Abstract: This paper studies an emergency rescue network that integrates the distribution centers, cities and replenishment resources into a multi-level system to achieve time-based efficiency. Based on the relationship between the amount of supply and the vaccination rate, we develop a collaboration model for such a multi-level network to ensure continuous supply and consumption. Validity and feasibility of the model is tested through simulation studies.

Keywords: Emergency rescue networks; Collaboration optimization; Emergency logistics; Multi-level systems

1. Introduction

Emergency logistics distribution is one of the major activities in disaster response. When disaster happened, evacuation activities is taken place during the initial response phase whereas logistics support operations tended to continue for a longer time for sustaining the basic needs of survivors who remained in the affected area [1]. Quick response to the urgent relief needs right after natural disasters through
efficient emergency logistics distribution is vital to the alleviation of disaster impact in the affected areas, which remains challenging in the field of logistics and related study areas [2].

Despite the vital importance of emergency logistics distribution in disaster response activities, relative to business logistics and supply chain management, only a few of related research has been carried out. Considering the multi-commodity supply problems under emergency conditions, three liner programming formulations were proposed in Rathia et al. (1992), where the routes and the supply amount carried on each route were assumed to be known in each of the given origin–destination (O–D) pairs [3]. And the efficiency of evacuations were investigated by Sato and Ichii (1996) [4]. Tzeng and Chen (1999) conducted a study on scheduling programming for restoration, construction and salvaging work for road networks [5]. Brown et al. (1993) combined optimization theory, simulation technology, judgment of decision-makers, and proposed a real-time decision support system, which is used to supply and deliver rescue materials after disasters[6]. Other relative research was done by Haghani et al. (1996)[7], Fiedrich et al. (2000)[8] at the latter years. Suleyman Tufekc and William A.Wallace(1998) pointed out that emergency management is a complex multi-object optimization problem on essence[9]. A bi-level hierarchical decomposition approach was proposed in Barbarosoglu, G. et al (2002) for helicopter mission planning during a disaster relief operation [10]. Another case studied by Ozdarmar, L. et al (2004) was unique in incorporating the vehicle routing problem into the relief distribution process, in which vehicles were treated as commodities to facilitate decomposing the
comprehensive emergency logistics distribution problem into two multi-commodity network sub-problems, and then solved using Lagrangean relaxation [11].

Although these studies provided insight into various disaster recovery efforts, the distribution of emergency logistics distribution was not properly addressed. More recently, a meta-heuristic of ant colony optimization (ACO) for solving the logistics problem arising in disaster relief activities was proposed in Wei Yi and Arun Kumar (2006), which conducted the relief activities as a two stage decision model and solved with CPLEX software [12]. A scenario planning approach for the flood emergency logistics preparation problem under uncertainty was studied by Mei-Shiang Chang et al (2006), which supplied a decision-making tool that can be used by government agencies in planning for flood emergency logistics [13]. Based on some ideal assumptions pre-set, a multi-objective optimal planning for designing relief delivery systems was constructed by Gwo-Hshiung Tzeng et al (2006), which featured three objectives: minimizing the total cost, minimizing the total travel time, and maximizing the minimal satisfaction during the planning period [14]. However, only flows among relief collection points, transfer candidate depots and relief demand points were considered in objective functions in this paper, time and cost during the transshipment in transfer depots were neglected. Moreover, penalty function, which conducted by the un-satisfaction of demand points, were not reflected in it.

Wang xuping et al. (2005) hold that emergency logistics is an entity flow process which abnormally organizes good from supply places to receipt places to meet sudden logistics demand[15]. Zhao lindu(2007) researched on emergency logistics network of
urban major dangerous sources, proposing that urban emergency management network and emergency logistics network constitute the two major networks of urban emergency management system[16]. Wu yiwei and Zhao lindu (2007) researched the recovery mode and inventory control model at the respect of emergency rescue material manufactures, proving that recovery of emergency rescue materials is benefit for improving the operation efficiency of the whole emergency logistics system[17], however, distance between emergency rescue materials’ repair place and storage is not considered in the study.

The remainder of this paper is organized as follows. Methodological framework of the proposed approach is introduced in Section 2. Formulation and arithmetic analysis is presented to illustrate the feasibility and effectiveness of this model in Section 3. Finally, concluding remarks and directions for future research are summarized in Section 4.

2. Model assumption and symbols specification

To smooth the progress of model formulation in the following subsections, some assumptions are postulated as follows.

(1) The numbers of distribution centers or hubs (denoted by \(i\)) and the corresponding geographic relationship between each of them are known.

