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Research on Emergency Supplies Dispatching Problem Based on Genetic Algorithm

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Abstract: The Emergency Supplies Dispatching Problem, as an extension of Vehicle Routing Problem is an important subject in emergency relief. In this paper, the focus is on a specific kind of Emergency Supplies Dispatching Problem which considers the accessibility of vehicles and different vehicle types. In consideration of the actual conditions, the vehicle types may be various and some emergency locations cannot be reached by certain types of vehicles due to the destruction of roads. Therefore, the problem addressed in this paper is more practical. A mathematical model of the Emergency Supplies Dispatching Problem is built which includes multiple depots and emergency locations, multiple kinds of emergency supplies and multiple types of vehicles. Then, genetic algorithm is adopted to solve an example based on the model. The effectiveness of the model has been proven by analyzing the computational results.

Keywords: Accessibility, Emergency supplies dispatching problem, Genetic algorithm, Vehicle routing problem.

1. INTRODUCTION

The Vehicle Routing Problem (VRP) was first formulated by Dantzig and Ramser as a generalization of the Traveling Salesman Problem (TSP) addressed by Flood [1]. The VRP is usually treated as an NP-hard (Non-deterministic Polynomial time hard) problem and no exact algorithms can solve VRP while there are fifty customers or more [2]. Besides the traditional VRP, a lot of extensions of VRP have been developed in recent years. The VRP with Time Windows (VRPTW) [3, 4] assumes that each customer must be served in a specific time frame. Another extension of VRP is the VRP with Pickup and Delivery [5, 6]. It is a category of vehicle routing problems in which objects or people have to be transported between an origin and a destination [7]. VRPs where vehicles have different capacities are referred to as the Heterogeneous fleet VRP (HVRP) [8, 9]. VRPs have a lot of implementations in many circumstances such as emergency reliefs and city logistics.

Yücenur and Demirel developed a new type of geometric shape based on genetic clustering algorithm for the multiple depots dispatching problem. They proved that it was more efficient than the traditional nearest neighbor algorithm in terms of both solution quality and computational speed [10]. Zhang *et al.* restricted it to one emergency location and solved it by adopting the genetic algorithm mutate operator with binary space partitioning (BSP) tree and acquired better solutions than the canonical genetic algorithm [11]. Yi and Kumar presented a meta-heuristic ant colony optimization for it. They focused not only on dispatching materials to the affected areas, but also on evacuating wounded people to the medical centers [12]. Sadjadi *et al.* presented a new mixed integer nonlinear stochastic scheduling model to solve the single-depot problem with uncertain demands and gave a solution with a general probability distribution [13]. Sheu proposed a hybrid fuzzy clustering-optimization approach to emergency dispatching problem. In this method, demands could be predicted and the severity of damages in emergency locations could be estimated [14]. Hu modeled a system of container multimodal transportation emergency relief as an affinity network inspired by the immune system. He then proposed an integer linear programming model to build the path selection [15]. Jeon *et al.* improved the genetic algorithm with three different heuristic processes and a float mutation rate and adopted it under the condition of multiple types of vehicles, double trips and multiple depots [16]. Yan and Shih adopted the weighing method to solve two problems simultaneously, namely the pathway repair and emergency material dispatching following a natural disaster, which were generally tackled separately despite their interrelationship [17]. Ho *et al.* incorporated the Clarke and Wright's saving method and the nearest neighbor heuristic approach into the initialization procedure of genetic algorithm and reduced the total completion time of the dispatching process [18]. Mirabi *et al.* presented a hybrid heuristic method combining constructive heuristic search with simulated annealing (SA) method to deal with the multiple depots dispatching problem and showed that it outperformed as one of the best-known existing heuristic search methods [19].

Traffic restrictions have also been considered in many researches. Among those works, Luís Santos, *et al*. presented a wSDSS integrating optimization methodology, considering traffic restrictions (*e.g.*, one-way streets, prohibited left U-turns). Their system can be used for short-term analysis (*e.g.*,

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the design of daily vehicle routes) and long-term analysis (*e.g.*, deciding how many vehicles to operate in a fleet) [20]. Q Mu, *et al.* proposed a formulation for one type of disrupted VRP that involves a vehicle breakdown. In their model, when such a disruption happens, a support system can figure out a new routing plan [21]. In a certain city, logistics problems and the process of choosing a route can be vehicle-dependent. For example, Barceló, *et al.* addressed that the route choice models can also be vehicle type dependent. Dynamically guided vehicles can be allowed to dynamically change the route according to the available information [22]. F Alonso, *et al.* considered that some constraints must be observed relating to the accessibility of the vehicles to the customers, in the sense that not every vehicle should visit every customer [23]. This accessibility restriction is also found in the work of Dennis Weyland, *et al.* [24].

