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Resources Allocation Problem for Local Reserve Depots in Disaster Management Based on Scenario Analysis

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Abstract Resource allocation problem for local reserve depots in disaster management is considered in this paper. In order to prepare for natural and manmade disasters of various scales, local government need to decide what kinds of and how much amount of commodities should be maintained in local reserve depots in order to cope with slight disasters, while cooperating with central government for serious disasters. Resource requirement in each district is represented as a random variable, and links connecting the depots and districts are uncapacitated but might have failed. The randomness is represented by a finite sample of scenarios for demand and link. All scenarios are divided into two set, slight scenarios and serious scenarios.

A resource allocation model, which aims to minimize the total rescue cost subjected to the local reserve depots' capacity constraints, is presented. In this model, a multi-commodity and multi-modal transportation flow is also considered. Then, we design an LP-relaxation algorithm by introducing LP-rounding technique. Finally, a case study shows that this model can help local government to make decisions on resource allocation in case of disaster relief efforts and the corresponding algorithm can provide decision maker better advice.

Keywords Resource allocation; Scenario analysis; Disaster

1 Introduction

The World Health Organization defines a disaster as any occurrence that causes damage, destruction, ecological disruption, loss of human life, human suffering, deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community or area. Earthquakes, hurricanes, tornadoes, volcanic eruptions, fire, floods, blizzard, drought, terrorism, chemical spills, nuclear accidents are included among the causes of disasters, and all have significant devastating effects in terms of human injuries and property damage [1].

In order to enhance the capacity of response to disaster, Chinese central government sets up national reserve depots of disaster relief commodities such as tents, food, drinking water, medicines and equipment, etc. and every province has local reserve depots.

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The distributed reserve system in one country is always hierarchical. It is assumed that locations of the reserve depots have been determined in advance. The local government often needs to decide the type and amount of commodities in these local reserve depots. The main principle in planning these reserves is up to a certain disaster degree they are prepared to respond. That means local government should itself cope with slight disasters below this degree. Based on this multi-level reserve system, local government may respond to disasters based on to its own level of reserves. This level may be determined by its reserve depots' capacity and its rescue ability. Namely, some slight disasters without causing too much loss can be rescued only with local reserve depots, while large scale disasters must be rescued with both local and national reserve depots. Different district may opt to face different disaster. For example, due to their geological locations, a district along large river may prepare for floods, while districts along the coastal areas need to be ready for tsunami, etc. Then local government needs to do the preparation for all possible disasters in its own province.

In this paper, we consider two kinds of supplier of relief resources, local government suppliers and central government suppliers. Local government suppliers mainly refer to local reserve depots, while central government suppliers consists all national reserve depots. The purpose of local reserve depots is to satisfy the demand of disaster areas (districts) when the disaster impact is under a certain degree. These disasters are slight. For example, according to earthquake magnitude, the local reserve depots must meet the demands when it has a lower magnitude. While the affect is above this certain degree, local government has not enough resources. In this case, rescue efforts need not only local government resources but also all central government resources. We assume there always are enough commodities in national reserve depots, because central government may call all social resources in case of large scale emergencies. In other words, this assumption means the whole country has enough resource to do the rescue. Also, for simplification, we assume that all social resources are collected into national reserve depots first before being used. In this paper, determination of the amount of resource in each local reserve depot is considered, so as to satisfy the demand of districts below the certain degree, and cooperate with all central resource to cope with disaster above this degree.

Since it is almost impossible to know the timing and the intensity of a natural disaster, it is very difficult to estimate the impact, damage and resource needs exactly in advance. Thus, the planning problem should be naturally treated as a stochastic problem where randomness arises from demand. Obviously, the decision process must be responsive to the variations in these random parameters. The realization of these parameters represents an exact disaster damage which calls for demand in each potential district area. Then allocation decision in each depot must consider all possible realization of these parameters. Such a realization in each district is called a disaster damage scenario, which can be represented as a series of demands in each district. Also, the impact on transportation facilities will be considered because some roads can be broken in some scenarios. Since the importance of a district is different between each other due to its population, geographical location and local industrial infrastructures, and the probability of scenario occurring is different too, we define a weight function of scenario to describe each scenario's importance factor in the decision making process.

