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# An order allocation model in logistics service supply chain based on the pre-estimate behaviour and competitive-bidding strategy

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In previous studies on the order allocation of the supply chain, suppliers involved in order allocation are expected to accept orders passively. However, in the actual order allocation process of logistics service supply chain (LSSC), functional logistics service providers (FLSPs) are strategic. They will pre-estimate the order allocation results to decide whether or not to participate in order allocation. Besides, FLSPs will compete for orders by bidding strategy when there are more than one FLSP in order allocation. Therefore, it is necessary to introduce the pre-estimate behaviour and competitive-bidding strategy of FLSPs into the study of order allocation in LSSC. In this article, the pre-estimate behaviour and competitive-bidding strategy are considered and the bidding range of each FLSP is obtained. It is assumed that the logistics service integrator (LSI) allocates the order sequentially to FLSPs from the lowest price to highest price. Then, a multi-objective dynamic programming model with the objectives of the cost of LSI and the order satisfaction of FLSPs is built. Numerical analysis is followed to discuss the effects of some parameters on the order allocation results. Research shows that the quote of a FLSP only depends on its own cost and the highest industry cost but irrelevant to the industry lowest cost when considering competitive-bidding strategy of FLSPs; besides, too low or too high in industry cost affects the performance of order allocation; furthermore, pre-estimate behaviour and competitive-bidding strategy of FLSPs can help reduce the order allocation cost of LSI and improve the performance of LSSC. In the end, an example of Tianjin Baoyun Logistics Company is used to introduce the order allocation process of logistics service when Baoyun considers pre-estimate behaviour and competitive-bidding strategy of FLSPs, which helps to illustrate the application of model conclusions.

**Keywords:** logistics service supply chain; order allocation; pre-estimate behaviour; competitive-bidding strategy; rational expectations equilibrium (REE)



## 1. Introduction

Service supply chain (SSC) is a new trend in supply chain research (Ellram, Tate, and Billington 2004), whereas logistics service supply chain (LSSC) is a type of SSC centred on the cooperation of logistics service capacity (Liu, Ji, and Zhang 2006; Choy et al. 2007). The main structure of the LSSC is the mode where the functional logistics service providers (FLSPs) flow to the logistics service integrator (LSI) and then to the manufacturers or retailers (Choy et al. 2007; Liu et al. 2011). FLSPs consist of traditional functional logistics enterprises, such as transportation and storage enterprises, among others, whose service function is simple and standardised, and the business is limited within a certain area; they are integrated as the suppliers by the LSI when a domestic or international logistics service network is established. For instant, as a LSI, Baogong logistics company in China integrates over 500 warehousing companies and 1200 highway transport companies as his FLSPs to provide personalised logistics services for many world famous companies such as P&G and Unilever.

In general, a LSI always has many FLSPs. After receiving the order from the customers, LSI allocates it to FLSPs, and FLSPs provide the corresponding logistics service capacity to fulfil the logistics service order. We call this process 'order allocation', and the model established is known as the order allocation model. Lummus, Vokurka, and Alber (1998) pointed out that the capacity allocation decision is one of the most important decisions of supply chain strategies. When faced with a number of FLSPs, the way the LSI allocates the order rationally is critical to the long-term stability of the LSSC (Liu et al. 2011).

Many empirical studies have shown that actual individual behaviour has a significant impact on operation decisions in the operation management system. Thus, innovative research with behaviour operation management theory is

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necessary (Bendoly, Donohue, and Schultz 2006). It is found that previous studies on order allocation model pay no attention to the pre-estimate behaviour and competitive-bidding strategy of FLSPs; however, the two behaviours may have influences on order allocation results. For one hand, in previous studies, suppliers involved in the order allocation always accept orders passively; however, in the actual order allocation process, they will consider the profit and the possibility of getting the order before participating in order allocation (Liu, Ge, and Yang 2013). The strategic pre-estimate behaviour of FLSPs has such an important influence on the results of order allocation that we must consider it in later study. For the other hand, there are more than one FLSP participating in order allocation, quotes of FLSPs are relative not only to their cost but also to other FLSPs' quotes. So, competitive-bidding strategy should also be considered to explore its effects on order allocation.

Recently, some researchers focus on order allocation in service supply chain (especially in LSSC) (Liu et al. 2011; Yang, Qi, and Wei 2011; Liu, Ge, and Yang 2013) and consider the effect of behaviour parameters in their studies. The paper closest to ours is Liu, Ge, and Yang's (2013), which introduced the pre-estimate behaviour of FLSPs in order allocation process and discuss the influence of FLSPs' behaviour on allocation results, but not covered bidding strategy of FLSPs. On the basis of Liu, Ge, and Yang (2013), the competitive-bidding strategy of FLSPs is introduced in order allocation modelling. Through our study, the following important issues would be discussed.

(1) The bidding strategy of FLSPs has an important influence on the results of order allocation. How to describe this behaviour using the quantitative method and embody it in order allocation modelling?
(2) What is the difference in results when only considering one behaviour of FLSPs (pre-estimate behaviour or competitive-bidding strategy) in order allocation modelling compared with considering two behaviours together?
(3) There are many parameters affecting FLSPs' quotes, what impact laws will these parameters bring to the order allocation results?
(4) How does LSI utilise the order allocation model and its results to improve the performance of LSSC better?

This study has some important findings. The behaviours of pre-estimate and competitive-bidding strategy of FLSPs can help reduce the order allocation cost of LSI and improve the performance of LSSC. The quote of FLSP, which is irrelevant to the industry lowest cost (ILC), only depends on his own cost and the highest industry cost. Furthermore, too low or too high industry cost affects the performance of order allocation.

This paper is organised as follows. Section 2 presents the literature review. Section 3 is problem description and some important assumptions. In Section 4, a multi-objective dynamic programming model of order allocation in LSSC is established based on the pre-estimate behaviour and competitive-bidding strategy of FLSPs. In Section 5, numerical analysis is performed to observe the effects of competitive-bidding strategy on order allocation. Main conclusions and management implications are obtained in Section 6. In Section 7, an example of Tianjin Baoyun logistics company is used to illustrate the application of model conclusions. The last section presents the limitations and future research directions.

## 2. Literature review

This paper mainly involves three fields: order allocation in the supply chain, bidding strategy and the pre-estimate behaviour. So, we will begin by reviewing the research literature relating to these three fields.

### 2.1 *Supply chain order allocation*

The problem of how to allocate orders to the proper suppliers tends to be an important topic, especially in case of the multiple-supplier environment. Many works have been taken on this issue since 1990s. Many papers have discussed the principle of supplier selection (Demirtas and Üstün 2008; Amin, Razmi, Zhang 2011; Arikan 2013). Current studies on the order allocation of supply chain (Chan, Humphreys, and Lu 2001; Menon and Schrage 2002) mainly consider the maximal order service level and the minimum procurement cost, and mostly focus on the order allocation of the manufacturing industry. Wadhwa and Ravindran (2007) built a multi-objective mixed integer programming model with the objective of simultaneous minimisation of production price, lead-time and rejected total number. Razmi and Maghool (2009) proposed a fuzzy bi-objective model for supplier selection in multiple periods under capacity constraint and budget limitation. In the case of multiple-supplier, quite a few literatures first select suppliers, then allocate orders to selected suppliers (Mendoza and Ventura 2008; Swaki 2010; Amin, Razmi, and Zhang 2011). For example, in the paper of Amin, Razmi, and Zhang (2011), the fuzzy logic, triangular fuzzy numbers and SWOT analysis are applied in the context of supplier selection, and then a fuzzy linear programming model is proposed to determine how much should be purchased from each supplier.

