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Volunteer rescue dispatch during the Coronavirus Disease 2019 epidemic: Using the recruitment of volunteers for pneumonia epidemic prevention and control in Chun’an County as an example

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A R T I C L E   I N F O

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A B S T R A C T

To solve the problem of volunteer dispatch during the Coronavirus Disease 2019 (COVID-19) epidemic, a many-to-many two-sided matching volunteer dispatch method based on an improved predator-search algorithm is proposed. First, different evaluation index sets for volunteers and rescue tasks were developed, and weightings were determined using the analytic hierarchy process. Subsequently, the actual and expected values of the different indicators of the two parties were determined, and the triangular fuzzy number was used to calculate the satisfaction of the two parties. Based on this number, we used a linear weighting method to calculate the combined satisfaction and build a many-to-many two-sided matching model according to the demands of both parties. Subsequently, an improved predator-search algorithm was used to solve the model. Finally, taking the recruitment of volunteers for pneumonia epidemic prevention and control in Chun’an County as an example, the method proposed in our study was verified. A comparison and analysis of the results further demonstrated the feasibility and advantages of this method.

1. Introduction

Public health disasters have frightened the world. With the emergence and transmission of COVID-19, researchers have conducted corresponding studies [1,2]. In the early stages of an emergency, it takes some time for the government’s rescue force to respond to the crisis. This is a vital period during which volunteers can provide an important supplementary force for the government. Volunteers are scattered across a wide and varied area. The effective participation of volunteers can reduce government rescue costs and improve rescue efficiency. Quick and effective dispatch of volunteers has become the most important issue in rescue activities.

At present, research on personnel dispatch or assignment in other contexts has yielded specific results. For example, Topaloglu and Ozkaran [3] established a mixed-integer programming model that can obtain the optimal assignment plan for medical staff for the scheduling problem of medical staff considering factors such as on-the-job time and work intensity and designed a column generation algorithm to solve the model. Larson et al. [4] highlighted the importance of rescue workers’ dispatch to a disaster area immediately after an emergency occurs. Topaloglu et al. [5] pointed out the necessity of flexibility in restraining personnel in response to the changing shifts of medical staff during the rescue process. This solved the problem of up-and-down floating when personnel perform their own abilities in the face of an emergency, and solved the problem of fluctuations in the performance of personnel in emergency situations. Ren et al. [6] considered the collaborative relationship between personnel when considering personnel dispatch. This study emphasizes the use of information technology to complete collaborative matching between personnel. The mentioned literature focuses on personnel dispatch in emergencies, which lays the foundation for research on volunteers in emergencies. However, there is little research on volunteer dispatch in emergencies. For example, Falasca and Zobel [7] addressed the issue of volunteer dispatch in humanitarian organizations by considering the ability of volunteers and their willingness to participate in various tasks. They established a multi-objective optimization model and obtained the best volunteers through the solution of the model. Sampson [8] established a goal planning model for the dispatch of personnel as volunteers in public services, considering the number and willingness of volunteers to participate together in different service tasks. Chen et al. [9] constructed a matching and fusion model based

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on the evidence of volunteers, peer volunteers, and tasks to obtain an overall optimal solution. These studies provide decision-making technical support for volunteer dispatch issues but mainly consider the needs of one party unilaterally, which is a one-way assignment. The dispatch of volunteers and rescue missions should consider both sides simultaneously to achieve optimal dispatch.

Research on bilateral matching has been widely used in the fields of economy and management, for example, matching personnel and positions in human resource management [10,11], matching buyers and sellers in commodity transactions [12,13], pairing men and women in marriage [14–16], and matching banks and enterprises in the credit market [17,18]. Regarding task distribution in a ridesharing company, Yang et al. [19] proposed a two-sided matching decision model with two objectives. Regarding balance evaluation criteria in the two-sided matching (TSM) decision, Liang et al. [20] proposed a quantitative matching decision model to select an optimal matching scheme for Public-Private Partnership (PPP) infrastructure projects based on the Hesitant Fuzzy Set (HFS). The problem of bilateral matching is widespread in real life, and also applies to the problem of bilateral matching between volunteers and rescue missions in volunteer dispatch.

Determining the satisfaction of both parties is a key step in the process of bilateral matching decision-making. Different forms of evaluation indicators must be considered simultaneously when determining the satisfaction of volunteers and rescue missions. Therefore, the decision to dispatch volunteers is a multi-attribute decision-making problem. At present, extensive research on triangular fuzzy multi-attribute decision-making has been conducted globally, and certain research results have been obtained [21–31]. For example, focusing on project quality, Hou et al. [23] proposed an evaluation method of engineering the quality coupling effect based on a triangular fuzzy number (TFN). Du and Song [24] used a TFN analytic hierarchy process (AHP) to comprehensively evaluate the quality management system of a building engineering testing laboratory in Tangshan. Regarding groundwater problems, Yang et al. [26] established risk assessment models for adult and child health risk assessments in the wet and dry seasons, respectively, using TFNs. For hospital-related problems, Karimi et al. [28] introduced the best worst method to solve multi-attribute decision-making (MADM) problems in a fuzzy environment. For coal mining, Zhao et al. [29] used the triangular fuzzy number-AHP method to establish a TFN-AHP prominent forecasting model and determined the weight of each outstanding risk assessment index, while Zhou et al. [30] established a quantitative analysis model of accidents based on TFNs and accident trees. Triangular fuzzy MADM has made certain achievements in various fields, providing guidance and reference values for the dispatch of volunteers during emergencies.

