Analysis on the cost structure of product recall for reverse supply chain

Feng Yanhua\(^1,2\), Xia Xuhui\(^{1,2,*}\) and Yang Zheng\(^{1,2}\)

\(^1\)Key Laboratory of Metallurgical Equipment and Control Technology of Ministry of Education, Wuhan University of Science and Technology, 430081 Wuhan, China; \(^2\)Hubei Key Laboratory of Mechanical Transmission and Manufacturing Engineering, Wuhan University of Science and Technology, 430081 Wuhan, China;

\(^*\) Corresponding author : xiaxuhui@wust.edu.cn

Abstract. The research on the reverse supply chain of product recall mainly focused on the recall network structure, logistics mode and so on. In this paper, when product recall and supply channel are fixed, the specific structure and function expression of cost are analyzed according to the peak season and off-season of recall activities, and whether the assembly manufacturer, supplier and recyclers are cooperated situation, respectively, to build the total cost structure of the function model. Finally, the model is validated correctly through the automotive industry and the electromechanical industry.

1. Introduction

The existing product recall research mainly focuses on the conditions the cooperation mechanism can be achieved, the different pricing strategies for effective measurement and the distribution of benefits, etc. In the supply chain management, in order to achieve the rapid response to the needs of the middle and lower reaches of the node, and continue to reduce the overall inventory level of the supply chain, many scholars found the problem in the system is particularly prominent by assembly to order in the supply chain collaboration\(^{[1-2]}\). There are two major difficulties affecting the manufacturer, one is the customer's needs in constant change, the other is the uncertainty of the delivery of the manufacturer. In the process of reverse supply chain, manufacturers supply situation on the downstream manufacturing enterprises processing and storage will costs more prominent because of the changing for the time and quantity. Therefore, the overall benefits of remanufacturing optimization has an important role according to the reverse supply chain raw material supply characteristics. Xia Xuhui believed that the general concept of reverse supply chain includes the basic concepts of reverse supply chain, the path of reverse supply chain, the open-loop and closed-loop characteristics of reverse supply chain, the characteristics of reverse supply chain, the meaning of reverse supply chain and the supply chain of reverse supply chain strategic\(^{[3]}\). He put forward the reverse supply chain is the whole recycling process that the market waste products back to the original manufacturer or remanufacturing to disassemble, and then create a new product back to the market.

The reverse supply chain research focuses on the recovery of old commodities, including the reverse supply chain coordination of the main incentives, pricing mechanism, recycling products remanufacturing and so on\(^{[4]}\). In recent years, the recall of the incident is more frequent, but the research on product recall is relatively small. Reverse supply chain for product recall contains too
many unstable factors. Firstly, the quantity of product recall can not be estimated; Secondly, product recall quality is uncertain, that is, recall products meet remanufacturing processing of the standard conditions can not be estimate; Next, product recall recovery time is unknown. So, these uncertainties present a serious challenge for the product recall for reverse supply chain system. In this paper, the replacement of parts and components for product recall activities as an example, the co-supply problem will be discussed between the assembly manufacturer, suppliers and recyclers, and the cost structure and its model for product recovery reverse supply chain will be further studied.

2. Model hypothesis
In the product recall activities, the cost of product recovery reverse supply chain can be reduced effectively by the management of replacement part of the delivery time and the rapid sharing of product information. Due to factors such as production capacity constraints and the bottleneck of the replacement part of the assembly manufacturer delivery time will have a greater impact. But the use of methods to shorten the delivery time of the supplier may increase the storage costs and give the enterprise an unnecessary burden. The timing of supply of replacement parts and the control of supply volume are the key factors that affect the delivery time of the assembly manufacturer and reduce the cost of recall activities. The uncertainty of the recall quantity is the core information of the whole recall activity. The reference model hypothesis is as follow[5]:

1) In the production of reverse supply chain, all the maintenance activities of the assembly manufacturer for the recalled product are the replacement of the replacement part A and the recovery part B. The supplier A is responsible for providing the replacement part A, the recycler B is responsible for recycling B, the two originals are assembled by the assembly manufacturer and returned to the customer. The quantity ratio of the replacement part A and the part B is 1: 1, and the replacement part A supply shortage will directly lead to fracture of production chain after the recall, thus affecting the entire recall activities;

