Inventory-Transportation Optimization in Online Shopping Supply Chain Based on Retailer’s Decision-Making Power on Pricing

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Abstract — Inventory here refers to the stock held by the retailer. There exists typical “anti-back benefits” phenomenon between stock held and transportation costs in online shopping supply chain, reduction of cost of stock storage lead to rising of transportation cost. Although there are many inventory and transportation studies, there is little literature integrating them together. The term ‘inventory-transportation integrated optimization’ (ITIO) combines the two aspects into one problem. We attempt to find an optimal solution to the joint problem rather than single problem for online shopping supply chain. This not only has theoretical value, but is also of practical significance. Under the condition that the retailer has decision-making powers on pricing, we solve the manufacturer and retailer’s optimal strategy in individual optimizations, and then solve the optimal ITIO strategy of online shopping supply chain. Finally, we compare the optimal strategies of ITIO and individual optimization, then analyze the efficiency and performance of different strategies. The study shows that: the total profits of the ITIO is greater than that of individual optimization, unit cost production, unit transportation costs and unit inventory cost have positive impact on ITIO retail price.

Keywords - Inventory-transportation Integrated Optimization; Retailer; Supplier; Decision-making Power of Pricing

I. INTRODUCTION

The problem of inventory and transportation is one of the most important in online shopping supply chain management, many scholars made a depth study of it. In stock research, Lee(1997), Disney(2002) made a detailed state about the function of VMI to alleviate the bullwhip effect and reduce supply chain costs[1-2]; Cachon (2004) made a comparative analysis between VMI and RMI, the inventory management mode in two-layer supply chain[3]. Under the fixed demand, Mishra (2004) discussed the inventory coordination model of a single supplier and multiple retailers based on common replenishment epoch[4]. Zhou(2007) then studied the supply chain coordination under the random demand by a single manufacturer and the retailer’s price strategy quantity discount policy[5]. Shin and Benton(2007) studied a single supplier and retailer’s quantity discount problem in the actual competition[6]. Li Zhiyue(2005) discussed under the VMI system based on suppliers and distributors, the distributor out of stock, as a supplier of core enterprise how to motivate distributors[7].

In transportation research, Feng Huizong (2004) and Zhang Zhifu(2005), in view of the vehicle allocation problem in the process of logistics distribution, presented the mathematical model of optimal operation which adopted genetic algorithm and the improved genetic algorithm, and write the implementation algorithm[8-9]; Zhou Tao(2007) and Zhang Jingchun(2008) in view of the ant colony algorithm premature stagnation, show convergence speed, long search time and into local optimal solution and other shortcomings, put forward the improvement strategy[10-11]; CHEN(2006) put the vehicle optimization scheduling problem application to the transport of dangerous substances[12]. Tarantilis and Kiranoudis(2009) against no full vehicle optimization scheduling problem under the restriction of time window, at the same time, considering the specific time windows, vehicle capacity and distance constraints, studied the distribution transportation using the theory of the mathematical programming[13].

In fact, in an online shopping supply chain distribution system, manufacturers and retailers inevitably conflict: the saving of manufacturers transportation cost will lead to increase the retailer inventory cost, and vice versa. Under the condition of invariable in wholesale prices, the increase of manufacturers’ earnings depends on transportation cost savings, which requires the manufacturer to conduct mass transport as soon as possible, sum up the retailer’s demand for centralized transportation, resulting in the increase of retailers out of stock risks. In order to reduce the loss and customer churn out of stock, retailers need to increase their inventory to buffer the shortage risk, so the retailer’s inventory costs increase. On the other hand, if the retailer want to reduce inventory cost but not to lower the service level, inevitably requires manufacturers to more frequent and small batch of distribution, which has increased the difficulty of the manufacturers distribution and transportation costs. The conflicting phenomenon of manufacturers and retailers on the inventory and transportation cost saving known as the “benefits antinomy”.

