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Allocation of Resources for Emergency Response to Coal-to-Oil Hazardous Chemical Accidents under Railway Transportation Mode

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Abstract: Railways of the National Energy Group using their own trains have become an important mode of transportation for coal-to-oil hazardous chemicals. Under the circumstances of the shortage of emergency resources and the coupling of multiple disasters, how to establish an effective and reasonable emergency resource allocation scheme for the railway transportation of dangerous chemicals from a disaster site is of great significance to the national task of ensuring safety for the transportation of energy. This paper focuses on the allocation of emergency rescue resources for railway transportation accidents involving coal-to-oil hazardous chemicals, considering the scenarios of the leakage of coal-to-oil, railway line damage, etc. According to the number of trapped people at the initial moment, the disaster situation and accident type, affected areas, etc., a multi-objective optimization model with the shortest response time of the emergency team and the lowest cost of transporting emergency materials along the railway transportation channel of coal-to-oil hazardous chemicals is constructed, based on the calculation method using the initial weight and the emergency weight assigned by the emergency rescue team. Furthermore, in order to avoid the problem of the weight of the local accident points being too small to participate in a rescue, a bee colony algorithm model based on pre-allocation was designed and compared with two traditional algorithms, allowing the realization of the search and selection of allocation methods. The analysis of the examples shows that the proposed method is efficient and fast, and the research results are practical and feasible, which can provide a scientific basis for the rapid decision of emergency rescue resource allocation in multi-disaster scenarios for large energy groups, and provide a reference for the allocation of public security emergency resources in the national emergency response.

Keywords: railway transportation of coal-to-oil hazardous chemicals; accident rescue; emergency resource allocation; emergency weight; bee colony algorithm

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1. Introduction

Emergency resource allocation generally refers to the distribution of emergency resources from the rescue point to each incident point to support the rescue response after the occurrence of an accident, which is one of the key aspects of the emergency response phase and is an important guarantee for rapid and effective rescue. Emergency resources generally include emergency teams, emergency equipment, emergency supplies, emergency security, and other aspects. Especially when a major industrial hazardous chemical production accident occurs, characteristics such as multi-disaster coupling, large hazards, a wide range, casualties, environmental pollution, etc., are presented, which require multiple types of rescue points to collaborate to complete the immediate deployment of emergency resources and realize regional collaborative rescue.

The National Energy Investment Group Co., Ltd., Beijing, China (formerly Shenhua Group Co., Ltd., Beijing, China, changed on 28 November 2017, hereinafter referred to as "NEC") is involved in coal production and transportation, power production, coal-to-oil chemical, and other industries, with 30 coal-to-oil coal chemical projects and 4 national demonstration projects in stable operation, namely, 4 million tons of coal indirect liquefaction, 1 million tons of coal direct liquefaction, 600,000 tons of coal olefin, and 500,000 tons of coal propylene. The scale of production capacity ranks first in the world; among these industries, the capacity of oil products is 5.31 million tons/year, the capacity of polyolefin is 3.88 million tons/year, and the capacity of coke is 6.09 million tons/year. The National Energy Group's coal, coal-to-oil chemical production, and railway transport trunk lines are mainly distributed in Jin, Shaanxi, Mongolia, Ning, and the Hebei Province area. Taking the Shenhua Ordos coal-to-oil liquefaction project in Shendong mining area as an example, the enterprise's own vehicle as a carrier has become the main mode of transport. Due to the industrial layout and geographical location factors, the optimal fast rescue channel built with the enterprise's own railway as the carrier can quickly transport emergency resources to the scene of major industrial accidents [1,2].

Many scholars have studied the location of emergency facilities and the material distribution of hazardous chemicals [3–7]. The safety of hazardous chemicals themselves and their transportation has become a widespread concern for the railway industry and all walks of life. The safety control of coal-to-oil and coal chemical production is difficult and the possibility of major industrial production accidents is high. From the current international energy situation, it is of great significance to ensure the safe and efficient transportation of coal-to-oil based on railways. To ensure safe production, a practical emergency resource deployment method is a fundamental prerequisite for an effective emergency response. This paper is oriented toward the rescue scenarios of railway transportation accidents involving hazardous chemicals, focusing on the consequences of accidents brought about by railway multi-disaster coupled emergency disposal sites, a shortage of multiple types of emergency resources, and the spillage and volatilization of multiple hazardous chemicals. This paper constructs constraints including hazardous chemical leakage levels and studies the problem of railway transportation emergency resource allocation for multi-disaster points, multi-rescue points, and multi-disaster coupled states.

The problem of where to position emergency relief points has been studied by scholars at home and abroad. Liu Song [8] et al. constructed a multimodal transport path optimization model for emergency supplies under time-varying networks by designing an ant colony algorithm to quickly select the fastest transport solution for emergency supplies to reach the disaster site and provide decision support for decision makers. By studying the vehicle path planning problem, Wei Lu [9] et al. efficiently solve the problem of emergency supplies deployment and vehicle path solution generation under a resource constraint, which can effectively identify the critical transportation sections. Li et al. [10] proposed a hybrid artificial bee colony (ABC) algorithm to solve the parallel batch distributed flow slot problem (DFSP) with deteriorating operations. A novel reconnaissance bee heuristic algorithm is investigated, which effectively improves the search performance by considering useful information collected from global and local best solutions. Yi et al. [11] used the large-scale optimization problem based on human EEG signal processing to benchmark the performance of three cross operators of the NSGA-III algorithm. By introducing the concept of study and designing several improved crossover operators of SBX, UC, and SI, an enhanced version of the NSGA-III algorithm is proposed. Cui et al. [12] designed a hybrid multi-objective particle swarm optimization (HMaPSO) algorithm to solve the established multi-objective optimization model, tested the HMaPSO algorithm on the DTLZ function, and applied the HMaPSO algorithm to solve the multi-objective green coal production optimization model to maximize the use of resources.

