A Novel Multi-Objective Programming Model Based on Transportation Disruption in Supply Chain with Insurance Contract

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Abstract. Supply chain risk management is becoming increasingly a hot research issue. When the disruption occurs, insurance can be used to reduce the risk. In this paper, we set a novel multi-objective programming model based on transportation disruption in supply chain with insurance contract in order to protect the whole supply chain members. Then use a case to investigate the applicability of this model. From this mathematical model, we obtain the optimal order quantity and the pure premium, which can help the manufacture and the retailer make a better plan. And the insurance can protect the manufacturer and the retailer's profits. In the future, the insurance will be used in supply chains widely.

Keywords: Supply chain risk management · Transportation disruption · The optimal order quantity

1 Introduction

Since the 21st century, with the global procurement, non-core business outsourcing, and development of business models in supply chain management, such as the lean management, the space distance on the supply chain becomes longer and longer, while the time distance becomes shorter. The change of the temporal and spatial variation of the supply chain improves the possibility of an interrupt occurance. Every firm's supply chain is susceptible to a diverse set of risks, such as natural disasters, terrorism, war, financial crisis, supplier bankruptcy and transportation delays. A lot of strategies used by firms to mitigate disruption risks include emergence purchases, multi-sourcing, inventory reserve and some reliability improvement of supply process [6]. The awareness regarding the importance of supply chain risk management (SCRM) has grown in the recent years. Supply chains are becoming increasingly competitive and complex in order to effectively meet customer demands. Supply chain disruptions often lead to declining sales, cost increases, and service failures for the company. There are several kinds of mode of supply chain disruptions. Different scholars have different classifications for it. It can be clearly seen in Table 1.

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Table 1. The classifications of supply chain disruption

Year	Author	Classification
2013	Hishamuddin [3]	Supply disruption, transportation disruption
2015	Nooraie [7]	Financial risk, transportation disruption
2015	Heckmann [2]	Financial risk, demand disruption
2016	S. Tong [8]	Node disruption, chain disruption

Transportation disruption, in particular, is slightly different from other forms of SC disruptions, in that it only stops the flow of goods, whereas other disruptions may stop the production of goods as well. The transportation disruption of the supply chain is a non-negligible factor that it can reduce the manufacturer and the retailer's profits. For instance, in October 2000, two typhoons damaged the oil gas pipeline belonging to Shanghai Petroleum Natural Gas Co., Ltd. in China, leading to a 178-days service disruption of oil gas. Terrorist attacks on the world trade center on September 11, 2001, causing a stagnation of goods which came from the border of America. This led to a force to the Ford motor company to stop production activities temporarily. In March 2011, an earthquake happened in Japan, which caused 22 automobile manufacturing companies' shutdown, such as Toyota, Honda, nissan. Affected by the earthquake the Japanese exports of cars fell 12.5% in April compared with the year 2010, being the biggest drop since the 18 months. As you can see from the above cases, transportation disruption caused by emergency events not only leads manufacturers to stop production, but also brings irreparable damages to the downstream enterprises of the supply chain. Furthermore, a transportation disruption may affect the condition of the valuable goods in transit.

Once transportation interrupts, it has a great influence for each member on the supply chain, leading to transport delay, increasing the transportation time and the transportation cost, even bringing serious damage to related companies. Although realizing that there is a disruption risk in the supply chain, most of the enterprises in the aspect of risk management of supply chain disruptions have very little money and resources. To make sure for the firm's profit, we tend to make the insurance strategy according to the degree of risk. Purchasing an insurance for the emergency is a kind of protection for enterprises. The model that we have developed in this research addresses this vital aspect of transportation disruption.

This paper proposes a newly multi-objective programming model for a supply chain system subject to transportation disruption. In this model, we consider the insurance contract to deal with the transportation disruption risk.

The contents of this paper are organized as follows. Section 2 presents the related literature review. A description of the model and its formulation are given in Sect. 3. Section 4 shows the analysis of numerical example. Section 5 provides a conclusion of this paper and offers potential directions for future research.

