Research Article
Contingent Strategies to Backup Food Supplier Chain Management Based on Disruptions

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Abstract: In this study, food supply chain disruption management strategies involving food supply management strategies, demand management strategies, product management strategies and information management strategies are analyzed and then a strategy system is constructed. Also, in order to offer decision-making support for adopting reasonable food supply chain disruption management strategies, an optimization model is developed. It presents four information acquirement models, including perfect information model, advance-acquirement information mode, post-acquirement information and missing information model.

Keywords: Food supply chain, perfect information model, strategy system

INTRODUCTION

As the food supply chain system spans more and more countries and its structure becomes more and more complex, plenty of uncertainties appear. Contemporary food supply chain management technology and thinking focuses on Lean Manufacture, Just in Time, Zero Inventory and so on, which brings great success, but also results in the food supply chain more vulnerable to various disruptions (Hou, 2013). In fact, when a disruption occurs, many food supply chains are forced to stop the normal businesses and some even go bankrupt. With the rapid development of modern information technology, globalization of economy and global competition, the dynamics, complexity and uncertainty of the food supply chain environment increases, which makes the food supply chain often interrupted and the environmental quality deviate from steady state easily (Sheffi, 2002). Those increase the uncertainties of operational process of food supply chain and then make the food supply chain is often vulnerable to various disruptions (Tomlin, 2009). Therefore, considering that it is difficult to avoid the occurrence of disruptions, it is necessary to develop the theory of food supply chain disruption management and discuss on how to make the food supply chain rapid recovery to normal operation after the food supply chain is influenced by a disruption (Tang and Kouvelis, 2011). The large number of well-publicized food supply-chain disruptions in recent years has heightened awareness of the significant risks posed by food supply failure and the need for effective disruption-management strategies (Wu *et al.*, 2013). Extreme weather disasters continued deterioration of the global environment brought about and political conflicts caused by man-made terrorist incidents often occur, which have brought tremendous shock for normal operations of many companies (Sting and Huchzermeier, 2010). Under the complicated and changeable environment, the characteristics of cross-regional and multi-link among food supply chain participants make the food supply chain easily influenced by many unexpected events from the external environment and internal system, resulting in food supply disruption (Sheng and Ji, 2008).

On the basis option theory, we investigate how to improve the operational performance of food supply chain by enabling backup supplier and obtaining disruption information in advance. Assuming price-dependent demand, we study a single-product setting in which a food supply retailer can source from two suppliers, one is a strategic supplier facing food supply disruption and another is a backup supplier of complete reliable but more expensive. According to the sequence of the interrupt information acquisition, four decision models are explored with perfect information model, advance-acquirement information mode (Lv *et al.*, 2011), post-acquirement information and missing information model. We examine the order quantity, preserved capacity amount and the optimal profit in different modes and explore the impact of strategic supplier reliability coefficient and the potential market capacity on the food supply retailer's optimal expected profits.

We also analyze and compare the impact of the backup supplier and food supply disruptions information acquirement on operation performances of food supply chain. The research conclusions are as follows:

- When a strategic supplier's reliability coefficient increases, the food supply retailer's decisions also transform from only using backup supplier, using

both strategic supplier and backup supplier, to using only strategic supplier.

- The effect of backup supplier is reduced with the increases of reliability coefficient.
- The earlier the information is available, the higher the profit of food supply retailer.
- Under different information acquirement models, the optimal profits of the food supply retailer reduce successively.
- The information value is significant when reliability coefficient is on the medium, while the information value is lower when reliability coefficient is close to 0 or 1.
- The value of information is more sensitive to reliability coefficient but less sensitive to potential market capacity.
- In most cases, strategic supplier's order quantity and backup supplier's reservation capacity is only related to their costs and have nothing with the other party's cost.
- Optimal profit increases with the reliability coefficient as well as potential market capacity and it will increase faster and faster.

