball-Cook and Stephenson [2] first proposed the importance of logistics management when transporting relief materials in order to improve transport efficiency. Eldessouki [3] studied the emergency supplies distribution problems for the objective of minimizing transportation costs under different constraint conditions. Dai and Da [4] presented the model of multiresource emergency problem according to the characteristics of multiresource and multigarage problem and obtained the solution by citing the concept of continuous feasible and using the results of single resource problem. Liu and He [5] studied the emergency supplies scheduling problems with multigarage on the constraint condition of material requirement. According to the characteristics of consecutive emergency, an emergency model aiming at minimizing the succor nodes was established respectively under the precondition of best emergency in response to times and the restriction periods. Kejun and Wang [6] classified the burst events in the process of logistics and distribution as three categories: the effect on the state of goods, vehicles and the state of the road status raised the static, dynamic, and the functional model based on burst events. Zhang et al. [7] proposed a multiobjective multiperiod emergency logistics model to deal with Split-delivery Vehicle Routing Problem (SDVRP), and aimed to minimize the unsatisfied demand, total delivery time and supply unbalance among demanders. Sen Chen et al. [8] considered the repair of the destroyed roadways from the view of transformation between material relief and the delay of logistics distribution, and gets the best solution according to the purpose of the decision maker through roadway network and vehicle routing combinative optimization.

45.2 Emergency Logistics Distribution System Structure

Assume that emergency supplies have been transported to the railway stations, airports, and docks which are located in the affected areas through railway, air, water carriage, and other methods. Therefore, the railway stations, airports, and docks are treated as emergency supplies warehouses. What this paper studies is the process that the emergency supplies are transported from various warehouses including local storehouses, railway stations, airports, and docks to affected sites by dispatching vehicles available at disaster bursting areas.

The emergency logistics distribution system is a chart of three-layer structure. The first layer is garages, all vehicles needed with different types set out from this layer and the number of the vehicles has known in advance. The second layer is emergency supplies warehouses, including local storehouses at all levels, railway stations, airports, and docks. There are several categories of emergency supplies and their quantity at each storehouse is known and does not change during the emergency respond periods. The bottom layer is the disaster sites, namely, the
destination of the whole emergency logistics distribution. Once the disaster bursts, each disaster site will generate certain number of emergency supply demands for every type of emergency supplies after disaster assessment, and each emergency supply warehouse will deploy certain numbers of vehicles according to the demands of the affected areas to deliver the emergency supplies. There only exists vehicle flows between the first layer and the second layer without material flows. That is to say, the vehicles are running empty and on single orientation, transport from garages to emergency supply warehouses and not return to garages during the emergency respond times. There are both vehicle flows and material flows between the second layer and third layer, the material flows from the second to the third is one-way, while vehicles are in two-ways between the two levels. When vehicles arrive at the disaster sites, they do not return to the garage immediately but wait at the disaster site for new orders. Once there is a new assignment they will return to material warehouses to deliver the emergency supplies again. Thus, there are two states after the vehicles transport from material warehouses to disaster sites, one is waiting at the disaster site for new order, the other is returning to the emergency supplies warehouses to begin next distribution after receiving a new assignment and, as the dotted line in Fig. 45.1, the vehicles are running converse empty.

As a result, there are material flows or vehicle flows between the two layers, but nodes at the same level have nothing to do with one another. On one hand, because there need large quantities emergency supplies after burst disaster, it is the same with general business logistics which often combine with small quantities. On the other hand, it reflects the characteristic that the emergency logistics distribution is oriented by the demand of disaster sites, which aims at meeting the need of the disaster sites and shortens the distribution time as soon as possible in order to cut down the losses of affected areas and the vehicle running costs. Vehicles can be used continuously in the whole distribution system, namely, they flow repeatedly between the second layer and third layer until all disaster sites meet their needs.

