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Research Article

A Contract Coordination Model of Dual-Channel Delivery between UAVs and Couriers Considering the Uncertainty of Delivery for Last Mile

Ming-fei Chen ,[1] Yan-qiu Liu,[1] Yang Song ,[1,2] and Qi Sun [3]

[1] *School of Management, Shenyang University of Technology, Shenyang 110870, China*
[2] *College of Economics and Management, Liaoning Finance Vocational College, Shenyang 110122, China*
[3] *Antai College of Economics & Management, Shanghai Jiao Tong University, Shanghai 200030, China*

Correspondence should be addressed to Ming-fei Chen; cmfsy2014@163.com

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For the traditional last-kilometer delivery, commodities are sent from the distribution center to the distribution transfer station, which are then delivered by the couriers from the distribution transfer station to the consumers. This single distribution channel cannot prioritize services for consumers closer to the distribution center, resulting in a waste of distribution resources. To deal with the last-kilometer delivery problem, this paper attempts to build a dual-channel distribution system consisting of UAVs and couriers. And the impact of the market allocation proportion on the expected profit of the last mile service through the two different distribution channels is discussed and analyzed. It is proved that the improved revenue sharing contract can realize the coordination of the dual-channel distribution between UAVs and the couriers. The numerical examples verify the effectiveness of the model and contract coordination. According to the research, first, with the increase in the uncertainties of the delivery quantity, the profit of the UAV channel shows a downward trend, while the profit of the courier channel remains basically the same. This is because the labor cost of the courier channel is relatively stable. Second, with the increase in the market allocation proportion of the last-kilometer delivery, the optimal delivery quantity of the UAV channel and the optimal order quantity of the courier channel are both increasing, while the overall profit of the last-kilometer is first rising and then decreasing. Third, the expected profit of the UAV channel and the courier channel can achieve Pareto improvement through the improved revenue sharing contract.

1. Introduction

The last-kilometer delivery is the last link of the courier to the customer and is closely associated with the customer [1, 2]. Its biggest features lie in the dispersal of consumers, the large number distribution sites, couriers, and customers, and less controllability [3]. At this final stage, the loss of express parcels, delivery to the wrong destination, delayed delivery, bad attitude of the couriers and even some security incidents occur quite often [4]. Many sudden problems have caused great damage to each courier company in terms of cost and efficiency, and also brought many negative effects [5].

With the development of technology, express warehousing, and transshipment have realized the replacement of labor by some robots, which have greatly improved the work efficiency [6]. However, the last-kilometer delivery still requires the operation of a large number of couriers, and the labor cost is always very high. Thus, how to reduce the cost of the last-kilometer and the use of UAV (Unmanned Aerial Vehicle) distribution to improve operational efficiency has become a problem which major courier companies and scholars have to think about [7].

The market for the last-kilometer logistics in urban areas is huge, and when combined with the UAV model, consumer demand is fully reflected [8]. Consumers are gradually forming the habit of online shopping, and the trend of globalization provides consumers with richer and safer choices [9]. With the ever-increasing size of the e-commerce market, only the matching high-efficient last-kilometer distribution can help achieve this goal [10]. In order to optimize the last-kilometer distribution, this paper reviews the key and difficult issues which are involved and need to be disposed of as well as the development status of the dual-channel model in the second section. In Section 3, a dual-channel distribution system composed of UAVs and couriers is constructed. In Section 4, the optimal decision-making models of the courier channel and the UAV channel are constructed, respectively. In Section 5, the uncertainties of the last-kilometer delivery and the impact of the market allocation proportion on the expected profit of the service are discussed and analyzed. In Section 6, according to the case study of Jingdong Company, the optimal decision results, which are used to test the dual channel model, are presented based on different contract parameters. Section 7 summarizes the research of the whole paper and shows the direction of future research.