2. PROBLEM DESCRIPTION AND MATHEMATICAL MODEL

2.1. Problem Description

The problem proposed in this paper is based on VRP. Suppose that an emergency event, *e.g.* earthquake, happens in a certain region and some emergency locations in this region are badly in need of emergency supplies. Several kinds of emergency supplies are stored in a number of depots which are geographically separated, so some vehicles are needed to transport supplies to the emergency locations. Considering the real emergency relief, the vehicle types are diverse and different types of vehicles have significant differences in loading and unloading time, velocity and load capacity. Some emergency locations cannot be served by several specific types of vehicles because the roads connecting the emergency locations are partly damaged due to the emergency event. Therefore, the problem to be solved in this paper is an Emergency Supplies Dispatching Problem (ESDP) with the accessibility of vehicles and different vehicle types. In usual disaster relief, the transportation time of emergency supplies is the most concerned factor. For the objective of minimizing the transportation time, a high-efficiency dispatching scheme as well as practical algorithm are needed. Assumptions of the problem are listed below:

1). The emergency supplies that the vehicles are delivering in one task belong to one single kind of supply, which means the mixed loading of emergency supplies is not to be considered;

2). Each vehicle departs with full load capacity;

3). Once a vehicle has started a transportation task, it should complete its task. This means a vehicle cannot be diverted until it has completed its current transportation task;

4). Vehicles can park at depots or emergency locations before dispatching. Each vehicle does not need to return to its initial parking place after completing a transportation task;

5). Each vehicle has its loading and unloading time, which depends on the vehicle type; the loading and unloading time should be added to the completion time of a transportation task;

6). The velocity of each vehicle is according to its vehicle type therefore a distinction should not be made between full load velocity and empty load velocity;

7). The costs of the transportation process are not to be included.

The objectives of the problem are explained below:

1). Demands of supplies at emergency locations should be satisfied;

2). The completion time of the dispatching process should be minimized.

2.2. Mathematical Model

To describe the problem mentioned above, a mathematical model is established. The notations used in our model are explained as follows:

- $M=\{m_1,m_2,\ldots,m_s\}$ is the set of s kinds of emergency supplies.
- $D=\{d_1,d_2,\ldots,d_p\}$ is the set of p depots.
- $E=\{e_1,e_2,\ldots,e_q\}$ is the set of q emergency locations.
- $H=\{h_1,h_2,\ldots,h_y\}$ is the set of y types of vehicles.
- $Dm=\{dm_1,dm_2,\ldots,dm_p\}$ is the set of emergency supplies stored in p depots. dm_i is the set of emergency supplies stored in each depot, which contains two components, *i.e.* the kind of emergency supplies (m_{iu}) and its corresponding quantity(α_{iu}), *i.e.* $dm_i=\{(m_{i1}, \alpha_{i1}),(m_{i2}, \alpha_{i2}),\ldots,(m_{is}, \alpha_{is})\}$, $i=1,2,\ldots,p$, $u=1,2,\ldots,s$.
- $Em=\{em_1,em_2,\ldots,em_q\}$ is the set of emergency supplies demanded in q emergency locations. em_j is the set of emergency supplies demanded at each emergency location, which contains two components, *i.e.* the kind of material (m_{ju}) and its corresponding quantity (β_{ju}), $j=1,2,\ldots,q$, $u=1,2,\ldots,s$.
- $h_k=\{l_k, v_k, t_k, n_k\}$ is the set of information of the k^{th} type of vehicle, which contains four components: the load capacity l_k, the velocity v_k, the loading and unloading time t_k and the number n_k of the k^{th} type of vehicle, *i.e.* $h_k=\{l_k, v_k, t_k, n_k\}$, $k=1,2,\ldots,y$.
- R is the route distance matrix, which is represented as follows:

$$R=\begin{bmatrix} R_{11} & R_{12} & \ldots & R_{1q} \\ R_{21} & R_{22} & \ldots & R_{2q} \\ \ldots & \ldots & \ldots & \ldots \\ R_{p1} & R_{p2} & \ldots & R_{pq} \end{bmatrix}$$

