A Human-Asset-Compromised Allocation Model of Multiple Emergency Projects in Service-Focused Enterprises

Yan Wang, Liang-Jie Zhang and Wei Wang
Kingdee Research
Kingdee International Software Group Co. Ltd.
Shenzhen, China 518057
{corrie_wang, zhanglj, david_wang}@kingdee.com

***Abstract*—Chinese enterprises have been conducting low-end processing for foreign brands. In recent years, they want to get rid of this high-pay low-income pattern and develop towards the high-end of the value chain. Most of them are transforming to service-focused enterprises that aim to provide customers with customized service. In service-focused enterprises, the human asset – like industry experts, technology experts, product experts and so on – is very important. Sometimes, the services provided by experts can directly affect the satisfaction of customers. Service-focused enterprises always have to face this challenge: multiple projects occur in emergency situations at the same time and need to dispatch multiple suitable experts from multiple places in order to respond. Under the constraint of human asset requirements on time and cost, this paper establishes an uncompromised resource allocation model for human asset emergency response. According to the characteristics of human asset emergency issues, the mathematical model can be presented to help solve the large-scale emergency difficulties among multiple projects, multiple experts' types and multiple experts' locations. Finally, a case study is carried on to prove the algorithm's effectiveness.**

Keywords - compromised resources allocation; allocation model; human asset; decision support

I. INTRODUCTION

After 30 years of rapid development, Chinese enterprises have completed "the accumulation phase," which grants access to enterprise-wide restructuring and then upgrading their core mission to the "quality improvement stage." This enables access to new international and domestic markets. Chinese enterprises have to pay more attention to industrial structures, product structures and service values added; and then focus on enhancing core competitiveness, competition in the industry, and new horizons to broaden their high ground.

High value-added and quality-improvement requirements are creating a new type of innovative business: the service-focused enterprise. The service-focused way of conducting business can provide customers personalized diagnoses and targeted customized services, exclude their real obstacles of current or future development, maximize their customers' trust and support, and maximize enterprises' own development and benefits. From this, enterprises and their customers can earn mutual gains.

The human asset – like industry experts, technology experts, product experts and so on – is very important for service-focused enterprises to perform customized services. Sometimes, the services provided by experts can directly affect the satisfaction of customers. However, the service-focused enterprise always has to face this challenge: multiple projects occur in emergency situations at the same time and need to dispatch multiple suitable experts from multiple places in order to respond.

There are many researches on resource allocation algorithms in emergency situations, but most of them are for disasters or crisis. Suleyman Tufekci and William A. Wallace(1998) [1], as the authoritative emergency management experts, consider emergency management as a complex multi-objective optimization problem and that utilizing limited resources compromisingly is the best method of optimization to be adopted. Fiedrich etc. (2000) [2] perform research on an optimized resources allocation situation based on search-and-rescue work after strong earthquakes. Liu etc. (2000) [3] propose an optimized resources allocation model for a single emergency place and prove the model is optimal. Liu etc. (2004) [4] proposed an agent-based resource discovery method for environmental emergency management. Linet etc. (2004) [5] abstract the disasters' resource allocation problems into network flow problems and establish a model for them. Barbarosoglu and Arda (2004) [6] propose a two-stage stochastic programming framework in disaster response. Verma etc. (2006) [7] propose a resources allocation method for forest fires rescue. Pan etc. (2007) [8] establish a particle swarm optimization algorithm to solve the emergency resources continuous consumption problem in a disaster place. Sun etc. (2007) [9] establish a nonlinear integer programming model to set aside resources for potential emergency sites in order to minimize disasters' detrimental effects. Wang etc. (2007, 2011) [10-12] researched emergency resources allocation among multiple disaster sites with the continuity constraint. Zhang etc. (2011) [13] built an emergency resources scheduling model that simulates realistic problems. The model includes multiple suppliers with a variety of resources, a single accident site and some restrictions.

The above-mentioned researches on resources allocation models mainly divide into two categories:

One is concentrated on the issue of continuity of supplies. This involves resource supplies that must not be

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removed after rescue activities have started; otherwise the consequence of supply loss may be very unfavorable or even catastrophic. However, human assets are not as the same as goods and materials, which are not continuous, but discrete. Human assets allocation problems require only the furthest available unit that can arrive on the project site soonest.

The second category has many restrictions although researchers have considered the issue of discreteness of human assets such as special type disaster, single disaster site, single type resource, and so on. These researches cannot be directly applied to the human asset allocation problem among multiple projects, multiple expert types and multiple experts' locations.

Therefore, we built a mathematical model to solve the human asset emergency allocation problem among multiple emergency projects, multiple expert types and multiple experts' locations, which also satisfies the discrete condition. The mathematical model allowing for calculation of a compromised resource schedule can help solve the large-scale emergency projects difficulties, whose optimized objective is to reduce the earliest start time of emergency projects. Finally, a case study is carried on to show the model's validity

II. RELEVANT COMPONENTS

Suppose that D_1, D_2 ,… D_m are m emergency projects; $E_1, E_2, \cdots, E_v$ are v types of human assets or experts; $y_{i;w}$ is the quantity of the w th human assets or experts demanded by D_i project. $y_i = (y_{i;1}, y_{i;2}, \cdots, y_{i;v})$ is all experts demanded by D_i project, $i = 1,2,\cdots,m$, $w = 1,2,\cdots,v$. s_i is the start time of D_i project, $i = 1,2,\cdots,m$.