2) In the production of reverse supply chain, the assembly manufacturer is ordered by the Q_B to the supplier A according to the quantity Q_B of the recalled product. The supply ratio of the supplier A and the recovery part B is α: 1, the supply quantity is Q_A, the Q_B of the recovery of the quantity B is subject to the normal distribution, that is, Q_B~N (μ, σ^2), and the assembly manufacturer using continuous inspection (Q,R) strategy;

3) In order to ensure the efficiency of the processing activities to win the trust of the customer, the recycler B will return the product to the assembly manufacturer in a very short period of time after the customer returns the product. The recycler B does not generate the storage cost, that is Recycling B storage cost D_B=0;

4) In order to save costs and the rapid operation of the reverse supply chain, the recycler B often choose near the processing enterprises to build sites, and even some recyclers will be located in the processing enterprises at the recovery point, so the cost of transport B can be ignored, that is Recycling B transport costs T_B=0;

5) Assembly manufacturer with sufficient processing capacity of the recall products for maintenance, parts replacement and other activities, will not produce the recall of the product accumulation;

6) Assembly manufacturer and recycler B in the reverse supply chain behavior are completely rational, that is, in accordance with the principle of the lowest cost and maximize the principle of efficiency to implement the decision.

3. Reverse supply chain supply cost composition

3.1. Symbol Description
Q_A: The supply of replacement part A  
α: Ratio of replacement part A to recovery part B  
Q_B: The supply of recovery part B  
q: Unit shortage cost of replacement part A  
C_A: Unit storage cost of replacement part A  
C_B: Unit storage cost of recovery part B
3.2. The supply cost of the assembly manufacturer at peak season

Such recall behavior has a relatively obvious recall season. In the early stages of product recall information release, there will be a recall boom, that is recall peak season, terminal market demand is volatile and it is often difficult to obtain relatively accurate predictions.

1) Storage cost of replacement part A

Since replacement part A need to be procured from other production sectors, a certain amount of replacement pieces A will be kept in advance in order to ensure a relatively stable production operation before the arrival of the recall season. A and B components of the assembly ratio of 1:1, so there may be the assembly manufacturer reserves more replacement A before the recall peak season (i.e. \( \alpha > 1 \)). The storage cost of replacement part A is

\[
S_A = C_A \cdot Q_B \cdot (\alpha - 1)
\] (1)

2) Storage cost of recovery part B

Since the ratio of part A and B is 1:1, and the number of products recalled in the reverse supply chain is large. Therefore, when the supply of the replacement part A is insufficient (i.e. \( \alpha < 1 \)), it leads to the assembly manufacturer reserves a certain amount of recovery part B. The storage cost of recovery part B is

\[
S_B = C_B \cdot Q_B \cdot (1 - \alpha)
\] (2)

3) Shortage cost

Due to the error in the forecasting information of the assembly manufacturer and the uncertainty of the production capacity of the replacement part supplier, there may be a shortage of replacement parts A, resulting in an out-of-stock cost of the assembly is

\[
L = q \cdot Q_B \cdot [1 - \min(\alpha, 1)]
\] (3)

4) Purchase cost

By the actual supply of the replacement part A, it can be concluded that the purchase cost of the assembly manufacturer is

\[
G = P_A \cdot \alpha \cdot Q_B
\] (4)

5) Recovery compensation cost

In order to promote the active participation of consumers in the recall activities, improve consumer satisfaction with business services, enterprises will be a certain recovery compensation in the provision of recall services you can get the recovery compensation cost

\[
P = Pr \cdot Q_B
\] (5)

6) Reorder cost

As the estimated recovery is less than the final recall of the number of products, the assembly manufacturer may be in the process of adding additional purchase A to meet the needs of consumers recall, for which the purchase cost

\[
Z = R_A \cdot Q_B \cdot [1 - \min(\alpha, 1)]
\] (6)

3.3. The supply cost of the assembly manufacturer at off-season

After the peak period of the recall, the number of product recalls in the reverse supply chain will gradually decrease and tend to be gentle. At the off-season, the demand for the market is close to that of the assembly manufacturer. Therefore, enterprises can reasonably predict the level of demand for recovery part B, and in order to ensure the smooth progress of the recall, the assembly manufacturer may reserve a certain number of replacement part A.