MATERIALS AND METHODS

Model assumptions: Based on option theory, we study a two-stage food supply chain with two suppliers leading by one food supply retailer. Operational performance in four decisions mode is explored based on food supply disruption information. The strategic supplier is in the face of food supply disruption and the backup supplier is completely reliable without capacity constraints. In Fig. 1, firstly, food supply retailer to the backup supplier ordering predetermined capacity of K, that is, pre-process options. Then to the strategic supplier ordering Q, finally to the backup suppliers ordering K_1 (strategic supplier without disruption food supply) or K_2 (strategic supplier in disruption food supply state) in the capacity constraint conditions, this is option execution process. Strategic supplier acquisition food supply disruption information sooner or later can be divided into four modes, perfect information model, advance-acquirement information mode, post-acquirement information and no information model.

Model parameters:

- Food supply retailer orders Q from strategic supplier. In the event of disruption for strategic supplier the food supply retailer received nothing; otherwise the actual delivery is all of Q, i.e., food supply uncertainty of strategic supplier is of "all-or-noting" type. We consider the probability of food supply disruptions is $(1-\gamma)$, the probability of food supply normal state is γ, called by the reliability coefficient, with $0<\gamma<1$.
- Food supply retailer pays the unit cost of λc when ordering the strategic supplier, $0\leq\lambda\leq1$. Then food supply retailers pay $(1-\lambda)c$ when food supply state is normal and no longer pay in food supply disruption state. $\lambda>0$ mainly applied to purchase bio-pharmaceutical products or other special products (Sheng and Ji, 2008). $\lambda = 1$ represents the strategic supplier is the food supply retailer internal corporate, $\lambda = 0$ represents the strategic supplier is the food supply retailers outside enterprise, $0<\lambda<1$ represents equity investments or mutual relationship between supplier and food supply retailer.
- Food supply retailer reserves capacity K from backup supplier, the unit cost is c_o. Then according to the delivery from the strategic supplier the food supply retailer determines the executive quantity under the reservation constraint. Food supply retailer orders k_1 from backup supplier when strategic supplier in normal state and order k_2 when strategic supplier in disruption state. The unit execution cost from backup supplier is c_e, with $c<c_o+c_e$.
- Based on strategic supplier state and backup supplier capacity constraints, food supply retailer determines the executive order from backup supplier. Food supply retailer orders k_1 from backup supplier when strategic supplier is in normal state and orders k_2 when strategic supplier is in disruption state.
- Customer demand is dependent on the sales price, thus inverse demand function is $p = a-bQ$, a, b are both greater than 0. Assuming $a>c_o+c_e$.

In addition, the superscript * indicates optimal value, superscript' represents one derivative and superscript "denotes second derivative. Subscript P, A, N and C, respectively represent post-acquirement information, advance-acquirement information, missing information and perfectly information.

| Capacity reservation K from backup supplier | Order quantity Q from primary supplier | Order execution of k_1 or k_2 from backup supplier |

sequence

C modle A model P model N model

The information reveal about supply disruptions or not for the primary supplier (yes/no)
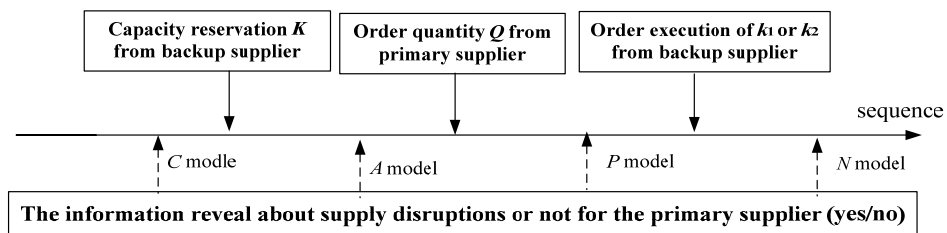
Fig. 1: Emergency decision based on backup supplier and food supply disruption information