- R_{ij} is the route distance between a depot and an emergency location, $i=1,2,\ldots,p, j=1,2,\ldots,q$.
- τ_g is a single transportation task through which vehicle g will execute.
- $\varphi_g=\{\tau_{g1}, \tau_{g2},\ldots\}$ is a scheduling sequence of vehicle g, which consists of all tasks that vehicle g will execute.
- $\Phi=\{\varphi_1,\varphi_2,\ldots\}$ is a dispatching scheme of all vehicles.
- $T=\{t_1,t_2,..\}$ is the set of completion time of all vehicles,

t_g is the completion time of φ_g, $g=1,2,...$

- $Ts=max(t_g)$ is the completion time of the emergency supplies dispatching scheme.
- min(Ts) is the objective function of the model.

Our objective is to fulfill the demands of emergency supplies with the shortest completion time.

3. GENETIC ALGORITHM

Since the VRP is NP-hard, it cannot be accurately solved with linear programming algorithm. Heuristic algorithm is usually applied to solve VRP, so genetic algorithm is introduced to solve ESDP in this paper. Flow chart of the algorithm is shown in Fig. (**1**).

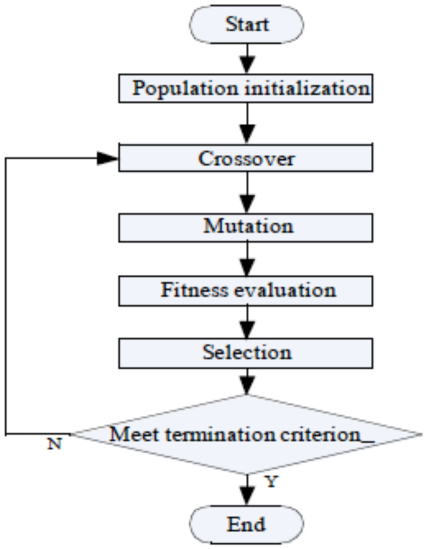

Fig. (1). Flow chart of the algorithm.

(1) In population initialization, the population size is set as thirty, *i.e.* a population consists of thirty chromosomes. A dispatching scheme Φ is defined as a chromosome. A scheduling sequence φ_g is defined as a gene. A single transportation task τ_g is defined as a gene unit. A gene usually contains a number of gene units, *e.g.*, gene φ_g ($d_2m_1e_2d_3m_2e_3$) means that vehicle g starts from depot d_2 with emergency supplies m_1, to emergency location e_2, then returns to depot d_3 without supplies, and starts from there with emergency supplies m_2 to the emergency location e_3.

(2) The crossover probability is set as 1 which means that every chromosome in the population will go through this operation. For a specific chromosome which is called a parent chromosome, another chromosome is chosen randomly in the population as another parent chromosome. A gene unit is randomly chosen as the cross point, then the gene fragments are exchanged following their corresponding cross points. The crossover operation is illustrated as follows:

φ_1:$(d_1m_1e_3)(d_2m_3e_1)(d_1m_2e_2)(d_3m_2e_1)(d_2m_2e_2)(d_1m_3e_3)$

$(d_1m_1e_4)|(d_1m_1e_1)(d_1m_2e_2)(d_2m_3e_1)(d_4m_2e_5)$ $(d_2m_1e_4)$

φ_2:$(d_2m_2e_4)(d_2m_2e_1)(d_1m_1e_3)(d_1m_1e_2)(d_3m_2e_5)(d_1m_2e_5)|(d_3m_3e_2)$

$(d_3m_3e_3)(d_1m_1e_4)(d_2m_3e_2)$

φ_1*:$(d_1m_1e_3)(d_2m_3e_1)(d_1m_2e_2)(d_3m_2e_1)(d_2m_2e_2)(d_1m_3e_3)$

$(d_1m_1e_4)|(d_3m_3e_2)(d_3m_3e_3)(d_1m_1e_4)(d_2m_3e_2)$

φ_2*:$(d_2m_2e_4)(d_2m_2e_1)(d_1m_1e_3)(d_1m_1e_2)(d_3m_2e_5)(d_1m_2e_5)|(d_1m_1e_1)(d_1m_2e_2)(d_2m_3e_1)(d_4m_2e_5)(d_2m_1e_4)$

(3) The mutation rate is set as 0.05. For each gene of a chromosome, its gene loci are chosen successively by the mutation rate and the chosen gene loci are then replaced by other acceptable gene loci. For example, gene φ_g ($d_2m_1e_2d_3m_2e_3$) may become ($d_2m_2e_2d_1m_2e_3$) after the mutation operation if m_1 and d_3 are the chosen gene loci.