Beginning with Cooper [2] in 1963, facility location-allocation (FLA) provides a valuable method in deciding where to place facilities coupled with determining how to assign demand to the located facilities in order to utilize resources effectively. Logendran and Terrell [5] firstly introduced the stochastic uncapacitated FLA model in which customers' demands was assumed to be random variables. Next, by introducing fuzzy theory into FLA problem, the capacitated FLA problem with fuzzy demands of customers as the expected cost minimization model, K-cost minimization model and possibility maximization model were formulated (Zhou and Liu [11]). Wen and Iwamura [9] considered the FLA problem under random fuzzy environment using (K,L)-cost minimization model under the Hurwicz criterion. Different from the above-mentioned papers, we introduce scenario analysis when dealing with random variables.

Emergency logistics management has also emerged as a worldwide-noticeable theme. Sheu [7] presented four main challenges that emergency logistics management can be characterized. Also as a sponsor, Sheu edited a special issue of Transportation Research Part E, in which six papers on emergency logistics were included. These papers concentrated on addressing the issue of relief distribution to affected areas. In some of the studies, the issue of evacuating affected people was also considered. When dealing with uncertainty, Potvin et al.[6] list a number of reactive dynamic strategies for vehicle routing and scheduling problems. In this paper, we consider cost of the transportation plan in disaster response as one of the objectives in our resource allocation model.

One of the earliest studies conducted on location of emergency service facilities is by Toregas et al.[8] modeling the problem as a set covering problem and using a linear programming as the solution method. Consignment of goods is typically examined in the literature as a multi-commodity network flow problem, with a multi-period and/or multi-modal setting. Haghani and Oh [4] formulated a multi-commodity, multi-modal network flow model with time windows for disaster response. Two heuristic algorithms are proposed. The flow of goods over an urban transportation network is modeled as a multi-commodity, multi-modal network flow problem by Barbarosoglu et al. [1]. A two-stage stochastic programming framework is formed as the solution approach. Another study on the topic, conducted by Fiedrich et al.[3], model the problem similar to a machine scheduling problem proposing two heuristics, Simulated Annealing and Tabu Search. Yi and Ozdamar [10] consider a dynamic and fuzzy logistics coordination model for conducting disaster response activities. The model is illustrated on an earthquake data set from Istanbul. Also, Barbarosoglu et al. [1] proposed that their model could be used effectively within a decision-aid tool by public and non-public response agencies that are obscured by the variability of impact estimations under large number of different earthquake scenarios. Different from these works, we mainly consider Resource Allocation Problem (RAP) in reserve depots under two kinds of scenario sets, slight impacts and serious impacts.

The remainder of this paper is organized as follows. In Section 2, we specify the Resource Allocation Model (RAM). In Section 3, an algorithm for solving this problem is described. Computational results are presented in section 4. In Section 5, we conclude this paper.

2 Model Description

According to the resource allocation problem, the main task of our model is to determine the amount of commodity in each local depot. In this process, many disaster scenarios are considered to help to make such a decision. In this section, we will specify the Resource Allocation Model (RAM).

Based on impact of disaster, we separate all scenarios into two sets, W and U. W includes all scenarios below a certain degree, which can be called slight impacts scenario set. Namely, local government depots can totally cope with the disaster of any scenario in W. On the other hand, when scenario from serious impacts set in U occurs , the rescue needs all social resources. Let $p(w)$ be the weight function of scenario w, which satisfies $0 \leq p(w) \leq 1$. Similarly, $p(u)$ is the weight function of scenario u and $0 \leq p(u) \leq 1$. These two weighted functions can be specified by two factors, the occurring probability of scenario and the relative importance of districts.

The model includes K commodities that are to be determined the amount stored in each local reserve depot. The cost of purchase and maintenance can be different between any two depots. Then, let h_i^k be the holding cost for one unit of commodity k in local reserve depot i. Namely, the price of purchasing and maintaining commodity k in local reserve depot is h_i^k. Because of the disaster damage, some roads may be broken. Then let $SM_{ij}^k(w)$ be the set of available modes for commodity k from local reserve depot i to district j in scenario w. C_{ij}^{kv} is the cost for carrying one unit of commodity k transporting from local reserve depot i to district j by mode v. Also, it may represent time cost. κ_1, κ_2 are parameters to balance the holding cost, taking cost and transportation cost. All parameters in this model are shown below.