Suppose that A_1, A_2 ,…, A_n are n expert supply locations. The quantity of the w th human assets or experts of A_i is $x_{j;w}$ (>0), $j = 1,2,\cdots,n$, $w = 1,2,\cdots,v$.

Suppose that $x_{ij} = (x_{ij;1}, x_{ij;2}, \cdots, x_{ij;v})$ is used to symbolize all experts D_i get from A_j ; $x_{ij;w}$ symbolizes the real quantity of the w th human assets or experts that D_i get from A_j .

Suppose that $T_{i;w}$ symbolizes the time vector composed of arrival times of the w th human assets or experts from each supply location to D_j , $T_i = (t_{i1}, t_{i2}, \cdots, t_{in})$, and $t_{ij} > 0$ is the time from A_i to D_i . Ordered elements of the vector T_j from near to far can be used to get an arrangement $t^1_{ij^\forall} \le t^2_{ij^\forall} \le \cdots \le t^n_{ij^\forall}$, and $j^\forall$ stands for the initial subscript of each element. There are many researches on the optimal path choice problem [14], yet we do not discuss the path problem in this paper. With regards to D_i , accordingly, we can obtain the w th human assets or experts supply locations arrangement from near to far: $A^1_{j^\forall}, A^2_{j^\forall}, \cdots, A^n_{j^\forall}$, which can offer maximum quantities are $x^1_{j^\forall;w}, x^2_{j^\forall;w}, \cdots, x^n_{j^\forall;w}$ and really supply quantities are $x^1_{ij^\forall;w}, x^2_{ij^\forall;w}, \cdots, x^n_{ij^\forall;w}$. For the sake of succinct expression, we will leave out $j^\forall$ in following contexts without different meanings.

We use matrix form to describe a full-scale emergency response scheme $\varphi = \begin{bmatrix} \varphi_1 & \varphi_2 & \cdots & \varphi_m \end{bmatrix}$, φ_i is D_i 's local solution:

$$\varphi_i = \begin{bmatrix} \varphi_{i;1} \\ \varphi_{i;2} \\ \vdots \\ \varphi_{i;v} \end{bmatrix} = \begin{bmatrix} x_{i1;1} & x_{i2;1} & \cdots & x_{in;1} \\ x_{i1;2} & x_{i2;2} & \cdots & x_{in;2} \\ \vdots & \vdots & \ddots & \vdots \\ x_{i1;v} & x_{i2;v} & \cdots & x_{in;v} \end{bmatrix}$$

Row w of φ_i is the real quantity vector of the w th human assets or experts that D_i get from A_j .

If $x_{ij;w} \neq 0$, it means the w th human assets or experts of A_j takes part in D_i project. Then, we mark it as $A_j \in \varphi_{i;w}$, $i = 1,2,\cdots,m$, $j = 1,2,\cdots,n$, $w = 1,2,\cdots,v$; Column j is a supplying resource vector from A_j to each project place, and if the vector equates to 0, it means A_j is from the D_i project, $j = 1,2,\cdots,n$.

We then impart the important definitions on a feasible scheme φ :

Definition 1: If the quantity of human assets or experts at supply site A_k supply all human resources to $\varphi_{i_1} \cdots \varphi_{i_r}$ is not equal to 0 and $x_{i_1k;w} + \cdots + x_{i_rk;w} > x_{k;w}$, emergency projects $D_{i_1}, \cdots, D_{i_r}$ involving the w th human assets or experts invoke **human assets confliction**. $i_1, \cdots, i_r \in \{1, \cdots, m\}$, $k \in \{1,2,\cdots,n\}$, $w \in \{1,2,\cdots,v\}$.

Definition 2: If $\forall \varphi_i \in \mathrm{X}_{s_i}$ satisfies $\mathrm{X}_{s_i} \neq \Phi$, and $\sum_{i=1}^{m} x_{ij;\forall w} \le x_{j;\forall w}$, we say that all scalable emergency response schemes φ is feasible. $j = 1,2,\cdots,m$.

We can understand definition 2 in this way: only when every emergency project has the feasible scheme φ_i , all scalable emergency response schemes φ are feasible.

III. COMPROMISED HUMAN ASSETS ALLOCATION MODEL

Suppose that the set of feasible plans is X_s, the objective function of emergency plans of multi-emergency projects or places could be:

$$\min_{X_s \neq \Phi, X_{s_i} \neq \Phi} Z(\varphi) = \sum_{i=1}^{m} (s_i^* - s_i^{'}) + \varepsilon \sum_{i=1}^{m} C_i \quad (1a)$$

$$\text{s.t.} \quad s_i^* - s_i^{'} \geq 0 \qquad i = 1, 2, \cdots, m \quad (1b)$$