2. Literature Review

The “last-kilometer” of logistics means not only to meet the basic requirement that goods are not damaged in the transportation process, but also to gradually develop to a high speed of distribution and attract consumers with higher quality services [11]. There are two main logistics modes and the first is warehousing mode. Zhang et al. [12] studied distribution through the three-level process of "distribution center-distribution transfer station-customers". Memari et al. [13] found that the "just-in-time" service was also based on self-built warehousing logistics, which was delivered to customers on time to ensure the speed of distribution. The other is a point-to-point distribution scheme based on crowdsourcing model such as Krykewycz et al. 2011 [14] and Huang et al. 2019 [15]. Guiffrida et al. [16] and Lyu et al. [17] thought while providing high-speed and high-quality services, the cost of manpower and material resources had increased significantly, and other problems had followed. Xiao et al. 2019 [18] solved the problem of warehousing mode was that intermediate warehousing and sorting lead to a weak timeliness, and Ayachi Ghannouchi et al. 2010 [19] pointed out many warehouses were set up in cities, which will also bring great costs to the site, facilities, etc. The other is crowdsourcing mode. As Paloheimo et al. 2016 [20] said, in crowdsourcing mode, the cost was higher when the distance was longer. In addition, while the types of goods are limited for UAV, safety issues cannot be ignored [21–23]. In order to retain the advantages of the two modes, combined with the two modes, one channel in the three-level process is delivery by courier [11–19], the other channel uses third-party logistics equipment [20–23].

With the rapid development of electronic commerce, information technology and logistics technology, more and more enterprises use dual-channels to provide services to consumers such as Yan et al. [24], Dan et al. [25], Xie et al. [26] found that enterprises can also expand market coverage and increase sales growth rate by using dual channels. Chiang et al. [27] researched that one of the advantages of the two channels was that each channel showed a unique set of characteristics, providing enterprises with opportunities to adapt to changing customer needs and purchase patterns. In the process of managing multiple distribution channels, there are many tasks and decisions that need to be coordinated as Chen et al. [28] showed. Based on the research outcome so far, it can be seen that dual-channel is a double-edged sword for enterprises [29]. As Eshghi et al. [30] shown, business managers need to seek advantages and avoid disadvantages of dual channels and control the conflicts brought by them within a reasonable range. This is also the focus and difficulty of research to think and study carefully in light of company's actual situation from previous studies [11–23].

Aized et al. [31] pointed out that last mile logistic distribution system is the final step in business-to-customer supply chain which needs careful investigation in order to efficiently and economically deliver goods to customers. Therefore, it is necessary to build the model from the perspective of supply chain channel optimization. Hübner et al. [32] developed a planning framework for last mile order fulfilment in OC grocery retailing and discusses the advantages and disadvantages of different design concepts. Samaranayake et al. [33] summarized that planning, control, and execution of components in supply chain had been a significant problem area, due to these interfaced systems and complexities such as the large number of components, and additional component relationships, including networks. In fact, different modes of transport have their own characteristics. If different modes of transport are considered in the supply chain system, it will be conducive to the innovation of the mode of transport.

In order to encapsulate the delivery mode of drones and couriers in the supply chain system, we need to study the multi-channel supply mode. Bernstein et al. [34] solved what is the equilibrium structure of enterprises with double channel distribution on consumer problems. Dumrongsiri et al. [35] studied further on manufacturers' motivations for opening online sales channels. Cai et al. [36] studied the selection and coordination of dual-channel supply chain channels, and specifically analyzed the influence of channel structure, and channel coordination on suppliers, retailers and the whole supply chain. Khouja et al. [37] researched manufacturers such as channel selection strategy and pricing strategy. Yoo and Lee [38] studied a variety of alternative mixed channel structures and analyzed how the channel structure and changing market conditions adapt to the online channel. Xiao et al. [39] constructed the retailer Stackelberg pricing model and considered the product diversity and channel structure strategy of manufacturers in order to avoid channel conflicts. Hsiao et al. [40] studied the interaction between the introduction of online channels, pricing strategies, and channel structure. Lei et al. [41] studied the multi-channel supply chain structure composed of a manufacturer and multiple retailers, analyzed the influence of vertical information sharing and horizontal information sharing on the channel selection strategy of manufacturers. Matsui et al. [42] studied the optimal product distribution strategy when two symmetrical manufacturers adopt a single retail channel, a single direct channel and a double channel.