Parameters

K	:	Set of commodities
D	:	Set of districts
LRD	:	Set of local reserve depots
NRD	:	Set of national reserve depots
W	:	Set of scenarios that rescue must be supported by local reserve depots
$p(w)$	:	weight function of scenario w
U	:	Set of scenarios that rescue needs not only local reserve depots but also national reserve depots
$p(u)$	:	weight function of scenario u
c_i^k	:	capacity of commodity k in local reserve depot i
s^k	:	size of one unit of commodity k
c_i	:	capacity of local reserve depot i
h_i^k	:	holding cost for one unit of commodity k in local reserve depot i
V	:	Set of modes
$SM_{ij}^k(w)$	:	Set of available modes for commodity k from local reserve depot i to district j in scenario w
$SM_{ij}^k(u)$	:	Set of available modes for commodity k from local reserve depot i to district j in scenario u
$SM_{lj}^k(u)$	:	Set of available modes for commodity k from national reserve depot l to district j in scenario u
$D_j^k(w)$	:	demand for commodity k at district j in scenario w
$D_j^k(u)$	:	demand for commodity k at district j in scenario u
C_{ij}^{kv}	:	cost for carrying one unit of commodity k from local reserve depot i to district j by mode v

C_{lj}^{kv} : cost for carrying one unit of commodity k from national reserve depot l to district j by mode v

C_l^k : cost for taking one unit of commodity k from national reserve depot l

κ_1, κ_2 : parameter

Up to these parameters, the following decision variables need to be determined.

Decision variables

z_i^k : amount of commodity type k stored in local reserve depot i

$x_{ij}^{kv}(w)$: amount of commodity type k sent from local reserve depot i to district j by mode v in scenario w

$x_{ij}^{kv}(u)$: amount of commodity type k sent from local reserve depot i to district j by mode v in scenario u

$y_{lj}^{kv}(u)$: amount of commodity type k sent from national reserve depot l to district j by mode v in scenario u

$z_l^k(u)$: total amount of commodity type k required from national reserve depot l in scenario u

The first objective aims at minimizing total holding cost for commodity in all local reserve depots.

$$\sum_{i\in LRD}\sum_{k\in K} h_i^k z_i^k \qquad \text{(i)}$$

The second objective is to minimize the weighted taking cost for commodity in all national reserve depots.

$$\sum_{u\in U} p(u)(\sum_{l\in NRD}\sum_{k\in K} C_l^k z_l^k(u)) \qquad \text{(ii)}$$

The third objective aims at minimizing total transportation cost, which include two parts. The first one is weighted cost for all slight scenarios.

$$\sum_{w\in W} p(w)(\sum_{i\in LRD}\sum_{j\in D}\sum_{k\in K}\sum_{v\in SM_{ij}^k(w)} C_{ij}^{kv} x_{ij}^{kv}(w)) \qquad \text{(iii)1}$$

The second one is weighted cost for all serious scenarios, in which the transportation cost from local reserve depots to districts and national reserve depots to district are both considered.

$$\sum_{u\in U} p(u)(\sum_{i\in LRD}\sum_{j\in D}\sum_{k\in K}\sum_{v\in SM_{ij}^k(u)} C_{ij}^{kv} x_{ij}^{kv}(u) + \sum_{l\in NRD}\sum_{j\in D}\sum_{k\in K}\sum_{v\in SM_{lj}^k(u)} C_{lj}^{kv} y_{lj}^{kv}(u)) \qquad \text{(iii)2}$$

Then, the Resource Allocation Model (RAM) may be described as,

Model RAM:

$$\begin{aligned}\textbf{minimize}\quad & \kappa_1 \sum_{i\in LRD}\sum_{k\in K} h_i^k z_i^k + \kappa_2 \sum_{u\in U} p(u)(\sum_{l\in NRD}\sum_{k\in K} C_l^k z_l^k(u)) \\ & + \sum_{w\in W} p(w)(\sum_{i\in LRD}\sum_{j\in D}\sum_{k\in K}\sum_{v\in SM_{ij}^k(w)} C_{ij}^{kv} x_{ij}^{kv}(w)) \\ & + \sum_{u\in U} p(u)(\sum_{i\in LRD}\sum_{j\in D}\sum_{k\in K}\sum_{v\in SM_{ij}^k(u)} C_{ij}^{kv} x_{ij}^{kv}(u) + \sum_{l\in NRD}\sum_{j\in D}\sum_{k\in K}\sum_{v\in SM_{lj}^k(u)} C_{lj}^{kv} y_{lj}^{kv}(u))\end{aligned}$$