Lina Gao [13] analyzed the donor contributions under different emergency resource allocation policies and how to choose the optimal emergency resource allocation policy from the government's point of view, provided the necessary proofs for the theoretical solutions derived from each part, and drew the corresponding conclusions. Guo [14] et al. addressed the problems of the low efficiency and low precision of resource allocation in current grid resource allocation management, and proposed a grid resource allocation management algorithm based on an optimal multi-task objective decision allocation management algorithm, which makes the resource allocation method smoother and effectively improves the resource allocation efficiency. Zhang [15] et al. proposed a permutation-based model to analyze the overhead constraints of disordered resources and applied the proposed permutation-based model to resource allocation analysis. Zhao [16] et al. used evolutionary game theory simulations to explore the role and applicability of various resources by exposing their constrained situations in different stabilities of allocation. Wang [17] et al. developed a resource allocation optimization problem for distributed decision making to obtain the optimal resource allocation strategy by finding a Nash equilibrium (NE) strategy with an improved best response dynamic (IBSD) algorithm. Wang [18] et al. proposed an optimization model for the multi-cycle allocation of emergency resources based on regional self-help and cross-regional collaborative rescue efforts by combining inter-domain and neighboring inter-zone allocation principles to achieve optimal, multi-cycle, cross-regional resource allocation.

When resource allocation involves multi-objective function optimization, multiple heuristic algorithms are often used to solve the problem. Nansheng Pang [19] et al. constructed a dynamic activity group GRA to generate multiple resource allocation schemes by rearranging the order of activities within the group to find the best robust scheme from the solution space. Wen-Chiu Li [20] et al. proposed a self-guided multi-objective culture genetic algorithm with an elite exploitation strategy (S-SANSGA-II), using a simulated annealing operator with Gaussian probability density function introduced into the algorithm as a local search operator, and designed an acceptance strategy based on the variance of the crowding distance. Jukai Zhang [21] et al. conducted a resource optimization design and performance analysis for load-balancing adaptation, fragmentation suppression, and low-crosstalk resource allocation algorithms in air-division multiplexed elastic optical networks. Yintao Hou [22] et al. established an ant colony algorithm-based resource allocation model for a TDMA satellite communication system, and used MATLAB software to simulate and verify the resource allocation method, which improved the resource allocation algorithm's optimization capability and had certain reference value. Zhentao Hu [23] et al. proposed a heuristic algorithm to solve the scheduling plan with the shortest duration, design a dynamic resource weight calculation method, and conduct experiments on cases with different parameter settings. The results show that the new algorithm has obvious advantages compared with the random resource allocation algorithm and static resource weight algorithm. Pei [24] et al. proposed a multi-objective resource allocation model considering the uncertainty and persistence in the rescue process. The results show that MOCGA can better solve the multi-objective dynamic emergency resource allocation model. Lu [25] et al. considered the unpredictability of different emergency scenarios in the subway system, applied the scenario–response model in the resource allocation decision, established a multi-objective model of emergency resource allocation in the subway emergency rescue process, and used a particle swarm optimization algorithm to solve the model, which enhanced the subway emergency rescue capability in practice. Tang [26] et al. studied the optimization model of railway emergency resource scheduling considering the fuzziness of parameters such as resource demand, scheduling time, and satisfaction, and designed the constrained parameter interval method to solve the optimal solution, which achieved the fast search of the Pareto optimal solution. Erfan [27] et al. proposed a bi-objective mixed integer linear programming (MILP) model for the allocation and scheduling of disaster relief units, based on robust optimization techniques for uncertainty sets and multiple choice goal programming (MCGP) with utility functions, verifying the high complexity of the problem and the significant effect of uncertainty on the solution. Sun [28] et al. proposed a multi-period optimization model for EMA under uncertainty with the objectives of minimum time, minimum cost, and minimum risk. A cycle optimization model with stochastic and fuzzy constrained programming deterministic transformation methods and an improved genetic algorithm (IGA) were used to solve the proposed model, illustrating the relationship between risk, time, and cost, and the flexibility dimension in various optimized multi-cycle EMA scenarios. The existing resource allocation method is not suitable for the special railway transportation of dangerous chemicals. In order to make more reasonable use of resources, the resource allocation method in this paper is proposed.

The main contributions of this paper are as follows:

(1) We propose an emergency response resource allocation model using the coal-to-oil railway transportation mode, which is used to allocate emergency rescue materials after the leakage of hazardous chemicals;
(2) We propose an improved bee colony algorithm, which adds pre-allocation when initializing the population and improves the directional search ability of the population.

In the multi-hazard coupled scenario of railway freight accidents involving hazardous chemicals, with the serious consequences and rapid development of such disasters, there is a lack of research on the existing emergency resource allocation methods for hazardous chemical railway transport accidents. On the basis of existing research, based on the determined location of rescue points, and according to the weight coefficients of various types of accidents, this paper allocates rescue materials according to the mode of rescue teams. With the goal of minimizing the time and cost of delivering rescue materials, the bee colony algorithm, genetic algorithm, and particle swarm algorithm are used to solve the objective function to obtain the optimal resource allocation scheme.

2. Problem Description and Analysis

For special railway transport lines for hazardous chemicals, such as coal-to-oil in a certain region, in the case of an emergency in the railway transport of hazardous chemicals under extreme conditions, or in the case of an extreme emergency, such as earthquake, landslide, mud rock flow, and other natural disasters, leading to the leakage of hazardous chemicals on the railway and damage along some transport networks, as well as production safety accidents in the hazardous chemicals' production area, the regional emergency management department needs to quickly study the disaster and carry out emergency disposal.