2 Literature Review

There is a great deal of literature on supply chain. In recent years, the research in supply chain disruption is becoming a hot spot. Disruption has the characteristics of low probability of occurrence and big influence on the part of the supply chain, even the whole supply chain. Many scholars classified the types of supply chain disruption, and provided several operational strategies for managing disruption. But there are few papers which are mentioned the insurance to solve the risks.

Our study is related to studies focusing on the transportation disruption in supply chain. Zhen et al. [9] investigated four strategies: basic strategy, BI insurance strategy, backup transportation strategy, and mixed strategy, in order to deal with distribution centers' daily risk management. They used the mathematic model to compare BI insurance strategy with backup transportation strategy, and found that the choice of BI insurance strategy and the backup transportation strategy depended on transportation market, insurance market and distribution center's operational environments. Hishamuddin et al. [3] built a recovery model for a two-echelon serial supply chain when transportation disruption occurred. This model determined the optimal ordering and production quantities with the recovery window, and ensured the minimum total relevant costs. They developed an efficient heuristic to solve the problem. In 2015, they developed a simulation model of a three echelon supply chain system with multiple suppliers subject to supply and transportation disruptions [4]. The objective of the paper is to examine the effects of disruption on the system's total recovery costs. Hernn et al. [1] provided a novel simulation-based multi-objective model for supply chains with transportation disruptions, aiming to minimize the stochastic transportation time and the deterministic freight rate.

In this paper, we apply a novel multi-objective programming model for supply chain with transportation disruption. We reference about the method of calculating profit of Lin's paper [5] to study the problem of the manufacturer and retailer's profit when there is a transportation disruption. And we introduce the insurance contract to the model.

3 System Description and Modeling

In the following subsections, we address the system's description of the model. Then present the mathematical representation of the model.

3.1 System Description

In this study, we consider a single supply chain model which has a manufacturer and a retailer. We assume that the information between them is symmetrical. The manufacturer has production, while the retailer has inventory. Before the selling season, the manufacturer and the retailer agree on an insurance contract, but the retailer needs to pay part fees to the manufacturer. And the premium is decided by the insurance company. In our model, we assume that the transportation disruption occurs in the delivery from the manufacturer to the retailer, which interrupts the timely delivery of goods to the retailer. The transportation disruption may be caused by an accident or a natural disaster, such as a earthquake, or flood. In addition, the goods in transit may or may not be damaged during the disruption. Because of the transportation disruption, the insurance contract comes into action.

In this paper, we use a multi-objective programming model to solve the problem. The notations are explained as follows:

Denotes

m: represent the manufacturer;
r: represent the retailer;
I: represent the insurer;
D: the market demand;
π_m: the expected profit of the manufacturer;
π_r: the expected profit of the retailer.

Parameters

x: a random variable presenting the market demand D;
c: a unit cost of the product provided by the manufacturer;
w: a wholesale price that the manufacturer charges the retailer;
p: a retail price that the retailer serves the customers;
h: the shortage cost per unit;
c_t: the transport cost per unit;
s: the salvage value of any unsold product per unit;
α: the retailer's share of losses generated by the deviation of his order quantity from the market demand, and $\alpha \in [0,1]$, so the manufacturer's share is $1-\alpha$;
P: the pure premium that the insurer guarantees to pay the manufacturer with the transportation interruption insurance, and it's set by the insurer;
R: the rate of the pure premium to pay to the insurer;
β: the ratio that the retailer takes from the compensation, and $\beta \in [0,1]$, so the manufacturer takes $(1-\beta)$L;
$f(x)$: probability density function with the market demand D;
$F(x)$: cumulative density function with the market demand D.

Decision variable

q: an order made by the retailer and the manufacturer based on their forecast of the market demand D.