Operation performance of food supply disruptions under missing information: Under missing information N model, food supply retailer doesn't know entirely the condition of food supply disruption to strategic suppliers, order from strategic suppliers and backup suppliers and then to learn that whether strategic suppliers can normally delivery. Then N model is converted to the dual-source purchasing mode where food supply retailer sources from unreliable supplier and reliable supplier:

$$\max \pi(Q,K) = \gamma[(a-b(Q+K))(Q+K)-cQ-c_eK]$$
$$+(1-\gamma)[(a-bK)K-c_eK-\lambda cQ]-c_oK$$
$$= \gamma[(a-b(Q+K))(Q+K)-cQ]$$

- If $\gamma \geq \dfrac{\lambda c}{c_e+c_o-c+\lambda c}$ $(c_e+c_o \geq c+(1-\gamma)\lambda c/\gamma)$

Then:

$$Q^* = \frac{a-c-(1-\gamma)\lambda c/\gamma}{2b} - K^* \qquad (1)$$

$$K^* = [\frac{a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma)}{2b}]^+ \qquad (2)$$

○ If $\gamma < \dfrac{a+\lambda c-c_e-c_o}{a+\lambda c-c}$ $(a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma) > 0)$

Then:

$$K^* = \frac{a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma)}{2b} \qquad (3)$$

$$\pi_N^* = \frac{\gamma[a-c-(1-\gamma)\lambda c/\gamma]^2+(1-\gamma)[a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma)]^2}{4b} \quad (4)$$

○ If $\gamma \geq \dfrac{a+\lambda c-c_e-c_o}{a+\lambda c-c}$ $(a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma) \leq 0)$

Then:

$$K^* = 0 \qquad (5)$$

$$\pi_N^* = \frac{\gamma[a-c-(1-\gamma)\lambda c/\gamma]^2}{4b} \qquad (6)$$

- If $\gamma < \dfrac{\lambda c}{c_e+c_o-c+\lambda c}$ $(c_e+c_o < c+(1-\gamma)\lambda c/\gamma)$

Then:

$$Q^* = 0 \qquad (7)$$

$$K^* = \frac{a-c_e-c_o}{2b} \qquad (8)$$

$$\pi_N^* = \frac{[a-(c_e+c_o)]^2}{4b} \qquad (9)$$

Theorem 1: Under missing information N model, food supply retailer faces three kinds of mode selection: Only use Strategic suppliers (Model S), only use the Backup supplier (Model B) and use Strategic suppliers and Backup suppliers at the same time (Model SB).

Proof: When $c_e+c_o \geq c+(1-\gamma)\lambda c/\gamma$ and $a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma) > 0$, using model SB; When $c_e+c_o \geq c+(1-\gamma)\lambda c/\gamma$ and $a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma) \leq 0$, no longer use backup suppliers and only use strategic suppliers; When $c_e+c_o < c+(1-\gamma)\lambda c/\gamma$, no longer use strategic suppliers and only use backup suppliers.

Theorem 2: Missing information N mode is similar to post acquirement information P mode with upfront cost to strategic supplier, when the strategic supplier reliability coefficient is smaller. But when the reliability coefficient is larger, model P is superior to model N.

Proof: When $\gamma < \dfrac{\lambda c}{c_e-c+\lambda c}$, missing information N mode is same to post acquirement information P mode with upfront cost to strategic supplier. But when $\gamma \geq \dfrac{\lambda c}{c_e-c+\lambda c}$ and $a-c_e-c_o/(1-\gamma) > 0$:

$$\pi_P^* = \frac{\gamma[a-c-(1-\gamma)\lambda c/\gamma]^2+(1-\gamma)[a-c_e-c_o/(1-\gamma)]^2}{4b}$$

$$\pi_N^* = \frac{\gamma[a-c-(1-\gamma)\lambda c/\gamma]^2+(1-\gamma)[a+\lambda c-(c_e+c_o-\gamma c)/(1-\gamma)]^2}{4b}$$

Now, $\pi_P^* > \pi_N^*$. This difference is the value of food supply disruption information in advance. Because the strategic supplier reliability coefficient is larger, the role of strategic supplier is bigger, especially when strategic suppliers is in normal and food supply retailer doesn't executes reserved option capacity, all delivered from strategic suppliers.