Under scenarios such as the leakage of hazardous chemicals, including coal-to-oil and damage to railway network lines, the initial weight and emergency weight calculation methods for the allocation of safety production emergency rescue teams are proposed according to the trapped personnel, disaster situation, accident type, and the scope of the ripple effect at the initial moment, and a multi-objective optimization model with the shortest team response time and the smallest cost of transporting emergency materials along the railway transport channel of hazardous chemicals as the objective function is constructed.

In the area of the transportation of hazardous chemical products such as coal-to-oil by rail, there are h collections of disaster areas that need to be involved in the rescue $I_1, I_2, \ldots, I_h$. There are m collections of rescue points $J_1, J_2, \ldots, J_m$ and b command center collections $K_1, K_2, \ldots, K_b$ at the rescue point $J_m(m = 1, 2, \ldots, m)$ on the stockpile of the first $c(c = 1, 2, \ldots, C)$. The number of rescue emergency supplies is $number(c_{cj})$ in the command center $K_b(b = 1, 2, \ldots, b)$ on the first $c(c = 1, 2, \ldots, C)$. The number of emergency supplies stored at the rescue point is $number(c_{ck})$. Here, h represents the total number of disaster points, m represents the total number of rescue centers, and b represents the total number of command centers.

The type of accident determines the type of rescue material. In this paper, the rescue material is divided into three types of rescue squads for configuration according to the number of people trapped in the disaster, the level of hazardous material leakage, and the priority of the line.

3. Optimization Model

The following assumptions are given in order to develop the model to meet the needs of the distribution as much as possible and to increase the operability of the model.

(1) The time from the rescue point to the incident point is known and the emergency resource requirements do not change with time.
(2) The various types of resources required to stock the incident point at the rescue site are greater than the needs of the incident point.
(3) Each rescue material is equipped by a special rescue team and does not carry redundancy.

3.1. Multi-Objective Optimization Modeling

Once an accident occurs, the timely arrival of rescue materials can effectively curb the secondary occurrence of injury. The total time for dispatching emergency resources defined in this paper is as follows: Based on the emergency weighting, the amount of rescue materials contained in the rescue point and the command staff are allocated. The dispatching of rescue resources after an accident is not uncontrolled and often requires a consideration of costs. In this paper, the total cost of dispatching is defined as the cost of transporting the materials needed to transport trapped personnel, the cost of transporting the materials needed to clean up hazardous material leaks, and the cost of transporting the materials needed to resume interval operation.

$$minF1 = T_k + T_s + T_c = \sum_{i=1}^{3} (\sum_{j=1}^{m} t_{ij} + \sum_{k=1}^{b} t_{ik}). \tag{1}$$

$$minF2 = C_k + C_s + C_c = \sum_{i=1}^{3} \begin{pmatrix} \sum_{j=1}^{m} C_{cij} number(C_{cij}) \\ +\sum_{k=1}^{b} C_{cik} number(CC_{cik} \end{pmatrix} \tag{2}$$

$$\text{s.t.} \begin{cases} number(c_{cij}) < J_i, i = 1, 2, \ldots, m \\ number(C_{cik}) < K_i, i = 1, 2, \ldots, b \\ number(C_{kI_n}) = w_n(P) \cdot M_k \\ number(C_{sI_n}) = w_n(C) \cdot M_s \\ number(C_{cI_n}) = w_n(R) \cdot M_c \end{cases} \tag{3}$$

where $F1$ denotes the total time for dispatching emergency resources, T_k denotes the time for transporting the supplies required for trapped personnel, T_s denotes the time to transport the materials required to handle hazardous material leaks, T_c denotes the time to deliver the materials needed to resume interval operation, t_{ij} is the time cost required to transport supplies from J to I, and t_{ik} is the time cost of transporting the material from K to I. $F2$ denotes the total cost of dispatching emergency resources, C_k denotes the cost of transporting the supplies required to transport trapped personnel, C_s denotes the cost of transporting the materials required to clean up a hazardous material spill, C_c denotes the cost of transporting the materials needed to resume interval operation, C_{cij} is the unit cost of transporting c from J to I, $number(c_{cij})$ is the quantity required of c material from J to I, C_{cik} is the unit cost of c from K to I, $number(c_{cik})$ is the required quantity of c material from K to I, and $number(C_{kI_n})$ denotes the number of supplies needed to rescue the trapped people in I_n. M_k denotes the collection of supplies contained in each rescue team, and $number(C_{sI_n})$ denotes the quantity of hazardous materials needed to handle the incident point in I_n. M_k denotes the collection of materials contained in each hazardous material handling team, $\text{number}(C_{cI_n})$ denotes the amount of line repair materials required at the incident point in I_n, and M_k denotes the collection of materials for each line repair team.

In this paper, the dual objective function is solved under the constraints of weights and resource ceilings, with the objective of achieving the shortest arrival time of rescue supplies and the lowest cost of delivering rescue supplies.

3.2. Determining Emergency Weights

The allocation of emergency resources needs to calculate the weighting of people trapped, the level of hazardous material leakage, and the priority of repairing the railway section according to the initial situation of the disaster area, and allocate various rescue materials to the incident point for rescue according to the percentage of various weights. Rescue teams carry different types and quantities of materials for different rescue targets.

(1) Rescue of trapped persons

Based on the number of people trapped at each incident site at the time of the disaster, we determine the number of rescue teams that need to be dispatched to each incident site.

$$w_n(P) = \left\lceil \left(\frac{I_n(P)}{p} \right) \right\rceil \tag{4}$$

where $w_n(P)$ indicates the number of rescue teams required at the incident point I_n, $\lceil \left(\frac{I_{ink}}{p} \right) \rceil$ denotes the upward rounding of the number of trapped personnel, $I_n(P)$ is the number of trapped persons at the incident point I_n, and p denotes the expected number of trapped persons per rescue team.