Subject to:

$$\sum_{i\in LRD} z_i^k \geq \sum_{j\in D} D_j^k(w), k\in K, w\in W \tag{1}$$

$$s^k z_i^k \leq c_i^k, i\in LRD, k\in K \tag{2}$$

$$\sum_{k\in K} s^k z_i^k \leq c_i, i\in LRD \tag{3}$$

$$\sum_{i\in LRD}\sum_{v\in SM_{ij}^k(w)} x_{ij}^{kv}(w) \geq D_j^k(w), j\in D, k\in K, w\in W \tag{4}$$

$$\sum_{j\in D}\sum_{v\in SM_{ij}^k(w)} x_{ij}^{kv}(w) \leq z_i^k, i\in LRD, k\in K, w\in W \tag{5}$$

$$\sum_{i\in LRD}\sum_{v\in SM_{ij}^k(u)} x_{ij}^{kv}(u) + \sum_{l\in NRD}\sum_{v\in SM_{lj}^k(u)} y_{lj}^{kv}(u) \geq D_j^k(u), j\in D, k\in K, u\in U \tag{6}$$

$$\sum_{j\in D}\sum_{v\in SM_{ij}^k(u)} x_{ij}^{kv}(u) \leq z_i^k, i\in LRD, k\in K, u\in U \tag{7}$$

$$\sum_{j\in D}\sum_{v\in SM_{lj}^k(u)} y_{lj}^{kv}(u) = z_l^k(u), l\in NRD, k\in K, u\in U \tag{8}$$

$$z_i^k \geq 0, integer, i\in LRD, k\in K \tag{9}$$

$$x_{ij}^{kv}(w) \geq 0, integer, i\in LRD, j\in D, k\in K, v\in SM_{ij}^k(w), w\in W \tag{10}$$

$$x_{ij}^{kv}(u) \geq 0, integer, i\in LRD, j\in D, k\in K, v\in SM_{ij}^k(u), u\in U \tag{11}$$

$$y_{lj}^{kv}(u) \geq 0, integer, l\in NRD, j\in D, k\in K, v\in SM_{lj}^k(u), u\in U \tag{12}$$

$$z_l^k(u) \geq 0, integer, l\in NRD, k\in K, u\in U \tag{13}$$

Combining cost objective function (i), (ii), (iii)1 and (iii)2 with parameter κ_1 and κ_2, we design the weighted cost function in model RAM. When we care more about the transportation costs, smaller κ_1 and κ_2 will be chosen. Constraint (1) is the total amount commodities constraints for each slight scenario. Capacity constraints on each local reserve depot are (2) and (3). Constraint (4) means that district j must get enough commodity k from local depots in slight scenario w. And constraint (5) and (7) force the amount of commodity k carried from local depot i to all districts not exceed its whole capacity. Constraint (6) is the demand satisfaction constraint in serious scenario u. Last constraint (8) is an equation on national reserve depot for each commodity.

3 Model Analysis and Algorithm Design

In this section, we will present LP-rounding Algorithm for RAM after model analysis.

3.1 Model Analysis

From the constraints (1) and (3) in model RAM, there may be no feasible solution. But in fact, the level between slight scenario and serious scenario is up to local government decision makers and its rescue ability. When the model has no feasible solution, it means the level they have made is much higher. So the decision makers need to consider lower disaster level, or increase local depot's capacity.

This model is obviously an integer linear programming with huge number of integer variables. Hence it is difficult to find the optimal solution when the size of problem becomes bigger. Thus, we design approximation algorithm to give a better solution for this model.

