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Impact analysis of slow steaming on inland river container freight supply chain

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Abstract: Based on the literature research and related concepts of inland river container freight supply chain, this paper analyzes the influence of inland river container freight supply chain under the reduced vessel speed. Firstly, this paper describes the research problems and makes assumptions. Then a two-echelon inventory management model based on controllable lead time and stable demand is presented and the impact of slow steaming on inland river container freight supply chain is quantitatively analyzed. Finally, the impact of slow steaming on the inventory cost and inventory strategy of the shipper and consignee in the container freight supply chain is studied and some feasible suggestions are given.

Key Words: Slow Steaming, Inland River, Container, Supply Chain, Inventory Analysis

1 Problem Description

1.1 Basic Problem Description

Fuel cost in shipping companies was responsible for an important proportion of the total cost. In recent years, with fuel prices rising, the proportion of fuel costs in the total cost is growing greater and greater. At the same time, the global economic crisis has leaded to excess capacity. With the global financial crisis, the Belt and Road initiative has been proposed. Therefore, an additional strategy for shipping companies has been put in place to slow down vessels compared to sailing at full speed.

Maloni M[1] simulates a high volume Asia-North America container trade lane to estimate slow steaming impacts under different vessel speeds, volumes and fuel prices so that the costs and benefits of slow steaming relative to carriers and shippers can be quantified. Lee C Y[2] proposes a model to quantify the relationship among shipping time, bunker cost and delivery reliability and their findings lead to a simple and implementable policy with a controlled cost and guaranteed delivery reliability. Rahman N S F A[3] uses a Fuzzy Rule-based Bayesian Reasoning method which incorporates the membership function and 14 selected nodes to analyze the necessity of super slow steaming on containerships despite uncertainties. Mallidis I[4] propose an analytical modeling methodology for quantifying the impact of slow steaming on the carrier's voyage cost and on the shipper's total landed logistics costs. But among these papers, no one combines the slow steaming with the inventory model in the supply chain.

Thus, in this paper, considering the effect of slow steaming[5][6][7] on the lead time in inland river, it is proposed to establish a simple two-echelon inventory system based on demand determination and controllable lead time in the container freight supply chain. The system contains a shipper and a consignee, and it is not considered container transport from downstream to upstream.

In the basic inventory control strategy, it is assumed that both the consignee and the shipper choose (t, R) strategy to manage inventory[8][9][10][11], and determine the optimal inventory control strategy in the environment of reduced vessel speeds and then obtain the decision variables in the corresponding inventory model. First, the inventory control strategy is determined by the lowest cost of the consignee, then considering the interaction between two nodes in the secondary inventory system, the shipper's inventory control strategy is determined.

1.2 Mathematical Notation

S, S*: Inventory level of the consignee and the shipper, decision variables;

T, T*: Order cycle of the consignee and the shipper, decision variables;

L, L*: Lead time of the consignee and the shipper;

L1, L2, L3: L1 Shipping time of the shipper to the consignee, L2 the order waiting time due to stock-out caused by the shipper, L3 the order processing time of the shipper;

t: The time interval between the consignee receives the first order and places the second order;

Q: The shipper's order quantity;

SS: The consignee's safety stock;

D: Average demand of the consignee per unit time;

σ: Standard deviation of the consignee's demand per unit time;

C, C*: The consignee's and the shipper's unit order cost;

h, h*: The consignee's and the shipper's cost of holding one unit of the inventory per unit time;

β: The proportion of delayed delivery of the consignee, 1-β is the proportion of sales loss;

1-α: Service level of the consignee indicating that the existing inventory can meet the percentage of customer needs;

k: Safety factor;

π1: Cost of delay in delivery of unit goods;

π2: Marginal profit per unit goods;

F: The expected freight cost per unit time of the shipper;

Fb: Basic freight cost of the shipper;

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Fs1: Shipper's goods depreciation surcharge;

Fs2: Other surcharges of the shipper;

V: The speed of the vessel;

f: Rate of single container;

m: Number of transported containers;