In summary, relatively few studies have been conducted on volunteer dispatch during emergencies. Existing dispatches are often one-way; however, volunteers also have their own wishes. To improve rescue efficiency, the satisfaction of both parties should be considered simultaneously. In reality, the evaluation indicators for volunteers and rescue tasks are often different. Therefore, the dispatch of volunteers and rescue tasks is a MADM problem with different attribute values and weights. In this study, a decision-making method that combines triangular fuzzy numbers and an AHP was applied to volunteer dispatch. At the same time, there is a basic assumption that in most situations, the personnel dispatched is sufficient. However, in actual situations, particularly in the early stages of rescue, the number of volunteers is often insufficient to meet all rescue missions. Therefore, in the process of volunteer dispatch, one rescue task is often completed by multiple volunteers, and in some cases, one volunteer completes multiple tasks. It is a many-to-many matching process.

In this study, we examined the methods of volunteer rescue and dispatch during the COVID-19 epidemic and completed the following research work: (1) We applied the AHP to the study of volunteer dispatch. According to a real-life situation, we developed different evaluation index sets for volunteers and rescue missions through the pairwise comparison between different indexes and used the AHP to calculate the index weight. (2) The actual values and expectations of the different evaluation indicators on both sides were expressed in the form of interval values and language information using triangular fuzzy numbers to calculate the satisfaction of both subjects. (3) We used the linear weighting method to calculate the combined satisfaction. (4) According to the needs of both parties, we built a volunteer rescue dispatch model for the COVID-19 pandemic.

2. Problem description

The problem to be solved for volunteer rescue dispatch during the COVID-19 epidemic is as follows: first, how to set different evaluation index sets according to the actual situation; second, how to calculate the index weight based on the pairwise comparison of different evaluation indexes; third, how to calculate the satisfaction of both parties based on the actual value and expected value of different evaluation index sets; and finally, according to the actual demand of both parties, using an intelligent optimization algorithm to obtain the best dispatch plan.

To clearly describe the concentration and amount of volunteer rescue and dispatch during the COVID-19 pandemic, the following notations are important:

\[ M = \{ M_1, M_2, \ldots, M_f \} \] task set, where \( M_i \) represents the \( i \)th task, \( i = 1, 2, \ldots, f \).

\[ V = \{ V_1, V_2, \ldots, V_g \} \] collection of volunteers, where \( V_j \) represents the \( j \)th volunteer, \( j = 1, 2, \ldots, g \).

\[ A = \{ A_1, A_2, \ldots, A_k \} \] set of indicators used in task-evaluation volunteers, where \( A_k \) represents the \( k \)th indicator considered by task-evaluation volunteers, \( k = 1, 2, \ldots, n \).

\[ B = \{ B_1, B_2, \ldots, B_m \} \] set of indicators used by volunteers in evaluating tasks, where \( B_i \) represents the \( i \)th indicator considered by volunteers in evaluating tasks, \( i = 1, 2, \ldots, m \).

\[ \hat{w}_{ki} \] actual indicator value of task \( M_i \) under the interval number indicator \( B_k \).

\[ \hat{v}_{kj} \] expected value of task \( M_i \) under interval index \( A_k \).

\[ \hat{u}_{ij} \] actual index value of volunteer \( V_j \) under the interval number index \( A_k \).

\[ \hat{v}_{ij} \] volunteer \( V_j \)'s expected value under interval index \( B_k \).

\[ \hat{u}_{ij} \] actual index value of task \( M_i \) under the language information index \( B_k \).

\[ \hat{v}_{ij} \] expected value of task \( M_i \) under language information indicator \( A_k \).

\[ \hat{u}_{ij} \] volunteer \( V_j \)'s actual index value under the language information index \( A_k \).

\[ \hat{v}_{ij} \] volunteer \( V_j \)'s expected value under language information indicator \( B_k \).

\[ \hat{u}_{ij} \] volunteer \( V_j \)'s satisfaction task \( M_i \) under index \( B_k \).

\[ \hat{u}_{ij} \] task \( M_i \)'s satisfaction with volunteer \( V_j \) under indicator \( A_k \).

\[ \hat{u}_{ij} \] weight of the index set \( A_i \), where \( A_i \) represents the weight of the index \( A_i, k = 1, 2, \ldots, n \).

\[ 
\begin{align*}
Q & = \{ Q_1, Q_2, \ldots, Q_m \} \text{ weight of the index set } B_i, \\
X & = \{ X_1, X_2, \ldots, X_f \} \text{ collection of the number of volunteers required by the } f \text{ task, where } X_i \text{ represents the number of volunteers required for the } i \text{th task} \text{ equal to } X_i, i = 1, 2, \ldots, f \text{.} \\
Y & = \{ Y_1, Y_2, \ldots, Y_g \} \text{ collection of the number of tasks that } g \text{ volunteers want to perform, where } Y_j \text{ indicates that the number of tasks that the } j \text{th volunteer wants to perform is not greater than } Y_j, j = 1, 2, \ldots, g. 
\end{align*}
\]

