Research on Coordination and Optimization Model of Emergency Supplies for Manufacturing Accidents Based on Scenario Analysis

Tao CHEN, Tao CHEN* and Hong-yuan YUAN
Institute of Public Safety Research, Tsinghua University, Beijing 100084, China
*Corresponding author

Keywords: Manufacture accident, Emergency material reserve system, Location model, Oil tank fire.

Abstract. Enterprises should fully mobilize and utilize the resources independent of the enterprises to deal with the frequent accidents and meet the emergency supplies need. This paper analyzes the reserve coordination patterns of enterprise’s reserves combined with production capability reserves, to optimize, coordinate and meet the emergency supplies need under multisite manufacture accidents scenarios. And to reduce the enterprise's emergency reserve cost and maintain its daily emergency rescue ability. The effectiveness of the model is then verified by an example of emergency supply reserve of oil tank fire. This paper provides the necessary theoretical support for the enterprise emergency material reserve system.

Introduction

China is one of the countries with the most severe manufacturing safety accidents in the world. The accidents usually cause enormous casualty and property damage and bring companies heavy losses. In the past 10 years, there were about 700,000 various types of manufacturing accidents happening in China every year, resulting in more than 120,000 deaths and about 700,000 injuries, and about 250 billion Yuan with direct and indirect losses in total. The frequent occurrence of manufacturing accidents brings serious threats to social harmony and national security, and it is therefore necessary to conduct research on this field.

In order to better cope with the unexpected manufacturing accidents and solve the problem of emergency reserves, academics suggest that enterprises should cooperate with others regarding emergency reserves. Zheng [1] analyzes some of the major manufacturing accidents in recent years in China and points out that enterprises relying only on their entity reserves cannot meet the demand for emergency supplier under critical situations. Zheng further proposes that enterprises should make full use of the social forces and establish a reserve system of emergency supplies in combination of entity reserves and production capacity reserves. Lu [2] thinks that the socialization of emergency supplies reserves could fundamentally make up for the deficiency of enterprises’ current reserves system and be a useful addition to the existing reserve system of emergency supplies. Some scholars suggest that on the basis of the entity reserve, enterprises should cooperate with others and combine entity reserves with the production capability reserves from cooperative enterprises based on the different types of emergency supplies. From the point of laws on tackling emergency affairs and emergency supplies management, Zhang [3] points out the problems existing in the management of emergency supplies for manufacturing accidents and put forward two methods for enterprise’s joint reserve, entity reserve and production capability reserve. Whybark [4] categorizes the production capability reserves of emergency supplies as “social inventory”, considering some of the supplies are consumed heavily in the disaster relief and the storage cost is relatively high, thus large-scale entity reserves should not be carried out. Some scholars propose the use of entity reserve, urgent procurement and compulsory requisition as countermeasures of emergency supplies reserve. Liu [5] proposes to realize the openness of reserve network, build social mobilization mechanism for emergency supplies and establish collaborative approach with other enterprises regarding materials difficult to store. Pu
[6] proposes that, for emergency supplies that are difficult to be kept for a long time or in a huge demand, enterprises can sign urgent procurement contracts with relevant manufacturers to facilitate the production and transportation of materials when coming across emergencies. Li [7] suggests emergency material support is a key factor in emergency management and to compensate the consuming materials timely and effectively becomes critical in tackling emergency affairs. According to the characteristics of emergency supplies, including timeliness, supply capability, source of supply and appropriation of funds, Wang [8] put forwards the combination reserve strategy of entity reserve and production capability reserve based on the reserve strategies for different type of emergency supplies.

However, few scholars combine the reserve strategy of entity reserve and production capacity reserve into a coordinated optimization analysis of reserve site selection. By analyzing the coordination reserve strategy, this article facilitates to establish a reserve system for emergency supplies with extensive significance, which optimizing the location and distribution of entity reserves and agreement reserves and finally improving the coordination of emergency supplies.

**Architecture of Emergency Supplies Reserve System for Manufacturing Accidents**

The sudden of the emergency cause the demand for emergency supplies with uncertainties, even prodigiousness. Past records show that intuitively, supplies reserves in form of enterprises cooperation before manufacturing accident is better than supplies reserves in form of emergency procurement and production in manufacturing accident on the number of emergency demand, quality requirements and structural needs. However, emergency procurement plays a vital role in dealing with unconventional emergencies. Therefore, in order to deal with work safety accidents better, we need to combine cooperative enterprise reserve procurement with enterprise daily emergency material reserve to constitute a work safety accident emergency supplies reserve system, as shown in Figure 1.

![Emergency supplies reserve system for work safety accidents](image)

Figure 1. Emergency supplies reserve system for work safety accidents.

According to the characteristics of emergency supplies production, reserves, consumption, demand, etc. the emergency supplies reserve system for work safety accidents is discussed as below.

1. For the high timeliness requirements emergency supplies, as well as large demand but market maintenance is small and non-expendable emergency supplies, enterprises should use the way of entity reserves.
(2) For the low timeliness requirements, short supply cycle, market supply adequate emergency supplies, enterprises can use entity reserves of cooperative enterprises and sales enterprises for the main, emergency procurement and production for the supplement.

