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Research on the mechanism of reserve logistics transportation in emergency logistics center from the perspective of supply chain

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Abstract. The construction of emergency logistics center under the background of military-civil integration has important realistic function for establishing military-logistics integration system of military-civilian integration and military-land strategic delivery force system. From the perspective of military supply chain, this paper focuses on the key issue of establishing an efficient contract mechanism for the emergency logistics centers, also analyzes the income level of the military and economy before and after the implementation of the mode of storage and transportation of military materials by game theory. It is the material reserves model to improve the benefits of an effective contract allocation and coordination, and finally the paper uses the data to verify and discuss the result.

Key words. Military supplies, military supply chain, emergency logistics, pre-storage transport, contract mechanism..

1. Introduction

Under the new situation of innovation and development, military and civilian integration of emergency delivery security base is our army's a new type of logistics support force with the support of air transport, protection of the emergency supplies transport and the support local emergency rescue and other functions. In the military and civilian combination of military logistics system and the integration of military and strategic delivery force system, it has an important supporting role for current innovation and the use of substantive military transport security forces to explore the useful practice.

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2. Problem raised

Both sides of emergency logistics center should establish an efficient cooperation mechanism. The command and coordination mechanism based on strategic cooperation takes "military and strategic cooperation agreement" as the core, and also bases on common national defensive strategic objectives by which the cooperative mechanism can carry on military-led, military and local parties in close cooperation. In this operating mechanism, in order to complete the state of emergency response to emergency delivery security tasks, and also to achieve efficient operation which is the integration of military and civilian emergency delivery security base, the military authorities will take as a leading force which will command and coordination the resources initiatively.

If the military and material suppliers will establish an effective operational mechanism which is based on the assumption that actual material consumption of the military needs is determined by its storage level, it will not only can effectively enhance the coordination between the military and suppliers, but also greatly reduce the entire military supply chain storage costs and also enhance the security benefits of military supplies.

3. Literature Review

Foreign (take US military as the representative) military supplies emergency security strategy emphasized on the timely and appropriate, sensitive, appropriate and accurate implementation of emergency supplies [1]. The US military believes that material security can promote the development of military strategy [2], [3]. Its principles are applicable to military operations and materials supplement [4].

The domestic study on the mechanism of stockpiling and storage of military materials is relatively late. The time of military logistics thought is not long, and the control method of stocking and transportation of military materials is relatively backward. Huang Dingzheng [5], according to the relationship between military and materials suppliers, the degree of participation and the use of time, think that military and civilian integration of emergency delivery security base has three different forms of the operating mechanism, which are command and coordination mechanism based on strategic cooperation, control mechanism based on government guidance and win-win cooperation mechanism based on mutual benefit. Chen Xiangjun [6] analyzes the mechanism and planning of the integration of military and civilian development. Li Xin [7], based on the dynamic line SLP method, has completed prefabricated storage and transportation system which is on the basis of analyzing the pre-storage and transportation process. Wang Min [8] has established a quantitative decision model of military material reserves based on uncertainty optimization, and also the model's verification is carried out. The results show that this model has good feasibility and also provide a reference value for the reserve pre-storage decision-making of emergency delivery security base. Li Xin [9], based on the analysis of the demand of diversified military action emergency materials, has reseached that the pre-storage items of the base reserve were selected and the fuzzy comprehensive evaluation model was established to calculate the pre-storage demand.

In summary, both foreign and domestic, the study on the strategy of pre-storage and transportation of emergency military materials is not deep enough. In particular, the military authorities have no scientific basis for strategy formulation and path selection in the game process with military material suppliers. In order to improve the security capability of military logistics in the emergency logistics center under the background of military and civilian integration and also effectively balance the military and economic benefits between the military and the economy, it is urgent to establish a scientific theory system of pre-storage and transportation strategy of emergency military materials.

4. Scenario assumptions and symbols

This paper considers the actual demand of the troops in the supply chain of military materials, and assumes that the demand of military materials is uniform but exists possible shortage, and also considers a existence of return contract based on the supplier's pre-storaging and transshipment model which is developed to coordinate the benefits of the military material supply chain.