In the process of distribution system optimization, almost all of them are faced with the following problems. Firstly, there are tremendous fluctuations in demands of customers. The importance of this problem has been recognized in previous studies when building the model, but it has not been well solved in the last-kilometer optimization problem. Secondly,

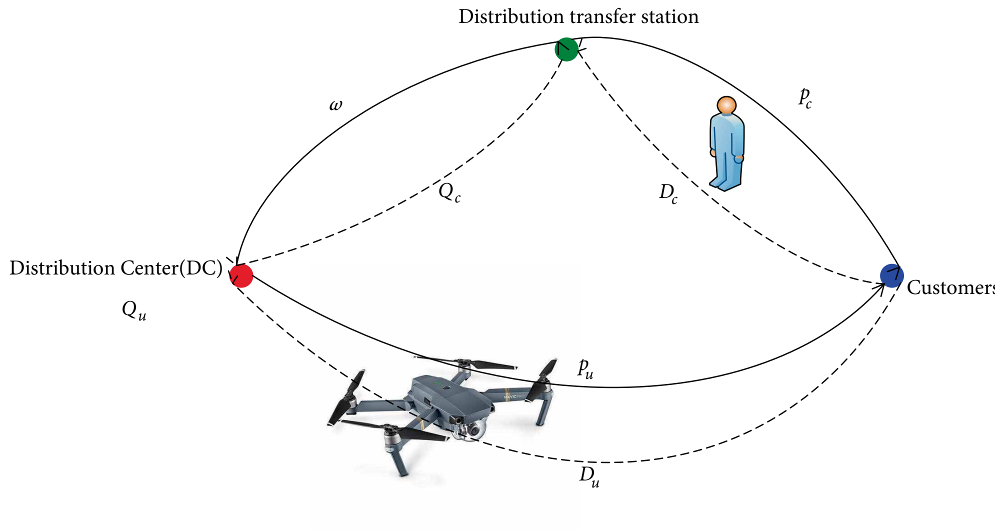

Figure 1: The last-kilometer dual-channel structure under the uncertainty of DC.

the behavior of courier will affect the distribution of transportation capacity. It is necessary to separate the last-kilometer of service quality from the courier channel.

3. Problem Description and Research Hypothesis between UAVs and Couriers

If the express industry wants to provide high-quality service, the most basic thing is to meet the rapid distribution service, but in the actual distribution process, in order to be able to dispatch all the express in time, the delivery time of the courier is very urgent. In the last miles of express delivery, it is often difficult to achieve real-time delivery service. There are overlaps between express delivery staff's working time and customer's working time, which undoubtedly aggravates the time conflict between express delivery and customers. For example, college students have become the champions of e-commerce, students in colleges and universities are basically in class during the day, express delivery in the process of delivery often cannot be delivered to students in time, thus resulting in a waste of manpower and time in secondary distribution. And the UAV has intelligent terminals, consumers can transfer the delivery time to the UAV system in real time, which is equivalent to regular distribution, which cannot be achieved by express delivery. The two modes of transportation have their own characteristics. On the basis of the existing research, inspired by the dual-channel supply chain, we regard UAV and courier as two modes of transportation, encapsulated in the last-kilometer supply chain system, and formulated a contract model through game theory.

3.1. Problem Definition and Description. According to the last-kilometer courier supply chain model, this paper expands the previous research model and constructs a dual-channel coordination model for UAV distribution and courier distribution for the last-kilometer, with the aim to maximize the benefits of each member involved in this process. Under the uncertainty of distribution department delivery, the dual-channel structure is shown in Figure 1.

In this paper, the distribution transfer station is DTS, and the distribution center is DC. DC is the starting point of the UAV channel. The planned distribution quantity is Q_u; the actual distribution quantity is yQ_u;y is the non-negative random variable; the distribution function is $G(y)$; the probability density function is $g(y)$. Assume $g(y)$ is distributed in the interval [a, b], $0 < a < b \leq 1$. The distribution quantity allocated by the DC to the DTS is Q_c; the consumer demand for the distribution of the DTS is D_c, and the consumer demand for the distribution center service is Du, wherein $D_c = \theta X - p_c + \beta_c p_u$ and $Du = (1-\theta)X - pu + \beta_u p_c$. θ is the distribution share for the courier channel. The distribution function of X is $F(x)$, and the probability density function is $f(x)$. $\beta_i (i = r, d)$ is the cross price influence coefficient, $0 < \beta_i < 1$.

The operation process of the last-kilometer dual channel can be specifically described as follows.

(1) Courier channel: based on the predicted market random demand D_c, DTS will order quantity of the package Q_c from DC. Then, the courier provides services to consumers.