Order allocation is an optimization problem; numerous studies (Kawtummachai and Hop 2005; Liu et al. 2011; Pan et al. 2011) have solved this problem using a multi-objective programming method, such as multi-objective integer programming (Demirtas and Üstün 2008) and 0–1 planning (Xiang, Huang, and Wang 2006). When the models are complicated, intelligent optimization techniques have the potential to provide effective solutions for complicated combinatorial optimization problems due to their heuristic nature. Various intelligent algorithms have been developed and employed in production decision-making, such as tabu search (Cesaret, Oguz, and Salman 2012), simulated annealing (Loukil, Teghem, and Fortemps 2007), genetic algorithm (Engin, Ceran and Yilmaz 2011), ant colony algorithm (Xing et al. 2010) and hybrid intelligent algorithms (Guo, Wong, and Leung 2013), in which GA is the most commonly used.

As a new trend of in supply chain research, SSC has been concerned by more and more practitioners and scholars. *Journal of Supply Chain Management* published a special issue on SSC in October 2012, which covered some new progress in SSC, such as Tate and Ellram (2012), Sampson and Spring (2012), Oflaç, Sullivan, and Tunçdan (2012) and Maull, Joana, and Robert (2012). With the emergence of SSC research, studies on the order allocation of SSC have been given much attention. Liu et al. (2011) presented a multi-objective planning model for the emergency order allocation of LSSC and then used numerical methods to identify the properties of the model. Liu, Ge, and Yang (2013) introduced pre-estimate behaviour of FLSPs in order allocation process and discuss the influence of FLSPs' behaviour on results. Liu, Liu, and Ge (2013) used cumulative prospect theory to build order allocation model and analyse its effects on the performance of LSSC. These researches on SSC provide an important reference for this article.

### 2.2 *Bidding strategy*

In the competitive environment, in order to maximise individual profit, participants compete against each other in order allocation process. Bidding strategy is a common way. An article entitled with 'A Competitive-Bidding Strategy' published by Lawrence Friedman in 1956 starts the academic researches on bidding strategy, which has been one of the most important field in building economy. Competition among bidders mainly embodies in the tender offer. Auction theory is commonly used in bidding strategy, in which game analysis is used to determine the optimal bid price. Among auction theory, the first-price sealed auction is relatively simple. In this auction, the bid prices of bidders are sealed into envelopes and offered to auction party at the same time, the highest bidder wins the bid finally. In this case, the bid maximising the bidder's expected revenue is the optimal bidding strategy. In addition, the British auction (Kosmopoulou, Dakshina, and Slive 2007) and the Dutch auction (Li and Kuo 2011) are also commonly used in the practical application of the auction strategy. For example, Dutch auctions have also been found in cloth sales (Crawford and Kuo 2003), plant sales (Katok and Roth 2004), vehicle slot sales and initial public offerings (Robicheaux and Herrington 2007).

In the order allocation of LSSC, LSI allocates the order in terms of the quotes of FLSPs, and FLSPs with a lower quote usually get more orders. Thus, the bidding strategy could be employed to determine the optimal bid for FLSPs to maximise the expected profit. However, bidding strategy is rarely seen in the order allocation researches; so in later section, bidding strategy will be used to get the optimal bid of FLSPs.

### 2.3 *Rational expectations and rational expectations equilibrium*

Initially proposed by Muth in 1961, the rational expectations hypothesis has been widely applied in economics. The rational expectations hypothesis suggests that no systematic bias should emerge between economic operation results and people's expectations (Qi, Yang, and Liu 2010). Recently, the rational expectations hypothesis has been applied in supply chain management, especially in contact coordination, in which the rational expectations of both cooperation partners are consistent with actual operation results (i.e. rational expectations equilibrium (REE) exists). Some scholars have introduced the REE into supply chain management, such as the REE between upstream and downstream supply chain (Su and Zhang 2008), the REE analysis on the newsvendor model (Du 2009) and supply chain pricing (Qi, Yang, and Liu 2010; Wang, Zhang, and Zheng 2011; Yang et al. 2011). However, the REE is still not applied to the order allocation of supply chain, especially in LSSC. The existing studies on order allocation have not considered the impact of the pre-estimate behaviour of FLSPs on supply chain decision-making. Nevertheless, the behaviour of participants in supply chain, especially pre-estimate behaviour, plays a significant role in operation management (Bendoly, Donohue, and Schultz 2006). Therefore, in this article, the REE is applied to the order allocation problem to explore the effects of the pre-estimate behaviour of FLSPs on LSSC order allocation, which provides a reference for the LSI to manage the supply chain scientifically.

Literature review shows that existing studies on order allocation ignore the pre-estimate behaviour of supply chain members and the influence of competitive-bidding strategy among FLSPs on supply chain decisions, but these two factors really exist in actual operations of LSSC. Therefore, introducing these two factors to order allocation has more practical value. For this reason, this paper establishes an order allocation model with the objectives of the total cost of LSI and the order satisfaction of FLSPs, considering pre-estimate behaviour and competitive-bidding strategy of FLSPs. Based on the order allocation model, we explore the effects of pre-estimate behaviour and competitive-bidding strategy on order allocation.

## 3. Problem formulation and assumptions

In this paper, a two-echelon LSSC consisting of one LSI and $n$ FLSPs is considered. FLSPs compete with each other for getting more orders. Before the LSI allocates orders, each FLSP gives the quote of his unit logistics service. Assume that the service level of FLSPs has no difference, when allocating orders to FLSPs, LSI only considers the price of logistics service provided by FLSPs. So, LSI allocates the order sequentially to FLSPs from the lowest price to highest price until all the orders are allocated.

Generally, FLSP has strategic behaviour namely pre-estimate behaviour before cooperating with the LSI. Therefore, FLSP will not accept the order passively. It will estimate the possibility of acquiring the orders firstly, then decide whether or not to participate in the order allocation. Meanwhile, LSI will make order allocation decisions after considering the pre-estimate behaviour of FLSPs.

It is assumed that the total logistics service demand is $R$, and the order quantity of the $i$th FLSP allocated by LSI is $x_i$. In addition, the capacity of each FLSP is independent. Considering the uncertainty of customer demand, $R$ is assumed to be a random variable following the normal distribution $N(\mu, \sigma^2)$.

The notations used in this model are listed in Table 1.

Table 1. Notations for the model.

| Notation | Description |
|---|---|
| $n$ | The number of FLSP |
| $U_i$ | The utility of the $i$th FLSP |
| $v_i$ | The expected revenue of the unit logistics capacity of the $i$th FLSP |
| $c_i$ | The operation cost of the unit logistics capacity of the $i$th FLSP |
| $c_{fi}$ | The fixed cost of the $i$th FLSP participating in order allocation |
| $\varepsilon_i$ | The expected discount coefficient of the $i$th FLSP |
| $\Psi_i$ | The competitiveness of the $i$th FLSP |
| $b_i$ | The unit logistics capacity quoted price of the $i$th FLSP |
| $\zeta_i$ | The expected probability of the $i$th FLSP getting orders |
| $\beta_i$ | The order meeting degree by the logistics capacity of the $i$th FLSP |
| $\kappa_i$ | The business reputation of the $i$th FLSP |
| $Q_i$ | The logistics capacity of the $i$th FLSP |
| $p_i$ | The unit logistics service price of LSI offering to the $i$th FLSP |
| $R$ | The total logistics service demand from customer |
| $C_L$ | The industry lowest cost of providing unit logistics service |
| $C_H$ | The industry highest cost of providing unit logistics service |
| $R_s$ | The quantity of orders unallocated |
| $a_i$ | The coefficient describing the linear relationship between $b_i$ and $c_i$ |
| $e_i$ | The coefficient describing the linear relationship between $b_i$ and $c_i$ |
| $d_{i1}$ | The quantity satisfaction of the $i$th FLSP |
| $d_{i2}$ | The price satisfaction of the $i$th FLSP |
| $d_i$ | The order allocation satisfaction of the $i$th FLSP |
| $v_i^0$ | The lowest income of unit logistics capacity acquired by the $i$th FLSP if he participates in order allocation |
| $d_{i2}^0$ | The initial price satisfaction of the $i$th FLSP |
| $w_{i1}$ | The weight of quantity satisfaction of the $i$th FLSP |
| $w_{i2}$ | The weight of price satisfaction of the $i$th FLSP |
| $s_k$ | The quantity of orders that can be allocated in the $k$th stage |
| $t_k$ | The price range of logistics service in the $k$th stage |
| $f_k^1(s_k, t_k)$ | Total cost of LSI in the $k$th stage |
| $f_k^2(s_k, t_k)$ | Order satisfaction of FLSPs in the $k$th stage |
| $f_k(s_k, t_k)$ | The synthetic objective function which is the performance of LSSC in the $k$th stage |

## 4. Model building

In this section, a multi-objective dynamic programming model of order allocation in LSSC is established based on pre-estimate behaviour and bidding strategy of FLSPs. In Section 4.1, two constraints of the model are proposed. In Section 4.2, satisfaction objective function of FLSP is presented. In Section 4.3, a multi-objective dynamic programming model on order allocation is given. The model solution method is also put forward in Section 4.3.