3. Dispatch method

3.1. Calculation of indicator weight

This study uses the AHP [32] to determine the index weight. First, the problem to be solved is stratified and serialized, that is, according
to the nature of the problem and the goal to be achieved, the problem is decomposed into different constituent factors; the hierarchical cluster combination is formed according to the mutual influence and membership relationship between the factors, thus, building an orderly hierarchical structure model. Then, the relative importance of each level of factors in the model is given a quantitative expression based on people’s judgments of objective reality. Mathematical methods were used to determine the relative importance of all factors at each level. Next, the weight vector was calculated, and consistency was checked. Finally, the combination weight vector was calculated, and the consistency of the combination was checked again. The specific steps are as follows [33].

3.1.1. Construct judgment matrix

The judgment matrix was constructed based on the relative importance of the various indicators obtained from the investigation. Pairwise comparisons generally use relative scales, expressed according to the 1–9 scale method of Satie (note: Seaty), as shown in Table 1.

This study collects data through investigation and obtains judgment matrices \(A = [a_{ki}]_{n \times n}\) and \(B = [b_{ij}]_{m \times m}\).

3.1.2. Judgment matrix solution steps

Step 1: Find the product \(O_k\) of each row element in matrix \(A\) and the product \(P_i\) of each row element in matrix \(B\):

\[
O_k = \prod_{i=1}^{n} a_{ki} (k = 1, 2, \ldots, n) \tag{1}
\]

\[
P_i = \prod_{j=1}^{m} b_{ij} (t = 1, 2, \ldots, m) \tag{2}
\]

Step 2: Calculate \(O_k\’s\) nth degree equation root \(W_k\) and \(P_i\’s\) degree equation root \(Q_t\):

\[
W_k = n\sqrt[ n ]{ O_k } (k = 1, 2, \ldots, n) \tag{3}
\]

\[
Q_t = m\sqrt[ m ]{ P_t } (t = 1, 2, \ldots, m) \tag{4}
\]

Step 3: Normalize \(W_k\) and \(Q_t\) to obtain weight vectors \(W_k\) and \(Q_t\):

\[
W_k = \frac{ W_k }{ \sqrt{ \sum_{k=1}^{n} W_k } } (k = 1, 2, \ldots, n) \tag{5}
\]

\[
Q_t = \frac{ Q_t }{ \sqrt{ \sum_{t=1}^{m} Q_t } } (t = 1, 2, \ldots, m) \tag{6}
\]

Step 4: Calculate the maximum eigenvalue \(\lambda^A_{\text{max}}\) of judgment matrix \(A\) and maximum eigenvalue \(\lambda^B_{\text{max}}\) of judgment matrix \(B\):

\[
\lambda^A_{\text{max}} = \frac{1}{ n } \sum_{k=1}^{n} (AW_k)_k \tag{7}
\]

\[
\lambda^B_{\text{max}} = \frac{1}{ m } \sum_{t=1}^{m} (BQ_t)_t \tag{8}
\]

Table 1

| Scaling | Meaning |
|---------|---------|
| 1       | The two indicators have the same importance. |
| 3       | The former indicator is slightly more important than the latter. |
| 5       | The former indicator is obviously more important than the latter. |
| 7       | The former indicator is more important than the latter. |
| 9       | The former indicator is extremely more important than the latter. |
| 2, 4, 6, 8 | Represents the intermediate value of the adjacent judgment. |

Reciprocal: if the ratio of importance of index i to index j is \(a_{ij}\), then the ratio of importance of index j to index i is \(\frac{1}{a_{ij}} = 1\).

Table 2: RI values.

| Order(2) | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|----------|----|----|----|----|----|----|----|----|----|
| RI       | 0.00  | 0.00  | 0.58  | 0.90  | 1.12  | 1.24  | 1.32  | 1.41  | 1.45  |

Among them, \(W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix}\) weight vector is the eigenvector of judgment matrix \(A\). \(Q = \begin{bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_m \end{bmatrix}\) weight vector is the eigenvector of judgment matrix \(B\).

3.1.3. Consistency inspection

After calculating the weight value, consistency must be tested. At this time, the consistency index CI is introduced:

\[
CI = \frac{ \lambda_{\text{max}} - n } { n - 1 } \tag{9}
\]

Among them, a CI \(\leq 0.1\) is required. This represents the judgment matrix of the order \(\gamma\), \(CR = \frac{ CI } { RI }\). Among them, CR is a consistent ratio and RI is the average random consistency index; the specific values are listed in Table 2. When \(CR < 0.1\), the judgment matrix has acceptable consistency; otherwise, it needs to be revised.