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Although scholars have a lot of fruitful research on the inventory and transportation problem, but very few integrate research literature put the inventory and transportation problem together. In the cost of the contradiction in inventory and transportation, Inventory-Transportation Integrated Optimization can find a balance point, making the sum of the minimum. ITIO can effectively solve the “benefits antinomy” phenomenon. ITIO fused inventory control and transportation management into a big problem, to seek the joint problem rather than the optimal solution of one problem, not only has important theoretical value, also has great practical significance.

First of all to set the assumptions and conditions of the model, manufacturer and retailer’s profit function are obtained. Then under the condition of retailers with price decision and without price decision, make the analysis and conclude the optimal strategy of manufacturers and retailers when the decentralized optimization, obtains the inventory-transportation joint optimization strategy of online shopping supply chain system. Finally, put a comparison on decentralized optimization and inventory-transportation integrated optimization, analyse the performance of different strategies and the related properties.

II. PROBLEM DESCRIPTION AND MODEL ASSUMPTIONS

Assume that the online shopping supply chain system is composed of a manufacturer and a retailer. The unit wholesale price of manufacturers sell products to retailers is , manufacturers have unlimited production ability, and even no inventory. Manufacturer’s production cost per unit product is , the variable costs of per unit product for distribution is the batch of distribution the manufacturer to the retailer is , delivery quantity is the same as the retailer’s demand D. To limit the retailer demands for small batch and multiple batches of distribution, in the real distribution manufacturers charge a fixed cost of distribution to retailers, manufacturers for this part of the fixed income at a cost of , it can be said some fixed costs with every time vehicle dispatching and distribution of manufacturers, such as the cost of start a bus, etc. So the charge for manufacturers to retailers T is made up of fixed distribution costs and wholesale revenues.

Manufacturers have the ability to develop a plan of production and distribution according to the product market demand. The function relationship between the demand for production D and the retailer price is, the coefficient. Assuming that the regardless of the manufacturer’s inventory, only consider the retailer’s inventory, the holding cost of every per retailer’s inventory is the risk’s appetite of manufacturers and retailers is neutral.

From the above analysis, we can get the manufacturer’s profit = the revenue of retailer’s sales – the cost of production – the cost of part of the fixed distribution income – the cost of the variable distribution proceeds, that is

\[ \pi_m = F + p_m Q - c_r Q - f - c_f Q \]  

The retailer’s profit consist of the product sales revenue minus the payment to the manufacturer, minus inventory costs, can be expressed as

\[ \pi_r = pQ - (F + p_d Q) - \frac{hQ}{2} \]  

With the analysis of formula (1) and (2), can get the profit of online shopping supply chain:

\[ \pi_r = pQ - \frac{hQ}{2} - c_r Q - f - c_f Q \]  

There exist a “benefit antinomy” phenomenon between transportation-distribution cost and inventory cost of the manufacturers and retailers, their pursuit of self-interest maximization, give rise to the conflicts in individual interests and the interests of the whole online shopping supply chain, so it is difficult to achieve the overall optimal online supply chain system. In order to be able to cut down the cost of inventory and transportation-distribution in the whole online shopping supply chain system, which require both manufacturers and retailers collaborate, form the perspective of the whole online shopping supply chain, joint saving the inventory cost and the transportation cost, that is to launch the business of inventory-transportation integrated optimization.

III. THE ANALYSIS OF OPTIMAL INVENTORY-TRANSPORTATION BASED ON THE GENERAL CONTRACT

In non-cooperative game, from their own interests respectively, manufacturers and retailers maximize personal profits, manufacturers reduce their transportation costs as much as possible, retailers reduce their inventory costs as much as possible. And in order to achieve this goal, they spare no sacrifice the interests of the partners, such as in order to reduce inventory cost, the small amount and batches distribution will be required by retailers, which leads to the increase of distribution costs of manufacturers. On the other hand, in order to cut down the transportation-delivery costs, manufacturers tend to have large quantities of distribution, which will inevitably increase the retailer’s inventory costs. The only consider the individual benefit maximization, while ignoring the interests of the whole system maximization, which can be called as transportation-inventory scattered optimization model.