(2) Disposal rescue for coal-to-oil and other hazardous chemical leaks

According to the area of hazardous chemical leaks at the rescue point and the nature of the hazardous chemical itself, the hazard class is divided. Based on the Regulations on Safe Management of Hazardous Chemicals (revised in 2011), the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (GHS), and the Interim Provisions on the Management of Railway Transportation of Dangerous Goods, we here refer to the volatile characteristics of hazardous chemicals and the volatile hazard zoning table to determine the hazard class of flammable liquids (such as coal-to-oil, lubricating oil, and other dangerous chemicals), and quantify the emergency weights $w_n(C)$ as shown in the following equation.

$$w_n(C) = \begin{cases} 0, \textit{if} \text{ not leaked} \\ 1,\ if\ s(C) < 10\ \text{m}^2 \text{and not volatile} \\ 2,\ if\ 10\ m^2 \le s(C) \le 30\ \text{m}^2 \text{and not volatile} \\ \text{or } s(C) \le 10\ \text{m}^2 \text{and volatile} \\ 3,\ \text{else} \end{cases} \tag{5}$$

where $w_n(C)$ indicates the rescue team needed to deal with the hazardous chemical spill at the incident point I_n.

(3) Damage repair of railway transport lines

Hazardous chemical railway transportation accidents have the characteristics of a wide range and a large range of derivative accidents. In the emergency disposal process, the leaked hazardous chemicals should be disposed of in a timely manner, the emergency supplies should be assembled and deployed to the incident point, and the line should be unblocked to ensure the normal operation of the line and avoid secondary disasters.

According to the zone importance and zone density of the incident point, the zone importance of transporting hazardous chemicals is more important than the zone density, and at the same time, in order to avoid the situation of not assigning rescue teams to an incident point where the priority of a zone is too low, the formula for calculating zone priority is given as follows.

$$w_n(R) = (1 - \eta \cdot n) \\ \frac{Xw_a(I_n) + \delta w_b(I_n)}{\sum_{i=1}^{n} (Xw_a(I_n) + \delta w_b(I_n))} \tag{6}$$

$$w_a(I_n) = \frac{number(I_n)}{\sum_{i=1}^{n} number(I_n)} \tag{7}$$

$$w_b(I_n) = \frac{d_{inc}^{\alpha} + d_{ing}^{\beta}}{\sum_{i=1}^{n} (d_{inc}^{\alpha} + d_{ing}^{\beta})} \tag{8}$$

where $w_n(R)$ indicates the required repair teams for damaged railway transport lines at the incident point I_n, η is the pre-assigned value for each incident point, n is the number of incident points, χ, δ is the balance coefficient between $w_a(I_n)$ and $w_b(I_n)$, $w_a(I_n)$ denotes the importance of the zone, $w_b(I_n)$ denotes the intensity of the zone, and $number(I_n)$ is the number of damaged train cars carrying hazardous chemical materials at each rescue point I_{n}. d_{inc} is the number of trains per unit time (per hour) at the incident point I_n, d_{ing} is the number of damaged meters of railway tracks at the incident point I_{n}, and α, β is the price-based importance adjustment parameter.

3.3. Solution of Multi-Objective Optimization Model

In this paper, we use the artificial bee colony algorithm, genetic algorithm, and particle swarm algorithm to solve the multi-objective function for comparison experiments. The artificial bee colony algorithm (ABC algorithm) is an algorithm inspired by bee colony behavior, which was proposed by the Karaboga group in 2005 for optimizing algebraic problems, mainly for solving multivariate function optimization problems.

The fitness function of the swarm algorithm achieves the lowest cost and shortest time for delivering relief supplies. The method of dealing with solutions of multiple objective functions in the swarm algorithm is to use pareto solutions; because of the conflict of objective functions or the phenomenon of incomparability, a solution may be good in one form but may not be good in another objective, and in improving one of the objective functions, it may weaken the other set of solutions. The set of non-dominated solutions is established, and in the process of each iteration, the sub-generation that makes at least one objective function better is released into the set of non-dominated solutions, while the inferior solutions are sieved out from the dominated solutions in the set according to greedy selection. The objective functions in this paper do not belong to complete contradiction, as long as the solution with the shortest time is selected in the set of non-dominated solutions, which is the lowest cost at the same time.

The ABC algorithm flow chart is shown in Figure 1.

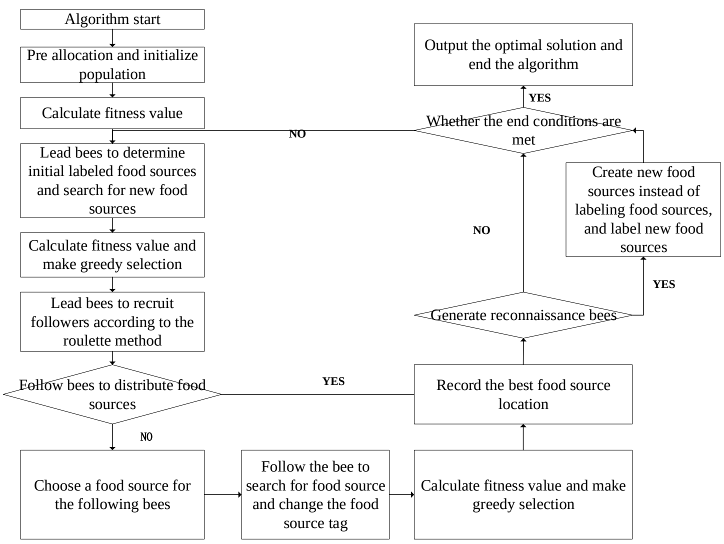

Figure 1. Solution flow chart based on the bee colony algorithm.