The article will be a single-cycle military supply chain model to study, which consists military supplies suppliers, a military material procurement departments and military forces. For the sake of convenience, the assumptions of military supply chain are as follows:

1. Assume military supplies as random demand x, which is subject to uniform distribution, that is $D \sim (0, d)$. The distribution function is a continuous function $F(x)$. Demand density function is $f(x)$. And also $F(x)$ is derivative and increment function, which is subject to $x \geq 0$, $f(x) \geq 0$, $\overline{F}(x) = 1 - F(x)$, $u = E(d)$.

2. For the same military supplies, the unit of production costs are the same.

3. Military material suppliers, within a certain geographical range of the country, are built emergency support network, and military materials can be directly to the adjacent military forces, and its transportation costs are negligible.

The parameters involved in the model are defined as follows: q is the military order for certain military supplies; c is the unit production cost of military supplies; w is the wholesale price of military supplies; p is the military unit gain from the consumption of military supplies; h_{s} is the unit holding cost of the supplier; h_{a} is the unit holding costs of the military; l is the out-of-stock cost of military supplies; v is the residual value of the unused military material, and also it can be assumed that $p > w > c > v$.

From a large number of relevant literatures and its assumptions, we can see that the stochastic demand of military contingent forces is subject to uniform distribution, so we can get:

$$S\left(q\right)=q-\frac{q^{2}}{2d},\ I\left(q\right)=\frac{q^{2}}{2d},\ L\left(q\right)=\frac{d}{2}-q+\frac{q^{2}}{2d} \tag{1}$$

5. Analysis of the profit before and after the supplier's storage and transportation mode

5.1. Profit analysis before implementation of pre-storage transportation mode

Taking into account the above costs, the military and material suppliers expected returns π_{a1} and π_{s1} is available that

$$\pi_{\mathrm{a1}}=pS\left(q\right)-wq-h_{\mathrm{a}}I\left(q\right)-lL\left(q\right)+vI\left(q\right)\ , \tag{2}$$

$$\pi_{\mathrm{s1}}=\left(w-c\right)q\,. \tag{3}$$

First of all, we assume that the material supplier is dominant and the military is the dependent. Therefore, the process of military supply chain's game can be described as: First, the supplier, as the dominant, will propose a wholesale price; and then the military will decide material quantity based on the wholesale price given by the supplier, so as to maximize their own revenue; Finally, after speculateing military's making decision, the supplier will determine its optimal wholesale price.

According to the reverse solution, firstly, material amount should be determined so as to maximum profit. Put function (1) into the military income function, it can be obtained that

$$\pi_{\mathrm{a1}}=\left(p+l-w\right)q-\left(p+l+h_{\mathrm{a}}-v\right)\frac{q^{2}}{2d}-ul\,. \tag{4}$$

The second partial derivative of the income function is obtained that $\frac{\partial^2\pi_{\mathrm{a}}}{\partial q^2}=-\frac{p+l+h_{\mathrm{a}}-v}{d}$. Since l, h_{a}, d are greater than zero, and also $p>v$, so we can reach to the conclusion that $\frac{\partial^2\pi_{\mathrm{a1}}}{\partial q^2}=-\frac{p+l+h_{\mathrm{a}}-v}{d}<0$. Therefore, the military income function is concave, there exists the optimal amount of orders as to the best military returns.

Let $\frac{\partial\pi_{\mathrm{a1}}}{\partial q}=0$, we can get

$$q_{\mathrm{a}}^{*}=\frac{\left(p+l-w\right)}{p+l+h_{\mathrm{a}}-v}d\,. \tag{5}$$

From the formula (5), it can be seen that the military order amount is proportional to unit holding cost of the military.

Substituting q_{a}^* into the supplier's revenue function (3), it can be yield that

$$\pi_{\mathrm{s1}} = (w - c)\, q_{\mathrm{a}}^* = (w - c) \left(\frac{p + l - w}{p + l + h_{\mathrm{a}} - v} \right) d\,. \tag{6}$$

After the military determines the quantity of materials q, the local supplier will determine its wholesale price of the materials w to maximize its returns.

(6) The second partial derivative of the wholesale price is obtained that $\frac{\partial^2 \pi_{\mathrm{s1}}}{\partial w^2} = -\frac{2d}{p+l+h_{\mathrm{a}}-v} < 0$. There exists the optimal wholesale price w to maximize the supplier's profit.