Theorem 3: Based on the sequel to acquire strategic supplier's interrupt information, we can obtain $\pi_C^* \geq \pi_A^* \geq \pi_P^* \geq \pi_N^*$.

Proof: Model A is equivalent to model P ignoring strategic supplier's upfront costs. Model A tend to be converted to model C and so $\pi_C^* \geq \pi_A^* \geq \pi_P^*$. From theorem 2, we can get $\pi_P^* \geq \pi_N^*$. The difference between profits is the value of interrupt information acquirement in advance.

Theorem 4: In most cases, strategic supplier's order quantity and backup supplier's reservation capacity is only related to their own costs and have nothing with

the other party's cost. When strategic supplier's ordering quantity satisfies $Q^* \leq [a - c - (1-\gamma)\lambda c / \gamma]/(2b)$, strategic supplier's ordering quantity and backup supplier's reservation capacity are associated with the cost of the other party.

Proof: As under the *P* model, only when $c_e + c_o \geq c + (1-\gamma)\lambda c / \gamma$, $c_e < c + (1-\gamma)\lambda c / \gamma$ and $a + \lambda c - (c_e + c_o - \gamma c)/(1-\gamma) > 0$, then $Q^* = \dfrac{a - c - (1-\gamma)\lambda c / \gamma}{2b} - K^*$

$K^* = \dfrac{a + \lambda c - (c_e + c_o - \gamma c)/(1-\gamma)}{2b}$. Strategic supplier's order

quantity and backup supplier's reservation capacity are associated with the cost of the other party.

RESULTS AND DISCUSSION

Decision choice of four food supply chain operations modes: Suppose a two-stage food supply chain consisting of one food supply retailer and two suppliers in which a strategic supplier is unreliable and a backup supplier is reliable, with $a = 200$, $b = 5$, $c = 20$, $\lambda = 0.2$, $c_o = 12$, $c_e = 25$. Then the unit loss of the unsatisfied demand is $\lambda c = 4$, retail price is $p = 200-5Q$, the total cost for the backup suppliers is $c_o + c_e = 37$. In the case of strategic supplier reliability coefficients γ for different values, the food supply retailer optimal profits under four different modes are as shown in Table 1. where,

$$\rho_1 = c_e - c - (1-\gamma)\lambda c / \gamma$$

$$\rho_2 = c_e + c_o - c - (1-\gamma)\lambda c / \gamma$$

$$\tau_2 = a - c_e - c_o /(1-\gamma)$$

$$\tau_1 = a + \lambda c - (c_e + c_o - \gamma c)/(1-\gamma)$$

$$\tau_3 = a - (c_e + c_o - \gamma c)/(1-\gamma)$$

$$\pi_S^* = \gamma \frac{(a - c - (1-\gamma)\lambda c / \gamma)^2}{4b}$$

Tendency analysis of operation performance under different decision-making modes: Figure 2 show the variation of optimal profit with reliability coefficient γ, a and c_o in the four model. Where a is assigned from 40 to 220 and a special case of $\gamma = 0.7$:

- With the increase of reliability coefficient γ for strategic supplier, the food supply retailer's optimal expected profits all increase in four models. This is because with the increase of γ, the probability of food supply disruptions decreases, with the losses reducing.

- Four modes have different sensitivity of γ. When $\gamma = 0$ and $\gamma = 1$, the optimal profits in four modes are equal, because strategic supplier is in disruption when $\gamma = 0$, then food supply retailer only chooses backup supplier as the single source and when $\gamma = 1$, the food supply retailer choose the strategic supplier as the single source. When $0 < \gamma < 1$, π_C^* linearly increases in γ; π_A^*, π_P^* and π_N^* increases at convex, i.e., increasing faster and faster.