### 4.1 *Constraints of the model*

#### 4.1.1 *FLSPs' total capacity constraint*

The logistics service demand $R$ from customer is uncertain; in order to study conveniently, let $prob(\sum_{i=1}^{n} x_i \geq R) = \alpha$ represent the opportunity constraint of the total capacity provided by FLSPs, where $\alpha$ represents the probability of meeting customer demand. For example, when $\alpha = 90\%$, the total capacity of FLSPs can meet at least 90% of customer demand. According to Liu et al. (2011), the uncertain constraint can be transformed into certain one, so the total capacity of FLSPs should meet the following condition:

$$\sum_{i=1}^{n} x_i = \mu + \Phi^{-1}(\alpha)\sigma \tag{1}$$

where $\Phi^{-1}(\alpha)$ is the inverse function of standard normal distribution $\Phi(x)$.

#### 4.1.2 *Order price constraint*

Considering pre-estimate behaviour and competitive-bidding strategy of FLSPs, the order price constraint of each FLSP is obtained.

4.1.2.1 *Pre-estimate behaviour of FLSPs.* In the order allocation process, FLSPs will pre-estimate the order allocation results according to their logistics service capacity and the order demand from LSI. Participating in order allocation, the $i$th FLSP will be faced with two conditions: getting an order or not. When getting an order, the utility of FLSP equals to the revenue of providing logistics services capacity minus logistics operation cost and fixed cost; when getting no order, the utility of the FLSP is equal to the negative of the fixed cost of participating in order allocation. The utility function $U_i$ can be expressed as follows:

$$U_i = \begin{cases} (v_i q_i - c_i q_i) - c_{fi} & \text{if } ith \text{ FLSP gets the order} \\ -c_{fi} & \text{if } ith \text{ FLSP gets no order} \end{cases} \tag{2}$$

where $v_i$ represents expected revenue of the unit logistics capacity of the $i$th FLSP.

$q_i$ represents the expected order quantity of the $i$th FLSP getting from the LSI, and $q_i = \frac{\varepsilon_i}{n} Q_i$. $Q_i$ is the logistics capacity of the $i$th FLSP; $\varepsilon_i$ denotes the ratio of the $i$th FLSP's logistics capacity adopted by the LSI, and $0 < \varepsilon_i \leq 1$, which indicates that the service capacity of FLSP may not be entirely used; $n$ denotes the number of FLSPs involved in order allocation, as FLSPs compete with each other, $q_i$ decreases with number of FLSPs involved in order allocation.

$c_i$ is the operation cost of unit logistics capacity of the $i$th FLSP.

$c_{fi}$ represents the fixed cost of the $i$th FLSP participating in order allocation.

Another feature of the pre-estimate behaviour of FLSPs can be described as: when participating in order allocation, the $i$th FLSP will give an expected probability of getting the order. Assuming that the expected probability for the $i$th FLSP to get the order is $\zeta_i$, $\zeta_i$ is associated with the competitiveness $\Psi_i$, the degree to which the self-logistics capacity satisfies the order, $\beta_i$, and business reputation $\kappa_i$, $\kappa_i \in (0, 1)$.

$$\zeta_i = \kappa_i \beta_i \Psi_i \tag{3}$$

$\Psi_i$ and $\beta_i$ can be expressed as Equations (4) and (5) :

$$\beta_i = \frac{Q_i}{R} \tag{4}$$

$$\Psi_i = \frac{C_L}{b_i} \tag{5}$$

Equations (3–5) show that the FLSPs with a larger capacity and higher business reputation can expect a greater probability of getting the order, and FLSPs with higher quotes will have a lower expected probability.

According to Equation (2), we can conclude that to ensure the $i$th FLSP to participate in order allocation, the utility of FLSP must be positive, i.e. $\zeta_i[(v_i q_i - c_i q_i) - c_{fi}] + (1 - \zeta_i)(-c_{fi}) \geq 0$. Substituting Equations (3–5) into Equation (2), it will get Equation (6).

$$v_i \geq \frac{c_{fi}}{\zeta_i q_i} + c_i = \frac{nc_{fi}b_i R}{\kappa_i \varepsilon_i C_L Q_i^2} + c_i \tag{6}$$

According to the REE, no systematic bias should emerge between economic operation results and people's expectations. So, the unit logistics capacity price offered by LSI equals to the expected revenue of unit logistics capacity provided by FLSP, and the unit logistics capacity quoted price of the FLSP equals to his expected revenue of unit logistics capacity, which can be presented as:

$$p_i = v_i, \;\; bi = v_i \tag{7}$$

Substituting Equation (7) into Equation (6), the following equation can be easily obtained:

$$p_i \geq c_i + \frac{nc_i c_{fi} R}{C_L \kappa_i \varepsilon_i Q_i^2 - nc_{fi} R} \tag{8}$$

Equation (8) is lowest price constraint of FLSP when FLSP participates in order allocation.

4.2.1.2 *Competitive-bidding strategy of FLSPs.* It is assumed $c_i$ obeys a uniform distribution denoted as $c_i \sim U\,[C_L, C_H]$. When competing with the $j$th FLSP for getting more order, the utility function of the $i$th FLSP is:

$$U_i = \begin{cases} (b_i - c_i)\min(Q_i, R_s) & b_i < b_j \\ (b_i - c_i)\min\left(Q_i, \dfrac{R_s}{2}\right) & b_i = b_j \\ (b_i - c_i)\min(Q_i, \max(R_s - Q_j, 0)) & b_i > b_j \end{cases} \tag{9}$$

where in Equation (9), $b_i$ and $b_j$ stand for the quotes of FLSP $i$ and $j$, $Q_i$ and $Q_j$ stand for the logistics capacity of FLSP $i$ and $j$, $R_s$ is the quantity of orders unallocated.

If cost-plus pricing method is used by FLSP for bidding strategy, let $b_i(c_i) = a_i + e_i c_i (a_i \geq 0,\, e_i > 0,\, b_i > c_i > 0)$, $a_i$ and $e_i$ are coefficients describing the linear relationship between $b_i$ and $c_i$. As $c_i \sim U\,[C_L, C_H]$, then we can get $b_i \sim U\,[a_i + e_i C_L,\, a_i + e_i C_H]$. In the case of continuous distribution, the probability of two FLSPs giving the same quote is zero, so Equation (9) can be rewritten as:

$$U_i^* = \max[(b_i - c_i)\min(Q_i, R_s) prob(b_i < b_j) + (b_i - c_i)\min(Q_i, \max(R_s - Q_j, 0)) prob(b_i > b_j)] \tag{10}$$

Make first-order derivative of Equation (10) and set to 0, the expression of optimal quote $b_i$ is obtained as Equation (11). The detail derivation process could be seen in Appendix 1.

$$b_i = \frac{c_i + C_H}{2} \tag{11}$$

According to Equation (11), the optimal quote $b_i$ of FLSP $i$ depends on his own unit operation cost and the industry highest unit cost.

