The Research about Emergency Logistics Capacity Bottleneck Based on Emergency Logistics Network

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Abstract. This paper focuses on improving the overall capacity of the physical elements of the emergency logistics network. On the basis of emergency logistics network, this paper quantifies the logistics ability of emergency materials passing through each node and line in the network, and introduces the constraint theory to find out the bottleneck link of emergency logistics network, then improve the bottleneck link pertinently and improve the ability of the whole emergency logistics network. Finally, a concrete example is given to verify the method. It will help to better solve the logistics problems in emergencies such as disasters.

Introduction

In recent years, various natural disasters have brought great losses to Chinese national economy. The Wenchuan earthquake reflected some deficiencies in the emergency system of our country, and the ability of emergency logistics is not satisfactory[1]. Therefore, the research on emergency logistics capacity is a very urgent task for us currently. The logistics capacity, as a new conception in China, has been recognized and valued since the beginning of the study in 2004[2].

At present, domestic and foreign academicians have done a lot of research on emergency logistics capacity. Wang Fengzhong et al (2011) used grey analytic hierarchy process to evaluate the ability of emergency logistics support[3]. Zhou Yao (2009) studied the evaluation system of emergency logistics[4]. Linetzdamar et al (2004) studied emergency logistics plan in natural disasters[5]. Liu Xiaoqun et al (2007) analyzed the connotation of emergency logistics capacity and constructed the emergency logistics system[6]. However, most scholars’ research on emergency logistics capacity focused on its theoretical framework, elements composition, evaluation system and so on. But the quantitative research on emergency logistics capacity and the bottleneck of emergency logistics capacity are few.

As for emergency logistics capacity, Professor Donnard Ballsox of Michigan State University in the United States put forward the definition of logistics capacity in terms of cost reduction[7]. Wang Ming and Feng Hao put forward the concept of logistics capacity from the angle of operation process[8]. Tan Qingmei defined logistics capacity dishes from the perspective of logistics services[9]. MaShihua (2005) divided the logistics capacity into two parts: tangible elements and intangible elements[10]. The narrow sense of emergency logistics capacity refers to the ability of the whole emergency logistics system to control and reduce the impact of disasters in the disaster relief process. In this paper, the narrow sense of emergency logistics capacity is studied.

TOC is a management theory and decision method proposed by Israeli scientist Goldratt on the basis of OPT. The main idea is to find out the bottleneck that restricts the development of the whole system, and apply the limited resources to the improvement of the bottleneck, so as to maximize the overall efficiency of the system[11].

Emergency Logistics Network

After a disaster occurs, the emergency plan is started, an emergency command center is set up, emergency supplies are stored from various channels leasing and compulsory requisition are raised at various emergency material collection points, transported to various emergency material transfer
centers, and then transported through transport networks to the disaster areas where emergency supplies are needed, and finally distributed to the people in the disaster areas. The whole process formed an emergency logistics network as shown in the Fig.1.

**Emergency Logistics Capacity Model Based on Emergency Logistics Network**

**Basic Assumptions and Symbols**

**Hypothetic Condition.** The model we built was based on the following assumptions: (1) It is assumed that the handling efficiency of each rescue worker is the same and that of each machinery and equipment is the same, (2) the logistics operation of the emergency material preparation point only considers the two links of goods preparation and loading; (3) The materials in short supply will be transferred directly, only three operation links of unloading, sorting and loading will be considered; (4) the point of demand for emergency materials, that is, only two links of unloading and distributing in the logistics industry of disaster areas; (5) under normal conditions, the maximum transit capacity for each transport route is $Q_{\text{max}}$. After the disaster, different roads appear certain damage, its traffic rate is 0.