- The value of access to food supply disruption information about strategic supplier reflects in the difference of optimal profits between different modes. Some value exiting in $0 < \gamma < 1$ makes the difference maximum, at $\gamma = 0.8$ in *P* and *N* mode, at $\gamma = 0.5$ in *A* and *P* mode and at $\gamma = 0.9$ in *C* and *A* mode. That is to say as the reliability coefficient is larger in $0 < \gamma < 1$, the value of information is relatively larger. When the food supply retailer chooses strategic supplier and backup supplier at the same time, disruption information played the biggest role. When γ is smaller or larger, the food supply retailer chooses single-sourcing, the value of information is very small.

The food supply retailer's optimal profit π_C^*, π_A^*, π_P^* and π_N^* convex increase in potential market capacity a. At the same value of a, $\pi_C^* \geq \pi_A^* \geq \pi_P^* \geq \pi_N^*$, but they are in little difference between π_A^*, π_P^* and π_N^*, that is to say the sequel of disruption information acquirement have little impact on profits. The information value is more obvious in *C* mode.

Table 1: The tendency of optimal expected profit π of food supply retailer with the reliability coefficient γ

| γ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
ρ_1	-31.0	-11.0	-4.3	-1.0	1.0	2.3	3.3	4.0	4.6
ρ_2	-19.0	1.0	7.7	11.0	13.0	14.3	15.3	16.0	16.6
τ_1	165.1	162.8	159.7	155.7	150.0	141.5	127.3	99.0	14.0
τ_2	161.7	160.0	157.9	155.0	151.0	145.0	135.0	115.0	55.0
τ_3	161.1	158.8	155.7	151.7	146.0	137.5	123.3	95.0	10.0
π_C^*	1357.6	1386.8	1415.9	1445.1	1474.2	1503.4	1532.5	1561.7	1590.8
π_A^*	1338.1	1348.0	1358.2	1368.8	1380.0	1392.5	1407.4	1428.3	1473.1
π_P^*	1328.5	1328.5	1329.7	1332.5	1344.4	1363.9	1385.9	1413.9	1465.9
π_N^*	1328.5	1328.5	1329.7	1332.5	1336.9	1343.9	1355.7	1379.7	1451.8
π_S^*	103.7	269.0	436.9	605.5	774.4	943.4	1112.5	1281.6	1450.8
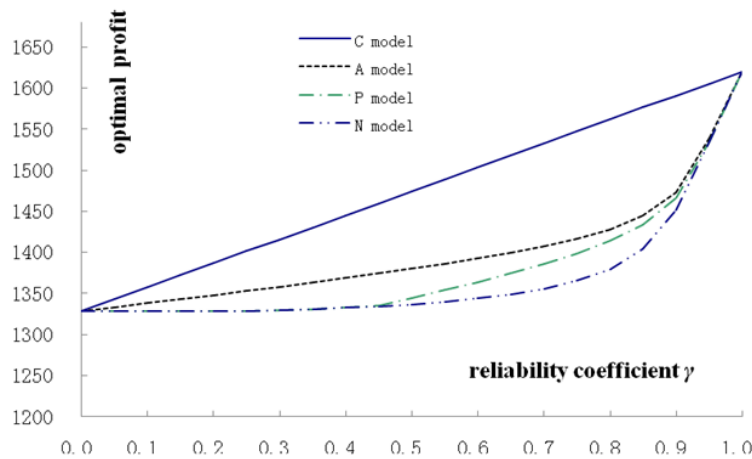
Fig. 2: Variation of optimal profit with respect to the reliability coefficient γ

CONCLUSION

In this study, we assume that the price depends on demand, without considering the impact of customer psychology and purchasing behavior on demand and price changes. We do not examine the impact of external free food supply market. The reliability coefficient of strategic suppliers is assigned a constant value, ignoring the influence of the randomness of the reliability coefficient on operation performance. All of these are the future research.

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