3.2 Algorithm Design

Considering that the RAM is an integer linear programming, we introduce LP-rounding technique. Firstly, the LP-relaxation of RAM is obtained by relaxing all variable's integer constraints. Secondly, solve the LP-relaxation. Finally, obtain integer solution according to the fractional optimal solution of LP-relaxation.

The following process contains steps of our LP-relaxation Algorithm (LPrA).

Algorithm LPrA LP-RELAXATION ALGORITHM

obtain the LP-relaxation of RAM by deleting all variable's integer constraints.
solve LP-relaxation, and get fractional optimal solution $((z_i^k)^*, (x_{ij}^{kv}(w))^*, (x_{ij}^{kv}(u))^*, (y_{lj}^{kv}(u))^*)$.
for each $(x_{ij}^{kv}(w))^*$
    if $(x_{ij}^{kv}(w))^* < 1, x_{ij}^{kv}(w) = 0$. **else**
        $x_{ij}^{kv}(w) = \lceil (x_{ij}^{kv}(w))^* \rceil$
    endif
endfor
for each $(z_i^k)^*$, $(x_{ij}^{kv}(w))^*$ and $(y_{lj}^{kv}(u))^*$
    $z_i^k = \lfloor (z_i^k)^* \rfloor$ $x_{ij}^{kv}(u) = \lfloor (x_{ij}^{kv}(w))^* \rfloor, y_{lj}^{kv}(u) = \lfloor (y_{lj}^{kv}(u))^* \rfloor$
endfor
for each $w \in W$ and each commodity k
    while $\sum_{i \in LRD} z_i^k < \sum_{j \in D} D_j^k(w)$
        choose i such that $s^k z_i^k < c_i^k, \sum_{k \in K} s^k z_i^k < c_i$
        if no such an i, algorithm stops and it means constraints are too tight. **else**
        $z_i^k \leftarrow z_i^k + \min\{\sum_{j \in D} D_j^k(w) - \sum_{i \in LRD} z_i^k, \lfloor c_i^k / s^k \rfloor - z_i^k, \lfloor (c_i - \sum_{k \in K} s^k z_i^k)/s^k \rfloor\}$
    endwhile
endfor
for each $w \in W$, each district j and each commodity k
    while $\sum_{i \in LRD} \sum_{v \in SM_{ij}^k(w)} x_{ij}^{kv}(w) < D_j^k(w)$
        choose i, v such that $x_{ij}^{kv}(w) > 0$, $z_i^k - \sum_{j \in D} \sum_{v \in SM_{ij}^k(w)} x_{ij}^{kv}(w) > 0$ and C_{ij}^{kv} is minimum
        $x_{ij}^{kv}(w) \leftarrow x_{ij}^{kv}(w) + \min\{D_j^k(w) - \sum_{i \in LRD} \sum_{v \in SM_{ij}^k(w)} x_{ij}^{kv}(w), z_i^k - \sum_{j \in D} \sum_{v \in SM_{ij}^k(w)} x_{ij}^{kv}(w)\}$
    endwhile

23. **endfor**
24. **for** each $u \in U$, each district j and each commodity k
25. **while** $\sum_{i \in LRD} \sum_{v \in SM_{ij}^k(u)} x_{ij}^{kv}(u) + \sum_{l \in NRD} \sum_{v \in SM_{lj}^k(u)} y_{lj}^{kv}(u) < D_j^k(u)$
26. choose l, v such that $y_{lj}^{kv}(u) > 0$, C_l^k is minimum and C_{lj}^{kv} is minimum
27. $y_{lj}^{kv}(u) \leftarrow y_{lj}^{kv}(u) + D_j^k(u) - (\sum_{i \in LRD} \sum_{v \in SM_{ij}^k(u)} x_{ij}^{kv}(u) + \sum_{l \in NRD} \sum_{v \in SM_{lj}^k(u)} y_{lj}^{kv}(u))$
28. **endwhile**
29. **endfor**
30. Output the integer solution $(z_i^k, x_{ij}^{kv}(w), x_{ij}^{kv}(u), y_{lj}^{kv}(u))$.