Let $\frac{\partial \pi_{\mathrm{s1}}}{\partial w} = 0$, we can get

$$w_{\mathrm{a}}^* = \frac{1}{2}\left(p + l + c\right)\,. \tag{7}$$

After substituting Eq. (7) into Eq. (5), it will be given that

$$q_{\mathrm{a}}^* = \frac{1}{2} \frac{(p + l - c)}{p + l + h_{\mathrm{a}} - v} d\,. \tag{8}$$

After considering the wholesale price provided by the supplier, military will determine an optimal stock of materials q_{a}^* to achieve its maximum return. Substitute the equilibrium solution q, w of the equations (5), (7) into equations (3), (4), the optimal income $\pi_{\mathrm{a1}}\left(q_{\mathrm{a}}^*\right)$ and $\pi_{\mathrm{s1}}\left(q_{\mathrm{a}}^*\right)$ of the military and the supplier can be obtained that

$$\pi_{\mathrm{a1}}\left(q_{\mathrm{a}}^*\right) = \frac{d\left(p + l - c\right)^2}{8\left(p + l + h_{\mathrm{a}} - v\right)} - ul\,, \tag{9}$$

$$\pi_{\mathrm{s1}}\left(q_{\mathrm{a}}^*\right) = \frac{d\left(p + l - c\right)^2}{4\left(p + l + h_{\mathrm{a}} - v\right)}\,. \tag{10}$$

5.2. Profit analysis after implementation of pre-storage transportation mode

After implementation of emergency logistics center pre-storage transpotation mechanism, the military will transfer the material storage decision-making power to the supplier, no longer needs to personally inventory managment, but the supplier supply directly to military force. At the same time, suppliers need to predict the actual needs of the troops, decide the military supplies and bear the corresponding shortage of material and management costs which is determined by military supplies procurement departments provided by the needs of military troops and inventory information.

According to the above assumptions, the expectation of the military material suppliers and the military income π_{s2} and π_{a2} under the pre-storage transpotation mode can be expressed as

$$\pi_{s2} = wS(q) - h_s I(q) + vI(q) - lL(q) - cq = (w + l - c)\,q - (w + l + h_s - v)\,\frac{q^2}{2d} - ul\,, \tag{11}$$

$$\pi_{a2} = (p - w)\,S(q) = (p - w)\left(q - \int_0^q F(x)\,dx\right) = (p - w)\left(q - \frac{q^2}{2d}\right). \tag{12}$$

The derivative of the supplier yield function for the stock of material q is $\frac{\partial^2 \pi_{s2}}{\partial q^2} = -\frac{w+l+h_s-v}{d}$. Since w, l, h_s, v is greater than zero, so the second order derivative is satisfied by $\frac{\partial^2 \pi_{s2}}{\partial q^2} = -\frac{w+l+h_s-v}{d} < 0$.There exists optimal inventory to achieve both optimal revenue.

Let $\frac{\partial \pi_{s2}}{\partial q} = 0$, the optimal stock q_s^* of the supplier in the decentralized pre-storage transportation mode is

$$q_s^* = F^{-1}\left(\frac{w + l - c}{w + l + h_s - v}\right) = \left(\frac{w + l - c}{w + l + h_s - v}\right) d\,. \tag{13}$$

Substituting Eq. (13) into Eq. (11), it can be given that

$$\pi_{a2} = \frac{\bar{p}}{2} d - \frac{\bar{p}\bar{c}^2}{2\bar{w}^2} d - \frac{\bar{w}}{2} d + \frac{\bar{c}^2}{2\bar{w}} d\,. \tag{14}$$

In the above Eq., we can get that $\bar{w} = w + h_s - v$, $\bar{c} = c + h_s - v$, $\bar{p} = p + h_s - v$.

Next, we find the first derivative of the military revenue function $\bar{w}$ and let it equals to zero, so the optimal wholesale price can be satisfied that

$$\bar{w}^3 + \bar{c}^2 \bar{w} - 2\overline{pc}^2 = 0\,. \tag{15}$$

It can be seen from the above equation (15) which is exsiting a standard cubic equation. By Karl Dan formula, it can be obtained that there is only a real solution, by soluting the equation, under decentralized decision-making the optimal wholesale price of military supplies can be obtained that

$$w_s^* = \overline{w} + v - h_s = \sqrt[3]{\overline{pc}^2 + \sqrt{\Delta}} + \sqrt[3]{\overline{pc}^2 - \sqrt{\Delta}} + v - h_s\,. \tag{16}$$