RC, RC*: Fixed order cost of the consignee and the shipper;

ETC, ETC*: The expected total cost per unit time of the consignee and the shipper;

EHC, EHC*: The expected inventory holding cost per unit time of the consignee and the shipper;

ESC, ESC*: The expected shortage cost per unit time of the consignee and the shipper;

1.3 Model Assumption

Assumption 1: The two-echelon inventory system runs indefinitely and each node decides independently to manage its own inventory

Assumption 2: The two-echelon inventory system only contains one goods, which does not cause a loss in supply chain transfer. Skip-level order and equal-level order within the supply chain are not permitted.

Assumption 3: In the two-echelon inventory management system, the shipper and the consignee adopt periodic order policy to manage their inventory.

Assumption 4: In the two-echelon inventory system, the replenishment quantity of the shipper must be an integer multiple of the replenishment quantity of the consignee.

Assumption 5: In the two-echelon inventory system, the ideal model is used, and the shipper's order cycle is an integer multiple of the consignee's.

Assumption 6: Consignee: the demand from the downstream enterprise X in the order cycle is normal distribution, mean is μT, the standard deviation is $\sigma\sqrt{T}$; Shipper: the demand comes from the replenishment requirement of the consignee.

Assumption 7: Without considering the shipper's lead time, namely the lead time of the shipper is 0, the lead time of consignee is composed of three parts (time of carriage of shipper to consignee, order waiting time due to the out of stock of the shipper and shipper's order processing time); assuming that the shipment time of the manufacturer to the seller is related to the speed, the shipper can respond quickly to the order of the consignee, that is, the order processing time of the shipper is 0.

Assumption 8: The shipper's system is not allowed to be out of stock; but the consignee's system is allowed to be out of stock, partly delayed delivery, partly the sales loss, and the consignee's service level is defined as 1-α, which shows the ratio of shortage quantity and order quantity in a period.

Assumption 9: The shipper conducts transactions with the consignee on the basis of CFR, but any accidents are not permitted to happen during the delivery of goods.

1.4 Model Definition

The model of this paper is to consider the impact of slow steaming on the transportation time, thus affecting the lead time of the consignee, and to provide some suggestions on the inventory control strategy of the consignee, and to develop the shipper inventory control strategy according to the mutual influence between two nodes.

1) Calculation of transportation time

According to the relationship between speed and time in kinematics, the transportation time = distance / speed.

2) Effect of slow steaming on lead time

By L=L1+L2+L3, knowing that the lower the speed, the longer the transportation time and the longer the lead time.

The order cycle: T=L+t, the lower the corresponding speed, the longer the order cycle.

2 Model Foundation of Supply Chain System

In the previous assumptions, in the two-echelon inventory system, the shipper and the consignee adopt (t ,S) periodic order policy. That is, inventory check point time is t, with different quantity, to keep inventory at optimal inventory level. Also ensure that within a single order cycle T, there is just one order. Before the model is built, some important variables are determined here:

a) Average demand in order period T

$$D_T = T \times D \quad (1)$$

b) Standard deviation of demand in order period T

$$\sigma_L = \sqrt{T} \times L \quad (2)$$

c) Safety stock

$$SS = k \times \sqrt{T} \times \sigma \quad (3)$$

d) Target stock level

$$S = D \times T + SS \quad (4)$$

2.1 Model of The Consignee

In this model, from the perspective of the consignee, the impacts of different lead time on the consignee are considered, and then the order cycle, optimal inventory level and safety inventory of different lead time can be figured out. The expected total cost of the consignee includes order cost, inventory control cost and shortage cost.