Based on the assumption in Section 3, when there are more than two FLSPs who participate the order allocation, LSI will allocate the order sequentially to FLSPs from the lowest price to highest price. Therefore, the quote game will exist in two FLSPs with adjacent quotes; Equation (11) is still valid when there are more than two FLSPs.

Combining the Equations (8) and (11), the price constraint of each FLSP $i$ is obtained as Equation (12).

$$\frac{c_i C_L \kappa_i \varepsilon_i Q_i^2}{C_L \kappa_i \varepsilon_i Q_i^2 - nc_{fi} R} \leq \; p_i \leq \frac{c_i + C_H}{2} \tag{12}$$

### 4.2 *Objective functions of the model*

There are two objective functions in order allocation model: the total cost of LSI and the satisfaction of FLSPs. For the total cost of LSI, it equals to the outsource cost, that is $\sum_{i=1}^{n} p_i x_i$. For the satisfaction of FLSPs, the detail building processes are shown as below.

The satisfaction of the $i$th FLSP is composed of quantity satisfaction $d_{i1}$ and price satisfaction $d_{i2}$, $d_{i1}$ and $d_{i2}$ can be defined as:

$$d_{i1} = \begin{cases} \dfrac{Q_i}{x_i} & x_i > Q_i \\ \dfrac{x_i}{Q_i} & x_i \leq Q_i \end{cases} \tag{13}$$

$$d_{i2} = d_{i2}^0 + \frac{p_i - v_i^0}{b_i - v_i^0}(1 - d_{i2}^0) \tag{14}$$

where in Equation (14), $v_i^0 = \frac{c_i C_L \kappa_i \varepsilon_i Q_i^2}{C_L \kappa_i \varepsilon_i Q_i^2 - n c_{fi} R}$ denotes the lowest revenue of unit logistics capacity acquired by the $i$th FLSP participating in the $j$th order allocation. $d_i2^0$ is the initial price satisfaction of the $i$th FLSP when the price offered by LSI is $v_i^0$.

Let $w_{i1}$ denote the quantity satisfaction weight of the $i$th FLSP and $w_{i2}$ denote the price satisfaction weight, which satisfies $w_{i1} + w_{i2} = 1$, the specific value of $w_{i1}$ and $w_{i2}$ can be obtained through a questionnaire. The final order allocation satisfaction of the $i$th FLSP can be described as:

$$d_i = w_{i1} d_{i1} + w_{i2} d_{i2} \tag{15}$$

### 4.3 *Multi-objective dynamic programming model on order allocation in LSSC*

As described above, the order allocation model established in this paper is as follows:

Objective functions:

$$\min f_1 = \sum_{i=1}^{n} p_i x_i \tag{16}$$

$$\max f_2 = \frac{1}{n} \sum_{i=1}^{n} (w_{i1} d_{i1} + w_{i2} d_{i2}) \tag{17}$$

Subject to:

$$\begin{cases} \sum_{i=1}^{n} x_i = \mu + \Phi^{-1}(\alpha)\sigma \\ \dfrac{c_i C_L \kappa_i \varepsilon_i Q_i^2}{C_L \kappa_i \varepsilon_i Q_i^2 - n c_{fi} R} \leq p_i \leq \dfrac{c_i + C_H}{2} \end{cases} \tag{18}$$

$f_1$ is the objective that minimises the total cost of the LSI and $f_2$ is the objective that maximises the satisfaction of FLSPs.

According to the assumption above, LSI allocates the order to FLSPs from the lowest price to the highest price, which can be seen a dynamic programme process with $n$ stages (the process of allocating order to one FLSP could be seen as one stage). So, the multi-objective programming model described in Equations (16–18) can be solved using dynamic programming method.

The model above is a multi-objective programming problem. Given the incompatibility and incommensurability among the goals of multi-objective decision-making problems, it is difficult to find an absolutely optimal solution. At present, special solutions have been developed for solving the multi-objective uncertainty issue, such as evaluation function methods (including linear weighting method, reference target method and maximum-minimum method), goal programming method, layered sequential method, interactive programming method, etc. In this article, linear weighted method is adopted to solve this multi-objective problem. Firstly, give a certain weight to each objective function, and then integrate all objective functions into a single objective function by linear weight. For example, in this paper, there are two objective functions: total cost function and satisfaction function, and their weight are $\lambda_1$ and $\lambda_2$, $\lambda_1, \lambda_2 \geq 0, \lambda_1 + \lambda_2 = 1$, then the single objective function is obtained as $\max F = -\lambda_1 f_1 + \lambda_2 f_2$ ($f_1$ is a minimum objective, so its weight coefficient is negative).

As each objective function may have different dimensions, their results should be normalised. For example, in the order allocation model presented in this article, two objective functions – the total cost of LSI, the satisfaction of FLSPs – are different in dimension, so each of them has to be normalised. Let $\bar{f_1} = -\frac{\min f_1}{f_1}, \bar{f_2} = \frac{f_2}{\max f_2}$. Therefore, the multi-objective dynamic programming model on order allocation can be expressed as:

Overall objective function:

$$\max F = \lambda_1 \bar{f_1} + \lambda_2 \bar{f_2} \tag{19}$$

Recurrence equation:

$$\begin{cases} F_k = \max(\lambda_1 \bar{f}_{1k} + \lambda_2 \bar{f}_{2k} + F_{k-1}) \\ f_{1k}(s_k, t_k) = \min\limits_{x_k \in D_1, p_k \in D_2} (x_k p_k + f_{1(k-1)}(s_{k-1}, t_{k-1})) \\ f_{2k}(s_k, t_k) = \max\limits_{x_k \in D_1, p_k \in D_2} (w_{k1} d_{k1} + w_{k2} d_{k2} + f_{2(k+1)}(s_{k-1}, t_{k-1})) \\ f_{1(n+1)}(s_{n+1}, t_{n+1}) = 0, \quad k = 1, 2, 3 \cdots n. \end{cases} \tag{20}$$

State transition equation:

$$s_{k+1} = s_k - x_k, \ s_1 = R, \quad k = 1, 2, 3 \cdots, n \tag{21}$$

Decision set:

$$\begin{aligned} & D_1(s_k, x_k) = \{x_k | 0 \leq x_k \leq s_k\} \\ & D_2(t_k, p_k) = \left\{ p_k \left| \frac{c_k C_L \kappa_k \varepsilon_k Q_k^2}{C_L \kappa_k \varepsilon_k Q_k^2 - n c_{fk} R} \leq p_k \leq \frac{c_k + C_H}{2} \right. \right\} \end{aligned} \tag{22}$$

where in Equation (21), $x_k$ and $p_k$ are decision variables, $x_k$ denotes the quantity of order allocated to the FLSP in the $k$th stage, while $p_k$ is the price of unit logistics service in the $k$th stage. ($s_k$, $t_k$)is a state variable, $s_k$ denotes the quantity of order that can be allocated in the $k$th stage, while $t_k$ is the price range of unit logistics service in the $k$th stage. $f_{1k}(s_k, t_k)$ denotes the cost offered to the $k$th FLSP and $f_{2k}(s_k, t_k)$ denotes the satisfaction of the $k$th FLSP.

It should be noted that overall objective function F makes a comprehensive consideration of the total cost of LSI and the satisfaction of FLSPs, which can be viewed as the comprehensive performance of LSSC. A bigger value of $f_k(s_k, t_k)$ indicates a better performance of the LSSC.

## 5. Numerical analysis

In this section, a numerical analysis of the model is presented in order to explore several properties and get some important management conclusions. As the effect of pre-estimate behaviour of FLSPs has been studied by Liu, Ge, and Yang (2013), we will focus on the effects of FLSPs' competitive-bidding strategy.

The order allocation results of the model are provided in Section 5.1. To further examine the allocation results, the effect of industry cost level and FLSP's own cost are investigated. More details are provided in Sections 5.2 and 5.3, respectively.