Put Eq. (13), (16) into (11), (12), the best income of both sides can be get that

$$\pi_{a2}(q_s^*) = (p - w_s^*)\,\frac{(w_s^* + l - c)(w_s^* + l + 2h_s - 2v + c)}{(w_s^* + l + h_s - v)^2} \times \frac{d}{2}\,, \tag{17}$$

$$\pi_{s2}(q_s^*) = \frac{d}{2}\,\frac{(w_s^* + l - c)^2}{w_s^* + l + h_s - v} - ul\,. \tag{18}$$

So the optimal income $\pi_{t2}(q_s^*)$ of the whole supply chain is

$$\pi_{t2}(q_s^*) = (p - w_s^*)\frac{(w_s^* + l - c)(w_s^* + l + 2h_s - 2v + c)}{(w_s^* + l + h_s - v)^2} \times \frac{d}{2} + \frac{d}{2}\frac{(w_s^* + l - c)^2}{w_s^* + l + h_s - v} - ul\,. \tag{19}$$

The following conclusions can be seen from before and after the implementation of the supplier preloading and transhipment model that: After the implementation of pre-storage transportation mode, the military supplies wholesale price w_s^* is less than before w_a^*. At the same time, the implementation of the supplier pre-storage transportation mode can improve the inventory level of the military supplies supply chain and also improve the overall optimal supply of the military material supply chain. In addition, the implementation of the supplier's pre-storage transportation model can reduce the cost of the military supply chain, increase the optimal expected return, but reduce the optimal expected return of the supplier.

The above conclusions show that although the overall efficiency of the military supply chain has increased, but the material supplier revenue has decreased, so in order to attract material suppliers to actively participate in pre-storage transportation mode the military, military must develop a reasonable contract coordination mechanism. The military saving part of the cost will compensate to the material suppliers, and it is enable to the military for both win-win situation.

6. Coordination mechanism based on the repurchase contract

A repurchase contract refers to that supplier will repurchase unconsumed military materials at a price e which is below to cost at the end of purchasing military materials cycle, so as to decrease military's inventory costs and improve the security benefits of military supplies.

The process of two sides to determine the repurchase price can be seen as a Stackelberg game. Military supplies supplier is dominant, firstly raising up repurchase price e. Military will determine the optimal order quantity under e. Because military materiel suppliers have a better understanding of the military's inventory and demand information, it will maximize its return based on military decisions and the amount of repurchases which is predicted.

The military repurchase fee $T(q, w, e)$ paid to the supplier is

$$T(q, w, e) = wq - eI(q) = wq - \frac{eq^2}{2d}\,. \tag{20}$$

At this point, the military revenue can be expressed as

$$\begin{aligned}\pi_a' &= pS(q) - wq - hI(q) - lL(q) + eI(q) = \\ &= p\left[q - \textstyle\int_0^q F(x)\,dx\right] - wq - (h - e)\textstyle\int_0^q F(x)\,dx - l\left[u - q + \textstyle\int_0^q F(x)\,dx\right]\end{aligned}\,. \tag{21}$$

The simplified form can be obtained: $\pi_a' = (p + l - w)\,q - (p + l + h - e)\,\frac{q^2}{2d} - ul$ (21)

Since $F(x)$ is continuous and strictly increasing, the first derivative of the military yield function can be obtained that $\frac{\partial \pi_{\mathrm{a}}'}{\partial q} = (p+l-w) - (p+l+h-e)\frac{q}{d}$. Due to $\frac{\partial^2 \pi_{\mathrm{a}}'}{\partial q^2} = -\frac{p+l+h-e}{d} < 0$. In this way, let $\frac{\partial \pi_{\mathrm{a}}'}{\partial q} = 0$, the military's optimal order amount is vailabled that

$$q_{\mathrm{a}2}^* = \frac{(p+l-w)\,d}{p+l+h-e}\,. \tag{22}$$

To achieve the coordination of military supply chain revenue, there must meet $q^* = q_{\mathrm{a}2}^*$. It can be get that

$$\frac{(p+l-c)\,d}{p+l+h-s} = \frac{(p+l-w)\,d}{p+l+h-e}\,. \tag{23}$$

After simplification, we can obtain that

$$w = c + \frac{(p+l-c)(e-s)}{p+l+h-s}\,. \tag{24}$$

From the above formula, it can be seen that, as long as the purchase price can be obtained, the wholesale price of military supplies is determined, so as to determine the order quantity, and also the wholesale price of military supplies w is proportion to the repurchase price e.