3.2 Model Formulation

When the transportation disruption occurs, the manufacturer and the retailer's expected profit will be decreased. But with the insurance contract, this situation can be mitigated. So the objective of the insurance contract is to maximize their profit. The objective functions are given as follows:

$$\begin{aligned}\max \pi_m =&(w-c)q - qc_t - (1-\alpha)\left[\int_0^q (p-s)(q-x)f(x)dx\right.\\&\left.+\int_q^\infty h(x-q)f(x)dx\right] - PR + (1-\beta)P.\end{aligned} \tag{1}$$

Objective function (1) maximizes the manufacturer's expected profit, where $(w-c)q$ is the earnings of the product for the manufacturer with the order quantity from the retailer, qc_t is the cost of transportation, $\int_0^q (p-s)(q-x)f(x)dx + \int_q^\infty h(x-q)f(x)dx$ is the expected losses generated by the deviation of the retailer's order quantity from the market demand, and PR is the cost of the manufacturer paying to the insurer.

$$\begin{aligned}\max \pi_r =&(p-w)q - \alpha\left[\int_0^q (p-s)(q-x)f(x)dx + \int_q^\infty h(x-q)f(x)dx\right]\\&+\beta P.\end{aligned} \tag{2}$$

Objective function (2) maximizes the retailer's expected profit, where $(p-w)q$ is the earnings of the product for the retailer while the assumption is that the whole product can be sold out. When the transportation disruption happens, the retailer can get a compensation βP. When the transportation disruption happens, the insurance contract belongs to the third party liability insurance, and its rate is usually a fixed value.

In order to guarantee the integrity of the model, there are constraints as follows:

$$0 < s < c < w < p. \tag{3}$$

If the product have not been sold off, the salvage value of the unsold product s is less than its cost. This is equivalent to a kind of punishment for the exceed quantity. And to make sure for the manufacturer and the retailer's profit, the relationship of unit cost c, the wholesale price w and the retail price p need to be $c < w < p$.

$$0 < h < w. \tag{4}$$

The shortage cost h is less than the wholesale price w.

$$P \geq qc. \tag{5}$$

The purpose to purchase the insurance contract is to minimise the manufacturer and the retailer's profit, so the pure premium P is not less than the cost of the product.

$$alpha \in [0,1], \tag{6}$$

$$beta \in [0,1], \tag{7}$$

where α is the proportion of the expected losses, and β is the proportion of the pure premium.

3.3 Global Model

From the formulation above, a multi-objective model under transportation disruption for the supply chain has been deducted. The aims are to maximize the profit of the manufacturer and the retailer. The global model is given:

$$\begin{aligned}
\max \pi_m =&(w-c)q - qc_t - (1-\alpha)\left[\int_0^q (p-s)(q-x)f(x)dx \right.\\
&\left. + \int_q^\infty h(x-q)f(x)dx\right] - PR + (1-\beta)P \\
\max \pi_r =&(p-w)q - \alpha\left[\int_0^q (p-s)(q-x)f(x)dx \right.\\
&\left. + \int_q^\infty h(x-q)f(x)dx\right] + \beta P \\
s.t. &\begin{cases} 0 < s < c < w < p \\ 0 < h < w \\ P \geq qc \\ \alpha \in [0,1] \\ \beta \in [0,1]. \end{cases}
\end{aligned} \tag{8}$$

Theorem 1. *The optimal order quantity for the supply chain system will achieve the maximum only if the following condition is satisfied:*

$$\alpha^* = \frac{p-w}{p-c-c_t}. \tag{9}$$

Proof. With the insurance contract, the system's expected profit is

$$\begin{aligned}
\max \pi = \max \pi_m + \max \pi_r = (p-c-c_t)q - &\left[\int_0^q (p-s)(q-x)f(x)dx \right.\\
&\left. + \int_q^\infty h(x-q)f(x)dx\right] - PR + P,
\end{aligned} \tag{10}$$

$$\frac{\partial \pi}{\partial q} = p - c - c_t - [(p-s+h)F(q) - h] = 0. \tag{11}$$