In LPrA, step 1 is to generate the LP-relaxation of RAM, and step 2 is to solve this LP-relaxation. The rounding process is from step 3 to step 29. In order to avoid small amount of variable, we round them to the closest integer below except $x_{ij}^{kv}(w)$ which we round to 0 while $x_{ij}^{kv}(w) < 1$ and round to the closest integer above while $x_{ij}^{kv}(w) \geq 1$. From step 12 to 17, we adjust z_i^k to meet all demands in scenario set W. Then, the transported amount for commodity is adjusted from step 18 to 29 to meet all demands in each district.

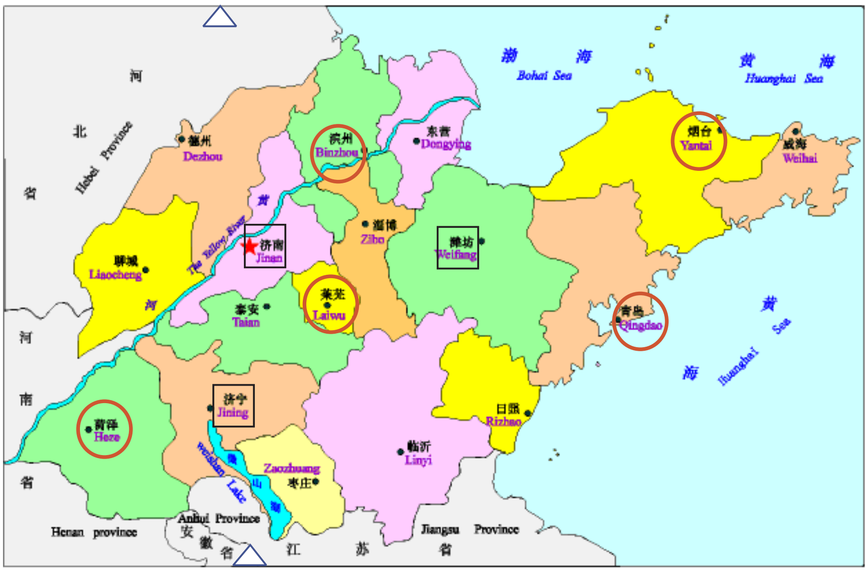

Figure 1: Map of Shandong Province, China

4 Computational Results

Shandong Province is along China's eastern coast and in the lower Yellow River area. It is also an area with many kinds of disasters in the past. The map of Shandong is shown in Figure 1. In 2007, there were 99 times earthquakes with magnitude above 2. Also local government needs to prepare for floods caused by Yellow River, and typhoons from the sea. Several districts that are easily destroyed by a disaster are shown in Figure 1. For example, Binzhou and Heze are constantly facing flood threats from Yellow River. Yantai and Qingdao are obvious under typhoons influence, while there can be earthquakes in mountain areas around Laiwu.

Table 1. Local reserve depots and districts

$LRD1$	Jining	d_1	Laiwu
$LRD2$	Jinan	d_2	Binzhou
$LRD3$	Weifang	d_3	Heze
$NRD1$	Tianjin	d_4	Yantai
$NRD2$	Hefei	d_5	Qingdao

In order to enhance the disaster relief and response capacity in dealing with earthquake, local government sets up three reserve depots $LRD = \{LRD1, LRD2, LRD3\}$ for holding three kinds of emergency commodities $K = \{rice, water, tent\}$ in Jining, Jinan and Weifang especially. The capacities of these three depots are 4000, 5000, 8000 cubic meter respectively, while the size of a bag of rice, a box of water and a tent are 0.5, 0.1, and 0.2 cubic meter.And the holding costs are 400, 50 and 2000 RMB according to current purchase prices. At the same time, there are two national reserve depots $NRD = \{NRD1, NRD2\}$ located at Tianjin and Hefei that can also provide these three kinds of commodities, and the amount of each commodity in every national reserve depot is assumed enough to satisfy the demand. The cost for taking one unit of commodity from national reserve depots are 800, 100 and 3000 RMB. $W = \{w_1, w_2, w_3\}$ is the set of slight scenarios that must be satisfied by local reserve depots, while $U = \{u_1, u_2, u_3\}$ is the set of serious scenarios above a certain degree. $D = \{d_1, d_2, d_3, d_4, d_5\}$ is the set of potential districts described in Figure 1. For each scenario, there is a vector with five elements which represent demand of the five districts, and details are given in Table 2. The weight of each scenario is given in Table 3.