(3) For high prices, low usage frequency emergency supplies with a specific supply source, enterprise can use registration before accidents, then reserve by borrow way according to registration record.

(4) For the large demand, fast consumption, long shelf life and low socialization emergency supplies, enterprise should take the form of entity reserve as the main form of reserve strategy.

Through using different strategies for different materials, emergency supplies reserve system for work safety accidents which proposed in this paper can meet variety needs of emergency supplies for work safety accidents.

Location and Allocation of Emergency Supplies Reserve for Work Safe Accident

Pattern Analysis of Emergency Supplies Reserve for Work Safety Accident

In order to meet the needs of emergency supplies for work safety accidents, enterprises sign cooperation cooperative with other enterprises to bring enterprises into emergency supplies reserve system. The cooperative enterprises over here are emergency production enterprises, emergency supplies can be reserved in two ways under such conditions.

(1) Entity reserve: put emergency supplies into enterprise’s internal reserve place directly, including large emergency supplies reserve storage and small storage station. The entity reserve is managed by enterprise management department directly to easy to transfer. But the disadvantage is that the high cost of management, low resource rotation rate and some resources are easy to expire and waste.

The standing emergency supplies are often use entity reserve, such as fire foam, dry powder, fire sand, chemical protective clothing, etc., which is characterized by saving for long time, lower reserve costs, but the production capacity of cooperative enterprise is relatively small. So such resources require substantial entity reserves.

(2) Production capacity reserves: uses production capacity reserves with cooperative enterprise to make reserve of emergency supplies more dispersed, reduce the cost of their own material reserves, and ensure the freshness of the materials when work safety accidents occurred, saving the early reserve investment. Arrange cooperative enterprises to carry out emergency production after work safety accidents to ensure the continuous supply of emergency resources. But the urgent produce emergency supplies should put disaster relief after a period of time; it is slower to response which compared with entity reserve materials.

Production capacity reserves are often used in contingency emergency reserves, such as the fire foam used in fire accidents, which have short shelf life, high reserve costs, but the social production capacity is large.

Integrated Model of Location and Allocation of Emergency Supplies Reserve

This paper comes from storage tank fire fighting; indicate the uncertainty of work safety accidents by discrete scenarios. Analysis the location and allocation of emergency supplies socialized reserves. The model assumes that there are two types of materials, named emergency accident supplies and standing emergency supplies, we generate a large number of accident scenarios by scenario generation method, optimize the location and allocation of emergency supplies reserve through mathematical model.

Model parameters:

- $z_j$: Whether to choose j point reserve material 1
- $r_j$: Whether to choose j point reserve material 2
- $c_{avg}$: The maximum number of material reserve on j point

453
\( \text{Vol}_1 \): The unit mass of material 1

\( \text{Vol}_2 \): The unit mass of material 2

\( IG^j \): The entity reserve number of material 1 on j point.

\( IG^j \): The entity reserve number of material 2 on j point.

\( IC^j \): The production capacity reserve number of material 1 on j point.

\( IC^j \): The production capacity reserve number of material 2 on j point.

\( d_{1s}^j \): Previous demand of material 1 under scenario s

\( d_{2s}^j \): Previous demand of material 2 under scenario s

\( d_{1s}^j \): Total demand of material 1 under scenario s

\( d_{2s}^j \): Total demand of material 2 under scenario s

\( ec \): Fixed costs of establishing reserve locations on j point

\( cc \): Reserve costs per reserve unit

\[
\begin{align*}
\min & \quad \sum_{j \in P \cup Q} e g_j \cdot (Z_j + Y_j) + \sum_{j \in P \cup Q} cc \cdot (IC^j + IG^j) \\
& \text{subject to} \\
IG^j \cdot vol_1 & \leq cap_j \cdot Z_j, \quad \forall j \in P \cup Q \tag{2} \\
IC^j \cdot vol_2 & \leq cap_j \cdot Y_j, \quad \forall j \in M \tag{3} \\
\sum_{j \in P \cup Q} IG^j & \geq d_{1s}, \quad \forall s \in S \tag{4} \\
\sum_{j \in P \cup Q} IG^j & \geq d_{2s}, \quad \forall s \in S \tag{5} \\
\sum_{j \in P \cup Q} (IG^j + IC^j) & \geq d_{1s}, \quad \forall s \in S \tag{6} \\
\sum_{j \in P \cup Q} (IG^j + IC^j) & \geq d_{2s}, \quad \forall s \in S \tag{7} \\
Z_j & \in \{0, 1\}, \quad \forall j \in P \cup Q \tag{8} \\
Y_j & \in \{0, 1\}, \quad \forall j \in P \cup Q \tag{9} \\
IG^j & \geq 0, \quad \forall j \in P \cup Q \tag{10} \\
IC^j & \geq 0, \quad \forall j \in P \cup Q \tag{11}
\end{align*}
\]

Formula 1 is objective function, the optimize target is total costs of material reserve minimum, where the costs include site construction fixed costs and reserve costs; Formula 2 and 3 are the limits of reserve capacity; Formula 4 and 5 are the limits of previous demand of emergency supplies after disaster, that means the entity reserves at least to meet the demand before new materials are arrival to ensure the sustainable of the rescue process; Formula 8 and 9 are the variable constraint of formula 0 to 1; Formula 10 and 11 are nonnegative restriction.