(2) UAV channel: The planned distribution quantity of the DC is Q_u, which is directly sent to the consumer through UAV, and the actual distribution quantity is yQ_u. If the actual distribution of DC cannot satisfy the order of the DTS and the demand of courier channel, DC will encounter the shortage loss, and shortage cost is g_u. If the actual distribution quantity of DC is greater than the planned distribution of DTS, the surplus packages of DC will gain residual value revenue, and the residual value per package is V_u.

3.2. Symbol and Parameter Specification. The symbols and parameters are described in Table 1.

Table 1: The description of symbols.

Symbols	Meaning	Symbols	Meaning
p_c	Distribution service price of couriers	θ	Market allocation proportion of courier channel
p_u	Distribution service price of UAVs	X	The total demand of package market
ω	Service price per package	y	The random delivery factor of DC ($0 \le y \le 1$)
V_u	The residual value per package of the residual package at DC	μ_1	Scale average value of package market demand
V_c	The residual value per package of the residual package at DTS	μ_2	Average value of the random delivery factor of DC
g_u	Shortage cost per unit of DC	Q_u	Planned delivery quantity of DC
g_c	Shortage cost per unit of DTS	Q_c	Planned package quantity of DTS
D_c	Customer demand for courier channel	C_u	Cost of DC
D_u	Customer demand for UAV channel	C_c	The distribution cost of DTS
β_c	The impact of price of UAV channel on demand quality of the courier channel	π_c	The profit of DTS
β_u	The impact of price of couriers channel on demand quality of the UAV channel	π_u	The profit of DC
λ_c	Revenue percentage at DTS under Positive revenue sharing contract	π_T	The overall profits of last-kilometer distribution
λ_u	Revenue percentage at DC under reverse revenue sharing contract		

4. The Independent Optimal Decision Model for the Courier Channel and the UAV Channel for the Last-Kilometer Delivery

4.1. Optimal Decision Model for Courier Channel. DTS serves as the starting point of the courier channel, and the profit function forthe courier channel (Eq. (1))

$$\pi_c = p_c \min(Q_c, D_c) + V_c[Q_c - D_c]^+ - g_c[D_c - Q_c]^+ - \omega Q_c - c_c Q_c. \quad (1)$$

Eq. (1) is service revenue, residual value revenue, shortage cost, order cost and the service cost of DTSfor the courier channel. The expected profit function of DTS for the courier channelis (Eq. (2)):

$$E(\pi_c) = p_c S(Q_c) + V_c(Q_c - S(Q_c)) - g_c(\theta\mu_1 - p_c + \beta_c p_u - S(Q_c)) - c_c Q_c - \omega Q_c, \quad (2)$$

wherein $S(Q_c)$ is the expected distribution quantity for the courier channel.

$$\begin{aligned} S(Q_c) &= E[\min(Q_c, D_c)] \\ &= \int_0^{x_c} (\theta x - p_c + \beta_c p_u) f(x)dx + \int_{x_c}^{\infty} Q_c f(x)dx \\ &= Q_c - \theta \int_0^{x_c} F(x)dx. \end{aligned} \quad (3)$$

Assume $Q_c = \theta x_c - p_c + \beta_c p_u$

$$S(Q_c) = \min(Q_c, D_c) = \begin{cases} \theta x - p_c + \beta_c p_u, & x < x_c \\ Q_c, & x \ge x_c. \end{cases} \quad (4)$$

Theorem 1. *There exits the only Q_c^d that maximizes the expected profit of the courier channel and Q_c^d satisfies:*

$$F\left(\frac{Q_c^u + p_c - \beta_c p_u}{\theta}\right) = \frac{p_c + g_c - \omega - C_c}{p_c + g_c - V}. \quad (5)$$

Proof. To make the first and second partial derivatives with respect to Q_c in Eq. (2), and get the Eqs. (6 and 7).

$$\frac{\partial E(\pi_c)}{\partial Q_c} = p_c + g_c - \omega - c_c - (p_c + g_c - V_c)F(x_c). \quad (6)$$

$$\frac{\partial^2 E(\pi_c)}{\partial Q_c^2} = -\frac{(p_c + g_c - V_c)}{\theta} f(x_c) < 0. \quad (7)$$

The second partial derivative is less than 0. Thus we can learn that there exits the only Q_c^d to maximize the profit of DTS. When the first partial derivative is 0, the Eq. (5) can be obtained. So we can prove Theorem 1.