$$ETC = EOC + EHC + ESC \quad (5)$$

1) Expected order cost per unit time of the consignee

$$EOC = \frac{RC}{T} + C \times D \quad (6)$$

2) Expected inventory holding cost per unit time of the consignee

The demand X in the order cycle obeys normal distribution, mean is μT, the standard deviation is $\sigma\sqrt{T}$. Assume that the implementation of the demand in T is x and B denotes the expected value at the end of each cycle, then

$$B = \int_R^{\infty} (x - R) f(x) dx$$

$$= \int_{\mu T + k\sigma\sqrt{T}}^{\infty} \left(x - \mu T - k\sigma\sqrt{T}\right) \frac{1}{\sqrt{2\pi}\sigma\sqrt{T}} e^{\left[-\frac{1}{2}\left(\frac{x-uT}{\sigma\sqrt{T}}\right)^2\right]} dx \quad (7)$$

Assume a= $\frac{x - \mu T}{\sigma\sqrt{T}}$, then $\sigma\sqrt{T}\varphi(k) - k\sigma\sqrt{T}\left[1 - \Phi(k)\right]$ can represent B.

Among them $\varphi(k)$ and $\Phi(k)$ respectively denote the probability density function and distribution function of the standard normal distribution. Thus, in the circumstances, let $\Psi(k) = \varphi(k) - k\left[1 - \Phi(k)\right]$, then $B(R) = \sigma\sqrt{T}\Psi(k)$.

Therefore, the expected inventory holding cost per unit time:

$$EHC = h \times \left[S + (1 - \beta) \times B - \frac{D \times T}{2}\right] \quad (8)$$

3) Expected stock-out cost per unit time of the consignee

$$ESC = \frac{\left[\pi_1\beta + \pi_2(1-\beta)\times B\right]}{T} \quad (9)$$

And satisfy constraints $\frac{B}{S} \le \alpha$.

4) model analysis

We already know that there is a quantitative relationship between S and D. Thus, put T in the formula (5):

$$ETC = \frac{RC}{T} + C\times D + h\times\left[k\times\sqrt{T}\times\sigma + (1-\beta)\times B + \frac{D\times T}{2}\right]$$

$$+\frac{\left[\pi_1\beta + \pi_2(1-\beta)\times B\right]}{T} \quad (10)$$

The partial derivative of T:

$$\frac{\partial ETC}{\partial T} = -\frac{RC}{T^2} + \frac{D\times h}{2} + \frac{h\times\sigma\left(k+(1-\beta)\times\Psi(k)\right)}{2}T^{-\frac{1}{2}}$$

$$-\frac{\sigma}{2}\left[\pi_1\beta + \pi_2(1-\beta)\times B\right]\times\Psi\left(k\times T^{-\frac{3}{2}}\right) \quad (11)$$

Second order partial derivative of T:

$$\frac{\partial^2 ETC}{\partial T^2} = \frac{2RC}{T^3} - \frac{h\times\sigma}{4}\left(k+(1-\beta)\times\Psi(k)\right)T^{-\frac{3}{2}}$$

$$+\frac{3\sigma}{4}\left[\pi_1\beta + \pi_2(1-\beta)\times B\right]\times\Psi(k)\times T^{-\frac{5}{2}} \quad (12)$$

From above, it is easy to know that the second order partial derivative of T is greater than zero, that is, the total cost function is a convex function on T, so the minimum value is obtained when the first derivative equals zero.

Thus, using the single variable solution, the optimal ordering period T can be found, and according to the quantitative relationship between S and D, the optimal inventory level can be determined.

2.2 Model of the Shipper

For the shipper, the demand for each order cycle comes from the order of the consignee. The demand is a discrete batch demand, but when the operating time of the system is indefinite, the quantity that the shipper's inventory reduced can be seen as a smooth linear change. From the previous hypothesis, the following can be known:

1) Ordering cycle

$$T^* = n\times T \quad (13)$$

2) Order quantity in order period

$$Q = D\times n\times T \quad (14)$$

3) Expect order cost per unit time of the shipper

$$EOC^* = \frac{RC^* + C^*\times D}{T^*} \quad (15)$$

4) Expected inventory holding cost per unit time of the shipper

$$EHC^* = \frac{h^*}{T^*}\left[\frac{n\times(n-1)\times T\times D}{2}\right] \quad (16)$$

5) Expected stock-out cost per unit time of the shipper

Because the shipper is not allowed to be out of stock under the assumption, and when the shipper delivers the goods to the container in the ship, the stock-out cost of the shipper can be regarded as zero, that is, ESC*=0.