Table 2. Actual demand amount

	Demand (rice(thousand bags), water(thousand boxes), tent(thousand))				
	d_1	d_2	d_3	d_4	d_5
w_1	$(3,8,4)$	$(1.5,5,2.5)$	$(1,3,1.5)$	$(0.7,2,1)$	$(0.8,1,0.6)$
w_2	$(2,4,3)$	$(3.5,9,4.5)$	$(0.8,1.5,1.5)$	$(0.7,1.5,1)$	$(1,1.5,1)$
w_3	$(1,2.8,1)$	$(1.5,4,2.2)$	$(3.5,8.5,4.5)$	$(0.9,2,1.5)$	$(0.5,1,0.7)$
u_1	$(15,40,20)$	$(7.5,25,12.5)$	$(5,15,7.5)$	$(3.5,10,5)$	$(4,5,3)$
u_2	$(10,20,15)$	$(17.5,45,22.5)$	$(4,7.5,7.5)$	$(3.5,7.5,5)$	$(5,7.5,5)$
u_3	$(5,14,5)$	$(7.5,20,11)$	$(17.5,42.5,22.5)$	$(4.5,10,7.5)$	$(2.5,5,3.5)$

Table 3. Probabilities for earthquake scenarios

	Scenario set W			Scenario set U		
	w_1	w_2	w_3	u_1	u_2	u_3
Probability	0.5	0.3	0.2	0.6	0.3	0.1

There are two kinds of transport modes, ground and railway. The costs for carrying one unit of commodity from depot to district are presented in Table 4. If the cost is infinite, it means no such a transportation mode between these two sites. And suppose these three commodities have the same transport cost per unit for simplification.

Table 4. Cost for carrying one unit of commodity from depot to district

	Cost for per unit commodity(ground, railway), RMB				
	d_1	d_2	d_3	d_4	d_5
$LRD1$	$(0.66,\infty)$	$(1.27,\infty)$	$(0.49,0.08)$	$(2.45,0.49)$	$(2.06,0.43)$
$LRD2$	$(0.53,\infty)$	$(0.52,\infty)$	$(0.91,0.22)$	$(1.87,0.39)$	$(1.47,0.29)$
$LRD3$	$(0.72,\infty)$	$(0.51,\infty)$	$(1.71,0.37)$	$(1.07,0.24)$	$(0.68,0.13)$
$NRD1$	$(1.71,\infty)$	$(1.10,\infty)$	$(1.89,0.43)$	$(2.68,0.65)$	$(2.29,0.56)$
$NRD2$	$(2.38,\infty)$	$(3.14,\infty)$	$(2.30,0.37)$	$(3.78,0.85)$	$(3.11,0.86)$

Let κ_1 be 1 and κ_2 change in an interval $[0.4860, 0.4985]$. Solving this instance with LP-rounding algorithm described in section 3, we may obtain the following results for local reserve depots in Table 5.

According to different value of κ_2, the corresponding value for LPrA, LP-relaxation programming and the gap are shown in Table 6.

From these computational results, the following observations can be made.

- The total rescue cost, which include holding cost, taking cost and transportation cost increases as parameter κ_2 increases.
- The algorithm LPrA gives better integer solutions for different weight parameters κ without causing too much cost increase. Obviously, the value for LP-relaxation programming is a lower bound for RAM. Also, if the gap is smaller, it means LPrA performs better.
- Since there are many variables in this model and the total value is a big number, the value is very sensitive for parameters κ_2.
- The gap reduces as the parameter κ_2 increases. It means better performance will be obtained if the weight parameter for taking cost from national reserve depots increases.

Examples for transportation are shown in Figure 2 and Figure 3, where $\kappa_1 = 1$ and $\kappa_2 = 0.4985$. In the figures, red circles are districts, black squares are local reserve depots, and blue triangles are national reserve depots.