4.2. Optimal Decision Model for UAV Channels. As the starting point of the UAV channel, DC directly serves consumers. The profit function of the UAV channel is Eq. (8):

$$\pi_u = p_u \min(D_u, yQ_u - Q_c) + V_u[yQ_u - Q_c - D_u]^+ - g_u[Q_c + D_u - yQ_u]^+ + \omega Q_c - c_u Q_u. \quad (8)$$

Eq. (8) is service revenue, residual value revenue, shortage cost, order cost and the service cost of DC for the UAV channel. The expected profit function for the UAV channel is Eq. (9):

$$\begin{aligned} E(\pi_u) = {} & p_u\left[\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} (yQ_u - Q_c) f(x)g(y)dydx + \int_0^{+\infty}\int_{(D_u+Q)_c/Q_u}^{b} D_u f(x)g(y)dydx\right] \\ & + V_u \int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b} (yQ_u - Q_c - D_u) f(x)g(y)dydx \\ & - g_u \int_0^{+\infty}\int_a^{(D_u+Q)_c/Q_u} (Q_c + D_u - yQ_u) f(x)g(y)dydx \\ & + \omega Q_c - c_u Q_u. \end{aligned} \quad (9)$$

Assume $y_u Q_u = Q_c + D_u = Q_c + (1-\theta)x - p_u + \beta_u p_c$.

Eq. (5) make the first partial derivatives with respect to ω, and can get Eq. (10).

$$\frac{dQ_c}{d\omega} = -\frac{\theta}{(p_c + g_c - V_c) f((Q_c + p_c - \beta_c p_u)/\theta)} = A. \quad (10)$$

Eq. (9) make the first partial derivatives with respect to ω, can get the only optimal ω^*, and satisfy the following conditions.

$$\begin{aligned} &-(p_u + g_u)\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} A dy dx \\ &+ V_u \int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b} A dy dx + Q_c + \omega A = 0. \end{aligned} \quad (11)$$

Theorem 2. *There exits only has the only Q_u^d to maximize the expected profit for the UAV channel and Q_u^d satisfies:*

$$\mu_2 V_u - C_u + (p_u + g_u - V_u)\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} y f(x) g(y) dy dx = 0. \quad (12)$$

Proof. To make the first and second partial derivatives with respect to Eq. (9) and get Eqs. (13 and 14).

$$\begin{aligned} \frac{\partial E(\pi_u)}{\partial Q_u} &= p_d \int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} y f(x) g(y) dy dx \\ &\quad + V_u \int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b} y f(x) g(y) dy dx \\ &\quad + g_u \int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} y f(x) g(y) dy dx - C_u \\ &= \mu_2 V_u - C_u + (p_u + g_u - V_u) \\ &\quad \cdot \int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} y f(x) g(y) dy dx. \end{aligned} \quad (13)$$

$$\frac{\partial E^2(\pi_u)}{dQ_u^2} = -\frac{p_u - V_u + g_u}{Q_u^3}\int_0^{+\infty} (D_u + Q_c)^2 f(x) g\left(\frac{D_u + Q_c}{Q_u}\right) dx < 0. \quad (14)$$

The second partial derivatives is less than 0, we can learn that there exists the only Q_u^d to maximize the expected profit for the UAV channel. When the first partial derivative is 0, the Eq. (12) can be obtained. So we can prove Theorem 2.

5. The Dual-Channel Distribution Contract Coordination Modal for the Last Kilometer

This paper introduces an improved bi-directional revenue sharing contract to coordinate the last-kilometer dual-channel of UAV and courier distributions, including positive and reverse revenue sharing contracts. That is, DC with UAV channel provides the discount to the DTS with courier channel. $(1-\lambda_c)$ indicates the proportion of the revenue that DC obtains through the UAV channel, $(1-\lambda_u)$ indicates the proportion of the revenue that the DTS receives from through the courier channel.