And at the same time, if you can see the manufacturers and retailers as a whole, joint optimization the transportation-distribution costs of manufacturers and inventory costs of retailers, make a decision from the perspective of the interests of the whole system, then to reduce the total cost of the entire online shopping supply chain system, and achieve optimum overall. The decision model can be called Inventory-Transportation Integrated Optimization.

A. The inventory and transportation decision analysis when retailers have price decision-making power

In this case, the decision-making process of both sides is as follows: first, manufacturers and retailers negotiate the fixed distribution costs; Then, according to the master of the retailer’s cost information, manufacturers determine the
optimal wholesale price per unit product to themselves, maximize its expected profits; Finally, according to their mastery of the manufacturer’s cost information, whether the manufacturer’s offer reasonable, retailers choose whether to accept the offer. If retailers accept the offer, two sides will reach an agreement, the retailer determine the retail price of optimal product; If retailers refused to the offer, manufacturers need to adjust the offer again, until the two sides reach a new agreement, or to suspend the cooperation.

In the process of pricing decision, we adopt backward induction to solve the dynamic game:

Given wholesale price of manufacturer’s products, retailers decide the optimal retail price and maximize the benefits. The retailer’s profit function.

\( \pi_r = pQ - (F + pM)Q - \frac{hQ}{2} \) can be turned into

\( \pi_r = (p - pM - \frac{h}{2})Q - F \) \hspace{1cm} (4)

The distribution of manufacturers in accordance with the retail demand, i.e. \( Q = D \), we can get distribution of \( Q = \frac{a - p}{b} \), then put \( Q \) into the retailer’s profit function, we can get the target problem:

\[
\max \pi_r = (p - pM - \frac{h}{2}) \frac{a - p}{b} - F \tag{5}
\]

Constraints: \( \pi_r \geq \pi_w \)

\( \pi_w \geq 0 \) can be expressed as retailers’ retained profits.

The Kuhn-tucker (K-T) condition can applied to solve the problem for the project, K-T conditions for the above problem are as follow:

\[
\begin{align*}
\left[ \frac{a - p}{b} + (p - pM - \frac{h}{2}) - \frac{1}{b} \right] + \gamma \left[ (p - pM - \frac{h}{2}) - \frac{1}{b} \right] &= 0 \\
\gamma \left[ (p - pM - \frac{h}{2}) \frac{a - p}{b} - F - \pi_r \right] &= 0 \\
\gamma &\geq 0
\end{align*}
\]

In order to solve the above equation, several cases should be considered:

1. Make \( \gamma \neq 0 \), \( \gamma \neq 1 \), conditions of satisfaction:
   \( \frac{a - p}{b} + (p - pM - \frac{h}{2}) - \frac{1}{b} = 0 \) and even
   \( p - pM - \frac{h}{2} \frac{a - p}{b} - F - \pi_r = 0 \)
   that to say meet
   \( \frac{a + pM + h}{2} = p \) and \( (p - pM - \frac{h}{2}) \frac{a - p}{b} - F - \pi_r = 0 \) at the same time, so no solution.

2. Make \( \gamma = 0 \), \( \gamma = 1 \), no solution

3. When \( \gamma = 0 \), the optimal solution:

\[
p = \frac{a + pM + h}{2} \tag{6}
\]

Verified, \( p^* \) is the retailer’s optimal retail price.