$$s_i^*, s_i^{'}, C_i \geq 0 \qquad i = 1, 2, \cdots, m \quad (1c)$$

$$\min_{\varphi_i \in \varphi} s_i(\varphi_i) = \max_{w \in \{\alpha | y_{i;\alpha} \neq 0, \alpha = 1,2,\cdots,v\}} \max_{h \in \{l | x_{ij;w}^l \neq 0, l = 1,2,\cdots,p_i, w = 1,2,\cdots,v\}} t_i^h \quad (2a)$$

$$\text{s.t.} \quad \sum_{k=0}^{p_i - 1} x_{ij^{\forall};w}^k < y_{i;w} \leq \sum_{k=0}^{p_i} x_{ij^{\forall};w}^k$$

$$i = 1, 2, \cdots, m \;; \quad w = 1, 2, \cdots, v \quad (2b)$$

$$\sum_{j=1}^{n} x_{ij;w} = y_{i;w}$$

$$i = 1, 2, \cdots, m \;; \quad w = 1, 2, \cdots, v \quad (2c)$$

$$\sum_{i=1}^{m} x_{ij;w} \leq x_{j;w}$$

$$j = 1, 2, \cdots, n \;; \quad w = 1, 2, \cdots, v \quad (2d)$$

$$y_{i;w}, x_{j;w}, x_{ij;w} \geq 0 \qquad i = 1, 2, \cdots, m \;;$$

$$j = 1, 2, \cdots, n \;; \quad w = 1, 2, \cdots, v \quad (2e)$$

$$\min_{\varphi_i \in \varphi} C_i(\varphi_i) = \sum_{w=1}^{v} \sum_{j=1}^{n} x_{ij;w} (c_{j;w} t_{ij;w} + \lambda_{ij;w} v_{ij;w}) \quad (3a)$$

$$\text{s.t.} \quad v_{ij;w} = \begin{cases} 1 & A_j \in \varphi_i \\ 0 & A_j \notin \varphi_i \end{cases} \quad i = 1, 2, \cdots, m \quad (3b)$$

$$c_{j;w}, x_{ij;w}, \mu_{ij;w}, t_{ij;w}, \lambda_{ij;w} \geq 0 \quad i = 1, 2, \cdots, m \quad (3c)$$

In order to make the main objective function expresses itself simply and clearly, this article separately lists the cost of every emergency project as a third layer. Its objective function remains consistent with the main objective function. This model is essentially a bi-level programming model.

Equation (1a) is the upper-level objective function of multiple emergency projects. The first item represents the lag of earliest starting time between the compromised emergency scheme and every partially-optimized scheme; the second item stands for the transporting expenses to the emergency projects, which is considered as the assistant goal under justice-first rule. When the compromised strategies reach minimization, the best emergency scheme would be decided by assistant objective functions. ε is an extremely small positive real number; for example: 10^{-4}. s_i is the earliest starting time of D_i under resources confliction; s_i^* is the partially-optimized solution of earliest starting time, which could also represent the earliest starting time of D_i when all the human assets provide transport resources to D_i. We can calculate s_i^* as the method shown in [4]. Equation (2a) and (3a) stand for the limits for emergency human assets and experts.

Equation (2a) is the mid-level objective function of emergency project D_i. t_i^h represents the arriving time of the h th expert. In order to exclude the types of expert resources that are not involved in the project D_i, we make $w \in \{\alpha | y_{i;\alpha} \neq 0, \alpha = 1, 2, \cdots, v\}$. In order to exclude expert resources suppliers that are not involved in project D_i, we make $h \in \{l | x_{ij;w}^l \neq 0, l = 1, 2, \cdots, p_i, w = 1, 2, \cdots, v\}$. Equation (2b) stands for the distance-first rule limit. Equation (2c) stands for the limit of human asset or expert resources saving rule. Equation (2d) stands for limits of human asset or expert resources.

Equation (3a) is the low-level objective function of projects D_i 's cost. $x_{ij;w}$ is the quantity of human assets or expert resources that emergency project D_i obtained from human asset or expert resources supplier A_j. In parentheses, the first expression is the cost of time spent by an expert's journey. $c_{j;w}$ is the unit time price of A_j 's the w th human assets or experts. $t_{ij;w}$ is the real time spent on the journal. The second expression is the transport cost of all experts who take part in emergency project D_i. $\lambda_{ij;w}$ is the transport cost of the w th human assets or experts. $v_{ij;w}$ is the participation control variable of emergency projects. Equation (3b) defines $v_{ij;w}$ as a 0-1 variable: if D_i accepts human assets or experts from A_j, $v_{ij;w} = 1$; or $v_{ij;w} = 0$.

Equation (1c), (2e), (3c) are the non-negative constraints of variables.

IV. ITERATIVE ADJUSTMENT ALGORITHM FOR BI-LEVEL PROGRAMMING PROBLEM

High complexity occurs when we try to solve the whole optimized solution of bi-level problems. For normal bi-level programming problems, it is a non-convex problem, even if objective functions and limit functions in both high-level and low-level programming have linear complexity growth. The non-convex problem has several partially-optimized solutions [3]. From the viewpoint of mathematics, there are some methods to solve the whole optimized solution of non-convex-optimized problems. However, most of them are quite complicated in their time complexity, which could not satisfy the requirement of time pressure. The emergency problem has its flaws, which requires the nearest human assets suppliers to join in the emergency projects. We can use this law to get the whole optimized solution with iterative adjustments based on the partially-optimized solution of D_i ; which could not only avoid the endless calculation of partially-optimized solutions based on the directly-seeking method, but also improve the speed of calculation. This is necessary for enacting upon spontaneous emergencies.