3.2. Satisfaction calculation

In TSM, matching between indicators affects the satisfaction of bilateral participants. The greater the satisfaction of both parties under the same indicator, the greater the likelihood of bilateral matching. Conversely, the lower the satisfaction of both parties under the same indicator, the less likely the bilateral match. In real-life matching problems, bilateral entities often yield inaccurate, nonquantified, and ambiguous data. In 1965, Zadeh [34] proposed the fuzzy set theory to analyze and deal with the problem of uncertain data. In reality, different evaluation indicators have different expressions. This study primarily used interval numbers and the linguistic information index satisfaction.

3.2.1. Number of intervals

When the index value is an interval number, the actual value of the subject \(M_i\) and \(V_i\) in the index \(B_i\) is \(m_i\), and the expected value is \(\bar{v}_{ij}'\), where \(\bar{v}_{ij} = \begin{bmatrix} \bar{v}_{ij}^1, \bar{v}_{ij}^2 \end{bmatrix}\), \(\bar{v}_{ij} = \begin{bmatrix} \bar{v}_{ij}^1, \bar{v}_{ij}^2 \end{bmatrix}\); the actual value of the indicator \(A_i\) is \(a_{ki}\), and the expected value is \(\bar{a}_{ki}\), where \(\bar{a}_{ki} = \begin{bmatrix} \bar{a}_{ki}^1, \bar{a}_{ki}^2 \end{bmatrix}\), \(\bar{a}_{ki} = \begin{bmatrix} \bar{a}_{ki}^1, \bar{a}_{ki}^2 \end{bmatrix}\).

The actual value is between \(m_i\) and expected value \(\bar{v}_{ij}'\). There are five relationships according to their positions: Relation 1 is when \(\bar{v}_{ij}'\) is completely greater than \(m_i\); Relation 2 is when \(\bar{v}_{ij}'\) is greater than \(m_i\), and the two cross; Relation 3 is when \(\bar{v}_{ij}'\) completely contains \(m_i\); Relation 4 is when \(\bar{v}_{ij}'\) is less than \(m_i\), and the two cross; Relation 5 indicates that \(\bar{v}_{ij}'\) is completely smaller than \(m_i\).
According to the five positional relationships, the satisfaction level of $V_j$ to $M_i$ under indicator $B_k$ can be obtained as follows:

\[
\alpha_{ijk} = \begin{cases} 
0, & (\text{Relation 1}) \text{or (Relation 5)} \\
\frac{(\bar{m}_{ijk} - \bar{v}_{ijk})}{(\bar{v}_{ijk} - \bar{v}_{ijk})}, & (\text{Relation 2}) \\
1, & (\text{Relation 3}) \\
\frac{(\bar{v}_{ijk} - \bar{m}_{ijk})}{(\bar{v}_{ijk} - \bar{v}_{ijk})}, & (\text{Relation 4})
\end{cases}
\]  

(10)

Among them, $i = 1, 2, \ldots, f$; $j = 1, 2, \ldots, g$; $k = 1, 2, \ldots, m$; $0 \leq a_{ijk} \leq 1$.

Similarly, five positional relationships between the actual value $\bar{v}_{kJ}$ and the expected value $\bar{m}_{kJ}$ can be obtained. According to the five positional relationships, the satisfaction level of $M_j$ to $V_j$ under indicator $A_k$ can be obtained as follows:

\[
\beta_{kij} = \begin{cases} 
0, & (\text{Relation 1}) \text{or (Relation 5)} \\
\frac{(\bar{v}_{kij} - \bar{m}_{kij})}{(\bar{m}_{kij} - \bar{v}_{kij})}, & (\text{Relation 2}) \\
1, & (\text{Relation 3}) \\
\frac{(\bar{m}_{kij} - \bar{v}_{kij})}{(\bar{m}_{kij} - \bar{m}_{kij})}, & (\text{Relation 4})
\end{cases}
\]  

(11)

Among them, $i = 1, 2, \ldots, f$; $j = 1, 2, \ldots, g$; $k = 1, 2, \ldots, n$; $0 \leq \beta_{kij} \leq 1$.

### 3.2.2. Language information

Although linguistic variables can easily express the current knowledge of both parties, it is difficult to use the collected language evaluation information directly. Therefore, it is not conducive to gathering opinions from both parties. Language evaluations of different granularities correspond to different TFNs. In this study, the elements in the seven-grain language evaluation set were converted into corresponding TFNs. Details are presented in Table 3.

### 3.3. Construction of the dispatch model

To meet the requirements of both parties and maximize their satisfaction, a multi-objective model was constructed.

\[
\max Z_1 = \sum_{i=1}^{f} \sum_{j=1}^{g} a_{ij} x_{ij}
\]

(16)

\[
\max Z_2 = \sum_{i=1}^{f} \sum_{j=1}^{g} \beta_{i} x_{ij}
\]

(17)

subject to:

\[
\sum_{j=1}^{g} x_{ij} = X_i, \quad i = 1, 2, \ldots, f
\]

(18)

\[
\sum_{i=1}^{f} x_{ij} \leq Y_j, \quad i = 1, 2, \ldots, g
\]

(19)

where:

\[
x_{ij} = 0 \text{ or } 1, \quad i = 1, 2, \ldots, f; \quad j = 1, 2, \ldots, m
\]

(20)

In this model, Eqs. (16) and (17) are both objective functions, and their purpose is to maximize the satisfaction of the task with the volunteers and maximize the satisfaction of the volunteers with the task. Eq. (18), $X_i$ volunteers were matched with task $M_i$ during the matching process. Under the constraint condition (19), volunteer $V_j$ can be matched with at most $Y_j$ tasks during the matching process. Eq. (20) is a 0–1 constraint, $x_{ij} = 0$ means task $M_i$ does not match volunteer $V_j$, $x_{ij} = 1$ means that volunteer $V_j$ is assigned to complete task $M_i$, and the model is a many-to-many TSM model.