Put \( p^* \) and \( Q = \frac{2(a - pM) - h}{4b} \) into \( \pi_r \), we can obtain the optimal profit of retailers by this time:

\[
\pi_r = \frac{(2(a - pM) - h)^2}{16b} - F \tag{7}
\]

Then solve the manufacturer’s optimal wholesale price. According to their mastery of the information about the cost of the retail, manufacturers can able to make an accurate prediction to optimal yields of retailers, and then get the optimal retail price. Manufacturer learned about retailers decide the market retail price \( p^* \) for sale, then to maximize their own benefits. The manufacturer’s profit function can be transformed into

\[
\pi_m = F - f + (pM - c_p - c_d)Q \tag{8}
\]

Put \( Q \) into the profit function of manufacturers, we can get

\[
\pi_m = F - f + (pM - c_p - c_d) \frac{2(a - pM) - h}{4b} \tag{9}
\]

Manufacturers can make the following decisions.

\[
\max \pi_m = F - f + (pM - c_p - c_d) \frac{2(a - pM) - h}{4b} \tag{10}
\]

ST: \( \pi_m \geq \pi_w \)

\( \pi_w \) can be expressed as manufacturers’ retain income. By K-T conditions and easy to work out the manufacturer’s optimal wholesale price for

\[
p^*_m = \frac{2(a + c_p + c_d) - h}{4} \tag{11}
\]

Put it into the manufacturer’s profit function and available

\[
\pi_m = F - f + \frac{(2(a - c_p - c_d) - h)^2}{32b} \tag{12}
\]

After manufacturers quote us product wholesale price, retailers judge whether manufacturers’ product wholesale price is reasonable in line with their mastery of the information about the manufacturer, and according to their own situation to choose to accept or refuse to offer quotation. If accept the offer, manufacturers and retailers will reach an agreement, and then retailers determine the optimal product price; If refuse the offer, the manufacturer must adjust the wholesale price of products, until the two sides reach an agreement, or suspend the cooperation.

B. The inventory and transportation decision analysis when retailers have no price decision-making power

When retailers do not have price decision-making power, its pricing game process is similar to retailers have market...
power, the game process between the two sides is the same as the analysis of the section 3.1, just in the last stage of the game, if the two sides reach an agreement, the price of the product is determined by factors outside the system, is immutable. If the two sides come to an agreement, we can get the optimal solution \((p^*_w, p^*_m)\), then \(p^*_w = p^* - \bar{p}\) mean exogenous product retail price; The product wholesale price \(p^*_m\) should satisfy the condition of

\[c_p + c_d \leq p^*_m \leq \frac{p - h}{2}\]

The specific value of product wholesale price \(p^*_m\) depend on the information that manufacturers and retailers held, strategic behavior, market power and bargaining negotiations ability. If manufacturers have mastered retailers’ detailed cost information, and make a negotiation strategies for their own accordingly, take the corresponding credible strategy behavior, then \(p^*_m\) may be higher, more conducive to the manufacturer. Conversely, \(p^*_m\) may be lower, more conducive to retailers.

C. Inventory-Transportation Integrated Optimization model

1) Inventory-transportation integrated optimization mode when retailers have price decision-making power

Assuming that there is a decision-making center, the decision center is responsible for the operation of entire online shopping supply chain, form the perspective of the whole online shopping supply chain, decision-making center can make the optimal decision. By introducing the decision center to put manufacturers and retailers into a system optimization, can effectively overcome the “benefit antimony” phenomenon between transportation and inventory costs in the traditional online shopping supply chain, and make overall optimal decisions for online shopping supply chain.

According to 3.1, 3.2, and model assumptions, we can get the whole optimization target of online shopping supply chain:

\[
\max \pi_w = \max_{p>0} (pQ - \frac{hQ}{2} - c_p Q - f - c_d Q) \quad (12)
\]

ST: \(\pi_w \geq \pi_{w^*}\)

we can find out the above optimal solution based on the optimal condition

\[
p^*_w = \frac{a + \frac{h}{2} + c_p + c_d}{2} \quad (13)
\]