**Symbol Definition.**

(1) $R_i$ $(1 \leq i \leq \alpha)$: The i emergency material collection points; $T_{f}$ $(1 \leq f \leq \beta)$: The f emergency material transfer centers; $L_{R\rightarrow f}$: Transport routes from the first emergency material collection point to the f emergency transit center; $\lambda$: The proportion of emergency materials transported in each transportation route; (2) $Q_i$ $(1 \leq i \leq \alpha)$: The logistics capacity of the i emergency material collection point; $Q_{f}$ $(1 \leq f \leq \beta)$: Logistics capacity of the f emergency transit center; $Q_{LQ}$: The logistics ability of each transportation route in the actual distribution of emergency materials; $Q_{\text{c}}$ : A transport route from the first emergency material collection point to the f emergency material transfer center during actual transportation; $Q_{\text{c}}$: Number of unmet needs; $Q_{\text{c}}$ : Number of emergency supplies to be adjusted on various transport routes $L$; (3) $Q_{\text{Loading}}$ $(1 \leq i \leq \alpha)$: Logistics capacity in the preparation link of the i emergency material collection point;

**Calculation of Logistics Capacity of Node and Line**

**Logistics Capacity of Emergency Material Raising Point.** The logistics capacity of the i emergency material collection point is $Q_{\text{Loading}}$ as the loading link will have the participation of machinery, equipment and rescue personnel, then the logistics capacity calculation index of the loading link is $m$: Number of rescuers; $v$ Unit emergency supplies/h: Rescuers‘ working efficiency; $n$: Number of machinery equipment; $k$: Unit emergency supplies/h: Working efficiency of machinery equipment; Then

$$Q_{\text{Loading}} = (m_i^{\text{Loading}} \times v_i^{\text{Loading}} \times n_i^{\text{Loading}} \times k \times v^{\text{Loading}}) \quad \text{(unit emergency supplies/h)} \quad (1)$$

(p.s. $m_i^{\text{Loading}} (1 \leq i \leq \alpha)$ represents number of rescuers of the i emergency material collection point, n and v, too)

Select the minimum value in the preparation and loading link as the logistics capacity of the emergency supply point: that is
Emergency Material Transfer Center Logistics Capacity. The logistics capacity of the high priority emergency material flow process is as follows:

\[ Q_i = \min \{ Q_{\text{Discharge}}^i, Q_{\text{Loading}}^i \} \quad (l \leq i \leq \alpha) \]  

(2)

\[ Q_{\text{Discharge}}^i = \left( m_{\text{Discharge}}^i \times v_{\text{Discharge}}^i \times n_{\text{Discharge}}^i \times k \times v_{\text{Discharge}}^i \right) \quad \text{(unit emergency supplies/h)} \]  

(3)

\[ Q_{\text{Loading}}^i = \left( m_{\text{Loading}}^i \times v_{\text{Loading}}^i \times n_{\text{Loading}}^i \times k \times v_{\text{Loading}}^i \right) \quad \text{(unit emergency supplies/h)} \]  

(4)

\[ Q_{T_i} = \min \{ Q_{\text{Discharge}}^i, Q_{\text{Loading}}^i \} \]  

(5)

Calculation of Logistics Capacity of Each Transport Route. In the event of an emergency, the road may be damaged and lead to a decline in the capacity of the road. Assuming that the road traffic rate after the disaster is 0, the maximum capacity of the road after an emergency is

\[ Q_{\text{max}} \times \theta \]  

(6)

In the actual distribution of emergency materials, the logistics capacity on the transportation route is determined by the length of the line L, the vehicle speed V, the number of vehicles on the road M, the quantity of each vehicle transported N, and the utilization rate of the vehicle. The logistics capacity of each transport route is:

\[ Q_i = \frac{M \times N \times V \times E}{L} \]  

(7)

Calculation of Logistics Capacity of the Whole Emergency Network

We select two typical processes in the emergency logistics network to calculate the logistics capability of the whole emergency logistics network.

Logistics Capability of Each Route from a Node to a Transportation Route. The first emergency material collection point distributes the emergency material according to a certain proportion \( \lambda_{[\beta \in \mathbb{K}]} \) to \( n(\alpha \leq \beta) \) emergency material transportation route, through the n transportation route to different emergency material transfer center. Then the first emergency material raising point \( R_i \) is assigned to the transportation route \( T_{L_i} \), the emergency material is \( Q_{L_i} \times \lambda_{T_i} \). Then the quantity of material that can be transported to the f emergency material transfer center via the transportation route \( T_{L_i} \), that is, the input of the emergency material transfer center \( T_f \) is

\[ \min \{ Q_{L_i} \times \lambda_{T_i}, Q_{L_i} \} \]  

(8)

Figure 3. Distribution of emergency supplies to emergency material collection points.