It is assumed that LSI B provides transportation services to a manufacturing enterprise and allocates the orders from the manufacturing enterprise to five FLSPs ($A_1$, $A_2$, $A_3$, $A_4$ and $A_5$). In addition, the transportation service demand follows the normal distribution $N$ (130, 16), and the probability of meeting customer demand $\alpha$ is 95%, the industry cost of unit transportation service follows the uniform distribution $U$ [8, 12], i.e. $C_L$ = 8, $C_H$ = 12, $c_{fi}$ = 1. Considering that the total cost of LSI and the satisfaction of FLSPs are of the same importance, let $\lambda_1 = \lambda_2 = 0.5$. The other parameters of $A_1$, $A_2$, $A_3$, $A_4$ and $A_5$ are shown in Table 2.

### 5.1 *Comparison of allocation results in different cases*

Order allocation results of the multi-objective dynamic model (Case C) are presented in Table 3. To better observe the changes brought by pre-estimate behaviour and competitive-bidding strategy of FLSPs to order allocation results, the results that only consider pre-estimate behaviour (Case A) or bidding strategy (Case B) as well as the results without

Table 2. Some parameters of FLSPs.

| FLSP | $c_i$ | $\kappa_i$ | $Q_i$ | $w_{i1}$ | $w_{i2}$ | $d_{i2}^0$ | $\varepsilon_i$ |
|---|---|---|---|---|---|---|---|
| $A_1$ | 10.0 | 0.80 | 40 | 0.4 | 0.6 | 0.70 | 0.8 |
| $A_2$ | 8.0 | 0.70 | 35 | 0.5 | 0.5 | 0.55 | 0.9 |
| $A_3$ | 8.8 | 0.90 | 30 | 0.3 | 0.7 | 0.75 | 0.7 |
| $A_4$ | 11.0 | 0.60 | 50 | 0.6 | 0.4 | 0.80 | 0.9 |
| $A_5$ | 10.6 | 0.85 | 40 | 0.65 | 0.35 | 0.90 | 0.8 |

pre-estimate behaviour and bidding strategy (Case D) are also explored, respectively. Compare Case C with other three cases, we can have a clear understanding of the influence of the pre-estimate behaviour and bidding strategy.

#### 5.1.1 *Effect of pre-estimate behaviour*

Observing and comparing the data in Table 3, some interesting conclusions can be found. In Case D, neither pre-estimate behaviour nor competitive-bidding strategy is considered in order allocation, LSI concerns with optimising his own profit when making order allocation decision. Thus, the total cost of LSI is lowest in four cases; however, the satisfaction of FLSPs and the comprehensive performance of LSSC are the lowest. It may combat the enthusiasm of FLSPs' participation in order allocation and affect the subsequent cooperation. Therefore, Case D is rarely applied in actual order allocation.

Comparing the data in Case A and Case D, we find that after considering the pre-estimate behaviour of FLSPs, the satisfaction of FLSPs has a relatively large rise while the total cost of LSI also increase, but the comprehensive performance of LSSC has a small increases. It indicates that the introduction of the pre-estimate behaviour of FLSPs into order allocation can improve FLSPs' satisfaction and the comprehensive performance of LSSC.

#### 5.1.2 *Effect of competitive-bidding strategy*

Comparing the results of Case B and Case D, when the competitive-bidding strategy is only considered, to satisfy the quote, request of FLSPs becomes the top priority. Consequently, the satisfaction of FLSPs is highest and the total cost raises up. In other words, competitive-bidding strategy can fully arouse the enthusiasm of FLSPs to participate in order allocation and enhance their satisfaction.

#### 5.1.3 *Combined effect of pre-estimate behaviour and competitive-bidding strategy*

If pre-estimate behaviour and competitive-bidding strategy are both considered in the model (see Case C), to balance the objective functions of the total cost of LSI and total satisfaction of FLSPs, in this case, the total cost of LSI is relatively lower and the satisfaction of FLSPs maintains a high level, the comprehensive performance of LSSC achieves the optimal. Therefore, pre-estimate behaviour and competitive-bidding strategy can improve FLSPs' satisfaction and supply chain performance by losing some profit of LSI, which is of great significance on sustainable cooperation of LSSC.

Based on the comparative analysis of Table 3, we can find that in Case C where the pre-estimate behaviour and competitive-bidding strategy of FLSPs are both considered, the total cost of LSI is relatively lower and the satisfaction of FLSPs maintains a high level. What is more, the comprehensive performance of LSSC achieves the optimal. This indicates that the pre-estimate behaviour and competitive-bidding strategy are combined to optimise the comprehensive

Table 3. Comparison of order allocation results in different cases.

| Case | Behavior considered in the model | Total cost of LSI | Satisfaction of FLSPs | Comprehensive performance of LSSC |
|---|---|---|---|---|
| A | Pre-estimate behaviour | 1102.0 | 0.781 | 0.4573 |
| B | Bidding strategy | 1151.5 | 0.814 | 0.4545 |
| C | Pre-estimate behaviour and competitive-bidding strategy | 1090.9 | 0.788 | 0.4652 |
| D | Nothing | 1007.6 | 0.6736 | 0.4407 |

performance of LSSC. Later in Section 6, we take Tianjin Baoyun Logistics Co. Ltd in China for example, and introduce how its supply chain performance of order allocation is improved under Case C.

### 5.2 *Effect of industry cost level*

As it can be seen from the order allocation model, the industry cost level $C_L$ and $C_{H,}$ affects the allocation results in a certain way that cannot be observed directly. Numerical analysis is used to explore the effects of industry lowest cost and highest cost on order allocation.

#### 5.2.1 *Effect of $C_L$ on order allocation*

Let $C_L$ vary in (6, 8.8) and keep other parameters unchanged, we observe the effect of $C_L$ on order allocation result. The results are shown in Table 4 and Figure 1.

As shown in Table 4 and Figure 1, with the increase of $C_L$, the total cost of LSI shows a trend of stepped down, which is opposite to common sense, i.e. the total cost of LSI increases with $C_L$. This is because the price lower limit of FLSP participating in order allocation, $\frac{c_i C_L \kappa_i \varepsilon_i Q_i^2}{C_L \kappa_i \varepsilon_i Q_i^2 - nc_{fi} R}$, falls down with the increase of $C_L$, the selectable range of unit

Table 4. The effect of industry lowest cost on order allocation result.

| $C_L$ | Total cost of LSI | Satisfaction of FLSPs | Comprehensive performance of LSSC |
|---|---|---|---|
| 6.0 | 1072.5 | 0.66524 | 0.4057 |
| 6.5 | 1066.5 | 0.71724 | 0.4136 |
| 6.6 | 1066.5 | 0.71724 | 0.4151 |
| 6.8 | 1066.5 | 0.71724 | 0.4151 |
| 7.0 | 1066.5 | 0.71724 | 0.4151 |
| 7.2 | 1052.4 | 0.66426 | 0.4232 |
| 7.4 | 1052.4 | 0.66426 | 0.4247 |
| 7.6 | 1052.4 | 0.66426 | 0.4247 |
| 7.8 | 1052.4 | 0.66426 | 0.4247 |
| 8.0 | 1043.4 | 0.66426 | 0.4492 |
| 8.2 | 1043.4 | 0.66426 | 0.4514 |
| 8.4 | 1043.4 | 0.66426 | 0.4514 |
| 8.6 | 1043.4 | 0.66426 | 0.4514 |
| 8.8 | 1043.4 | 0.66426 | 0.4514 |

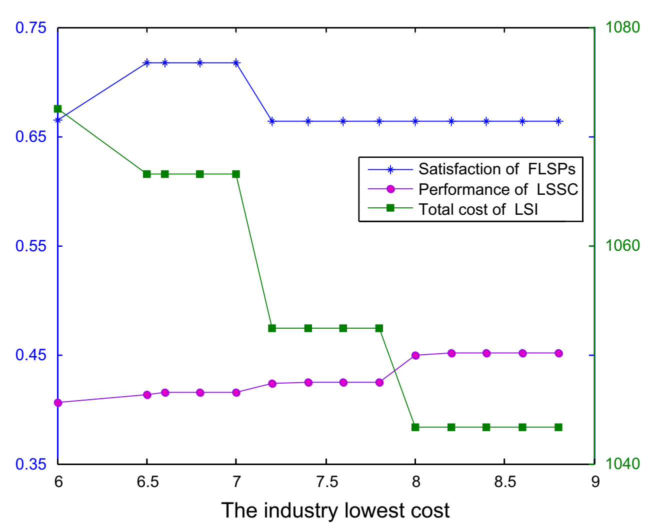


Figure 1. The effect of industry lowest cost on order allocation result.

transportation service price expanded correspondingly. So, the total cost of LSI decreases. As $C_L$ is discrete and kept one decimal place in numerical simulation, when $C_L$ changes little, $\frac{c_i C_L \kappa_i \varepsilon_i Q_i^2}{C_L \kappa_i \varepsilon_i Q_i^2 - nc_{fi} R}$ also changes little and keeps the same after rounding, the total cost of LSI does not change. Therefore, the graph of the total cost in Figure 1 shows a stepped downtrend instead of continuous decline.