(4) After the two genetic manipulations described above, a new population would be generated and the size of the new population would also be thirty. Both the original population and the new population would go through the fitness evaluation. The reciprocal of the completion time of a chromosome is defined as its fitness value so the chromosome with shorter completing time would have a higher fitness value.

(5) Thirty most excellent chromosomes would be selected according to their fitness values which would then constitute the next population.

(6) An appropriate upper limit of the iteration number is chosen as the termination criterion. If the iteration number meets the termination criterion, the loop ends and the dispatching scheme is then given.

4. EXPERIMENT RESULTS

4.1. Parameters of Example

Three depots and four emergency locations are introduced in the model, *i.e.* $D=\{d_1,d_2,d_3\}$ and $E=\{e_1,e_2,e_3,e_4\}$. Fig. (**2**) shows the route relation.

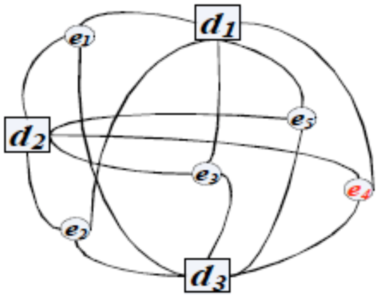

Fig. (2). Route relation.

The route distance is shown in Table **1**.

In this example, three kinds of emergency supplies are introduced, *i.e.* $M=\{m_1,m_2,m_3\}$, m_1 means food, m_2 means water and m_3 means tent. The storage quantities of emergency supplies in the depots are shown in Table **2** and the demanded quantities of emergency supplies in the emergency locations are shown in Table **3**.

Two types of vehicles are adopted in the example, *i.e.* $H=\{h_1,h_2\}$, h_1 means large truck and h_2 means small truck. For consideration of the accessibility of vehicles, it is assumed that the route connecting emergency location e_4 is not fit for a large truck, so a large truck cannot serve e_4. The information of vehicles is shown in Table **4**.

Table 1. Route distance (km).

	d_1	d_2	d_3
e_1	372	304	366
e_2	398	415	420
e_3	440	298	288
e_4	467	403	329
e_5	320	355	436

Table 2. Storage quantities of emergency supplies in the depots (ton).

	d_1	d_2	d_3
m_1	597	703	625
m_2	479	879	783
m_3	610	904	642

Table 3. Demand quantities of emergency supplies in the emergency locations (ton).

	e_1	e_2	e_3	e_4	e_5
m_1	145	135	130	90	150
m_2	180	150	125	100	165
m_3	155	130	110	95	145

Table 4. Information of vehicles.

Vehicle Type	No.	Load Capacity (ton)	velocity (km/h)	Loading and Unloading Time (h)
large truck	1-5	20	50	3
small truck	6-15	5	85	1.5

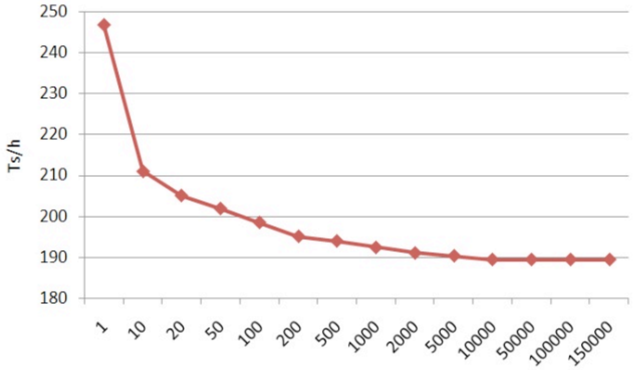

Fig. (3). Trend chart about iteration number and completion time.

4.2. Experiment Results

According to the parameters above, GA is adopted to program for solving this example. Fig. (**3**) shows the trend chart about iteration number and completion time of the dispatching process. It is obvious that the completion time is convergent with the increasing number of iterations. After the iteration number of 10000, the completion time remains constant, so the iteration number of 150000 is chosen as the termination criterion.

The dispatching scheme is shown in Table **5**; supplied quantities of emergency supplies are shown in Table **6**.