6) Expected freight cost per unit time of the shipper

$$F = F_b + F_{s1} + F_{s2} = 600\times 0.012\times V^{3.12}\times\frac{L}{T}$$

$$+\frac{m\times f\times(1+s1+s2)}{T^*} \quad (17)$$

7) Expected total cost per unit time of the shipper

$$ETC^* = EOC^* + EHC^* + ESC^* + F \quad (18)$$

8) Model analysis

In order to determine the optimal order quantity and order period of the shipper, the minimum positive number n is obtained when the above formula (18) gets the minimum value, so it can be expressed as:

$$C(n) = \frac{RC^*}{T^*} + \frac{h^*}{T^*}\left[\frac{n\times(n-1)\times T^2\times D}{2}\right] \quad (19)$$

Derivation of n:

$$\frac{dC(n)}{dn} = -\frac{RC^*}{n^2 T} + \frac{T\times D\times h^*}{2} \quad (20)$$

Make formula (20) be equal to zero, the optimal n will be obtained

$$n = \frac{1}{T}\times\sqrt{\frac{2RC^*}{D\times h^*}} \quad (21)$$

From above formula, it can be seen that the order cycle of the consignee will greatly affect the shipper's order cycle.

3 Model Validation

The demand of a product obeys normal distribution. The average demand per unit time D is 400 units. The standard deviation σ is 90 units / weeks. The fixed order cost of the consignee RC is 200 yuan / week. The unit order cost C is 25 yuan / unit. The inventory cost per unit time h is 0.05 yuan / unit. The fixed order cost of the shipper RC* is 800 yuan. The unit order cost C* is 20 yuan / unit. The inventory cost within the unit product unit time h* is 0.01 yuan /unit. The profit loss of the delayed delivery of the unit goods π1 is 10 yuan. The marginal profit per unit goods π2 is 20 yuan.

This product is transported by container from Wuhan port to Tianjin port. According to the data, the distance from Wuhan port to Tianjin port is 620 nautical miles. A container can hold 200 units, and transportation cost f is 5000yuan, and cargo stowage is 10%, and other surcharges are 5%.

3.1 Transportation Time under Five Speeds

According to the characteristics that freight volume in inland river is large and the speed of vessel is low, the transportation speed of vessels is between 9 knot and 13 knot, so we choose the following speeds: 7, 9, 11, 13 and 15knot. The transportation time under each speed on this route is shown in table 1 below.

Table1. Transport time under different speeds

Vessel speed(knot)	Transportation time(day)	Consignee's Leadtime L (day)	Shipper's order cycle(day)
7	3.7	3.7	3.7+t
9	2.9	2.9	2.9+t
11	2.3	2.3	2.3+t
13	1.9	1.9	1.9+t
15	1.7	1.7	1.7+t

3.2 The Optimal Solution of the Consignee's inventory model and Suggestion

1) When the proportion of delayed delivery β=0.8, the optimal order cycle and optimal inventory level of the consignee when the safety factor is 0, 0.25, 0.5, 0.75, 1, are shown in table 2 below.

Table2. Consignee's optimal order cycle and optimal inventory level under different safety factors

k	Optimal T	Optimal SS	Optimal S	Optimal ETC
0	9.24	0	3696.75	10256.88
0.25	7.96	63.48	3247.12	10218.24
0.5	6.90	118.21	2878.44	10185.69
0.75	6.07	166.33	2594.25	10159.75
1	5.46	210.28	2393.96	10140.43

From the above table, the optimal order cycle, the optimal inventory level and the inventory cost of the consignee decrease as the safety factor increases, and the optimal safety stock of the consignee increases as the safety factor increases. In this model, the stock-out cost of the consignee is far higher than the inventory cost, so the consignee must set a higher safety factor, that is, frequent ordering and maintaining a high safety stock in order to reduce the cost.