According to Figure 1, the comprehensive performance of LSSC gradually increases and finally tends towards stability. Obviously, with the increase of $C_L$, firstly the total cost of LSI decreases and the satisfaction of FLSPs improve, which leads to a rise in supply chain performance; then, the total cost and the satisfaction of FLSPs maintain stability, as well as the supply chain performance. This phenomenon demonstrates that a high $C_L$ can improve supply chain performance, but the improvement does not always exist. When $C_L$ increases to a certain degree, the supply chain performance achieves optimal and remains unchanged.

### 5.2.2 *Effect of $C_H$ on order allocation*

Let $C_H$ vary in (11.4, 12.8) and keep other parameters unchanged, the effect of $C_H$ on order allocation is made. The results are shown in Table 5 and Figures 2 and 3.

As we can see in Figure 2, the satisfaction of FLSPs first increases then falls down with $C_H$. This phenomenon can be explained as follows: the quote of FLSP $b_i$ increases with $C_H$, which results in the increase of FLSPs' satisfaction; however, when $C_H$ grows to a certain value (e.g. $C_H$ = 12 in Figure 2), the total cost of LSI begins to increase, then the LSI choose to sacrifice the satisfaction of FLSPs (e.g. allocating more orders to FLSPs with lower price) for controlling the growth of total cost and achieving the maximum of comprehensive performance, so the satisfaction of FLSPs decreases.

Table 5. The effect of IHC on order allocation result.

| $C_H$ | Total cost of LSI | Satisfaction of FLSPs | Comprehensive performance of LSSC |
|---|---|---|---|
| 11.4 | 1074.1 | 0.781 | 0.5902 |
| 11.5 | 1076.9 | 0.788 | 0.5935 |
| 11.6 | 1079.7 | 0.788 | 0.5925 |
| 11.7 | 1082.5 | 0.788 | 0.5915 |
| 11.8 | 1085.3 | 0.788 | 0.5905 |
| 11.9 | 1088.1 | 0.788 | 0.5895 |
| 12.0 | 1078.9 | 0.781 | 0.5885 |
| 12.2 | 1080.5 | 0.781 | 0.5879 |
| 12.4 | 1082.1 | 0.781 | 0.5873 |
| 12.6 | 1083.7 | 0.781 | 0.5868 |
| 12.8 | 1085.3 | 0.781 | 0.5862 |
| 13.0 | 1086.9 | 0.781 | 0.5856 |

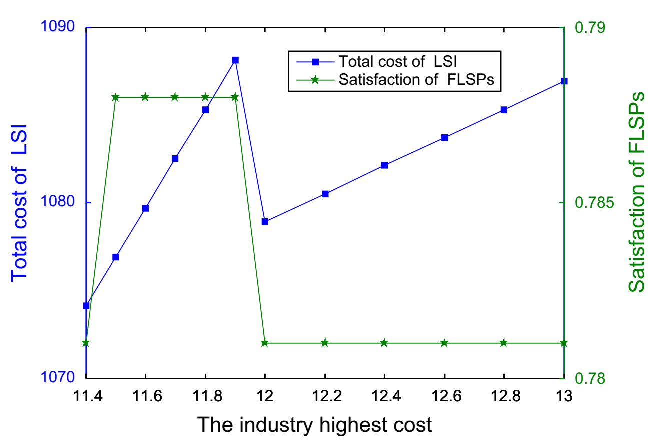


Figure 2. The effect of IHC on order allocation.

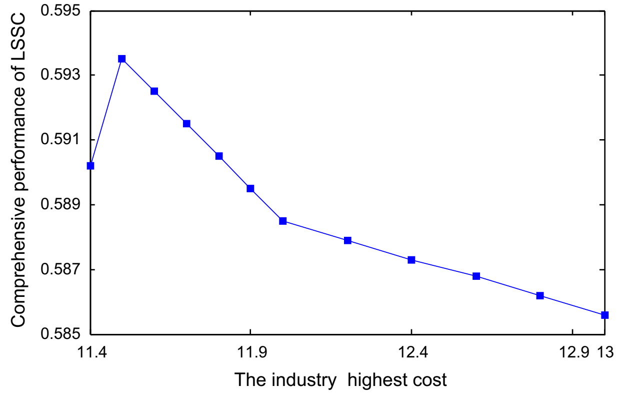


Figure 3. The effect of IHC on performance of LSSC.

The total cost of LSI presents an 'N' shape trend in Figure 2. The quote of FLSP $b_i$ increases with $C_H$, which results in the increase of total cost. When $C_H$ is higher than 11.9, LSI choose to sacrifice the satisfaction of FLSPs for controlling the growth of total cost and maximising the comprehensive performance, then the total cost falls down. When $C_H > 12$, continual reduction in satisfaction will affect the comprehensive performance of LSSC; so the satisfaction of FLSPs keeps unchanged while the total cost of LSI increases with $C_H$.

According to Figure 3, the comprehensive performance of LSSC achieves optimal at $C_H = 11.5$, where the total cost of LSI is relatively low and the satisfaction of FLSPs is high. After this point, the comprehensive performance of LSSC decreases with the increase of $C_H$. It can be concluded that appropriate level of industry highest cost can coordinate the conflict between the total cost of LSI and the satisfaction of FLSPs, and also get the maximisation of the performance of LSSC. However, too high $C_H$ brings adverse effects to order allocation, i.e. making the total cost increase and the satisfaction of FLSPs fall down, which reduces the comprehensive performance of LSSC.

### 5.3 *Effect of the cost of FLSPs*

Let the cost of one FLSP vary in $[C_L,\ C_H]$ and keep other parameters unchanged, we observe the changes in order allocation results. Take FLSP $A_4$ as an example, the results are shown in Table 6, and Figures 4 and 5.

Seen from Table 6, and Figures 4 and 5 that when $C_4 < 9.6$, the logistics service quote of FLSP $A_4$ is the lowest, FLSP $A_4$ gets priority in order allocation and the capacity of FLSP $A_4$ is fully used (the order quantity is 50) by LSI, so the satisfaction of FLSP $A_4$ is high and does not change with the growth of FLSP $C_4$.

When $9.6 < C_4 < 10.4$, the quote of FLSP $A_4$ is no longer the lowest in five FLSPs, thus the order allocated to $A_4$ declines, the total cost of LSI raises and the satisfaction of FLSP $A_4$ falls down. As the order given to other FLSPs increases, the satisfaction of all FLSPs improves.