Figure 4. Multiple transport routes converge various transport routes by emergency transit centers.

The Logistics Capacity of a Node in the Process of Transportation of Emergency Supplies to a Node via Various Transport Routes. The emergency materials of each emergency material collection point are transported to the emergency material transfer center \( T_f \) by different transportation routes. In this process, the logistics capacity of the emergency material transfer center
In this case, the bottleneck of the transportation route can be improved.

\[
T_i \text{ can be exported as follows} \\
\min \left\{ \sum_{i=1}^{n} \min \left\{ Q_{t_i} \times \lambda_{s_i, o_i}, Q_{o_i} \right\} \right\} 
\]

Similarly, it is possible to calculate the amount of output that passes through various transport routes to the emergency material transfer center \( T_f \) or the emergency material demand point \( b_i \).

**Construction of Demand Function for Emergency Materials Demand Point**

In the emergency rescue process, suppose that the number of victims is distributed from Poisson at a certain time: if \( N(t) \) is the number of emergency supplies at point \( D_i \) at time \( t \), and \( p_r(N(t)=m) \) is the probability that the number of victims at the point of need at \( t \) is \( m \), then there is \( p_r(N(t)=m) = (\lambda t)^m e^{-\lambda t} / m! \). Let \( \bar{q} \) denote the per capita demand for emergency supplies, and \( q_i \) denote the demand for emergency materials per unit time at the point of emergency material demand. The total demand function for emergency materials can be constructed at the point \( b_i \) at \( t \) time, namely:

\[
q_i = \bar{q} \times p_r(N(t)=m) \cdot m / t \]

### Identification and Improvement of Bottleneck in Emergency Logistics Network

#### Identification of Bottleneck in Emergency Logistics Network

**The Bottleneck Problem of Judging the Demand Point \( D_i \) of Emergency Materials.**

Compare the output of emergency material demand point \( D_i \) with its demand \( q_i \).

1. If the output is \( \min \left\{ \sum_{j=1}^{n} \left[ Q_{t_j} \times \lambda_{s_j, o_j} \right], Q_{o_j} \right\} \geq q_i \), then the emergency material demand point \( D_i \) is not the bottleneck. The whole system doesn’t need to make any improvements to meet the needs; 2. If \( \min \left\{ \sum_{j=1}^{n} \left[ Q_{t_j} \times \lambda_{s_j, o_j} \right], Q_{o_j} \right\} < q_i \), then there is bottleneck in emergency material demand point \( D_i \). We need to discuss it further.

Compare the input quantity of each emergency material transportation route to a certain emergency material demand point \( D_i \) and the logistics capacity of emergency material demand point \( D_i \) itself \( Q_{o_i} \). 1. If \( \sum_{j=1}^{p} \min \left\{ Q_{t_j} \times \lambda_{s_j, o_j} \right\} \geq Q_{o_i} \), then the logistics ability of emergency material demand point \( b_i \) is the bottleneck, and the logistics ability corresponding to emergency material demand point \( D_i \) should be improved; 2. If \( \sum_{j=1}^{p} \min \left\{ Q_{t_j} \times \lambda_{s_j, o_j} \right\} < Q_{o_i} \), then the emergency demand point \( D_i \) in front of the transport routes there are bottlenecks.

**The Bottleneck in Judging the Transportation Routes in Front of Point \( D_i \) of Urgent Material Demand.** In order to determine whether the bottleneck of each transportation route can be improved, we compare the maximum throughput of each transportation route which is gathered to the urgent material demand point \( b_i \) with the logistics capacity \( Q_{o_i} \) of the emergency material demand point \( D_i \).

1. If \( \sum_{j=1}^{p} Q_{t_j} \times \theta_j < Q_{o_i} \), the sum of goods transported at full load of each transportation route can’t reach the demand of emergency material demand point. At this point in order to meet the needs, can only find another path. 2. If \( \sum_{j=1}^{p} Q_{t_j} \times \theta_j \geq Q_{o_i} \), In this case, the bottleneck of the transportation route can be improved.