By comparing the \(p^*_w\) and \(p^* = \frac{a + h/2 + p_m}{2}\), and decision center of online shopping supply chain are not introduced in the decentralized decision, we can find that only when the manufacturer’s wholesale price is equal to the product manufacturing cost plus variable cost, that is \(p_m = c_p + c_d\), can the overall optimal online shopping supply chain achieved, and overall welfare of online shopping supply chain have no loss. But in fact, manufacturers can maintain such price level only in the short term, if this manufacturer pricing in a long-term, its wholesale earnings cannot make up for the fixed transportation costs, inevitably cause losses. Therefore, the rational manufacturer will deviate form the optimal inventory-transportation pricing, in order to obtain greater individual income, higher than the variable cost quotation, namely \(p_m > c_p + c_d\), cause loss of efficiency of online shopping supply chain system and overall welfare of online shopping supply chain.

2) Inventory-transportation integrated optimization model when retailers have no price decision-making power

When retailers do not have the price decision-making power, if the two sides take inventory-transportation joint optimization strategy, the optimal target for decision-making center:

\[
\max \pi_w = \max_{p>c} (\frac{p - h}{2} - c_p - c_d) \frac{a - p}{b - f} \quad (14)
\]

ST: \(\pi_w \geq \pi_{w^*}\)

At this point, the systematic exogenous factors determine the retail price of a product, so in the short term, the optimal profits of inventory-transportation joint optimization remain constant. Unless the influencing factors of exogenous price changes, the optimal profit of supply system will not change.

The fixed pay \(F\) and variable pay \(p_mQ\) which retailers pay to manufacturers will not change the optimal profits of inventory-transportation integrated optimization, only change the optimal profits allocation between the manufacturers and retailers.

IV. THE ANALYSIS OF MODEL NATURE

Proposition 1: in decentralized optimization, the retailer’s optimal product retail price \(p^*\) increased along with the increase of unit inventory cost and the manufacturer’s wholesale price; The manufacturer’s optimal wholesale price \(p^*_m\) increased with the increase of unit manufacturing cost and unit transportation-distribution cost, while \(p^*_w\) decreased with the increase of the retailer’s unit inventory cost.

The conclusions of proposition 1 can easily get form the analysis of the part 3.

Proposition2: in the inventory-transportation integrated optimization model, the retailer’s retail price increased along with the increase of unit production cost, unit transportation cost, unit inventory cost.

The conclusion of proposition 2 can be easily obtained form the analysis of third part.
Proposition 3: when retailers have decision-making power price, the retailer’s profit function is:

\[ \pi_r = \frac{[2(a - p_m) - h]^2}{16b} - F \]

The manufacturer’s profit function is:

\[ \pi_m = F - f + \frac{[2(a - c_p - c_d) - h]^2}{32b} \]

The profit function of whole online shopping supply chain system is:

\[ \pi_T = \frac{[2(a - c_p - c_d) - h]^2}{64b} - f \]

Proof: put:

\[ p^*_m = \frac{2(a + c_p + c_d) - h}{4} \]

\[ \pi_r = \frac{[2(a - p_m) - h]^2}{16b} - F \]

into, we can get

\[ \pi_r = (a - c_p - c_d - \frac{h}{2})^2 / 16b - F \]

The whole profits of the system:

\[ \pi_T + \pi_m = (a - c_p - c_d - \frac{h}{2})^2 / 16b - F + F - f + \frac{[2(a - c_p - c_d) - h]}{32b} \]

\[ = (a - c_p - c_d - \frac{h}{2})^2 / 16b + \frac{[2(a - c_p - c_d) - h]^2}{32b} - f \]

\[ = \frac{[2(a - c_p - c_d) - h]^2}{64b} - f \]

Proposition 4: in decentralized optimization when retailers have price decision-making power, the profit function of retailers is inversely proportional to unit production cost, unit distribution variable cost, unit inventory cost and the fixed distribution costs. The profit function of manufacturers is inversely proportional to unit production cost, unit distribution variable cost, unit inventory cost and fixed income cost, is proportional to the fixed distribution costs.