Table 6. The effects of $C_4$ on order allocation results.

| $C_4$ | Total cost of LSI | Satisfaction of FLSPs | Comprehensive performance of LSSC | Satisfaction of $A_4$ | Order quantity of $A_4$ | Price of $A_4$ |
|---|---|---|---|---|---|---|
| 8.8 | 1080.9 | 0.788 | 0.4691 | 0.92 | 50 | 9.2 |
| 9 | 1090.9 | 0.788 | 0.4652 | 0.92 | 50 | 9.4 |
| 9.2 | 1105.9 | 0.788 | 0.4593 | 0.92 | 50 | 9.7 |
| 9.4 | 1115.9 | 0.788 | 0.4554 | 0.92 | 50 | 9.9 |
| 9.6 | 1125.9 | 0.788 | 0.4514 | 0.92 | 50 | 10.1 |
| 9.8 | 1163.8 | 0.8136 | 0.4493 | 0.748 | 29 | 10.9 |
| 10 | 1166.7 | 0.8136 | 0.4482 | 0.748 | 29 | 11.0 |
| 10.2 | 1169.6 | 0.8136 | 0.4471 | 0.748 | 29 | 11.1 |
| 10.4 | 1172.5 | 0.8136 | 0.4459 | 0.748 | 29 | 11.2 |
| 10.6 | 1156.8 | 0.8024 | 0.4458 | 0.412 | 1 | 11.3 |
| 10.8 | 1158.7 | 0.8024 | 0.4457 | 0.412 | 1 | 11.4 |
| 11 | 1158.8 | 0.7864 | 0.4377 | 0.412 | 1 | 11.5 |

Note: $C_4$ denotes the cost of FLSP $A_4$.

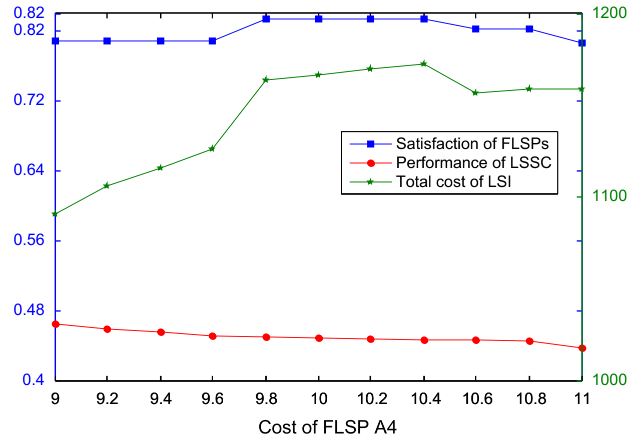


Figure 4. The effect of $C_4$ on order allocation results.

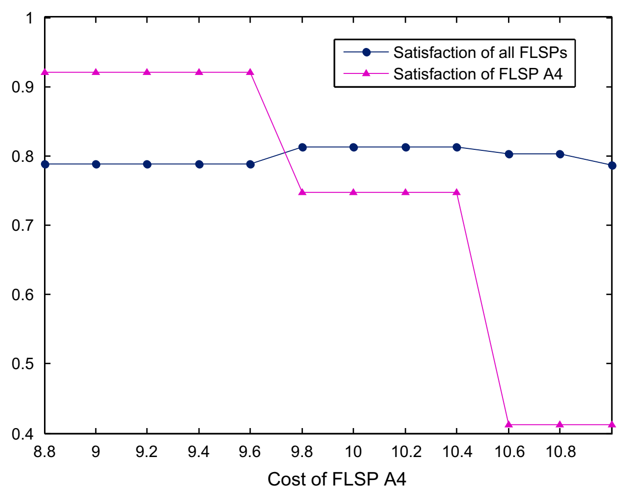


Figure 5. The effects of $C_4$ on satisfactions of all FLSPs and FLSP $A_4$.

When $C_4 > 10.4$, the quote of FLSP $A_4$ becomes the highest, LSI may cooperate with FLSP $A_4$ no longer or allocates few orders to it (e.g. one unit in Table 6), then more orders are assigned to other FLSPs, the total cost of LSI falls down and the satisfaction of other four FLSPs goes up. But, due to a marked decline in the satisfaction of FLSP $A_4$, the satisfaction of all FLSPs drops.

The comprehensive performance of LSSC keeps falling down during the whole process. It indicates that the increase of the cost of FLSP is not good for maintaining the comprehensive performance of LSSC in a higher level.

## 6. Main conclusions

Based on the numerical analysis above, we get the following important conclusions:

Firstly, after considering pre-estimate behaviour and bidding strategy of FLSPs, the results of order allocation is improved significantly, which demonstrates that pre-estimate behaviour and bidding strategy can help cut down the total cost of LSI and enhance the performance of LSSC. Consequently, LSI should fully consider the two factors when making order allocation decision.

Secondly, the quote of one FLSP depends on his cost and the industry highest cost (IHC), irrelevant to the ILC. So, LSI should pay more attention to the IHC when the order allocation decision is made.

Thirdly, the ILC is not the lower, the better. A high $C_L$ can improve supply chain performance, but the improvement does not always exist. When $C_L$ increases to a certain degree, the supply chain performance achieves optimal and remains unchanged. For IHC, there is also a value that can make the performance of LSSC achieve the optimal.

Therefore, it can be concluded that too low ILC or too high IHC will disturb the normal competition and affect the performance of LSSC.

Finally, the cost growth of FLSP not only leads to the decline of satisfaction and the order obtained, but also brings a decrease of supply chain performance. Therefore, FLSP ought to prevent the rise of cost and cut down cost to improve competitiveness in order allocation.

## 7. Application of order allocation model: an industrial case from Tianjin Baoyun logistics company in China

### 7.1 *Order allocation case from Tianjin Baoyun logistics company in China*

The order allocation model proposed in this paper has been put into practice. Tianjin Baoyun logistics company in China is one of the successful examples, whose operational experience is worth learning by many LSIs.

Tianjin Baoyun logistics Co. Ltd is a professional third-party logistics provider and also is an outstanding logistics integrator. In 2008, 2009 and 2010, the company was reputed as the Top 100 logistics enterprises in China and Top Five logistics enterprises in Tianjin city. Currently, the company has set up 28 divisions and built good collaboration relations with 32 large warehousing companies, 20 transportation companies and 15 professional logistics company. By integrating these functional logistics service providers, Baoyun has successfully established widespread business relations with more than 20 multi-national enterprises, such as P&G, Siemens, Delphi, etc. and provided personalised service according to clients' requirements.

Baoyun takes all advantages of pre-estimate behaviour and bidding strategy of FLSPs in order allocation, which help maximise FLSPs' satisfaction and minimise the total cost, thereby ensure the optimisation of supply chain performance. The main experiences of Baoyun are as follows:

(1) As an LSI, Baoyun logistics company makes full use of the competition between FLSPs to improve supply chain performance. After receiving orders from customers, informs each FLSP of the customer's logistics service requirements, and allows FLSPs to participate in the bidding. For instant, at the beginning of every year (usually in mid-January), Baoyun undertakes the logistics business of P&G in north China and opens bidding for undertaking logistics service. Before bidding, Baoyun lists the requests on quantity, operation standard and competition time required by the customer in request for proposals. According to the requests and their own logistics capacity, FLSPs design logistics service proposals to satisfy customer demand, and then submit their applications for tender to Baoyun. Only those FLSPs that meet the requirements of the customer can participate in the bidding. In addition, Baoyun discloses the service capacity and service standards of each FLSP, so FLSPs can compare each other and accurately predict the order allocation results to keep their expected discount coefficient within a reasonable range. After bidding, Baoyun sorts FLSPs in terms of their quote, and first allocates order to the FLSP with the lowest quote, then chooses FLSP with the second lowest quote until all orders are assigned. In this way, the order allocation result is reasonable with high satisfaction, and FLSPs have no reason to complain about unreasonable issues in the logistics service bidding.

(2) In the order allocation process with FLSPs, Baoyun finds that FLSPs providing different types of logistics services have different expected discount coefficients. For example, given that there are numerous road transportation enterprises in China, their price competition is fierce. As a result, in order allocation, they pay more attention to the service quantity assigned by Baoyun, and choose higher expected discount coefficients. However, warehousing enterprises in the country are relatively few, and considerable differences in warehouse facilities and service prices exist. Thus, FLSPs that provide warehousing services pay more attention to the service price set by Baoyun, and choose lower expected discount coefficients. Therefore, at every order allocation, Baoyun sets the weight of the total cost according to the rational expectations of FLSPs, so that to access maximal supply chain performance.