1) Storage cost of replacement part A
A and B components of the assembly ratio of 1:1, so there may be assembly (manufacturing) in the recall of the off-season reserve more replacement A (α>1), the reserve cost is
\[ S_A = C_A \cdot Q_B \cdot (1-\alpha) \] (7)

2) Recovery compensation cost
In order to promote the customer to take the initiative to recall activities to improve consumer satisfaction with the enterprise services, enterprises in the provision of recall services, often also a certain recovery compensation, the recovery of the recovery costs can be get, that is
\[ P = P_r \cdot Q_B \] (8)

3) Purchase cost
By the actual supply of the replacement part A, it can be concluded that the purchase cost of the assembly manufacturer is
\[ G = P_r \cdot \alpha \cdot Q_B \] (9)

4. Total cost of reverse supply chain

4.1. Models that are non-coordination between enterprises
In this reverse supply chain model, the assembly manufacturer only share the expected information on the recalled product with the recycler of the recovery part B, and does not pay attention to the sharing of information with the replacement parts supplier. At the same time, the total cost of the assembly manufacturer during the peak season is
\[ W_1 = S_A + S_B + L + G + P + Z = C_A \cdot Q_B \cdot (1-\alpha) + C_B \cdot Q_B \cdot (1-\alpha) + q \cdot Q_B \cdot [1 - \min(\alpha, 1)] + P_r \cdot \alpha \cdot Q_B + P_r \cdot Q_B + R_A \cdot Q_B \cdot [1 - \min(\alpha, 1)] \] (10)
The total cost of the assembly manufacturer during the peak season is
\[ W_2 = S_A + P + G = C_A \cdot Q_B \cdot (1-\alpha) + P_r \cdot Q_B + P_A \cdot \alpha \cdot Q_B \] (11)
Therefore, at the peak season the expected value of total cost is
\[ E(W_1) = E(S_A) + E(S_B) + E(L) + E(G) + E(P) + E(Z) = C_A \cdot Q_B \cdot \int_{\alpha \leq 1} (1-\alpha) f(\alpha) d\alpha + C_B \cdot Q_B \cdot \int_{\alpha \leq 1} (1-\alpha) f(\alpha) d\alpha + q \cdot Q_B \cdot \int_{\alpha \leq 1} (1-\alpha) f(\alpha) d\alpha + P_r \cdot Q_B \left[ \int_{\alpha \leq 1} (1-\alpha) f(\alpha) \right] d\alpha \] (12)
At the off-season the expected value of total cost is
\[ E(W_2) = E(S_A) + E(P) + E(G) = C_A \cdot Q_B \cdot \int_{\alpha \leq 1} (1-\alpha) f(\alpha) d\alpha \] (13)

4.2. Models that are coordination between enterprises
When the supplier, the recycler and the assembly manufacturer share information and effective collaboration, the parties can be clear each other's supply quantity and delivery time. They will reduce the holding cost of replacement part or recovery part and reduce the shortage cost and reorder cost due to a shortage of replacement part, thereby reducing the cost of the entire reverse supply chain. At this point, during the peak season of the recall, the total cost of the assembly manufacturer is
\[ W_1 = L + G + P = q \cdot Q_B \cdot [1 - \min(\alpha, 1)] + P_A \cdot \alpha \cdot Q_B + P_r \cdot Q_B \] (14)
During the off-season, the total cost of the assembly manufacturer becomes
\[ W_2 = P + G = P_r \cdot Q_B + P_A \cdot \alpha \cdot Q_B \] (15)
Therefore, the peak season at the same time expect the total cost of manufacturing is
\[ E(W_1) = E(L) + E(G) + E(P) = q \cdot Q_B \cdot \int_{\alpha \leq 1} (1-\alpha) f(\alpha) d\alpha + P_A \cdot Q_B \cdot E(\alpha) + P_r \cdot Q_B \] (16)
The expected total cost of the off-season association is
\[ E(W_2) = E(P) + E(G) = P_A \cdot Q_B \cdot E(\alpha) + P_r \cdot Q_B \] (17)
Compared with the total cost of manufacturing in different times, it can be seen that the establishment of information channels, information sharing and co-production can effectively reduce the production cost of reverse supply chain, to avoid product accumulation or lack of supply situation.