Proposition 5: when retailers have price decision-making power, the gross profits of online shopping supply chain using inventory-transportation integrated optimization strategy are greater than the total profits of the decentralized optimization in online shopping supply chain system.

Prove: the whole profits function:

\[ \pi_T = pQ - \frac{hQ}{2} - c_pQ - f - c_dQ \]

of online shopping supply chain system can be turned into:

\[ \pi_T = \left( p - \frac{h}{2} - c_p - c_d \right) \frac{a - p}{b} - f \]

Put the price of inventory-transportation integrated optimization \( p^*_T \) and the price of inventory transportation decentralized optimization \( p^*_T \) into \( p^*_T \), then the whole profits of integrated optimization \( \pi^*_T \) are greater than the whole profits of decentralized optimization \( \pi^*_T \), that is:

\[ \frac{[2(a - c_p - c_d) - h]^2}{32b} > \frac{[2(a - c_p - c_d) - h]^2}{64b} \]

V. Conclusion

Manufacturers and retailers can improve the whole profits of the online shopping supply chain system, enhance the efficiency and competitiveness of the online shopping supply chain system, by using inventory-transportation integrated optimization strategy. Inventory-transportation integrated optimization can effectively overcome “benefit antinomy” between manufacturers and retailers, manufacturers are willing to cooperate with retailers to save inventory costs, retailers are willing to cooperate with manufacturers to save transportation costs, reconcile the inconsistent of manufacturers in purpose of operation. And make both sides actively adopt the consistent strategy with transportation-inventory integrated optimization.

First of all to set the assumptions and conditions of a model, manufacturers and retailers’ profit function is obtained. Make analysis to the optimal strategy for manufacturers, the optimal strategy for retailers and inventory-transportation integrated optimization strategy, it is concluded that the decentralized optimization strategy and inventory-transportation integrated optimization strategy of manufacturers and retailers. And also make a comparison between the optimal retail price of retailers and the optimal retail price of inventory-transportation integrated optimization, then points out that the optimal retail price of individual retailer would produce efficiency and welfare loss.

Then make a comparison between retailers have price decision-making power and no price decision-making power, if they reach an agreement as retailers have no price decision-making power, so the optimal retail price is decided by exogenous factors and also fixed. While the manufacturer’s optimal wholesale price depends on the information that manufacturers and retailers mastered,
strategic behavior, market power and ability to bargaining negotiations. If manufacturers have mastered the detailed cost information of retailers, and make better negotiation strategies accordingly, and then take the corresponding credible strategy behavior, so the optimal wholesale price may be higher, more conducive to the manufacturer. Conversely, the optimal wholesale price may be lower, more conducive to the retailer. So in the short term, inventory-transportation integrated optimization optimal profits remain constant. Unless the influencing factors of exogenous price changes, the optimal profit of whole online shopping supply chain system will not change.

The study found that in the decentralized optimization of traditional contract, the retailer’s optimal product retail price increased along with the increase of unit inventory cost and the manufacturer’s wholesale price; The manufacturer’s optimal wholesale price increased with the increase of unit manufacturing cost and unit transportation-distribution cost, while wholesale price decreased with the increase of the retailer’s unit inventory cost. In the inventory-transportation integrated optimization model, the retailer’s retail price increased along with the increase of unit production cost, unit transportation cost, unit inventory cost. In decentralized optimization when retailers have price decision-making power, the profit function of retailers is inversely proportional to unit production cost, unit distribution variable cost, unit inventory cost and the fixed distribution costs. The profit function of manufacturers is inversely proportional to unit production cost, unit inventory cost and the fixed income cost, is proportional to the fixed distribution costs. When retailers have price decision-making power, the gross profits of online shopping supply chain using inventory-transportation integrated optimization strategy are greater than the total profits of the decentralized optimization in online shopping supply chain system.

Paper studies can be extended to different demand, transportation, inventory conditions that suppliers and retailers faced, it is also worth studying direction in the future.

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