### 3.4. Solving the dispatch model

To solve the multi-objective model, this study adopted the linear weighted method, and Eqs. (16 and 17) can be weighted: Let $u_1$ and $u_2$ be the weights of goals $Z_1$ and $Z_2$, respectively, satisfying $0 \leq u_1 \leq 1, 0 \leq u_2 \leq 1, u_1 + u_2 = 1$. The comprehensive satisfaction formula for both parties is obtained as follows:

\[
\delta_{ij} = u_1 a_{ij} + u_2 \beta_{ij}
\]

(21)

The multi-objective model is transformed into the following single-objective model:

\[
\max Z = \sum_{i=1}^{f} \sum_{j=1}^{g} \delta_{ij} x_{ij}
\]

(22)

subject to:

\[
\sum_{j=1}^{g} x_{ij} \leq 1, \quad i = 1, 2, \ldots, f
\]

(23)

\[
\sum_{i=1}^{f} x_{ij} \leq 1, \quad i = 1, 2, \ldots, m
\]

(24)

\[
x_{ij} = 0 \text{ or } 1, \quad i = 1, 2, \ldots, f; \quad j = 1, 2, \ldots, g
\]

(25)
In the aforementioned model, Eq. (22) is the objective function, which means that the satisfaction of volunteers and tasks is maximized. Under constraint (23), each task should be completed by at most one volunteer. Under constraint condition (24), each volunteer can complete at most one task. Eq. (25) is a 0–1 constraint condition, $x_{ij} = 1$ means that volunteer $V_i$ is assigned to complete task $T_j$, otherwise $x_{ij} = 0$.

The single-objective model can be solved using an improved predator-search algorithm.

By simulating the predation strategy of animals, Linhares proposed a new bionic calculation method in 1998, namely the predatory search algorithm (PSA) [35].

This study improves the traditional predator-search algorithm in two ways:
1. The traditional predator-search algorithm finds the minimum fitness value. In this study, the objective was to find the maximum fitness value.
2. For the optimal solution obtained, if the two conditions of the number of volunteers required for all tasks and the volunteers can complete at least one task are not satisfied, the global search is reentered.

The algorithm flow of the improved predator-search algorithm is as follows:
1. First, an initial point, $S$, is randomly selected. Let $R = S$, $count = 0$ and level = 0.
2. If level < numLevel, select $z$ solutions in the neighborhood of $S$, select the largest solution $P$ among them, and then proceed to Step 3; otherwise, proceed to Step 7.
3. If the optimal solution among the selected neighborhood solutions is $P > Restriction(level)$, set $S = P$ and proceed to Step 4; otherwise, proceed to Step 5.
4. If $f(S) > f(R)$, set $R = S$, level = 0, $count = 0$, recalculate the limit, and then proceed to Step 2; otherwise, proceed to Step 5.
5. If $count < Count_{Max}$, then let level = level + 1, $count = 0$ and then go to Step 6; otherwise, go to Step 2.
6. If $level = Level_{hold}$, set level = Level_{highhold}, and go to Step 2; otherwise, go directly to Step 2.
7. Judge whether the optimal solution meets the following conditions: the number of volunteers required for all tasks is met, and volunteers can complete at least one task. If it is satisfied, end the entire process; otherwise, go to Step 1.

In Step 4, if $f(S) > f(R)$, the limit must be recalculated. The operation is as follows.
1. Search for the best solution to $R$ by numLevel times, calculate $f$ and obtain the numLevel target values.
2. The numLevel values and fitness values of the best solution are arranged in descending order.
3. Assign the arranged numLevel values to Restriction[1], Restriction[2], and Restriction[numLevel]; the value of Restriction[0] is taken as $f(R)$.

Among them, Count is used to counting the number of times the domain is generated, Level is the number of restricted levels, CountMax is the maximum number of domain operations, numLevel is the total number of restriction levels, Levelhold is the level where Levelhold, and the algorithm gives up the search method of the domain limit; Levelhighhold is in the global search mode. If the algorithm still cannot find a new solution after searching under Levelhold restricted levels, the algorithm will terminate [36].

In summary, the specific steps for volunteer rescue and dispatch during the COVID-19 epidemic are as follows.

Step 1: Determine different evaluation indicators for volunteers and tasks. Owing to the complexity of real-life issues, the evaluation indicators of the parties when two parties are matched are not necessarily the same. Therefore, it is necessary to determine the different evaluation indicators for the two parties.