(3) Baoyun establishes a set of management rules on FLSPs' quote. Baoyun sets up a department of FLSP resource (DFR) that is responsible for collection, classification, sorting and management of FLSP resources. Before choosing FLSPs, DFR will give the middle, highest and lowest price of the order. As the quote of FLSPs is closely related to the IHC, DFR pays special attention to the trend of industry cost and sets the cost range of unit logistics service for every order. Specially, for long-term cooperation FLSPs, Baoyun requires them to strengthen their cost control and reduce cost so that to maintain long-term strategic partnership, and in this way Baoyun can operate the customer order in a low cost.

The successful experience of Tianjin Baoyun logistics company in order allocation proves the validity of the conclusions provided from this paper. For instance, in the process of FLSPs management, Baoyun chooses FLSPs from the lowest quote to the highest quote, and carries out transparent management in entire bidding process, which demonstrates the validity of multi-objective dynamic programming method. What is more, Baoyun considers the effect of the expected discount coefficients, and designs scientific order allocation mechanisms to ensure the rationalisation of the order allocation results. This condition also indicates that expected discount coefficient of FLSP has a significant influence on the order allocation results. The administrative rule on FSLPs' quote of Baoyun is a direct verification for the conclusion in Section 6.

### 7.2 *Management insights from the case*

The case on logistics service order allocation from Baoyun shows the great value of model building in this paper. For better cooperation between the LSI and FLSP in order allocation of LSSC, managers ought to understand the important factors that need to be considered so as to build a long-term strategic cooperative relationship with each other.

For the LSI, firstly, LSI should fully consider the pre-estimate behaviour and bidding strategy of FLSPs in order allocation, because it can help cut down the total cost of LSI and enhance the performance of LSSC. Secondly, as the quote of FLSP depends on FLSP's own cost and the IHC, and FLSP's own cost is difficult to obtain, so LSI should pay more attention to the IHC and consider them as the basis of decision. Thirdly, to cut down the total cost and enhance supply chain performance, LSI should choose FLSPs with low quote.

For FLSPs, their order quantity depends on their quotes which are associated with their costs; therefore, FLSPs must control their cost to improve their competitiveness in order allocation. In addition, FLSP with high quote may get no order, so FLSP should avoid being the one with highest price or he will be excluded from order allocation.

For the entire LSSC, to improve supply chain performance, the LSI and FLSPs should establish more stable strategic cooperative relationship and try their own efforts to make optimal decisions. For instance, the LSI should pay full attention to the pre-estimate behaviour of FLSPs and offer reasonable price for logistics service to FLSPs; FLSPs should strengthen their cost control, reduce rational expectations of acquiring order, improve their competitiveness of quotes and probability of getting orders, so as to achieve long-term cooperation with the LSI.

## 8. Research limitations and future work

In this article, an order allocation model of LSSC based on the pre-estimate behaviour and bidding competition behaviour is proposed under the uncertain customer demand. With the rational expectations equilibrium, a multi-objective dynamic programming model considering the objectives of the cost of LSI and the order satisfaction of FLSPs is built. Then, numerical analysis is followed to discuss the effects of some parameters on the order allocation results. Research shows that the behaviour of pre-estimate and bidding competition of FLSPs can help reduce the order allocation cost of LSI and improve the performance of LSSC. Too low or too high industry cost affects the performance of order allocation. In addition, FLSPs must control their cost to improve their competitiveness in order allocation. An example of Tianjin Baoyun Logistics Company is illustrated to show the application of model conclusions.

There are many limitations of this research. For example, consider one round quote game instead of multi-round game in model is considered. Price is considered as the main standard of FLSPs selection, while the non-price factors such as the capacity and business reputation are ignored. These non-price factors may influence order allocation in practice. Moreover, it is assumed that the competitiveness of one FLSP is only related with his own quote, but do not consider the effect of other FLSPs' quote. These problems can be further studied in future research.


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## Appendix 1. Proof of Equation (11)

As $prob(b_i < b_j) = 1 - prob(b_i > b_j) = 1 - prob(b_i > a_j + e_j c_j) = 1 - prob(c_j < (b_i - a_j)/e_j)$, and $c_i$ follows a uniform distribution $U[C_L, C_H]$, it is easily to get:

$$prob(b_i < b_j) = 1 - prob(c_j < (b_i - a_j)/e_j) = 1 - \frac{(b_i - a_j)/e_j - C_L}{C_H - C_L}$$

$$= 1 - \frac{b_i - a_j - C_L e_j}{(C_H - C_L)e_j} = \frac{C_H e_j - b_i + a_j}{(C_H - C_L)e_j}$$

Therefore,

$$U_i^* = \max\left[(b_i - c_i)\min(Q_i, R_s)\frac{C_H e_j - b_i + a_j}{(C_H - C_L)e_j} + (b_i - c_i)\min(Q_i, \max(R_s - Q_j, 0))\frac{b_i - a_j - C_H e_j}{(C_H - C_L)e_j}\right] \tag{1}$$

make a first-order derivative of $U_i^*$:

$$\frac{\partial U_i^*}{\partial b_i} = (-2b_i + C_H e_j + a_j + c_i)\left(\left[\frac{\min(Q_i, R_s)}{(C_H - C_L)e_j} - \frac{\min(Q_i, \max(R_s - Q_j, 0))}{(C_H - C_L)e_j}\right]\right) \tag{2}$$

Let $R$ follows a uniform distribution $U(0, m)$, then:

$$\begin{aligned} \min(Q_i, R_s) &= prob(Q_i < R_s)\cdot Q_i + prob(Q_i > R_s)\cdot R_s \\ &= \frac{m - Q_i}{m - 0}Q_i + \frac{Q_i - m}{m}R_s \\ &= \frac{(m - Q_i)(Q_i - R_s)}{m} \end{aligned} \tag{3}$$

$$\begin{aligned} \min(Q_i, \max(R_s - Q_j, 0)) &= \min(Q_i, R_s - Q_j > 0) \\ &= prob(R_s > Q_j)[prob(Q_i > R_s - Q_j)(R_s - Q_j) + prob(Q_i < R_s - Q_j)Q_i] \\ &= \frac{m - Q_j}{m}\left[\frac{Q_i + Q_j - m}{m}(R_s - Q_j) + \frac{m - (Q_i + Q_j)}{m}Q_i\right] \\ &= \frac{(m - Q_j)(Q_i + Q_j - m)(R_s - Q_j - Q_i)}{m^2} \end{aligned} \tag{4}$$

According to the Equations (2–5) is obtained.

$$\frac{\partial U_i^*}{\partial b_i} = \frac{-2b_i + C_H e_j + a_j + c_i}{(C_H - C_L)e_j} \cdot \left[\frac{(m - Q_i)(Q_i - R_s)}{m} - \frac{(m - Q_j)(Q_i + Q_j - m)(R_s - Q_j - Q_i)}{m^2}\right] = 0 \tag{5}$$

So

$$b_i = \frac{C_H e_j + a_j + c_i}{2} \tag{6}$$

Because $b_i(c_i) = a_i + e_i c_i$, Equation (7) is got.

$$(C_H e_j + a_j + c_i)/2 = a_i + e_i c_i \tag{7}$$

So Equation (8) can be calculated as:

$$\begin{cases} e_i = 1/2 \\ a_i = (e_j C_H + a_j)/2 \end{cases} \tag{8}$$

In a similar way:

$$\begin{cases} e_i = 1/2 \\ a_j = (e_i C_H + a_i)/2 \end{cases} \tag{9}$$

Solve these Equations (8) and (9), and it can be obtained that

$$a_i = e_j C_H, a_j = e_i C_H, e_i = e_j = 1/2, \tag{10}$$

So,

$$b_i = C_H/2 + c_i/2 = (c_i + C_H)/2 \tag{11}$$