A. *The lag of project D_i 's earliest starting time $\Delta s_i(\Delta x_i)$*

Firstly, we will conduct research on project D_i 's local plan φ_j about the w th human assets or experts. When the w th human assets or experts provided by A_τ^k reduce $\Delta x_{i;w}$, $0 \le \Delta x_{i;w} \le x_{i,\tau;w}^k$, the increase of $s_{i;w}$ is $\Delta s_{i;w}(\Delta x_{i;w})$. The lag of project D_i 's earliest starting time :

$$\Delta s_i(\Delta x_i) = \max_{w\in[1,v]}[\Delta s_{i;w}(\Delta x_{i;w}) + s_{i;w}] - s_i$$

Upon calculating $\Delta s_{i;w}(\Delta x_{i;w})$, there are two following conditions:

(1) If $\Delta x_{i;w} \le x_{j^\forall;w}^{p_i} - x_{i,j^\forall;w}^{p_i}$, $\Delta s_{i;w}(\Delta x_{i;w}) = 0$;

(2)If $\Delta x_{i;w} > x_{j^\forall;w}^{p_i} - x_{i,j^\forall;w}^{p_i}$, and q_i satisfies $\sum_{k=p_i}^{q_i-1}(x_{j^\forall;w}^k - x_{i,j^\forall;w}^k) < \Delta x_{i;w} \le \sum_{k=p_i}^{q_i}(x_{j^\forall;w}^k - x_{i,j^\forall;w}^k)$, $s_{i;w}$ increases $\Delta s_{i;w}(\Delta x_{i;w}) = \max_{l=p_i+1,\cdots,q_i} t_{i,j^\forall}^l - s_{i;w}$.

In order to ensure the calculation method of the emergency project's earliest starting time can be used by the iterative adjustment algorithm successfully, we establish the full parameter expression: $\Delta s_{i;w}(p_i, k, \Delta x_i, \delta_i, \omega)$. It stands for the variation of $s_{i;w}$ when the k th human asset supplies the location in p_i human assets supply locations of $\varphi_{i;w}$ reduces $\Delta x_{i;w}$. δ_i , which represents the set of human assets supply locations that supply 0 human assets. ω represents the quantity of human assets that can alleviate conflicts among the remaining human assets $x_{j^\forall;w}^{p_i} - x_{i,j^\forall;w}^{p_i}$ of the p_i th human assets supply location.

B. *The nearest non-conflicting human assets of D_i*

For the purpose of removing conflicts of human assets at supply location A_τ^k about the w th human assets, we have to know the computation methods of the nearest non-conflicting human assets supply location for D_i , the human assets quantity $\hat{x}_{i;w}$, transport time $\hat{t}_i$ and the lag of project D_i 's earliest starting time. Specific steps are as follows:

The first step is to determine ω 's value: If the p_i th supply location satisfies $x_{j^\forall;w}^{p_i} > \sum_{i=1}^{m} x_{ij^\forall;w}$, $\omega = x_{j^\forall;w}^{p_i} - \sum_{i=1}^{m} x_{ij^\forall;w}$, $\hat{x}_{i;w} = \min\{x_{ij;w}, \omega\}$, $\hat{t}_i = t_{ij^\forall}^{p_i}$, $\Delta\hat{s}_{i;w} = \Delta s_{i;w}(p_i, k, \hat{x}_i, \Phi, \omega)$; Or $\omega = 0$.

Suppose that $g_i = p_i$ and $p_i = p_i + 1$, judge the following conditions in a loop: if $x_{j^\forall;w}^{p_i} \le \sum_{i=1}^{m} x_{ij^\forall;w}$, $A_{j^\forall}^{p_i} \to \delta_i$, $p_i = p_i + 1$ and may return to loop again; or $\hat{x}_{i;w} = \min\{x_{ij;w}, (x_{j^\forall;w}^{p_i} - \sum_{i=1}^{m} x_{ij^\forall;w})\}$, $\hat{t}_i = t_{ij^\forall}^{p_i}$, $\Delta\hat{s}_{i;w} = \Delta s_{i;w}(g_i, k, \hat{x}_i, \delta_i, 0)$.

From there, the nearest non-conflicting human assets location about the w th human assets for D_i is $A_{j^\forall}^{p_i}$.

C. *Iterative adjustment algorithm*

The steps to perform an iterative adjustment algorithm are as follows:

Step0 Obtain D_i 's independent optimal solution from a single emergency project plan selection algorithm: in the case of not considering other projects, we compute the latest human asset or expert's arrival time for each type of human asset or expert; the maximum arrival time is emergency project D_i 's earliest starting time $s_i^{'}$; and then we identify the counter of human assets or experts: $w = 1$.

Step1 In the case of only considering the w th human assets or experts, use the method in Step0 to compute earliest starting time $s_{i;w}^{'}$, emergency plan $\varphi_{i;w}^{'}$ and the p_i th supply locations of human assets or experts, $i = 1, 2, \cdots, m$; identify the iterative adjustment counter: $j = 0$.