Step 2: The weights of the different evaluation indicators are calculated. The AHP is used to determine the weight of the indicators. The satisfaction of both parties was then solved according to the weight of the index.

Step 3: Determine the information form of the indicator value. Owing to the complexity of practical problems, this study considers the index values under two information forms, which are represented by interval numbers and language information.

Step 4: Determine the expected and actual values for each indicator. Collect the actual and expected values of the two parties under each indicator, according to the forms filled out by both parties.

Step 5: Calculate the satisfaction of the volunteers and tasks. According to the actual and expected value information of the indicators collected on both sides, Eqs. (10–13), calculate the satisfaction level under different indicators, and finally, according to the index weights and Eqs. (14–15), the satisfaction of both parties is determined.

Step 6: Build a dispatch model. To maximize bilateral satisfaction, we built a multi-objective model. Many-to-many bilateral matching was achieved by setting constraints.

Step 7: Model solving. This problem is solved using an improved predator-search algorithm.

Step 8: Analyze and compare the results. We compared and analyzed the results from two perspectives.

4. Simulation case taking the recruitment of volunteers for pneumonia epidemic prevention and control in Chun’an County as an example

With the frequent occurrence of natural disasters and the frequent holding of large-scale international events, it has become necessary to recruit volunteers for these events. This case is based on the recruitment of volunteers for the prevention and control of pneumonia in Chun’an County, and through a simulation, the problem of volunteer rescue and dispatch under the COVID-19 epidemic is solved.

4.1. Case description

On February 3, 2020, to give full play to the active role of volunteers in prevention and control work, the Chun’an County Party Committee of the Communist Youth League and the Chun’an County Volunteer Association established a youth volunteer service team for the prevention and control of pneumonia caused by the new coronavirus infection in the county. The young volunteers of the county were called on to fully carry forward the volunteer spirit of “dedication, friendship, mutual help, and progress,” actively sign up, pledge to fight for epidemic prevention and control work and make their own contributions [37].

1. Volunteer requirements

   • The volunteer should be 18–40 years; the individuals and their family residents should be in good health.
   • The volunteer has no history of fever or other illnesses in the past month and no history of contact with people in the epidemic area.
   • The volunteer has good health with no underlying diseases.
   • The volunteer has not left home within two weeks.
   • The volunteer must accept the dispatching command explicitly, not act without authorization, and always take protective measures.

2. According to the actual needs of volunteer services and volunteers’ wishes and expertise, volunteers must focus on the following types of volunteer services:

   • Convenient services and publicity ($M_1$)
   • Order maintenance ($M_2$)
   • Psychological counseling ($M_3$)
   • Material donation ($M_4$)
   • Other services ($M_5$)
Through the recruitment, 12 volunteers ($V_1, V_2, \ldots, V_{11}, V_{12}$) signed up.

4.2. Solution process

The detailed solution process for this case is as follows. The following are simulation data. According to the requirements of these five tasks, the indicators considered when formulating tasks to match volunteers were: age ($A_1$), sense of responsibility ($A_2$), physical fitness ($A_3$), education level ($A_4$), and income status ($A_5$). Recruitment agencies use the 1–9 scale method to score the judgment matrix of the A index set, as shown in Table 4. The indicators that volunteers consider when matching tasks are the following: logistics support ($B_1$), task difficulty ($B_2$), safety factor ($B_3$), and task duration ($B_4$). The volunteers used the 1–9 scale method to obtain the judgment matrix of the B index set, as shown in Table 5. Among them, age, education level, income status, and task duration are interval numbers, and the evaluation value of education level (doctor = 7, master’s degree = 6, undergraduate = 5, junior college/higher vocational = 4, senior high school = 3, junior high school = 2, primary school = 1, illiteracy = 0). Language information includes physical fitness, logistics support, task difficulty, safety factors, and responsibility consciousness. The actual index values submitted by the volunteers to the recruitment agencies are shown in Table 6, and the expected values are listed in Table 7. The actual index values submitted by recruitment agencies to volunteers are listed in Table 8, and the expected values of the indicators are listed in Table 9.

According to Table 4 and using Eq. (1), we calculated the product of the elements in the first row of the judgment matrix: $O_1 = 1 \times (1/2) \times 2 \times 3 \times 4 = 12, O_2 = 120, O_3 = 1, O_4 = 0.083, O_5 = 0.008$. Then, we used Eq. (3) to find $W_1 = \sqrt{O_1} = 1.664$, and so on $W_2 = 2.605, W_3 = 0.100, W_4 = 0.608, W_5 = 0.384$. We then use Eq. (5) to find $W_1 = \frac{1.664 \times 2.605 \times 0.100 \times 0.608 \times 0.384}{1.664 \times 2.605 \times 0.1000 \times 0.608 \times 0.384} = 0.26$, and so on, to find $W_2 = 0.42, W_3 = 0.16, W_4 = 0.10, W_5 = 0.06$. Finally, we use Eq. (7) to determine the maximum eigenvalue $w$ of matrix $\lambda_{\text{max}} = 5.068, Cl = 5.068 - 5 = 0.017, CR = 0.017 \times \frac{12}{11} = 0.017, CR < 0.1$; therefore, judgment matrix $A$ has acceptable consistency. The weight of the A index set is $(0.26, 0.42, 0.16, 0.10, 0.06)$.