Next, we need to compare the actual traffic volume \( Q_{t_j, o_j} \) on each transport route with its actual
maximum throughput $Q_{\text{max}} \times \theta_j$, and determine which route does not reach the maximum transport volume, that is, there is room for adjustment.

1. If $Q_i \cdot \theta_j = Q_{\text{max}} \times \theta_j$, this route has reached the maximum load, no adjustment. Only by adjusting the logistics capacity on other transport routes; 2. If $Q_i \cdot \theta_j < Q_{\text{max}} \times \theta_j$, there is room for adjustment of the transportation route.

First of all, we need to find out the amount of material $Q_j$ that has not been met. That is,

$$Q_j = Q_i \cdot \sum_{j} \min \{ Q_j \cdot \lambda_j - Q_i \cdot \theta_j \} \quad (11)$$

Then calculates the difference between the actual maximum throughput and the actual transport volume of each transport route which does not reach the maximum load, i.e. $Q_{\text{max}} \times \theta_j - Q_i \cdot \theta_j$. From the emergency material transfer center $T_j$, the total quantity of emergency supplies to be adjusted for all transportation routes is

$$\sum_{j} Q_{\text{max}} \times \theta_j - Q_i \cdot \theta_j \quad (12)$$

To determine whether the output of Emergency material transfer Centre $T_j$ can meet all shipments from it $Q_i \cdot \theta_j$. (1) If the export quantity of $T_j$ of the emergency material transfer center is $\min \{ \sum Q_j \cdot \lambda_j - Q_i \cdot \theta_j \} > \sum Q_j \cdot \lambda_j - \sum Q_j \cdot \theta_j$, there is no bottleneck in $T_j$ of the emergency material transfer center, so it is only necessary to adjust the distribution of each transportation route. Number of emergency supplies to be adjusted on each transport route $L_{\text{max}} \cdot \theta_j$, $Q_i \cdot \theta_j$ is $Q_i \cdot (Q_{\text{max}} \times \theta_j - Q_i \cdot \theta_j) / \sum Q_{\text{max}} \times \theta_j - Q_i \cdot \theta_j$; (2) If $\min \{ \sum Q_j \cdot \lambda_j - Q_i \cdot \theta_j \} < \sum Q_j \cdot \lambda_j - \sum Q_j \cdot \theta_j$, then the emergency material transfer center $T_j$ can’t meet the emergency needs, and there are bottleneck links.

In this case, the bottleneck judgment and perfection of one node can use the circumstance in 4.1.1 (2) to find the bottleneck of the remaining network. Then to find out the bottleneck of the whole network.

**Improvement of Bottleneck**

**Improvement of Situation 1. in 4.1.1.** There is a bottleneck inside one node in the network, which can’t deal with the emergency materials input from each line. Therefore, the nodes in the emergency logistics network need to increase their own logistics capacity, which can be improved by increasing the number of staff members and the number of hardware facilities such as machinery and equipment in the emergency logistics network.

**Improvement of Situation (1) in 4.1.2.** All transportation routes have reached the maximum load. It is not our best choice to improve the transportation efficiency of emergency materials through road repair in a short time. Therefore, we can consider the use of aircraft for cargo transport

**Improvement of Situation (1) in 4.1.3.** Each transport route is a bottleneck but does not reach the maximum load. We can increase the proportion of goods allocated to these routes by the previous node $\lambda_j$, and increase the number and speed of transport vehicles on the transportation routes.

**Overall Improvement of the Entire Emergency Logistics Network.** After finding the bottleneck link, take the bottleneck link as the key point of the whole network, take all kinds of safeguard measures to ensure the smooth progress of the bottleneck link. Second, we also need to improve the emergency logistics network intangibles ability.