5.1. The Contract Coordination Model for Courier Channel. The profit function of the contract coordination for courier channel is Eq. (15).

$$\begin{aligned} \pi_c = &\lambda_c\left(p_c \min(Q_c, D_c) + V_c[Q_c - D_c]^+\right) - g_c[D_c - Q_c]^+ \\ &- \omega Q_c - c_c Q_c + (1-\lambda_u)[p_u \min(D_u, yQ_u - Q_c) \\ &+ V_u[yQ_u - Q_c - D_u]^+]. \end{aligned} \quad (15)$$

Eq. (13) represents the retained income of DTS, shortage cost of DTS, the package pick-up cost of DTS, the service cost of DTS, and the revenue of DTS shared by DC. The profit function of contract coordinationmodel at DTS is Eq. (16).

$$\begin{aligned} E(\pi_c) = &\lambda_c[p_c S(Q_c) + V_c(Q_c - S(Q_c))] - \omega Q_c - c_c Q_c \\ &+ (1-\lambda_u)\Bigg[p_u\Bigg(\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} (yQ_u - Q_c) f(x) g(y) dy dx \\ &+ \int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b} D_u f(x) g(y) dy dx\Bigg) \\ &+ V_u \int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b} (yQ_u - Q_c - D_u) f(x) g(y) dy dx\Bigg]. \end{aligned} \quad (16)$$

Theorem 3. *The optimal order size Q_r^* of DTS under the contract coordination satisfies Eq. (17).*

$$\begin{aligned} &\lambda_c\left[p_c - (p_c - V_c)F\left(\tfrac{Q_c + p_c - \beta_c p_u}{\theta}\right)\right] + g_c\left(1 - F\left(\tfrac{Q_c + p_c - \beta_c p_u}{\theta}\right)\right) - \omega - C_c \\ &+ (1-\lambda_u)\left[(V_u - p_u)\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} f(x) g(y) dy dx + V_u\right] = 0. \end{aligned} \quad (17)$$

Equation (17) makes the first partial derivatives with respect to Q_m and gets Eq. (18) :

$$\begin{aligned} &\lambda_c\left[\frac{(V_c - p_c) f(x_c)}{\theta}\frac{dQ_c}{dQ_u}\right] - \frac{g_r f(x_c)}{\theta}\frac{dQ_c}{dQ_u} + (1-\lambda_u)(V_u - p_u) \\ &\cdot \int_0^{+\infty} f(x) g\left(\frac{D_u + Q_c}{Q_u}\right)\frac{Q_u(dQ_c/dQ_u) - (Q_c + D_u)}{Q_u^2} dx = 0. \end{aligned} \quad (18)$$

$$\frac{dQ_c}{dQ_u} = \frac{\theta(1-\lambda_u)(V_u - p_u)\int_0^{+\infty} f(x) g(D_u + Q_c/Q_u)(Q_c + D_u) dx}{Q_u^2[\lambda_c(V_c - p_c) - g_c] f(x_c) + \theta Q_u(1-\lambda_u)(V_u - p_u)\int_0^{+\infty} f(x) g(D_u + Q_c/Q_u) dx} = B. \quad (19)$$

Theorem 3 is proved.

5.2. The Contract Coordination Model for UAV Channel. The profit function of contract coordination model for UAV channel is Eq. (20).

$$\begin{aligned} \pi_u = &(1-\lambda_c)\left(p_c \min(Q_c, D_c) + V_c[Q - D_c]^+\right) \\ &+ \lambda_u\left[p_u \min(D_u, yQ_u - Q_c) + V_u[yQ_u - Q_c - D_u]^+\right] \\ &- g_u[Q + D_u - yQ_u]^+ + \omega Q_c - c_u Q_u. \end{aligned} \quad (20)$$

Eq. (20) represents the income of DC shared by DTS, the retained income of DC, the shortage cost of DC, and the storage cost of DC. The profit function of the contract coordination model at DC is Eq. (21).

$$\begin{aligned}E(\pi_u) &= (1-\lambda_c)[p_c S(Q_c) + V_c(Q_c - S(Q_c))] \\ &+ \lambda_u\left[p_u\left(\int_0^{+\infty}\int_a^{((D_u+Q)_c)/Q_u}(yQ_u - Q_c)f(x)g(y)dydx\right.\right. \\ &\left.+\int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b} D_d f(x)g(y)dydx\right) \\ &\left.+V_u\int_0^{+\infty}\int_{(D_u+Q_c)/Q_u}^{b}(yQ_u - Q_c - D_u)f(x)g(y)dydx\right] \\ &- g_u\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u}(Q_c + D_u - yQ_u)f(x)g(y)dydx \\ &+ \omega Q_c - c_u Q_u.\end{aligned} \tag{21}$$