5. Example verification
The model is validated through the automotive industry and the electromechanical industry. Assuming that in a certain area, a car repair shop is responsible for servicing the recall car in the area, and the
recall is in line with the set model. It is known that the density function of random variable $\alpha$ is $f(\alpha)$. It is assumed that $\alpha$ is uniformly distributed $U(a, b) | (a=0.8, b=1.2)$ at the peak season and uniformly distributed $U(a, b) | (a=1.1, b=1.5)$ at the off-season; In another area, a company flagship store appliance repair service department is responsible for the recall refrigerator door activities. It is assumed that $\alpha$ is approximate uniformly distributed $U(a, b) | (a=0.7, b=1.1)$ at the peak season and approximate uniformly distributed $U(a, b) | (a=1, b=3)$ at the off-season. The cost of each link remains the same during the recall season, and the relevant calculation parameters are shown in Table 1, and the the assembly manufacturer is processed at a ratio of 1:1 between $Q_A$ and $Q_B$. The relevant calculation results of the peak season and the off-season are obtained by generating the random variable of 10000 pairs of $\alpha$, which is the random distribution of $\alpha$, and the supply level of the replacement part supplier and the recycler. The relevant calculation results are shown in Table 2.

### Table 1. The relevant calculation parameters

| Business Model | $q$ | $C_A$ | $C_B$ | $P_A$ | $P_r$ | $R_A$ |
|----------------|-----|-------|-------|-------|-------|-------|
| Car            | 50  | 10    | 15    | 20    | 10    | 30    |
| Refrigerator   | 80  | 20    | 25    | 40    | 20    | 50    |

### Table 2. The relevant calculation results

| Business Model | Recall at peak season | Recall at off-season |
|----------------|-----------------------|----------------------|
|                | $f(\alpha)$ | $E(\alpha)$ | $E(W_1^\prime)$ | $f(\alpha)$ | $E(\alpha)$ | $E(W_1^\prime)$ |
| Car            | 2.5     | 1         | 35.25$Q_B$       | 2.5     | 1.3       | 39$Q_B$       |
| Refrigerator   | 2       | 0.9       | 71.95$Q_B$       | 0.5     | 2         | 120$Q_B$      | 100$Q_B$       |

Figure 1 shows the impact of the different callbacks on the total cost expectancy in the automotive industry, reflecting the total cost expectations and synergies between the recalled peak season and the recalled off-season replacement part supplier, recycler, and assembly manufacturer changes in cost expectations; Figure 2 shows the impact of the different recovery volumes on the total cost expectancy in the refrigerator industry, reflecting the total cost of the recall and the off-season replacement parts suppliers, flagship stores and appliance repair services, and the total cost of synergies The trend of change of expectation. It can be seen that the total cost of the firm in the cooperative state is lower than in the non-cooperative state, so the above model is assumed to be true. When the parts suppliers (replacement parts suppliers), car repair shop (flagship store) and 4S shop (home appliance repair service department) share information and effective collaboration, the parties can be clear each other's supply quantity and delivery time. They will reduce the holding cost of replacement parts or recovery part and reduce the shortage cost and reorder cost due to a shortage of replacement part.

Figure 1. The impact of different callbacks on total cost expectations in automobile industry
Figure 2. The impact of different callbacks on total cost expectations in refrigerator industry

6. Conclusion
In this paper, in the case of product recall channel and supply channel fixed, the specific structure and function expression of cost are analyzed according to the peak season and off-season of recall activities, and whether the assembly manufacturer, supplier and recycler are cooperated situation, respectively, to build the total cost of the function model.

1) When the assembly manufacturer, suppliers and recyclers share information and co-supply, the three can clear each other's supply and delivery time, it will effectively reduce production costs.

2) The recall activities have a significant difference at the recall peak season and off-season. At the peak season, the demand in the terminal market fluctuates greatly, and it is difficult to obtain relatively accurate forecast results. Compared with the recall of the off-season, due to the recovery of the reserves, replacement part out of stock, re-purchase of replacement part to bring new costs.

3) Assume that consumer product returns are subject to uniform distribution, which is somewhat different from the reality. The article does not consider whether the replacement part supplier will be able to meet the re-order of the assembly manufacturer in the peak season. In the follow-up study, gradually reduce the restrictions, more thinking the replacement part supplier and recycler in advance delivery, etc. So that the relevant enterprises to better participate in the collaborative process, play a greater role in collaborative supply.

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