By analogy, we use Eq. (2), (4), (6), and (8), according to Table 5. We then calculated the weight of the B index set as $(0.32, 0.14, 0.45, 0.09)$.

The following uses the calculation of $M_1$’s satisfaction with $V_1$ as an example to illustrate the calculation process. According to Tables 6 and 9, using Eqs. (11) and (13), we calculated the satisfaction level of $M_1$ to $V_1$ under indicator $A_2$; $\beta_{11} = 0.83 \times 0.67 = 0.55 = 0.845$ and so on to find $\beta_{11} = 0.515, \beta_{11} = 1.0$, and $\beta_{11} = 0.0$. According to Eq. (15), $M_1$’s satisfaction is with $V_1$; $\beta_{11} = 0 \times 0.26 + 0.485 \times 0.42 + 0.515 \times 0.16 + 1.0 \times 0.10 + 0.0 \times 0.06 = 0.39$, and so on. Using Eqs. (10–15), according to Tables 6 and 9, we obtained the task satisfaction matrix $B = [\beta_{ij}]_{5 \times 12}$ and volunteer satisfaction matrix $A = [a_{ij}]_{5 \times 12}$.

\[
\begin{bmatrix}
0.39 & 0.74 & 0.60 & 0.22 & 0.46 & 0.55 & 0.76 & 0.65 & 0.34 & 0.38 & 0.86 & 0.36 \\
0.10 & 0.92 & 0.73 & 0.78 & 0.36 & 0.44 & 0.63 & 0.36 & 0.47 & 0.50 & 0.63 & 0.57 \\
0.24 & 0.48 & 0.36 & 0.45 & 0.52 & 0.20 & 0.10 & 0.18 & 0.86 & 0.22 & 0.00 & 0.84 \\
0.68 & 0.26 & 0.46 & 0.52 & 0.92 & 0.26 & 0.62 & 0.68 & 0.42 & 0.26 & 0.46 & 0.34 \\
0.58 & 0.92 & 0.63 & 0.74 & 0.34 & 0.44 & 0.47 & 0.58 & 0.63 & 0.76 & 0.47 & 0.65 \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
0.41 & 0.89 & 0.09 & 0.49 & 0.61 & 0.33 & 0.30 & 0.77 & 0.23 & 0.56 & 0.59 & 0.59 \\
0.22 & 0.26 & 0.64 & 0.23 & 0.45 & 0.07 & 0.90 & 0.72 & 0.24 & 0.20 & 0.07 & 0.07 \\
0.45 & 0.61 & 0.09 & 0.77 & 0.07 & 0.46 & 0.25 & 0.07 & 0.61 & 0.36 & 0.70 & 0.36 \\
0.68 & 0.00 & 0.16 & 0.36 & 0.39 & 0.41 & 0.14 & 0.39 & 0.00 & 0.77 & 0.60 & 0.20 \\
0.46 & 0.61 & 0.09 & 0.46 & 0.53 & 0.61 & 0.07 & 0.30 & 0.61 & 0.23 & 0.71 & 0.59 \\
\end{bmatrix}
\]

According to the satisfaction matrices $A$ and $B$ and Eq. (21), we follow the principle of bilateral equality, that is, $w_{ij} = w_{ji} = 0.5$. Subsequently, a comprehensive satisfaction matrix $C = [c_{ij}]_{5 \times 12}$ of volunteers and tasks can be established.

\[
\begin{bmatrix}
0.4 & 0.81 & 0.34 & 0.42 & 0.48 & 0.58 & 0.54 & 0.47 & 0.56 & 0.31 & 0.71 & 0.47 \\
0.16 & 0.59 & 0.68 & 0.51 & 0.4 & 0.25 & 0.77 & 0.54 & 0.36 & 0.35 & 0.35 & 0.39 \\
0.35 & 0.54 & 0.22 & 0.61 & 0.3 & 0.33 & 0.18 & 0.13 & 0.74 & 0.29 & 0.35 & 0.6 \\
0.68 & 0.13 & 0.31 & 0.44 & 0.65 & 0.34 & 0.38 & 0.53 & 0.21 & 0.52 & 0.53 & 0.27 \\
0.52 & 0.76 & 0.36 & 0.6 & 0.43 & 0.53 & 0.27 & 0.44 & 0.62 & 0.49 & 0.59 & 0.62 \\
\end{bmatrix}
\]
Table 10
Number of volunteers required for task.

| Task | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|------|--------|--------|--------|--------|--------|
| Number of volunteers | 2      | 4      | 3      | 2      | 4      |

The number of volunteers required for the task is listed in Table 10, and the number of tasks that volunteers want to complete is listed in Table 11.

The total number of tasks completed by all the volunteers exceeded the number of volunteers required for all the tasks, as shown in Tables 10 and 11. We then constructed a volunteer rescue dispatch matrix, $G = [g_{ij}]_{17 \times 17}$, under the new crown epidemic.