45.3 Emergency Logistics Distribution Optimization Model

45.3.1 Problem Assumptions

Based on the analysis of emergency logistics distribution system, we make the following definitions and descriptions about the emergency relief supplies transport network model:

There are several emergency commodity supply nodes and demand nodes, the supply and demand quantities at each node have known beforehand, and the overall supplies is greater than or equal the overall demands.
More than one kind of emergency material need delivering, all of them have different weight, volume, and loading and unloading efficiency, suppose the loading efficiency at supply nodes is equal to the unloading efficiency at demand nodes.

There is more than one garage, each garage may have several types of vehicles, all the vehicles are sufficient for emergency logistics distribution and each vehicle has a serial number to mark it.

Vehicle only load one kind emergency material each task.

Each disaster site can be served by several vehicles.

Vehicles need not return to starting node (garage) immediately after finishing a distribution assignment but wait at the disaster site for next order.

Nodes at the same level have nothing to do with one another and there are neither vehicle flows nor material flows.

45.3.2 Mathematical Model

1. Sign Definitions

Sets: \( D = \{D_1, D_2, \ldots, D_m\} \), Set of demand nodes; \( G = \{G_1, G_2, \ldots, G_p\} \), Set of emergency supply types; \( S = \{S_1, S_2, \ldots, S_n\} \), Set of supply nodes; \( K = \{K_1, K_2, \ldots, K_k\} \), Set of garages; \( L = \{L_1, L_2, \ldots, L_L\} \), Set of vehicles; \( E =\{(k, i) (i, j)| k \in K, i \in S, j \in D\} \), Set of sides.

Emergency supplies parameters: \( w_g \), Unit weight of emergency supplies \( g \); \( c_g \), Unit volume of emergency supplies \( g \); \( t_g \), Loading or unloading unit emergency supplies \( g \) time.

Vehicle parameters: \( \text{cap}_l \), The load weight of vehicle \( l \); \( V_l \), The volume of vehicle \( l \); \( v_l \), The velocity of vehicle \( l \).

Distance parameters: \( d_{ki} \), Distance between garages and supply nodes; \( d_{ij} \), Distance between supply nodes and demand nodes.

Decision variables: \( x_{lij} \): Amount of emergency supplies type \( g \) traversing arc \((i, j)\) using vehicle \( l \)

\[
y_{ki} = \begin{cases} 
1 & \text{vehicle } l \text{ traversing arc}(i, j) \\
0 & \text{otherwise} 
\end{cases} \\
l \in L, k \in K, i \in S 
\]

\[
y_{ij} = \begin{cases} 
1 & \text{vehicle } l \text{ traversing arc}(i, j) \\
0 & \text{otherwise} 
\end{cases} \\
l \in L, i \in S, j \in D 
\]
vehicle \( l \) with commodity type \( g \) traversing arc\((i,j)\)

\[
z_{lijg} = \begin{cases} 
1 & \text{vehicle } l \text{ with commodity type } g \text{ traversing arc}(i,j) \\
0 & \text{otherwise}
\end{cases}
\]

\( l \in L, \ i \in S, \ j \in D, \ g \in G \)

2. Objective Function

\[
\min T = \sum_{l \in L} \sum_{i \in S} \sum_{j \in D} \sum_{g \in G} t_{ij} \cdot x_{lijg} \cdot y_{li} \cdot z_{lijg} \\
+ \sum_{l \in L} \sum_{k \in K} \sum_{i \in S} \frac{d_{ki}}{v_{li}} y_{lki} + \sum_{l \in L} \sum_{i \in S} \sum_{j \in D} \sum_{g \in G} t_{ij} \cdot x_{lijg} y_{lj} \cdot z_{lijg} \quad (45.1)
\]

\[
+ \sum_{l \in L} \sum_{i \in S} \sum_{j \in D} \frac{d_{ij}}{v_{lj}} y_{lij}
\]

3. Constraint Conditions

\[ x_{lijg} \cdot c_g \leq V_l \quad (45.2) \]

\[ x_{lijg} \cdot w_g \leq \text{cap}_l \quad (45.3) \]

\[ \sum_{i \in S} y_{lki} = 1 \quad (45.4) \]

\[ \sum_{g \in G} z_{lijg} = 1 \quad (45.5) \]

\[ y_{lki} \in \{0, 1\}, \ y_{lij} \in \{0, 1\}, \ z_{lijg} \in \{0, 1\}, \ y_{li} \in \{0, 1\}, \ y_{lj} \in \{0, 1\} \quad (45.6) \]

4. Model Explanation

The objective of this model is to minimize the total vehicle running time to meet the needs of affected areas, which includes the vehicle running time from garages to emergency supplies storehouses, the time from emergency supply storehouses to disaster sites, and the emergency supplies loading time at storehouses and unloading time at disaster nodes.