As long as the two sides consultate and ultimately agree to form a repurchase contract, then we can be obtained optimal solution $(w,\, e)$.

After substituting equation (24) into equation (21), we can get that

$$\pi_{\mathrm{a}}' = \frac{p+l+h-e}{p+l+h-v}\pi_{\mathrm{t}} - \frac{e-v}{p+l+h-v}ul = (1-\alpha)\,\pi_{\mathrm{t}} - \alpha ul\,. \tag{25}$$

The military supplies suppliers of income can also be get that

$$\pi_{\mathrm{s}}' = \pi_{\mathrm{t}}' - \pi_{\mathrm{a}}' = \frac{e-v}{p+l+h-v}\left(\pi_{\mathrm{t}} + ul\right) = \alpha\left(\pi_{\mathrm{t}} + ul\right)\,. \tag{26}$$

It can be obtained that $\alpha = \frac{e-v}{p+l+h-v}$, and $0 < \alpha < 1$, α is the proportion of the distribution of military supplies income.

Equation (25) shows that the military's return is the affine function to military supply chain, so the optimal order quantity of military procurement department is also the military supply chains'. The repurchase contract can achieve the coordination of the military supply chain revenue, and can determine the size of their income distribution by adjusting the income distribution ratio α whose size depends on the both final results of the game. The stronger the position of the military in the game, the greater the value α, and also the more the distribution of the military benefits.

Table 1. Comparison of optimal supply of military supply chain under different pre-warehousing and transportation management modes

	Distributed	Centralized	Repurchase contract			
c	40	40	40	40	40	40
w	45	—	42.31	42.88	43.46	42.40
p	60	60	60	60	60	60
h	10	10	10	10	10	10
l	10	10	10	10	10	10
l	28	28	28	28	28	30
e	− − −	− − −	− − −	33	34	34
q	961.54	1153.85	1000.00	1153.83	1153.85	1200.00
α	− − −	− − −	0.08	0.10	0.12	0.08
π_{a}	2019.23	− − −	5976.33	5643.49	5310.65	6560.00
π_{s}	4807.69	− − −	1331.36	1664.20	1997.04	1400.00
π_{t}	6826.92	7307.69	7307.69	7307.69	7307.69	8000.00

7. Numerical verification

Under supplier pre-storage transportation mode, the supplier supply a single species of military supplies to the military supply. The force requirements x obey uniform distribution $x \sim U\,(0,\, d)$, that d is 2000 $\sim$ 4000 units. The production cost of military supplies is c and its wholesale price is w. If the supply exceeds demand, the military value of the unused military supplies v will be owned by the military, if the demand exceeds supply, military material suppliers produce out-of-stock losses g. The influence of the parameters change under different models with the repurchase contract model and the whole military supply chain system is analyzed by MATLAB software.

Suppose that the military supplies provide a single cycle material to military. Military materials are subject to uniform distribution $U(0,\, 2000)$. The unit production cost of military supplies is $c = 40$. The military supplies prices is $p = 60$. The unit military holding cost is $h = 10$. The unit out of stock cost is $l = 10$. The unit residual value is v which is in excess of the demand.

The numerical results show that:

1. The whole the optimal revenue of decentralized military supply chain is less than centralized and using of repurchase contracts. After the repurchase contract, the sum of the two sides proceeds to the centralized military supply chain's the whole best state.

2. The use of repurchase contracts makes the wholesale price of military supplies lower. To a certain extent, the military order amounts and military supply chain total income increase, and also the cost of out-of-stock losses reduce.

3. Under the repurchase contract, with the distribution of income α increasing, the military supplies' revenue will continue to increase, and the military income will continue to decrease, But military supply chain's whole benefit is far greater than the total revenue of both military and land revenue under decentralized decision-making.

8. Summary

The effective implementation of the pre-storage transportation mechanism of the emergency logistics center can improve the overall income of the military supply chain, by reducing the purchase price of military supplies, increasing the quantity of procurement, and also reducing the double marginal effect and bullwhip effect to a certain extent. The established repurchase contract can effectively coordinate the military supply chain. The using of repurchase contracts further reduced the wholesale price of military supplies by further increasing the amount of military supplies ordered, thereby increasing the overall benefits of the military supply chain.

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