Step2 Judge the following conditions cyclically: $j = j + 1$; if $j \le n$, move on to Step3; otherwise, turn to Step7.

Step3 Compute the conflicting number of human assets or experts supply locations A_j : $Q_{j;w}=\sum_{i=1}^{m}x_{ij;w}-x_{j;w}$.

Step4 Judge the confliction: if $Q_{j;w}\le 0$, turn to Step2; otherwise, there exists a conflict and move on to Step5.

Step5 Find the best unused human assets or experts for the whole solution: ① obtain relief human assets or experts via a direct and indirect method: the direct method involves gathering human assets or experts from D_i's nearest non-conflicting human assets or experts suppliers; the indirect method involves gathering human assets or experts from other projects' plans, and then other projects have to indirectly obtain human assets or experts from their own nearest non-conflicting human assets or experts suppliers. ② Compare the two methods to get the best relief resources x^* and the best relief strategy.

Step6 Calculate $Q_{j;w}=Q_{j;w}-x^*$; If $Q_j>0$, conflictions stall exist, and turn back to Step5; otherwise turn to Step2.

Step7 Stop allocation plans of this type of human assets or experts; judge whether or not all types of human assets or experts have be allocated: $w=w+1$; If $w\le v$, turn to Step1; otherwise continue to Step8.

Step8 Determine that all types of human assets or experts don't exit confliction. The final point of the earliest starting time of project D_i is $s_i^*=\max\limits_{w\in[1,v]}[s_i^{'}+\Delta s_w^*]$. Afterwards, adjust the human assets and experts allocation plan based on these results.

Step9 Put together all projects' human assets and experts allocation plan to get the final plan; close this algorithm.

In this iterative algorithm, Step5 is the most important step. Its implementation method is very complex, so we individually state it as follows:

Step 5.1 Identify the counter: $i=0$.

Step 5.2 Judge the following conditions cyclically: $i=i+1$, record p_i's initial value $g_i=p_i$; If $i\le m$, turn to Step 5.3; otherwise, turn to Step 5.8.

Step 5.3 Judge whether the emergency project D_i contributes to human assets or experts confliction: if $x_{ij;w}=0$, D_i does not require A_j 's resources and also does not contribute to the confliction; then $\Delta s_{i;w}=\infty$, $t_i^{'}=\infty$, $x_{i;w}^{'}=0$ and turn to Step 5.2. Otherwise, D_i takes part in human assets or experts conflicting, and then turn to Step 5.4.

Step 5.4 Compute project D_i's $\hat{x}_{i;w}$ and $\Delta\hat{s}_{i;w}$, then judge the following conditions: If $A_{j^\forall}^{p_i-1}\notin\delta_i$ or $\Delta\hat{s}_{i;w}=0$, D_i's nearest non-conflicting human assets or experts are its best relief resources, $t_i^{'}=\hat{t}_i$, $x_{i;w}^{'}=\min\{\hat{x}_{i;w},Q_{j;w}\}$, $\Delta s_{i;w}^{'}=\Delta s_{i;w}(p_i,k,x_i^{'},\delta_i,\omega)$, and then turn to Step 5.7; however, if $\eta=\delta_i$, then turn to Step 5.5.

Step 5.5 Obtain D_i's relief resources indirectly: make $\alpha=p_i-1$ and judge the following conditions: if $A_{j^\forall}^{\alpha}\in\eta$, try to get the emergency projects $D_{i_1},\cdots,D_{i_\beta}$ which satisfy $x_{ij^\forall;w}\ne 0$; separately compute their $\hat{x}_{i_1;w},\cdots,\hat{x}_{i_\beta;w}$ and $\Delta\hat{s}_{i_1;w},\cdots,\Delta\hat{s}_{i_\beta;w}$ on $A_{j^\forall}^{\alpha}$. According to $\Delta\hat{s}_{i_1;w},\cdots,\Delta\hat{s}_{i_\beta;w}$ or the transport time order from small to large, we can get: $\Delta\hat{s}_{i_\forall;w}^{1},\cdots,\Delta\hat{s}_{i_\forall;w}^{\beta}$ and $\hat{x}_{i_\forall;w}^{1},\cdots,\hat{x}_{i_\forall;w}^{\beta}$. From $\sum_{k=1}^{\gamma_i^\alpha-1}\hat{x}_{i_\forall;w}^{k}\le x_{j^\forall;w}<\sum_{k=1}^{\gamma_i^\alpha}\hat{x}_{i_\forall;w}^{k}$, we can obtain the value of γ_i^α , $x_{i;w}^{\alpha}=\min\{Q_{j;w},x_{ij;w},\sum_{k=1}^{\gamma_i^\alpha}\hat{x}_{i_\forall;w}^{k}-x_{j^\forall;w}\}$ and $t_i^\alpha=t_{ij^\forall}^{\alpha}+\sum_{k=1}^{\gamma_i^\alpha}\hat{t}_{i_\forall}^{k}$. Remove $A_{j^\forall}^{\alpha}$ from η , then $\Delta s_{i;w}^{\alpha}=\Delta s_{i;w}(g_i,k,x_i^\alpha,\delta_i,0)+\sum_{k=1}^{\gamma_i^\alpha}\Delta\hat{s}_{i_\forall;w}^{k}$, $\alpha=\alpha-1$ and turn to Step 5.5; if $\eta=\Phi$, turn to Step 5.6.