(2) Each hub covers some demand cities (denoted by \(j\)).

(3) Each hub can transfer to be a replenishment resource of other hub once there is an emergency demand.

(4) Areas only that still are accessible through the current road network will be
considered, and those need helicopter or other extraordinary transportation means will be neglected.

(5) Only time element is considered and economic cost is ignored.

The hypothetical emergency logistics network constructed in this paper is depicted in Fig.1, which involves distribution centers, demand cities and affected areas, forming a specific three-layer relief supply chain. Moreover, each hub collaborates with others aside which made it has the same effect with a replenishment resource.

The definitions of parameters and variables specified in this paper are summarized in the following.

![Collaboration framework of emergency logistics network](image)

**Fig.1.** Collaboration framework of emergency logistics network

\[
f_l \quad \text{The total time cost in case } l, l = 1, 2, 3
\]

\[
m \quad \text{The total number of distribution centers (hubs), } i = 1, 2, \ldots, m
\]

\[
\tilde{i} \quad \text{The other numbers of hub except hub } i
\]

\[
n_i \quad \text{Each hub covers some demand cities, } j = 1, 2, \ldots, n_i
\]

\[
T_{ij}(t) \quad \text{The travel time from the distribution center } i \text{ to the demand city } j
\]

\[
T_{ia}(t) \quad \text{The travel time from the other distribution center } \tilde{i} \text{ to the demand center } i
\]
\( T_{ji}(t) \) The collect time of the emergency materials in the other distribution center \( i \)

\( D_j \) The quantity of emergency materials city \( j \) demanded

\( S_{ji} \) The quantity of emergency materials collected from city \( j \) to hub \( i \)

\( R_i \) The capacity of hub \( i \)

\( UNL_v \) The unit loading capacity associated with a given type of vehicle \( v \);

\( NV_v^i \) The number of vehicle trips associated with a given type of vehicle \( v \) available at hub \( i \)

\( UNV_{ij} \) The number of vehicle trip from hub \( i \) to the demand city \( j \)

\( AC_{ij} \) The pass capability of road network from hub \( i \) to demand city \( j \);

\( \alpha, \beta, \gamma \) The probability of case 1, 2, 3

3. **Formulation and arithmetic analysis**

In literature [18], we have proved that each hub collaborates with others aside which made it has the same effect with a replenishment resource, see Fig.2.

![Fig.2 collaboration effect analysis](image)

**Cases 1**, if all the areas are peaceful, then all the emergency hubs maintains its normal storage and distribution function, each hub has no connection with others, and the emergency logistics network show in Fig.3.
Fig.3 situation that without collaboration

The objective function is as follows

$$\min f_1 = \sum_i \sum_j T_{ij}(t)$$  \hspace{1cm} (1)

Subject to

$$\sum_{j=1}^{n_i} D_j \leq R_i, \forall i$$  \hspace{1cm} (2)

$$\sum_{j=1}^{n_i} D_j \leq \sum_v UNV_j \times NV_{ij}', \forall i$$  \hspace{1cm} (3)

$$UNV_{ij} \leq AC_{ij}, \forall ij$$  \hspace{1cm} (4)

$$UNV_{ij} \in \{0,1,2,...\}$$  \hspace{1cm} (5)

$$NV_{ij}' \in \{0,1,2,...\}$$  \hspace{1cm} (6)

$$AC_{ij} \in \{0,1,2,...\}$$  \hspace{1cm} (7)

**Case 2**, once one area has emergency situation, such hub become a transfer point, while the other hubs become replenishment resources, and the emergency logistics network show in Fig.4.
Objective function in this situation is show as follows

\[ \min f_2 = \sum_{i} \sum_{j} T_{ji}(t) + \sum_{i} \sum_{j} T_{ij}(t) + \sum_{i} \sum_{j} T_{ij}(t) \quad (8) \]

Subject to

\[ \sum_{j=1}^{n_i} D_j \leq \sum_{i=1}^{m} R_i, \forall i \quad (9) \]

\[ \sum_{j=1}^{n_i} D_j \leq \sum_{i} \sum_{v} UNL_v \times NV^i_v, \forall i \quad (10) \]

\[ \sum_{j=1}^{n_i} S_{ji} \leq R_i, \forall i \quad (11) \]

\[ UNV_{ij} \leq AC_{ij}, \forall ij \]

\[ UNV_{ij} \in \{0, 1, 2, \ldots\} \]

\[ NV^i_v \in \{0, 1, 2, \ldots\} \]

\[ AC_{ij} \in \{0, 1, 2, \ldots\} \]