Expression (1) stands for the emergency supplies loading time at supply nodes, the vehicle running time from garages to emergency supplies storehouses, the emergency supplies unloading time at demand nodes, and the time from emergency supply storehouses to demand nodes. Constraint (2) shows the volume of loading emergency supplies each vehicle every time cannot excessive the vehicle largest volume. Constraint (3) shows that the weight of loading emergency supplies each vehicle every time cannot excessive the vehicle largest dwt. Constraint (4) denote that vehicles setting out from garages can only arrive at one emergency
commodity supply nodes once a time, that is to say, they flow on single orientation without circle between the first layer and the second layer. Constraint (5) shows that each vehicle can only load one type emergency supplies from supply nodes to demand nodes, Constraint (6) expresses 0–1 integer.

45.4 The Solution Model with Improved Genetic Algorithm

45.4.1 Genetic Coding

This chapter adopts the improved natural coding methods, a chromosome on behalf of a program of transport emergency supplies. A chromosome makes up of two substrings, and the first substring has a gene which means the series number of vehicle. If there are $K$ vehicles, the change range of the first gene value is the natural number between one and $K$. The second substring has $3n$ gene, “$n$” means the assignment number of the vehicle. For example, the vehicle marked two owned by garage three transports emergency supplies type $G_2$ from supply node $I_1$ to demand node $J_3$, then arrives at the supply node $I_2$ delivery the emergency supplies $G_2$ to demand node $J_2$, namely, $K_3-I_1-G_2-J_3-I_2-G_2-J_2$, if expressed by gene is 3-1-2-3-2-2-2. The $(3n−1)$th gene means the series number of emergency supplies storehouse, the $3n$th gene means the series number of emergency supplies type, the $(3n+1)$th gene means the series number of disaster nodes. The gene segments of all vehicles rank by paralleling connection from small number to large number according the order and make up of a chromosome.

45.4.2 Initial Population

The Push Forward Insertion Heuristic (PFIH) has been frequently used by many researchers with this purpose [9]. In this paper, a modified PFIH is applied. The total randomized choice is used to define the first customer to be inserted in each new route. That is necessary to produce distinguished individuals in the first GA generation. After the first customer has been randomly selected, the second one will be the one with the minimal insertion cost. Each feasible customer position in the route in construction is evaluated. A new route is created only if no more customer feasible insertions are possible.

45.4.3 Fitness Function

Fitness is used to evaluate the individual’s adaptation degree to the environment, the greater adaptation degree of the individual, the greater probability of passing
down to next generation [10]. The lower individuals run the other way round. The function of evaluating the individual’s adaptive degree is called fitness function. Because this chapter is aiming at minimizing the time so we need to switch the objective function into fitness function, general to take the following form: 
\[ F(x) = M - f(x), \]
where \( M \) is a big number; \( f(x) \) is the objective function.

### 45.4.4 Selection Operation

Selection is one of the key steps of genetic algorithm, it decides which individual can be passed down to next generation. Common methods of selection are Roulette, Stochastic, and Tournament. Selection algorithm uses a selection strategy that combines the best individual reservations and roulette. \( M \) chromosomes in each generation are arranged according to descending fitness, ranked first in the chromosome which has high adaptation can be directly copied to next generation. The next generation remaining chromosome selects again using roulette wheel selection method. It ensures that the best chromosomes in each generation have been preserved and participate petition in the next generation, reduce the search time of algorithm effectively.