**Case Study**

This paper uses an emergency supplies reserve for fire accidents of large enterprise as the background design examples. Assuming there are three crude oil tanks sites in region A, B and C, respectively a 10,000 m³ tank, a 100,000 m³ tank and ten 100,000 m³ tanks. Oil tanks are prone to fire in work safety accidents, need to reserve fire water and fire foam. We generate ten work safety accident scenarios and establish scenarios library according to this situation. Some of the scene information is shown in Table 1.
Table 1. Some scenario information in scene library.

<table>
<thead>
<tr>
<th>Scene number</th>
<th>location</th>
<th>Number of fire storage tanks</th>
<th>The probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

There are three cooperative enterprises in this region, three internal entity reserve places. The relevant cost information is shown in Table 2.

Table 2. Reserve costs information.

<table>
<thead>
<tr>
<th>Entity reserve place</th>
<th>Production capacity reserve cooperative enterprise</th>
</tr>
</thead>
<tbody>
<tr>
<td>number</td>
<td>Construction cost(Yuan) Reserve cost(thousand Yuan/t)</td>
</tr>
<tr>
<td>number</td>
<td>Cooperative fixed cost Production capacity reserve cost(thousand Yuan/t)</td>
</tr>
<tr>
<td>number</td>
<td>Material1 Material2 Material1 Material2 Material1 Material2</td>
</tr>
<tr>
<td>number</td>
<td>Material1 Material2</td>
</tr>
<tr>
<td>1</td>
<td>20000</td>
</tr>
<tr>
<td>2</td>
<td>30000</td>
</tr>
<tr>
<td>3</td>
<td>45000</td>
</tr>
</tbody>
</table>

The demand for the two materials at each point is estimated in Table 3.

Table 3. Calculation table of reserve demand for tank fire.

<table>
<thead>
<tr>
<th>Tank capacity</th>
<th>diameter(m)</th>
<th>Upper surface(m$^2$)</th>
<th>Foam application density L/min/m$^2$</th>
<th>Foam mixture flow (L/s)</th>
<th>Total demand for fire water(t)</th>
<th>60% Redundant demand for fire water(t)</th>
<th>6% Foam liquid demand(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1million m$^3$ tank</td>
<td>30</td>
<td>707</td>
<td>6.5</td>
<td>77</td>
<td>299</td>
<td>478</td>
<td>28.7</td>
</tr>
<tr>
<td>10 million m$^3$ tank</td>
<td>80</td>
<td>5026</td>
<td>9</td>
<td>754</td>
<td>2941</td>
<td>4706</td>
<td>282.3</td>
</tr>
</tbody>
</table>

The Lingo software is used to solve the location and allocation optimization model of the emergency material socialization reserve. The final material reserve location and allocation scheme are shown in Table 4. The minimum storage cost is 1,168,400 Yuan. The results demonstrate the validity of the model and the reliability of the safety optimization system.

Table 4. Layout program of fire emergency supplies.

<table>
<thead>
<tr>
<th>Place number</th>
<th>storage quantity of fire water(t)</th>
<th>storage quantity of foam liquid(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entity reserve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2465</td>
<td>234</td>
</tr>
<tr>
<td>2</td>
<td>3124</td>
<td>317</td>
</tr>
<tr>
<td>3</td>
<td>4130</td>
<td>189</td>
</tr>
<tr>
<td>Cooperative reserve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1567</td>
<td>245</td>
</tr>
<tr>
<td>2</td>
<td>1389</td>
<td>196</td>
</tr>
<tr>
<td>3</td>
<td>2548</td>
<td>278</td>
</tr>
</tbody>
</table>
Conclusion
This paper synthesizes emergency reserve ways for work safety accidents of existing researches, constructs emergency supplies reserve system for work safety accidents. On this basis, studies the location and allocation optimization issues of entity reserve and production capacity reserve between enterprises and cooperative enterprises. Through analysis the characteristics of the two reserve ways, establishes the mathematical model. Finally, takes the fire in work safety accidents as an example, establishes a scenario library for case analyze and proposes a necessary theory support for emergency supplies reserve system.

In the optimization of enterprise emergency supplies reserve system, many problems need to in-depth study. Such as incorporate social donation into the optimization issues of emergency supplies reserve for work safety accidents, and refine the scenario database under different types of accidents, continue completes the system to provide direct recommendations for management of enterprises to develop relevant policies.

Acknowledgement
This work was partially supported by the National Natural Science Foundation of China (71373139,71673163), the 12th Five-Year Technology Support Program.

References