The matrix corresponding to the honey-picking bees is the solution of the algorithm, the fitness value is the objective function, the honey source is the rescue point, the observation bee is the iterative process, and the scout bee is the process of finding a new solution.

4. Example Analysis

4.1. Overview of the Algorithm

We take the railway transportation network of Shenhua Ordos Coal to Liquid Liquefaction Project as an example, which is located in the ecological protection area of the Yellow River basin and crosses the Taihang Mountains, the Loess Plateau, and the Ordos Basin. It may be affected by natural disasters such as mud rock flow and earthquakes, which may lead to railway transportation accidents. Moreover, the transportation along the line is inconvenient, the terrain is complex, and it is difficult to transfer goods, which may easily lead to secondary disasters. Especially for the trains transporting oil products, because the oil vapor is heavier than the air, it can spread to a relatively far place at a lower elevation, and can easily cause explosions and other secondary disasters in the case of open fire. However, the damage of goods, tanks, tracks, and surrounding buildings caused by dangerous chemical train accidents is extremely difficult to recover in a short time. Emergency rescue resources are limited and scattered, making rescue difficult. The ecology along the railway is fragile, which makes it easy to cause production environment pollution and ecological disaster for the Yellow River basin water system.

In this paper, we assume that the damage to the terminal facilities of the railway transportation network is accompanied by the spillage and volatilization of hazardous chemicals, which causes casualties in a certain area and requires the emergency treatment and rescue of the disaster site. We set a total of 10 rescue points of J_1, J_2, J_3, J_4, J_5, J_6, J_7, J_8, J_9, and J_{10} in the disaster surrounding and a command center K_1 involved in the rescue, for a total of five incident points of I_1, I_2, I_3, I_4, and I_5 and seven kinds of core material needs.

Each incident location requires different amounts of rescue materials to be dispatched. Among them, material 1, material 2, material 3, material 4, and material 5 are dispatched based on the weight of the number of people trapped, material 6 is dispatched based on the rescue of hazardous material leakage, and material 1, material 2, material 3, and material 7 are dispatched based on the priority of the zone. The following figure shows the type of supplies and the number of reserves contained in each rescue point and command center (Figure 2).

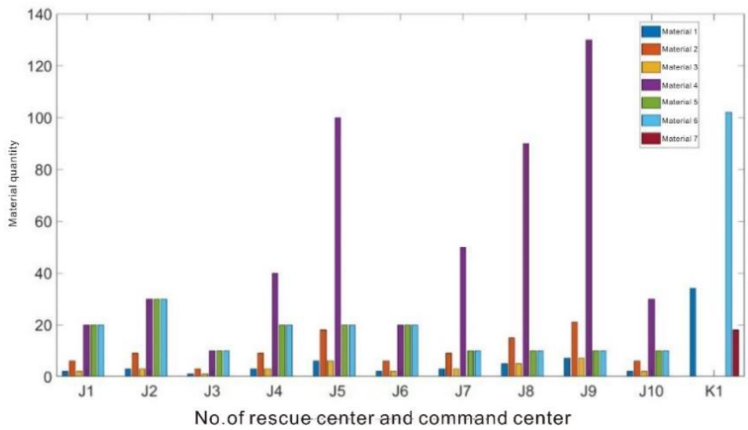

Figure 2. Types and reserves of materials contained in each rescue center and command center.

The cost and time of transporting supplies from the rescue point to the incident point varies, and the cost and time of transporting various supplies from the rescue point to the disaster area with the command center is shown in the figure below (Figure 3, Figure 4, Figure 5). In which, the x-axis and y-axis of each bar chart represent the corresponding rescue point and disaster area, and the height of z-axis represents the transportation cost or time cost of the corresponding material delivery.

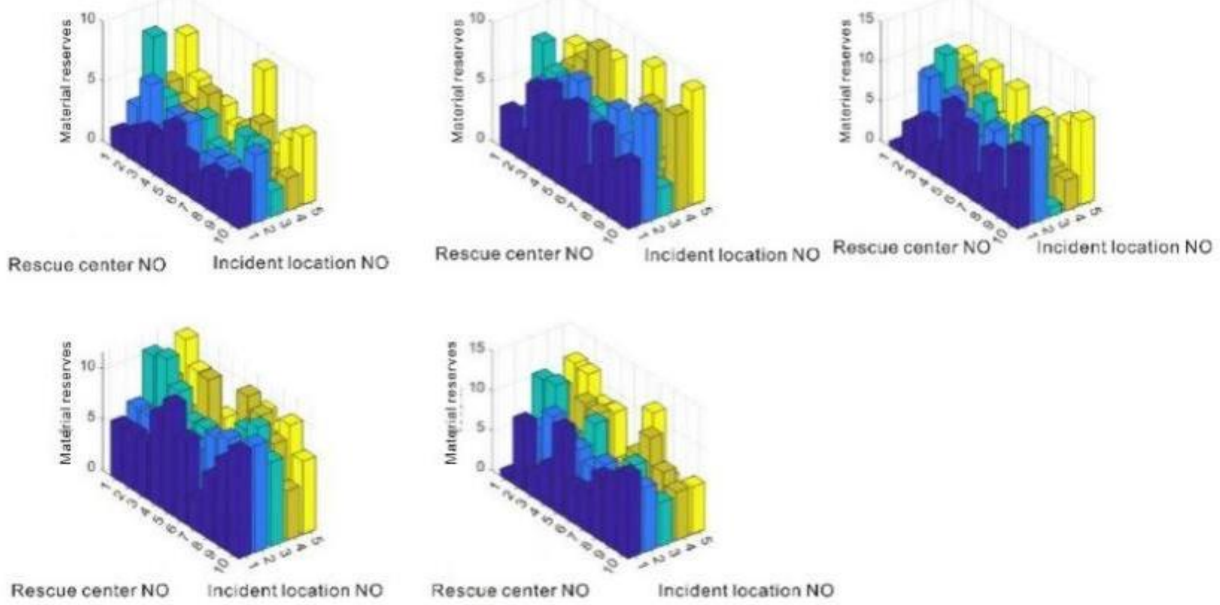

Figure 3. Transportation cost of various materials transported from each rescue point to each disaster-stricken point.