**Case 3**, all the area has emergency demand, and then all the hubs replenish each other, in other words, the emergency relief resources need to be re-coordinated united and the emergency logistics network show in Fig.5.
The objective function is as follows.

\[
\min f_3 = \sum_{i} \sum_{j} T_{ij}(t) \quad (12)
\]

Subject to

\[
\sum_{i} \sum_{j} D_{ij} \leq \sum_{i} R_i \quad (13)
\]

\[
\sum_{i} \sum_{j} D_{ij} \leq \sum_{v} \sum_{v'} (UNL_v \times NV_{ij}) \quad (14)
\]

\[
\sum_{i} \sum_{j} S_{ij} \leq \sum_{i} R_i \quad (15)
\]

\[
UNV_{ij} \leq AC_{ij}, \forall ij
\]

\[
UNV_{ij} \in \{0, 1, 2, \ldots\}
\]

\[
NV_{ij} \in \{0, 1, 2, \ldots\}
\]

\[
AC_{ij} \in \{0, 1, 2, \ldots\}
\]

In this paper, a simulation experiment analysis about a nature disaster occurred in east of China is taken as the analysis illustration. The collaboration emergency logistics network is shown in Fig.6, where the green lines connect the hub and the demand cities, and the red lines means that each hub can take the other hub aside as the replenishment resource once in the emergency situation. All data were made by
the random function tool with software MATLAB6.5 and obey $N(\mu, \sigma^2)$.

![Fig. 6 The collaboration emergency logistics network](image)

The objective function is as follows.

$$\min f = \alpha f_1 + \beta f_2 + \gamma f_3 \quad (16)$$

Subject to

$$\alpha, \beta, \gamma \in \{0, 1\}, \quad (2-7), \quad (9-11) \text{ and } (13-15).$$

The relative data are show table1 to 3. We set that the pass capability of road network $A_{ij}$ and the unit loading capacity associated with a given type of vehicle $v$ are equal to large number $M$. Then it becomes a simple mix integer programming function and the model is quite easily to solve using relative software such as LINGO or CPLEX. The universal arithmetic program is show as follows:

model:

sets:

relief/re1..reM/:variable;

demand/de1..deN/: variable;


min=@sum(relief: objective function);

@for constraint condition 1;
@for constraint condition 2;
......
@for constraint condition n;
@for(relief: @bin(variable));

data:
end

<table>
<thead>
<tr>
<th>Cities</th>
<th>Hub1</th>
<th>Hub2</th>
<th>Hub3</th>
<th>Hub4</th>
<th>Hub5</th>
<th>Hub6</th>
<th>Hub7</th>
<th>Hub8</th>
</tr>
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</table>
### Table 2: Travel time between each hub and its cover cities

<table>
<thead>
<tr>
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<th>Hub1</th>
<th>Hub2</th>
<th>Hub3</th>
<th>Hub4</th>
<th>Hub5</th>
<th>Hub6</th>
<th>Hub7</th>
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<td>City 1</td>
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<td>3</td>
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<td>3</td>
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<tr>
<td>City 2</td>
<td>2</td>
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<td>5</td>
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<tr>
<td>City 6</td>
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</table>

### Table 3: Travel time between each two hubs

<table>
<thead>
<tr>
<th>Hubs</th>
<th>Hub1</th>
<th>Hub2</th>
<th>Hub3</th>
<th>Hub4</th>
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<td>Hub 1</td>
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<tr>
<td>Hub 2</td>
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<td>3</td>
<td>3</td>
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<tr>
<td>Hub 3</td>
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<tr>
<td>Hub 4</td>
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</table>

The calculate result is show in table 4 and the optimal network is constructed as Fig.7.

### Table 4: The collaboration result

<table>
<thead>
<tr>
<th>Supply</th>
<th>Hubs</th>
<th>Hub1</th>
<th>Hub2</th>
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</table>
4. Conclusion

This paper studies an emergency rescue network that integrates the distribution centers, cities and replenishment resources into a multi-level system to achieve time-based efficiency. Three cases of emergency relief model were formulated and integrated, the program arithmetic and sound code for solve such problem was put forward at last. Nevertheless, there is still a great potential for improving the operations performance of emergency logistics network optimization. One example is integrating the logistic distribution programming which made the whole relief organization incorporated. Furthermore, an actually disaster would be much more complexity and expanding the present study scope and methodology to much more complex, time variability, demand uncertainty are also our interest, and warrants further research.
Acknowledgement

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Reference