Using an improved predator-search algorithm to solve the matrix $G$, the relevant parameters were set as follows:

1. Set the number of searches for the neighboring neighborhood is set as counter $= 7$.
2. Set the total number of limit values as numlevel $= 17$.
3. Maximum number of cycles under each limit: Count_M_sm = 51.
4. Upper limit of the limit level of the domain search mode Lhold = 10.
5. Lower limit of the global search limit level Lhighhold = 17.

The settings of the aforementioned parameters are determined for the problem itself; there is no theoretical basis at present. The specific algorithm flow is described in Section 3.4. The specific dispatch plan was as follows: $M_1 \leftrightarrow V_2, V_11; M_2 \leftrightarrow V_3, V_5, V_7, V_8, V_9; M_3 \leftrightarrow V_4, V_6, V_10; M_4 \leftrightarrow V_1, V_3, V_11, V_12$.

4.3. Results analysis and comparison

To verify the feasibility and rationality of the method outlined in this paper, the following analyses and comparisons were performed:

1. Comparison between unilateral and bilateral matching

Consider the case in which only the satisfaction of rescue missions to volunteers is satisfied. According to the B matrix, we used the improved predator-search algorithm to solve the B matrix. The unilateral dispatch plan for rescue missions is as follows.

$$M_1 \leftrightarrow V_2, V_11; M_2 \leftrightarrow V_3, V_5, V_7, V_8, V_9; M_3 \leftrightarrow V_4, V_6, V_10; M_4 \leftrightarrow V_1, V_3, V_11, V_12;$$

If the unilateral dispatch plan of the rescue mission is placed in matrix $\tilde{A}$, the specific situation is shown in Fig. 1.

It can be seen from Fig. 2 that, if one considers the needs of rescue missions, most of the tasks are undertaken by inappropriate volunteers. Therefore, it is unreasonable to consider only the wishes of the volunteers without considering the needs of the task.

According to the dispatch method proposed in this study, the solved bilateral matching results are placed in matrices $\bar{A}$ and matrix $\tilde{B}$. The specific situation is shown in Figs. 3 and 4.

It can be observed from Figs. 3 and 4 that, compared with unilateral dispatch, TSM can achieve better satisfaction of volunteers and tasks during rescue missions. It not only considers the needs of volunteers for
rescue missions but also considers the wishes of volunteers, which can effectively improve the efficiency of rescue.

(2) The criteria-level indicators determine the importance of the target level.

According to the weights of $A$ and $B$ index sets calculated earlier, we can obtain the importance of weighting each index of the criterion level to the target level index, as shown in Figs. 5 and 6.

From these figures, we can determine the importance ranking of each indicator in the criterion layer: responsibility $A_2$, age $A_1$, physical fitness $A_4$, education level $A_4$, income status $A_5$, safety factor $B_3$, logistics support $B_1$, task difficulty $B_2$, and task duration $B_4$. Among them, the sense of responsibility, age, safety factor, and logistical support were all greater than 0.2. Therefore, the sense of responsibility, age, safety factor, and logistical support are the most important evaluation indicators at the criterion level; the sense of responsibility and safety factors are especially important. From the perspective of rescue missions, volunteers’ sense of responsibility is very important. From the perspective of volunteers, the safety factor for rescue missions is also very important. Therefore, the sense of responsibility of volunteers and the safety system of rescue missions are decisive factors for improving the satisfaction of both parties.

**Table 11**

| Volunteer | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_7$ | $V_8$ | $V_9$ | $V_{10}$ | $V_{11}$ | $V_{12}$ |
|-----------|------|------|------|------|------|------|------|------|------|---------|---------|--------|
| Number of tasks | 1 | 1 | ≤2 | 1 | ≤2 | 1 | ≤2 | 1 | ≤2 | 1 |        |        |
5. Conclusion

In response to the dispatch of volunteers during the COVID-19 epidemic, to overcome the subjectivity of index weight in MADM, we introduced the AHP and calculated the index weight value. In this study, the actual and expected values of the indicator were expressed in the form of interval numbers and language information. Using triangular fuzzy numbers, we calculated the satisfaction of both parties. Using linear weighting, we calculated the combined satisfaction according to the demands of both parties. Subsequently, we constructed a volunteer rescue dispatch model for the coronavirus epidemic. An improved predator-search algorithm was used to solve the model and improve matching efficiency. Finally, a simulation case is used to verify the feasibility and practicability of the proposed method. The contributions of the proposed method are as follows.

1. To solve the problem of volunteer dispatch in the current COVID-19 epidemic, we considered the case where the index value is the language information and interval number. This compensates for the defect of using accurate value information in previous research, generating more refined matching results.

2. By improving the predator-search algorithm according to the needs of both parties, the result of bilateral matching can be obtained with precise numerical values. To overcome the limitations of previous bilateral matching research, only interval numbers were used to obtain the matching results.

Although the research conducted to produce this study has achieved certain results, further research is needed on the issue of volunteer rescue dispatch. For example, from the order of rescue time, we need to consider the problem of one volunteer completing multiple tasks in a many-to-many dispatch. The index values in this study only use interval numbers and language information, and other forms of index values have not been considered.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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