As shown in Table **5**, the completion time φ_g of each vehicle is similar to each other, which means the dispatching scheme is very approximate to the theoretical optimal solution. By comparing Table **6** with Table **3**, it is obvious that the demand of emergency supplies in each emergency location has been satisfied, *i.e.* the supplied quantities of emergency supplies are not less than the corresponding demand of quantities. Therefore, the dispatching scheme is a good solution of the example which proves that the model established in this paper is effective.

Table 5. Dispatching scheme.

No.	φ_g	t_g/h
1	$(d_1m_3e_5)(d_3m_1e_3)(d_2m_1e_5)(d_2m_3e_2)(d_1m_1e_2)$ $(d_3m_2e_3)(d_3m_3e_2)(d_1m_1e_5)(d_2m_2e_1)(d_2m_1e_5)$ $(d_2m_2e_2)$	182.7
2	$(d_1m_1e_2)(d_2m_1e_3)(d_3m_1e_3)(d_3m_3e_3)(d_2m_1e_2)$ $(d_1m_2e_1)(d_2m_2e_1)(d_2m_2e_3)(d_3m_2e_1)(d_2m_2e_1)$ $(d_2m_3e_1)(d_2m_2e_2)$	186.9
3	$(d_3m_3e_5)(d_2m_2e_2)(d_2m_2e_3)(d_3m_2e_2)(d_1m_3e_2)$ $(d_2m_3e_2)(d_3m_2e_3)(d_3m_3e_2)(d_2m_2e_1)(d_2m_1e_5)$ $(d_2m_2e_2)$	189.34
4	$(d_2m_1e_1)(d_3m_3e_3)(d_3m_1e_3)(d_2m_3e_3)(d_3m_1e_3)$ $(d_3m_3e_3)(d_2m_1e_3)(d_2m_2e_5)(d_3m_3e_2)(d_2m_2e_1)$ $(d_2m_1e_5)(d_2m_2e_2)$	186.7
5	$(d_3m_1e_1)(d_2m_3e_5)(d_3m_2e_3)(d_3m_3e_3)(d_2m_1e_3)$ $(d_2m_2e_5)(d_3m_2e_3)(d_3m_3e_2)(d_1m_1e_5)(d_2m_1e_5)$ $(d_2m_2e_2)$	177.08
6	$(d_2m_1e_2)(d_3m_2e_1)(d_2m_3e_5)(d_2m_3e_1)(d_2m_3e_4)$ $(d_3m_3e_4)(d_3m_1e_1)(d_2m_3e_4)(d_3m_3e_1)(d_2m_2e_4)$ $(d_1m_1e_2)(d_3m_2e_4)(d_1m_1e_4)(d_3m_1e_4)(d_3m_1e_2)$ $(d_2m_2e_5)(d_1m_2e_5)(d_3m_2e_4)(d_1m_3e_5)$	188.559
7	$(d_1m_3e_1)(d_3m_3e_1)(d_1m_1e_1)(d_3m_3e_4)(d_3m_1e_4)$ $(d_1m_2e_2)(d_2m_3e_4)(d_3m_3e_1)(d_3m_2e_5)(d_3m_1e_1)$ $(d_3m_1e_4)(d_3m_3e_4)(d_3m_1e_2)(d_2m_2e_5)(d_1m_2e_5)$ $(d_1m_2e_5)(d_3m_2e_4)(d_1m_3e_5)$	178.612
8	$(d_3m_2e_4)(d_1m_3e_1)(d_2m_2e_1)(d_3m_2e_1)(d_3m_3e_4)$ $(d_1m_3e_1)(d_2m_2e_5)(d_2m_3e_4)(d_1m_3e_5)(d_2m_3e_4)$ $(d_3m_3e_1)(d_2m_2e_5)(d_3m_1e_1)(d_2m_1e_4)(d_2m_1e_4)$ $(d_2m_2e_5)(d_1m_2e_2)(d_3m_3e_5)$	180
9	$(d_3m_2e_2)(d_3m_3e_1)(d_2m_3e_1)(d_1m_1e_1)(d_3m_3e_4)$ $(d_3m_1e_4)(d_3m_1e_1)(d_2m_3e_4)(d_3m_1e_1)(d_2m_3e_4)$ $(d_3m_3e_1)(d_2m_2e_4)(d_1m_1e_1)(d_3m_2e_4)(d_1m_1e_4)$ $(d_3m_1e_4)(d_3m_1e_2)(d_3m_2e_4)(d_1m_3e_5)$	187.653