Through the function of $\max \pi_m$ and $\max \pi_r$, we can acquire the optimal order quantity q_m^* and q_r^* solving the following equation:

$$\frac{\partial \pi_m}{\partial q} = w - c - c_t - (1-\alpha)[(p-s+h)F(q) - h] = 0, \tag{12}$$

$$\frac{\partial \pi_r}{\partial q} = p - w - \alpha[(p-s+h)F(q) - h] = 0. \tag{13}$$

Then the optimal order quantity is

$$q^* = F^{-1}\left[\frac{p-c-c_t+h}{p-s+h}\right]. \tag{14}$$

The the optimal order quantity of the manufacturer and the retailer is showed by:

$$q_m^* = F^{-1}\left[\frac{(1-\alpha)h + w - c - c_t}{(1-\alpha)(p - s + h)}\right], \tag{15}$$

$$q_r^* = F^{-1}\left[\frac{\alpha h + p - w}{\alpha(p - s + h)}\right]. \tag{16}$$

Generate Eq. (9) into Eqs. (15) and (16), then we can get $q_m^* = q_r^* = q^*$. So only when $\alpha^* = \frac{p-w}{p-c-c_t}$ is established, the order quantity is to the most optimal value. □

4 Numerical Analysis

In this section, we examine the model by numerical analysis. The data was obtained from the Lin's paper [5], which assumed that the market demand followed uniform distribution $D \sim [400, 500]$. The other parameters were as follows: $p = 18$, $w = 15$, $c = 12$, $s = 8$, $h = 3$, $\beta = 0.6$, $R = 15\%$, and $c_t = 1$.

Take the data into the formulations, and draw the trend chart Fig. 1, which shows that the manufacturer's optimal order quantity increases as α increases, while the retailer's optimal order quantity decreases as α increases.

Let $q_m^* = q_r^*$, then we get $\alpha^* = \frac{p-w}{p-c-c_t} = 0.6$. We can find $\alpha^* = 0.6$ from Fig. 1 that proves the model. And from Fig. 1, we can see that the crossing is the optimal order quantity q^* as Table 2, which is equal to 461. This is the best quantity for them. So the pure premium is not less than 5532, and the purchase to the insurer needs to be 830.

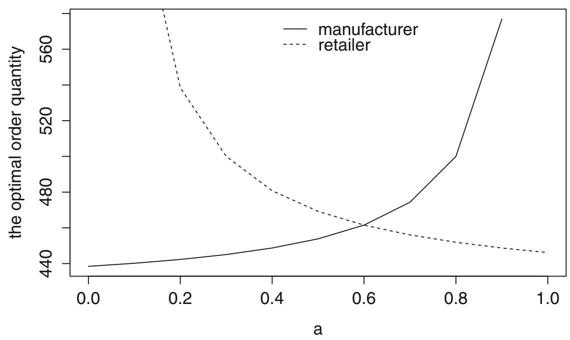

Fig. 1. The effects of α on the optimal order quantity

Table 2. The quantity under different α

Decision	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
m	438.46	440.17	442.31	445.05	448.72	453.85	461.54	474.36	500	576.92	∞
r	∞	653.85	538.46	500	480.77	469.23	461.54	456.04	451.92	448.72	446.15

5 Conclusion

In this paper, we describe the transportation disruption in supply chains. We set a mathematical model which we introduce the insurance contract to deal with transportation disruption the way from the manufacturer to the retailer, and use a case to investigate the applicability of this model. Although the insurance contract is effective in coordinating the supply chain, it also has some limitations. The most critical limitation is that the supplier incurs an administrative cost in monitoring the retailer's sales situation. The objective of the study is to determine the optimal order quantity in the case of the uncertainty of the market demand. This insurance contract transfers the risk from the manufacturer and the retailer to the insurance company, which protects the manufacturer and the retailer's profits and improves the efficiency of the supply chain. In particular, how much to purchase the insurance is discussed in this paper. The model is useful for decision makers to determine the product quantity.

There are several directions for this study to continue. We can extend the model to a complex supply chain with multiple manufacturers or retailers. In addition, we can apply different strategies to deal with transportation disruption.

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