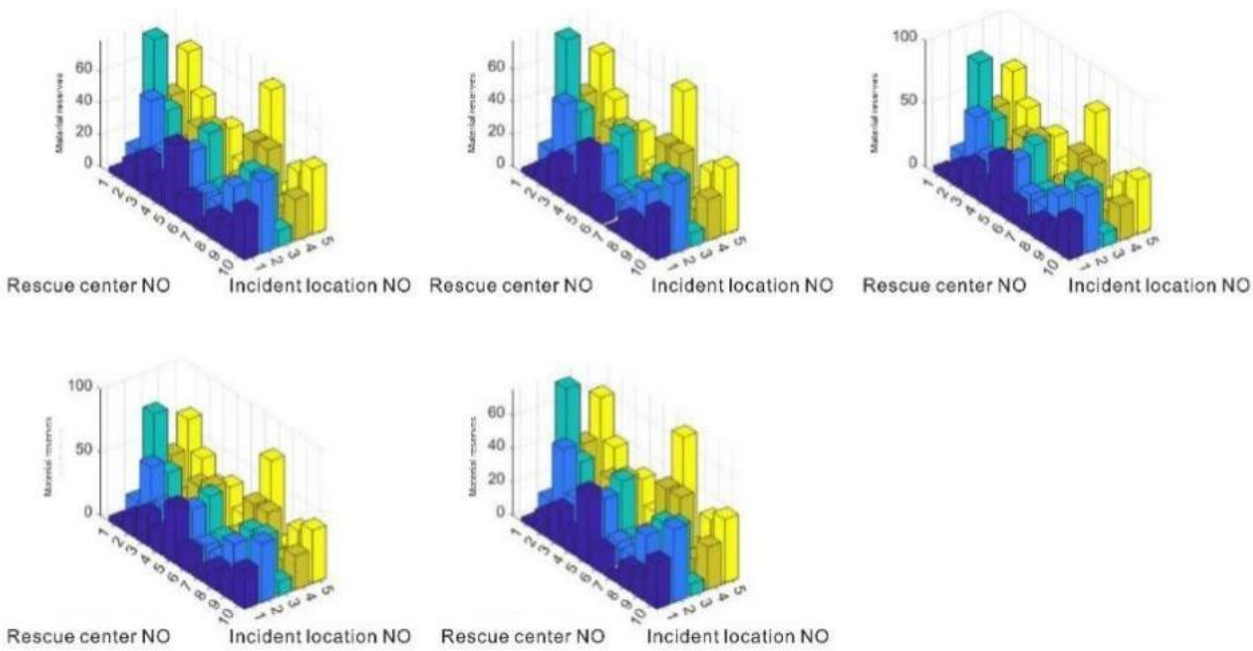

Figure 4. Time cost of transporting various materials from each rescue point to each disaster-stricken point.

Table 1. Initial disaster situation at the disaster site.

Category and Interval	Incident Point I_1	Incident Point I_2	Incident Point I_3	Incident Point I_4	Incident Point I_5
Number of people trapped	8	3	11	1	9
Hazardous material leakage situation	26 m^2 and non-volatile	37 m^2 and volatile	9 m^2 and not volatile	No hazardous material spills	No hazardous material spills
Number of damaged sections of the train	2	0	3	4	2
Number of meters of rail damage	320	260	110	330	280

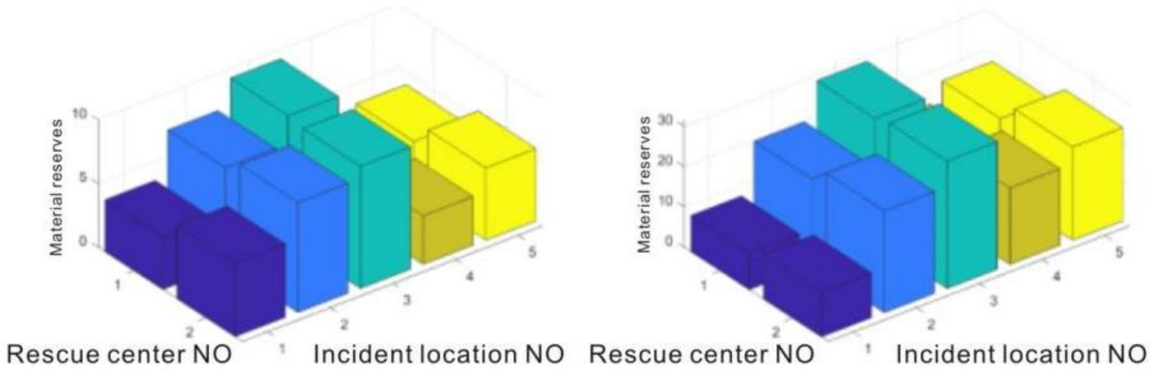

Figure 5. Transportation cost and time cost of various materials transported from the command center to the disaster-stricken areas The number of people trapped, hazardous material leaks, train damage, and track damage at the incident point are shown in Table 1 below.

The number of rescue teams of various types that need to be dispatched to each rescue point was determined according to the way the weights were calculated in Section 2, and the results are shown in Table 2.

Table 2. Number of rescue teams of various types to be dispatched to each disaster-stricken area.