### 45.4.5 Crossover Operation

Crossover means the reorganization and exchange of two parents, aiming at generating a new individual with higher adaptation degree value. Common methods of crossover are single point, two point, and uniform crossover [11]. This algorithm uses the single point, arithmetical, and heuristic crossover. Its overall crossing number proportion is 3:4:3. Thereby, it retains the male excellent genes and greatly increases the population average performance in the evolutionary process.

### 45.4.6 Mutation Operation

Mutation means randomly changing of the value of gene at any position, its aim is to improve the local search capabilities and maintain the diversity of groups and prevent premature. The probability of change named mutation probability. Common methods of mutation are basic position, reverse, and uniform mutation [12]. This algorithm takes the uniform, combined boundary, and nonuniform mutation, and the total variation percentage in the number is 3:3:4. This can prevent excellent genes in variability being damaged, but also introduce a new gene for the population on the local optimal solutions.
45.5 Experimental Analysis

Assume that a disaster burst in a certain place, and four nodes need emergency supplies, which are marked as $J_1, J_2, J_3, J_4$. A large part of emergency supplies have arrived at the local airport and railway station by air and train, added with a local storehouse amounts to three emergency commodity supply nodes, which are noted as $I_1, I_2, I_3$. The ministry of civil affairs can recruit totally 20 vehicles which are distributed randomly in three garages marked as $K_1, K_2, K_3$. There are four kinds of emergency supplies: tents, quilts, drinking water, and food, marked as $G_1, G_2, G_3$, and $G_4$. Tables 45.1, 45.2, 45.3, 45.4, 45.5 provide some relevant information.

The initial population is 20, crossover probability is 0.75, mutation probability is 0.1, and the max generation is 500. Using the improved genetic algorithm, as shown in Table 45.6, the shortest time is 15.27 h in emergency logistics distribution.

| Table 45.1 | Vehicles parameters |
|-------------|---------------------|
| Vehicle | Garage | Volume (m$^3$) | Dwt (t) | Speed (km/h) |
| 1 | $K_2$ | 45 | 7 | 35 |
| 2 | $K_1$ | 34 | 5 | 50 |
| 3 | $K_2$ | 27 | 3 | 55 |
| 4 | $K_3$ | 40 | 6 | 40 |
| 5 | $K_1$ | 40 | 6 | 40 |
| 6 | $K_2$ | 27 | 3 | 55 |
| 7 | $K_3$ | 34 | 5 | 45 |
| 8 | $K_2$ | 40 | 5 | 45 |
| 9 | $K_1$ | 34 | 5 | 45 |
| 10 | $K_2$ | 40 | 5 | 45 |
| 11 | $K_3$ | 40 | 6 | 40 |
| 12 | $K_1$ | 30 | 4 | 50 |
| 13 | $K_2$ | 27 | 3 | 55 |
| 14 | $K_3$ | 27 | 3 | 55 |
| 15 | $K_1$ | 30 | 4 | 50 |

| Table 45.2 | Emergency supplies parameters |
|-------------|-----------------|
| Supplies | Tent | Quilt | Food | Clothes |
| Weight (kg) | 20 | 5 | 20 | 10 |
| Volume (m$^3$) | 0.7 | 0.15 | 1.2 | 0.3 |
| Load efficiency (m) | 0.2 | 0.1 | 0.2 | 0.1 |

| Table 45.3 | Demand quantities in every disaster site |
|-------------|-----------------|
| Disaster site | Tent | Quilt | Food | Clothes |
| $J_1$ | 400 | 800 | 500 | 300 |
| $J_2$ | 600 | 1,100 | 800 | 400 |
| $J_3$ | 400 | 700 | 400 | 350 |
| $J_4$ | 500 | 1,000 | 500 | 450 |
This paper discussed the characteristics of rescue emergency logistics when disaster bursts, designed the system structure of emergency logistic distribution, and established an optimization model, with an aim to minimize the total vehicle running time. Then, an improved genetic algorithm is designed to solve the model, and a numerical example is presented to show the effectiveness and feasibility of this algorithm. As a result, the model and its algorithm are suitable for solving logistic distribution optimization under practical large-scale emergency logistics.
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