According to Figure 2, when scenario w_1 occurs, local reserve depots in Jinan and Weifang provide commodities for Binzhou by trucks. And depots in Jinan, Weifang,

Table 5. Resource in each local reserve depot and size occupied

	depot	rice	water	tent	size occupied (m^3)
	$LRD1$	2000	1501	1501	1.4503×10^3
$\kappa_2 = 0.4860$	$LRD2$	3941	14495	7900	5.0000×10^3
	$LRD3$	2061	3000	1601	1.6507×10^3
	$LRD1$	2000	1501	1501	1.4503×10^3
$\kappa_2 = 0.4885$	$LRD2$	3941	14495	7900	5.0000×10^3
	$LRD3$	2060	3000	1601	1.6502×10^3
	$LRD1$	2001	3000	1501	1.6007×10^3
$\kappa_2 = 0.4910$	$LRD2$	3000	19200	7900	5.0000×10^3
	$LRD3$	3000	3001	1600	2.1201×10^3
	$LRD1$	3501	3001	1501	2.3508×10^3
$\kappa_2 = 0.4935$	$LRD2$	201	33995	7500	5.0000×10^3
	$LRD3$	4300	3001	2001	2.8503×10^3
	$LRD1$	3501	3001	2300	2.5106×10^3
$\kappa_2 = 0.4960$	$LRD2$	1	36995	6500	5.0000×10^3
	$LRD3$	4500	25017	2201	5.1919×10^3
	$LRD1$	3501	8500	2900	3.1805×10^3
$\kappa_2 = 0.4985$	$LRD2$	1	38995	5500	5.0000×10^3
	$LRD3$	4500	40000	2601	6.7702×10^3

Table 6. Comparison between LPrA and LP-relaxation

	value for LPrA	value for LP-relaxation	the gap
$\kappa_2 = 0.4860$	0.9828×10^8	0.9827×10^8	6.5048×10^3
$\kappa_2 = 0.4885$	0.9865×10^8	0.9864×10^8	6.0832×10^3
$\kappa_2 = 0.4910$	0.9902×10^8	0.9901×10^8	4.3725×10^3
$\kappa_2 = 0.4935$	0.9938×10^8	0.9938×10^8	6.5476×10^3
$\kappa_2 = 0.4960$	0.9974×10^8	0.9974×10^8	4.5414×10^3
$\kappa_2 = 0.4985$	1.0009×10^8	1.0009×10^8	4.2099×10^3

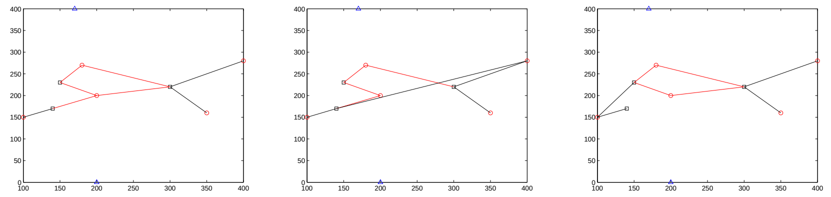

Figure 2: transportation in scenario set W, red line for ground and black line for railway

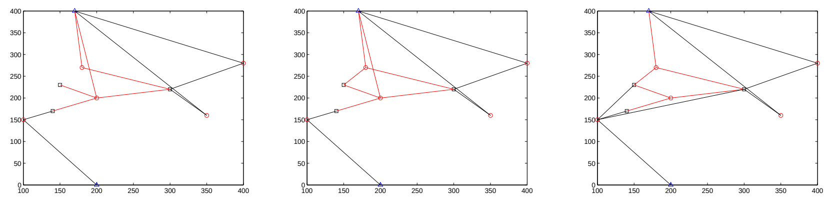

Figure 3: transportation in scenario set U, red line for ground and black line for railway

Jining transport commodities for Laiwu also by trucks. While Yantai and Qindao are served by depot in Weifang by railway, And Heze obtains commodities by depot in Jining also by railway. On the other hand, this figure suggests Jinan controls Binzhou and Laiwu, Weifang serves Binzhou, Laiwu, Yantai and Qingdao, Jining prepares for Heze and Laiwu.

5 Conclusion

In this paper, we consider the resource allocation problem in local reserve depots. A multi-commodity, multi-modal stochastic programming is presented based on scenario analysis. And we propose an approximation algorithm for this model by introducing LP-rounding technique. At the end, case study based on reserve depots' allocation problem in Shandong province, China, shows that our model and algorithm can provide the decision maker a better advice in local depot settings and transportation plans in coping with slight and serious disasters.

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