Squad Name and Incident Point	Incident Point I_1	Incident Point I_2	Incident Point I_3	Incident Point I_4	Incident Point I_5
Rescue of stranded squads	3	1	4	1	3
Hazardous materials clearance squad	3	5	2	0	0
Dredging operation squad	4	2	2	7	3

4.2. Comparison of Three Solution Methods

According to the allocation scheme of each rescue point, after calculating the weight of each incident point and the demand for emergency supplies, the following two resource allocation schemes can be obtained according to the multi-objective function solution designed in Section 3.

(1) The result of the swarm algorithm and the iterative process of the algorithm

Following the steps of the swarm algorithm, the resource allocation scheme of the swarm algorithm can be obtained as shown in Figure 6 (left), and the height of the corresponding point represents the amount of supplies dispatched from the rescue point to the corresponding incident point. The iterative process of the algorithm is shown in Figure 6 (right).

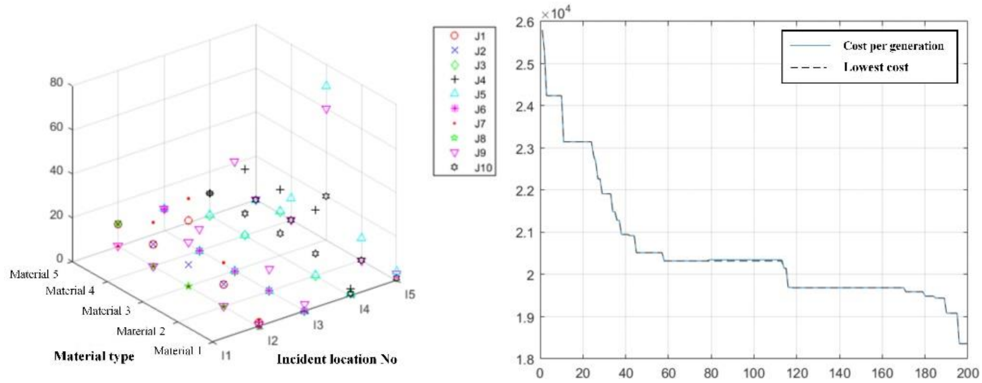

Figure 6. Solution result of bee colony algorithm and algorithm iteration process diagram.

The command center K_1 allocation scheme is shown in Table 3.

Table 3. Resource allocation scheme of command center K_1 obtained using the swarm algorithm.

Command Center K_1 Dispatch Material Volume	Material 1	Material 6	Material 7
Incident point I_1	7	21	4
Incident point I_2	3	9	2
Incident point I_3	6	18	2
Incident point I_4	8	24	7
Incident point I_5	10	30	3

(2) Genetic algorithm solution results

Following the steps of the genetic algorithm, the resource allocation scheme of the genetic algorithm, as shown in Figure 7 (left), and the iterative process of the algorithm of the genetic algorithm, as shown in Figure 7 (right), can be obtained.

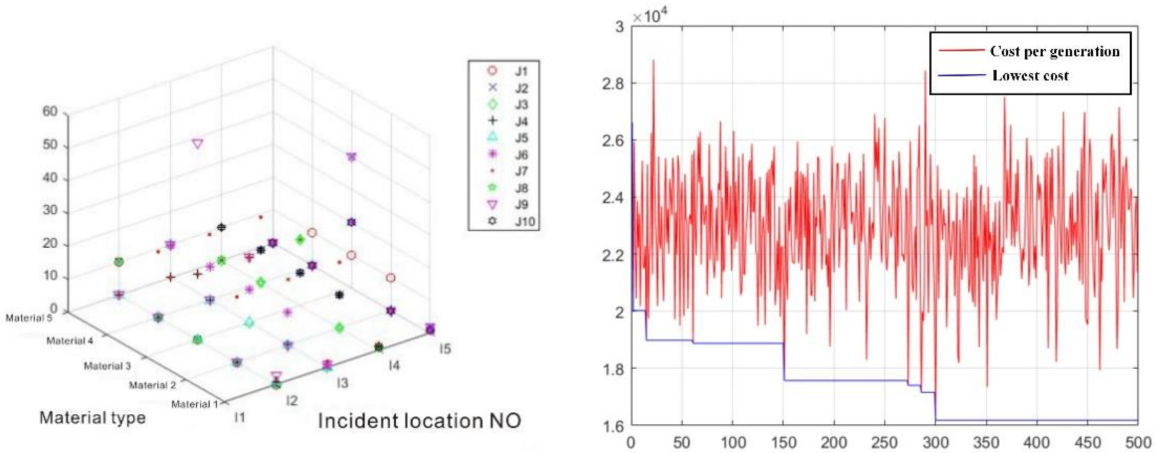

Figure 7. Genetic algorithm resource allocation scheme and algorithm iteration process diagram.

The command center K_1 distribution scheme is shown in Table 4.

Table 4. Resource allocation scheme of command center K_1 obtained using the genetic algorithm.

Command Center K_1 Dispatch Material Volume	Material 1	Material 6	Material 7
Incident point I_1	7	21	4
Incident point I_2	3	9	2
Incident point I_3	6	18	2
Incident point I_4	8	24	7
Incident point I_5	10	30	3

(3) Particle swarm algorithm solution results

Following the steps of the particle swarm algorithm, the resource allocation scheme of the particle swarm algorithm and the iterative process of the particle swarm algorithm, as shown in Figure 8 (left), can be obtained, as shown in Figure 8 (right).