Step 5.6 Obtain the best relief resources of D_i : Compute $\Delta s_{i;w}^{'}=\min\{\Delta\hat{s}_{i;w},\Delta s_{i_\forall;w}^{\alpha+1},\cdots,\Delta s_{i_\forall;w}^{p_i-1}\}$, then judge the following conditions: if $\Delta s_{i;w}^{'}$ has only one solution, we can get the unique solution of $t_i^{'}$ and $x_{i;w}^{'}$; if not, we have to choose the optimal solution from several; then, the choosing order is: $\Delta\hat{s}_{i;w}\succ$ the smallest $\gamma_i^\alpha\succ$ the smallest $t_i^\alpha\succ$ the smallest $c_i^\alpha\succ$ the largest $x_{i;w}^{\alpha}\succ$ random selection. From there we can get the end value of $t_i^{'}$ and $x_{i;w}^{'}$.

Step 5.7 To ensure the value of objective function $\sum_{i=1}^{m}(s_{i;w}^{*}-s_{i;w}^{'})$ as the smallest, we design $\Delta s_{i;w}^{'}$ as follows: if $\Delta s_{i;w}^{'}=0$, turn to Step 5.2; otherwise if $\Delta s_{i;w}^{'}=s_{i;w}+\Delta s_{i;w}^{'}-s_{i;w}^{'}$, turn to Step 5.2.

Step 5.8 Determine the overall optimal relief resources: Compute the smallest lag of emergency projects' earliest starting time $\Delta s_w^* = \min\{\Delta s_{1;w}^{'}, \quad \cdots, \Delta s_{m;w}^{'}\}$. If Δs_w^* corresponds to only one $\Delta s_{i;w}^{'}$, then $t_i^{'}$, $x_{i;w}^{'}$ are t^* , x^* ; otherwise, we have to choose the optimal solution from the following, the choosing order is: $\Delta \hat{s}_{i;w} \succ$ the smallest $\gamma_i^\alpha \succ$ the smallest $t_i^\alpha \succ$ the smallest $c_i^\alpha \succ$ the largest $x_{i;w}^\alpha \succ$ random selection. From this information, we can get the end value of t^* , x^* .

Step 5.9 Put the overall optimal relief resources into the emergency project's overall plan, adjust s_i , φ_i and δ_i , and close Step 5.

V. CASE STUDY

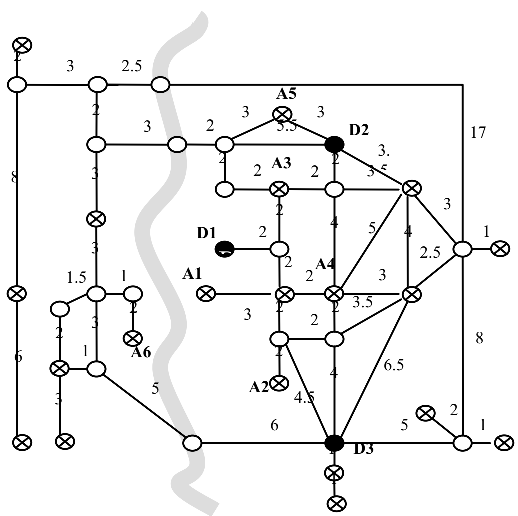

Figure 1. Project – human asset network

The model and algorithm proposed in this paper has been simulated more than one thousand times, and the results are satisfying. Due to article length restrictions, we will provide a relatively simple case to prove the algorithm's effectiveness, which includes 3 emergency projects, 6 human assets or experts supply locations and 3 types of human assets or experts.

The project - human asset network abstraction figure based on illustrations by [4] is shown as Figure 1. The fork mark nodes represent human assets or experts supply locations. These locations' numbering signifies the order of emergency response. The hollow nodes represent transit hubs. The solid nodes represent emergency projects' locations. The length of the arc connecting two nodes represents the transport time from one node to another.

All emergency projects' demand vector is:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} y_{1;1} & y_{1;2} & y_{1;3} \\ y_{2;1} & y_{2;2} & y_{2;3} \\ y_{3;1} & y_{3;2} & y_{3;3} \end{bmatrix} = \begin{bmatrix} 3 & 0 & 1 \\ 4 & 2 & 0 \\ 2 & 3 & 4 \end{bmatrix};$$

The available human assets or experts quantity vector of all supply locations is:

$$x = (x_{1;w}, x_{2;w}, \cdots, x_{6;w}) = \begin{bmatrix} 1 & 3 & 0 & 2 & 0 & 4 \\ 0 & 2 & 3 & 0 & 1 & 0 \\ 2 & 0 & 3 & 2 & 1 & 0 \end{bmatrix};$$

So $m = 3$, $n = 6$, $w = 3$.