2) When t = 5 days, under different safety factors, the consignee at different speed is the inventory cost.

Table3. Consignee's expected total cost under different speeds when t=5

V	k=0	k=0.25	k=0.5	k=0.75	k=1
7	10257.1	10218.9	10189.5	10168.27	10153.93
9	10258.7	10218.2	10187.1	10164.41	10149.02
11	10260.6	10218.5	10186.1	10162.43	10146.30
13	10264.4	10219.1	10185.73	10161.32	10144.63
15	10264.0	10219.8	10185.66	10160.67	10143.54

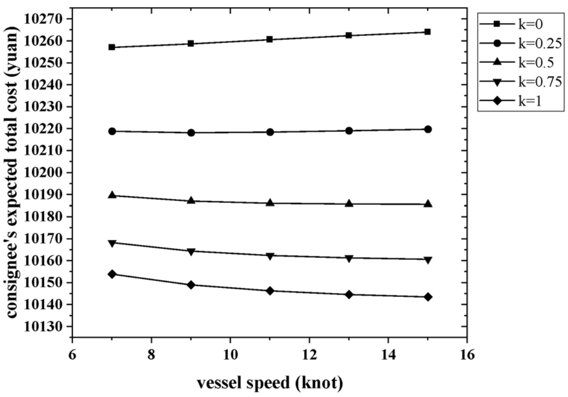

Fig 1. Relationship between the speed and total inventory cost of consignee under different k values when t = 5

In order to ensure the reliability of data, when the values of t are 8, 11, 14, the trend is shown in figures below.

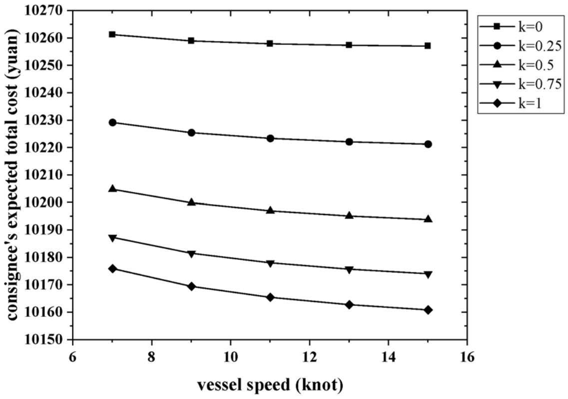

Fig 2. Relationship between the speed and total inventory cost of consignee under different k values when t = 8

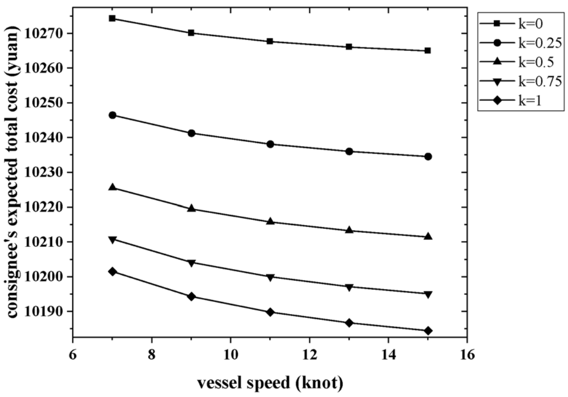

Fig 3. Relationship between the speed and total inventory cost of consignee under different k values when t = 11

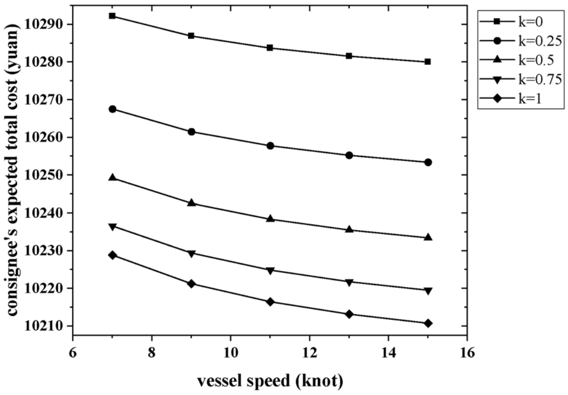

Fig 4. Relationship between the speed and total inventory cost of consignee under different k values when t = 14

From the consistency of the above data, it is not hard to find that when the speed is stable, the higher the safety factor, the lower inventory cost of the consignee, the reason may be that the cost of goods is far greater than the inventory cost; When the safety factor does not change, the lower the speed, the higher the inventory cost. This means that when the speed is lowered, in order to keep the safety factor, the consignee needs more costs.