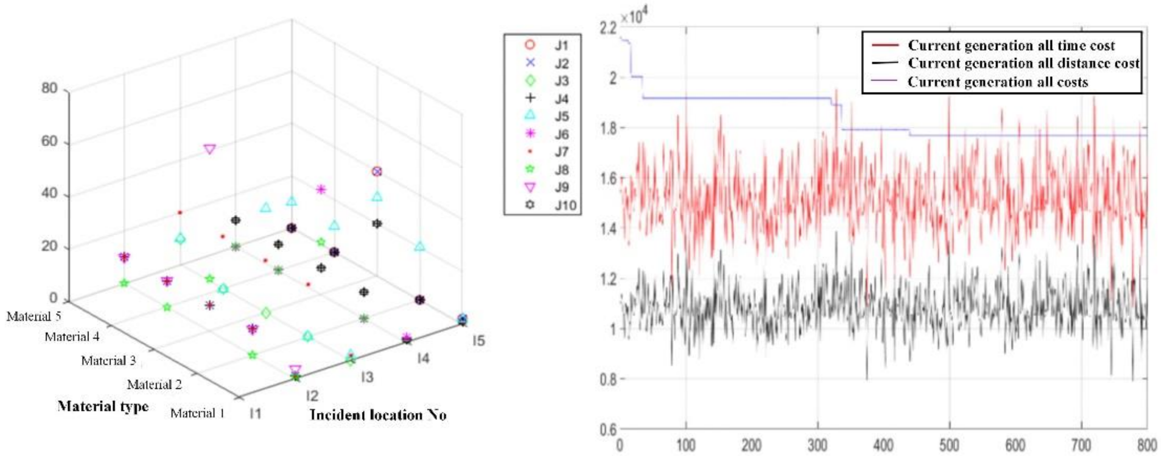

Figure 8. Particle swarm optimization algorithm resource allocation scheme and algorithm iteration process diagram.

The command center K_1 distribution scheme is shown in Table 5.

Table 5. Resource allocation scheme of command center K_1 obtained using the particle swarm algorithm.

Command Center K_1 Dispatch Material Volume	Material 1	Material 6	Material 7
Incident point I_1	7	21	4
Incident point I_2	3	9	2
Incident point I_3	6	18	2
Incident point I_4	8	24	7
Incident point I_5	10	30	3

4.3. Program Selection

According to the three heuristic algorithms, three resource allocation schemes are obtained and the cost and time for delivering materials are calculated, as shown in Table 6.

Table 6. Cost analysis of three algorithms.

Costs and Algorithms	Artificial Bee Colony Algorithm	Genetic Algorithm	Particle Swarm Algorithm
Cost of shipping materials	5988.0244	8499.9701	12,001.3475
Time cost	10,800.9042	14,304.6448	16,441.6453

It can be found that the results of the swarm algorithm are significantly better than those of the genetic algorithm in terms of both the cost of transporting supplies and the time to transport the required supplies, and the swarm algorithm takes less time to converge to the desired result, which proves that the swarm algorithm considering pre-allocation is more suitable for the problem of allocating emergency rescue resources and consumes less than the traditional genetic algorithm.

5. Conclusions

(1) This paper simulates the occurrence of leakage accidents in the railway transportation of hazardous chemicals, such as coal-to-oil, with large ripple effects, an uneven distribution of emergency resources, multi-hazard coupling, trapped railway transportation, production area accident disasters, and other accident scenarios. We form a multi-hazard point and multi-rescue point emergency resource allocation scheme, propose an emergency weight calculation method for emergency rescue team allocation oriented toward rescue points, and constructs a railway transportation channel using the multi-objective optimization model with the shortest response time of the team and the lowest cost of transporting emergency supplies as the objective function.

(2) Based on the characteristics of the suddenness, timeliness, and diversity of emergency resource deployment in the rescue of coal-to-oil and other hazardous chemical accidents, and in order to avoid the problem of not participating in the rescue because the weight of local incident points is too small, a swarm algorithm model solving method based on pre-allocation is designed and compared with the genetic algorithm and particle swarm algorithm to realize the search and selection of emergency resource allocation methods.

(3) The verification of the arithmetic cases elaborated in this paper shows that the two heuristic algorithms are able to complete the corresponding tasks under the set conditions; in terms of the distribution effect, the swarm algorithm is significantly better than the traditional genetic algorithm. The rescue solution can complete the established emergency rescue tasks with the shortest time and the least cost, which is useful for emergency rescue activities under multi-hazard coupling. In future research, model constraints that are more in line with the emergency response can be constructed according to the characteristics of various types of disasters and emergency resource reserves, so that the resource allocation results are aligned with the emergency response needs and can play an active role in accident rescue.

(4) The emergency resource deployment method of the swarm algorithm was effectively verified in an emergency drill of a Baotou chemical spill accident of the National Energy Group. The method constructs a railway channel [29] along the Shuohuang–Shenshuo–Baoshen line, which is owned by the enterprise, and quickly deploys the national mine emergency rescue Shendong team, national hazardous chemical emergency rescue Yulin team, Erdos team, Ningdong team, Nenergy Railway Shuohuang and Baoshen teams, and the electric fire department located in Yulin of Shaanxi, Shuozhou of Shanxi, Ordos of Inner Mongolia, Yinchuan of Ningxia, Cangzhou of Hebei, etc. Emergency resources and equipment are quickly deployed to transfer stations along the railway line, the response time is shortened, the rescue efficiency is improved, and disaster control is enhanced. Therefore, the algorithm can be used as the preferred method for emergency resource deployment during the major industrial (mining, coal chemical, and coal railway transportation) accident rescue strategy of the National Energy Group. At the same time, it can also be used as a reference practice for the central government to deploy the public safety emergency resources of local regional governments at all levels, or the production technology emergency resources of various enterprises in the national natural disaster rescue response through the rapid rescue channel formed by the railway network of the National Railway Group.

Due to the special line transportation, the factors considered for hazardous chemicals in this paper are relatively simple. In future research, different types of hazardous chemicals can be considered to solve the model by adding constraints in the case of public transportation.

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