The resource unit price (Unit: Hundred Yuan RMB/Day) vector is: $c = \begin{pmatrix} c_1 & c_2 & c_3 \end{pmatrix} = (10, 30, 50)$;

The transport unit price (Unit: Hundred Yuan RMB/Day) vector of human assets or experts is: $\lambda_{ij} = \begin{pmatrix} \lambda_{ij;1} & \lambda_{ij;2} & \lambda_{ij;3} \end{pmatrix} = \begin{pmatrix} 5 & 7 & 9 \end{pmatrix}$, $i = 1,2,3$, $j = 1,2,\cdots,6$, $w = 1,2,3$;

Coordination factor is $\varepsilon = 10^{-4}$.

The time vectors from the 6 human assets or experts supply locations $A_1, A_2, A_3, A_4, A_5, A_6$ to all emergency projects D_1, D_2, D_3 are:

$T_1 = (t_{11}, t_{12}, t_{13}, t_{14}, t_{15}, t_{16}) = (7, 8, 4, 6, 11, 22)$,

$T_2 = (t_{21}, t_{22}, t_{23}, t_{24}, t_{25}, t_{26}) = (11, 12, 4, 6, 3, 19.5)$,

$T_3 = (t_{31}, t_{32}, t_{33}, t_{34}, t_{35}, t_{36}) = (9.5, 6.5, 10.5, 6, 15, 17)$.

Obtain all emergency projects' independent optimal solution through a single emergency project plan selection algorithm introduced by [4].

About emergency project D_1 , we can get its independent optimal solution as follows: Ordered elements of the vector T_1 from near to far can be used to get an arrangement $t_{13}^1 \le t_{14}^2 \le t_{11}^3 \le t_{12}^4 \le t_{15}^5 \le t_{16}^6$; Obtain the 3 types of human assets or experts supply locations arrangement from near to far: $A_3^1, A_4^2, A_1^3, A_2^4, A_5^5, A_6^6$; According to the emergency projects' demand vector, we can know the quantity that D_i project need the first type of human assets or experts is $y_{1;1} = 3$; Do not consider other projects, we get the nearest human assets or experts for D_1 : $x_{3;1} = 0$, $x_{4;1} = 2$, $x_{1;1} = 1$; Then we can get D_1 's independent optimal solution on the first type of human assets or experts: $\varphi_{1;1}^{'} = [1 \quad 0 \quad 0 \quad 2 \quad 0 \quad 0]$ and $s_{1;1}^{'} = t_{11}^3 = 7$; similarly get the results on the other two types of human assets or experts; Finally, the D_1 's independent optimal solution can be computed: $s_1^{'} = \max[s_{1;1}^{'} \quad s_{1;2}^{'} \quad s_{1;3}^{'}] = \max[7, \quad 0, \quad 4] = 7$,

$$\varphi_1^{'}=\begin{bmatrix}\varphi_{1;1}^{'}\\ \varphi_{1;2}^{'}\\ \varphi_{1;3}^{'}\end{bmatrix}=\begin{bmatrix}1&0&0&2&0&0\\0&0&0&0&0&0\\0&0&1&0&0&0\end{bmatrix}.$$

Similarly, the independent optimal solutions of D_2 and D_3 are: $s_2^{'}=\max[12,\quad 4,\quad 0]=12$,

$$\varphi_2^{'}=\begin{bmatrix}\varphi_{2;1}^{'}\\ \varphi_{2;2}^{'}\\ \varphi_{2;3}^{'}\end{bmatrix}=\begin{bmatrix}1&1&0&2&0&0\\0&0&1&0&1&0\\0&0&0&0&0&0\end{bmatrix};$$

$s_3^{'}=\max[6,\quad 10.5,\quad 9.5]=10.5$,

$$\varphi_3^{'}=\begin{bmatrix}\varphi_{3;1}^{'}\\ \varphi_{3;2}^{'}\\ \varphi_{3;3}^{'}\end{bmatrix}=\begin{bmatrix}0&0&0&2&0&0\\0&2&1&0&0&0\\2&0&0&2&0&0\end{bmatrix}.$$

Among the first type of human assets or experts, two supply locations A_1, A_4 have an existing resource conflict in all 3 emergency projects. The real number of the first type of human assets or experts in A_1, A_4 is 3, but emergency projects need 8 from A_1, A_4. Then, the resource confliction is 8, which is 2.67 times of real resource quantity and 88.89% of aggregate demand 9. Therefore, 3 emergency projects' independent optimal solutions cannot combine and become the overall optimal solution. On the second and third type of human assets or experts, there are no resource conflicts.

According to the iterative adjustment algorithm proposed by this paper, we start to adjust all human assets conflictions.

Step0 Obtain D_1's independent optimal solution from a single emergency project plan selection algorithm as above method and get D_1's earliest starting time $s_1^{'}=7$; and then we identify the counter of human assets or experts: $w=1$.

Step1 Use the above method to compute earliest starting time $s_{1;1}^{'}$, emergency plan $\varphi_{1;1}^{'}$ and the $p_1=3$ th supply locations of human assets or experts; identify the iterative adjustment counter: $j=0$.

Step2 Judge the following conditions cyclically: $j=j+1=1$; $j\le n$, move on to Step3.

Step3 Compute the conflicting number of human assets or experts supply locations A_1 : $Q_{1;1}=\sum_{i=1}^{3}x_{i1;1}-x_{1;1}=1$.