**Examples Analysis**

On February 25, 2010, Lufeng County, Chuxiong Yi Autonomous Prefecture, Yunnan Province, and M 5.1 earthquake occurred at the junction of Yuanmou County, Yunnan Province, causing 17
villages and towns in 4 counties in Chuxiong Prefecture, Lufeng, Wuding and Mudung to varying degrees of disaster. So we select the same type of vehicle from 4 emergency material raising points, through 3 emergency material demand points to provide relief materials delivery services to the 4 disaster-stricken counties. It is assumed that the number of people affected by the earthquake per hour in each county is 100 people 120 people 110 people 55 people and the average demand for emergency supplies is \( q = 8 \) unit material per county 4 hours after the earthquake. The maximum throughput for each line is 500 units of emergency supplies per hour in the case of final damage. Other informations are shown in Fig.5.

![Figure 5. A diagram of emergency material delivery in an example.](image)

From Fig.5, we know that emergency materials are transported from raising point \( R \) to \( T \), chaff transfer center \( T \), respectively, from point \( R \) to line \( L_{R \cdot T} \) and \( L_{R \cdot T} \); transfer center \( T \) sends emergency materials from route \( L_{T \cdot D} \) and \( L_{T \cdot D} \) to demand point \( D \) and demand point \( D \); The same route of delivery of emergency supplies at other nodes and routes is shown in the figure.

\[
(1) \quad Q_{T \cdot D} - Q_{T \cdot D} = 300 + 400 < 800
\]

\[
Q_{T \cdot D} \times 0.9 + Q_{T \cdot D} \times 0.8 = 500 \times 0.9 + 500 \times 0.8 = 850 > 800
\]

At this time, there is a bottleneck on line \( L_{T \cdot D} \) and \( L_{T \cdot D} \). And in this figure, at this time, there is a bottleneck on line \( L_{T \cdot D} \) and \( L_{T \cdot D} \). And in this county, when the line reaches the maximum load, it cannot meet the demand of demand point \( D \). At this time, stop looking for bottleneck, and need to use other transportation methods such as air transportation to assist the transportation of goods to meet the demand point \( D \). Since the logistics capacity on line \( L_{T \cdot D} \) has changed from 300 to 400, the logistics capacity on line \( L_{T \cdot D} \) has not changed, 300+400=700>600, exceeding the maximum logistics capacity of transfer center \( T \). At this time, the transfer center \( T \) becomes the bottleneck, we can increase the logistics capacity by increasing the staff of emergency material transfer center and hardware facilities such as machinery and equipment. Make it increase the logistics capacity to be at least 700-600=100 unit per hour; (2) For the third demand point \( D \), the quantity of material delivered to the line \( L_{T \cdot D} \) does not meet its demand, that is, 300<440, then line \( L_{T \cdot D} \) is the bottleneck. Because of \( Q_{T \cdot D} \times 0.9 = 500 \times 0.9 = 450 > 440 \), the logistics capacity of line \( L_{T \cdot D} \) can be adjusted to meet the demand point. The regulating amount is 440-300=140. After adjustment, \( Q_{T \cdot D} + Q_{T \cdot D} = 450 + 440 = 890 < 1000 \), that is, transit center \( T \), is not the bottleneck, its logistics ability can meet the demand. At this point, the lines \( L_{R \cdot T} \) and \( L_{R \cdot T} \) are new bottlenecks and continue to regulate them. The amount of regulation on line \( L_{R \cdot T} \) is:

\[
\frac{[450 + 440] - 350}{450 - 350} = \frac{890}{10} = 89 = \frac{20}{15} = \frac{0}{10} = \frac{1}{10}
\]

The amount of regulation on line \( L_{R \cdot T} \) is:

\[
\frac{[450 + 440] - 350}{450 - 350} = \frac{890}{10} = 89 = \frac{20}{15} = \frac{1}{10}
\]
Conclusion
In this paper, TOC is applied to the research of emergency material flow capacity, and the bottleneck in emergency logistics network is found through quantitative analysis of emergency material flow capacity. At the same time, the whole ability of the whole emergency logistics network is proposed for the bottleneck link. Finally, a concrete example is given to study the method proposed. The ability of only the tangible elements in this paper is discussed. Further research can be carried out on the intangible elements of emergency material flow capacity in the future.

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Reference