3) Relevant recommendations for consignee's inventory management

Combined with table 2 and table 3, it is easy to find that after the slow steaming, the transportation time is longer, so order lead time is longer and the order period is lengthened. Finally, the inventory cost increases. In the reduced vessel speeds, the following recommendations are made to the inventory management of the consignee.

(1) For goods with high value, large cost, increase order times or shorten order period;

(2) For goods with strong market demand, increase their safety stock and avoid sales loss

(3) For general cargo, adjust the order period to the optimal order cycle as far as possible to minimize the cost.

3.3 The Optimal Solution of the Shipper's inventory model and Suggestion

1) Solution of n under different speed

The key to the shipper's inventory model, as described in the previous algorithm, is n. The values of n under different speed are given when t = 5.

Table4. Results of n under different speeds

V	n	T^*	Q	ETC^*
7	2	18	7200	10948.74
9	3	24	9600	12127.46
11	3	21	8400	13217.08
13	3	21	8400	15714.57
15	3	21	8400	19174.90

Similarly, when t is assigned other values, the following data is obtained.

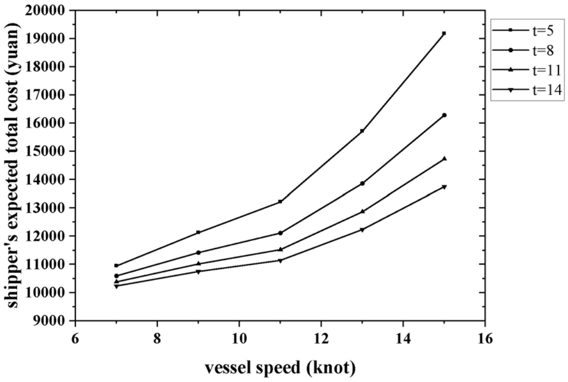

Fig 5. relationship between different speeds and expected total cost of shipper under different t values

When t is assigned four different values, the trend of the data is same. As the vessel speed goes up, the shipper's expected total cost increases. But When the vessel speed is in the range of 11 knot to 15 knot, the shipper's expected total cost increases more quickly than that when the vessel speed is in the range of 7 knot to 11 knot. The cause of this phenomenon may be fixed order cost and freight cost play the leading role. When the vessel speed is in the range of 11 knot to 15 knot, the freight cost increase more quickly.

2) Relevant recommendations for shipper's inventory management

Combined with the above data analysis, in the slow steaming environment, the following recommendation is given for the inventory management of shippers:

When the vessel speed goes up, the order cycle can be appropriately increased to apportion the high fixed order cost and transportation cost.

4 Summary

This paper studies the problem that combines the slow steaming in inland river with the inventory model in container supply chain for the first time.

In this paper, a two-echelon inventory management model based on controllable lead time and stable demand is presented and considering the effect of the speed on supply chain lead time, the influence of the speed on the cost of the shipper and consignee is analyzed. After considering these effects, recommendations are given on how the consignee and shipper adjust inventory strategies.

Using the specific data to validate the model, it is not hard to find that the linear relationship between the cost of the consignee and the speed. That is, the lower the speed, the higher the cost. And there is also a linear relationship between the cost of the shipper and the speed. That is, the lower the speed, the lower the cost.

In the future, on the basis of this paper, a lot of new problems can be studies. Such as the impact of slow steaming on multimodal transport and complicated supply chain that contains more than two members and so on.

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