10	$(d_1m_2e_3)(d_1m_3e_5)(d_3m_3e_4)(d_1m_1e_1)(d_2m_3e_1)$ $(d_2m_1e_1)(d_2m_1e_1)(d_2m_3e_1)(d_3m_3e_1)(d_2m_3e_5)$ $(d_2m_1e_1)(d_2m_2e_4)(d_1m_1e_2)(d_3m_2e_4)(d_1m_1e_4)$ $(d_3m_1e_4)(d_3m_1e_2)(d_2m_2e_4)(d_1m_3e_5)$	187.947
11	$(d_1m_1e_5)(d_1m_3e_5)(d_3m_3e_5)(d_3m_1e_1)(d_3m_3e_4)$ $(d_3m_3e_1)(d_2m_2e_5)(d_3m_3e_1)(d_2m_2e_5)(d_2m_1e_2)$ $(d_1m_1e_2)(d_3m_2e_4)(d_3m_1e_4)(d_3m_1e_2)(d_2m_2e_5)$ $(d_1m_2e_5)(d_2m_3e_3)(d_3m_2e_4)(d_3m_3e_5)$	185.1
12	$(d_3m_3e_4)(d_3m_3e_1)(d_1m_1e_1)(d_2m_3e_1)(d_2m_1e_1)$ $(d_2m_3e_1)(d_3m_3e_1)(d_2m_2e_5)(d_3m_3e_1)(d_2m_2e_5)$ $(d_2m_1e_2)(d_1m_1e_2)(d_3m_2e_4)(d_3m_1e_4)(d_3m_1e_2)$ $(d_2m_2e_5)(d_1m_2e_5)(d_3m_2e_4)(d_1m_3e_5)$	182.947
13	$(d_2m_1e_1)(d_2m_3e_1)(d_1m_1e_1)(d_3m_3e_4)(d_3m_1e_4)$ $(d_3m_1e_1)(d_3m_3e_4)(d_3m_1e_1)(d_3m_2e_5)(d_1m_2e_1)$ $(d_3m_3e_4)(d_3m_2e_4)(d_3m_2e_4)(d_1m_1e_4)(d_2m_1e_4)$ $(d_3m_1e_2)(d_2m_2e_5)(d_1m_2e_4)(d_1m_3e_5)$	186.524
14	$(d_2m_1e_4)(d_2m_3e_1)(d_1m_1e_1)(d_3m_3e_5)(d_2m_3e_1)$ $(d_3m_2e_1)(d_1m_2e_1)(d_3m_3e_5)(d_1m_2e_2)(d_1m_2e_1)$ $(d_3m_3e_4)(d_3m_2e_4)(d_2m_1e_4)(d_3m_1e_2)(d_2m_2e_5)$ $(d_1m_2e_5)(d_3m_2e_4)(d_2m_1e_5)(d_1m_3e_5)$	188.053
15	$(d_2m_3e_5)(d_1m_2e_1)(d_2m_3e_1)(d_2m_1e_1)(d_2m_3e_1)$ $(d_3m_3e_1)(d_2m_2e_5)(d_3m_3e_1)(d_2m_2e_5)(d_1m_1e_2)$ $(d_3m_2e_4)(d_1m_1e_4)(d_3m_1e_4)(d_3m_1e_2)(d_2m_2e_5)$ $(d_1m_2e_5)(d_2m_3e_3)(d_3m_2e_4)(d_1m_3e_5)$	181.418
completing time of dispatching process *Ts*		189.34

Table 6. Quantities supplied of emergency supplies.

	e_1	e_2	e_3	e_4	e_5
m_1	145	145	140	100	150
m_2	180	160	125	110	165
m_3	160	140	110	95	155

CONCLUSION

In this paper, genetic algorithm was adopted to solve an Emergency Supplies Dispatching Problem. Considering the complexity of dispatching actual emergency supplies, the problem included the accessibility of vehicles and different vehicle types. Based on this problem, a mathematical model was established. The experimental results of the example are in accordance with our expectations, which means that the supplied quantity of each kind of supply is not less than its corresponding demand quantity. Since the theoretical optimal solution cannot be found during limited iteration number, the dispatching scheme is a suboptimal solution under a certain precision.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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