Step4 Judge the confliction: $Q_{j;w}>0$, there exists a conflict and move on to Step5.

Step5 Find the best unused human assets or experts for the whole solution:

Step 5.1 Identify the counter: $i=0$.

Step 5.2 Judge the following conditions cyclically: $i=i+1=1$, record p_1's initial value $g_1=p_1=3$; $i\le m$, turn to Step 5.3.

Step 5.3 Judge whether the emergency project D_1 contributes to human assets or experts confliction: $x_{11;1}=1\ne 0$, D_1 takes part in human assets or experts conflicting, and then moves to Step 5.4.

Step 5.4 Compute project D_1's $\hat{x}_{1;1}$ and $\Delta\hat{s}_{1;1}$, then judge the following conditions: $\Delta\hat{s}_{i;w}\ne 0$, turn to Step 5.5.

Step 5.5 Obtain D_i's relief resources indirectly: get the relief resources $x^*=1$ from A_2, which supply 1expert to project D_2.

Step 5.6 Obtain the best relief resources of D_i: Compare the two methods to get the best relief resources $x^*=1$ from A_2, which supply 1expert to project D_2 as 1 relief resource and can't change the independent earliest starting time of all projects.

Step 5.7 To ensure the value of objective function $\sum_{i=1}^{3}(s_{1;1}^{*}-s_{1;1}^{'})$ as the smallest, we design $\Delta s_{1;1}^{'}$ as follows: $\Delta s_{1;1}^{'}=0$, turn to Step 5.2.

We can do step 5.2-5.7 on D_2 and D_3 like what to do on D_1. When $i>3$, we can move to Step 5.8.

Step 5.8 Determine the overall optimal relief resources: the best relief resources $x^*=1$ from A_2, which supply 1expert to project D_2.

Step 5.9 Put the overall optimal relief resources into the emergency project's overall plan, adjust s_1, φ_1 and δ_1, and close Step 5.

Step6 Calculate $Q_{1;1}=Q_{1;1}-x^*=1-1=0$, turn to Step2.

Then we can adjust all other suppliers' confliction like A_1. And adjust all other types of human assets or experts like the first one.

Step7 Judge whether or not all types of human assets or experts have be allocated: $w=w+1=4>v$,turn to Step8.

Step8 Determine that all types of human assets or experts don't exit confliction.

Step9 Put together all projects' human assets and experts allocation plan; close this algorithm.

According to the above method, we can obtain a satisfying value from upper-level objective function $z^* = 7.55329$, and the total cost is 532.9. The overall human assets allocation plan is as follows:

$s_1^* = \max[s_{1;1}^* \quad s_{1;2}^* \quad s_{1;3}^*] = \max[7, \quad 0, \quad 4] = 7$;

$s_2^* = \max[19.5, \quad 4, \quad 0] = 19.5$;

$s_3^* = \max[6.5, \quad 10.5, \quad 9.5] = 10.5$;

$$\varphi_1^* = \begin{bmatrix} \varphi_{1;1}^* \\ \varphi_{1;2}^* \\ \varphi_{1;3}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix};$$

$$\varphi_2^* = \begin{bmatrix} \varphi_{2;1}^* \\ \varphi_{2;2}^* \\ \varphi_{2;3}^* \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 3 \\ 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix};$$

$$\varphi_3^* = \begin{bmatrix} \varphi_{3;1}^* \\ \varphi_{3;2}^* \\ \varphi_{3;3}^* \end{bmatrix} = \begin{bmatrix} 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 2 & 1 & 0 & 0 & 0 \\ 2 & 0 & 0 & 2 & 0 & 0 \end{bmatrix}.$$

From the results, the algorithm successfully solves the human assets confliction problem among multiple emergency projects, multiple human assets types and multiple human assets supply locations. This algorithm can ensure the overall projects' starting times are as early as possible and the human assets are used as efficiently as possible. At the same time, this algorithm also considers cost saving. From the overall human assets allocation plan, we can know that the first type of human assets or experts of A_1, A_4 and the third type of human assets or experts of A_3 take part in emergency project D_1 ; the first type of human assets or experts of A_2, A_6 and the second type of human assets or experts of A_3, A_5 take part in emergency project D_2 ; the first type of human assets or experts of A_2 , the second type of human assets or experts of A_2, A_3 and the third type of human assets or experts of A_1, A_4 take part in emergency project D_3 .

VI. CONCLUSIONS

In the resource allocation field, the timeliness and efficiency allocation methods among multiple emergency projects, multiple human assets types and multiple human assets supply locations have been difficult to calculate. This paper establishes a bi-level human asset allocation model, which can obtain an optimal solution of all emergency projects and overcome non-convex optimization problems. The time complexity of this allocation model is only $O(mnv\sum_{j=1}^{n}\sigma_j)$. Nowadays, the computing power of a common personal computer is already more than 1G / s. This means that when there are 100 emergency projects, 100 human assets or experts supply location and 100 types of human assets or experts, we just need less than 1 second to acquire the overall human assets allocation plan with a common PC. The time complexity can realistically meet the strict time requirements during any emergency response phase. Therefore, this article provides very practical and significant help for enterprises that aim to reduce reputation and economic loss during high-risk scenarios.

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