The optimal planned delivery quantity of DC based on the contract coordination is Q_m^*, which satisfies the following equation:

$$\frac{dE(\pi_u)}{dQ_u} = \frac{\partial E(\pi_u)}{\partial Q_c}\frac{dQ_c}{dQ_u} + \frac{\partial E(\pi_u)}{\partial Q_u} = 0. \tag{22}$$

Eq. (22) can be obtained as follows.

$$\begin{aligned}&(1-\lambda_c)B[p_c + (V_c - p_c)F(x_c)] \\ &+ \lambda_u\left[(p_u - V_u)\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} yf(x)g(y)dydx + \mu_2 V_u\right] \\ &+ g_u\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} yf(x)g(y)dydx - c_u = 0.\end{aligned} \tag{23}$$

Theorem 4. *Under the improved bi-directional revenue sharing contract coordination model, contract parameters $(\omega, \lambda_r, \lambda_m)$ satisfy the following conditions:*

$$\begin{aligned}\omega &= (1-\lambda_u)\frac{\theta(p_u - V_u)F1[p_c + g_c + (V_u - p_u - g_u)F2 - (p_c + g_c - V_c)F(x_c) - C_c - V_u][(p_u - V_u)F2 + V_u]}{[\lambda_u(p_u - V_u)F3 + \mu_2 V_u + g_u F3 - C_u]Q_u(p_c - V_c)f(x_c)} \\ &+ (1-\lambda_u)\left[p_c - (p_c - V_c)F(x_c) + \frac{\theta(p_u - V_u)F1}{Q_u(p_c - V_c)f(x_c)}((p_u - V_u)F2 + V_u)\right] + \frac{g_c}{p_c - V_c}[(p_u - V_u)F2 + V_u] + g_u F2.\end{aligned} \tag{24}$$

$$\begin{aligned}\lambda_c &= (1-\lambda_u)\frac{\theta(p_u - V_u)F1[p_c + g_c + (V_u - p_u - g_u)F2 - (p_c + g_c - V_c)F(x_c) - C_c - V_u]}{[\lambda_u(p_d - V_u)F3 + \mu_2 V_u + g_u F3 - C_u]Q_u(p_c - V_c)f(x_c)} \\ &+ (1-\lambda_u)\frac{\theta(p_u - V_u)\int_0^{+\infty} f(x)g(y_u)dx}{Q_u(p_c - V_c)f(x_c)} + \frac{g_c}{p_c - V_c},\end{aligned} \tag{25}$$

wherein

$$\begin{aligned}F1 &= \int_0^{+\infty} y_u f(x)g(y_u)dx \\ F2 &= \int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} f(x)g(y)dydx \\ F3 &= \int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} yf(x)g(y)dydx.\end{aligned} \tag{26}$$

It is proved that the decision result after contract coordination is equal to that in the centralized case, and the dual-channel distribution coordination for the last one kilometer can be achieved. That is $Q_c^* = Q_c^r$, $Q_u^* = Q_u^r$ based on which Eqs. (21 and 23) can be obtained.

$$\begin{aligned}\omega &= (1-\lambda_c)[(p_c - V_c)F(x_c) - p_c] + g_u\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} f(x)g(y)dydx \\ &+ (1-\lambda_u)\left[(p_u - V_u)\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} f(x)g(y)dydx - V_u\right].\end{aligned} \tag{27}$$

$$\lambda_c = \frac{(1-\lambda_u)\left[(p_u - V_u)\int_0^{+\infty}\int_a^{(D_u+Q_c)/Q_u} yf(x)g(y)dydx + \mu_2 V_u\right] + B[p_c + (V_c - p_c)F(x_c)]}{B[p_c + (V_c - p_c)F(x_c)]}. \tag{28}$$

Theorem 4 is proved.

As can be seen from Theorem 4, the contract parameters correspond to each other and influence each other. If DC decreases the wholesale price, the income percentage $(1-\lambda_c)$ which DC obtains from DTS channel will increase, but the income percentage $(1-\lambda_u)$ which DTS obtains from couriers channel will decrease.

6. Numerical and Case Analysis

The effectiveness of the model and contract coordination is illustrated by the last-kilomenter delivery example of JingDong company (Figure 2) in Shenyang, China. In Figure 2, logistics department is noted as DC in dual-channel model, and the UAV channel starts at logistics department and ends at

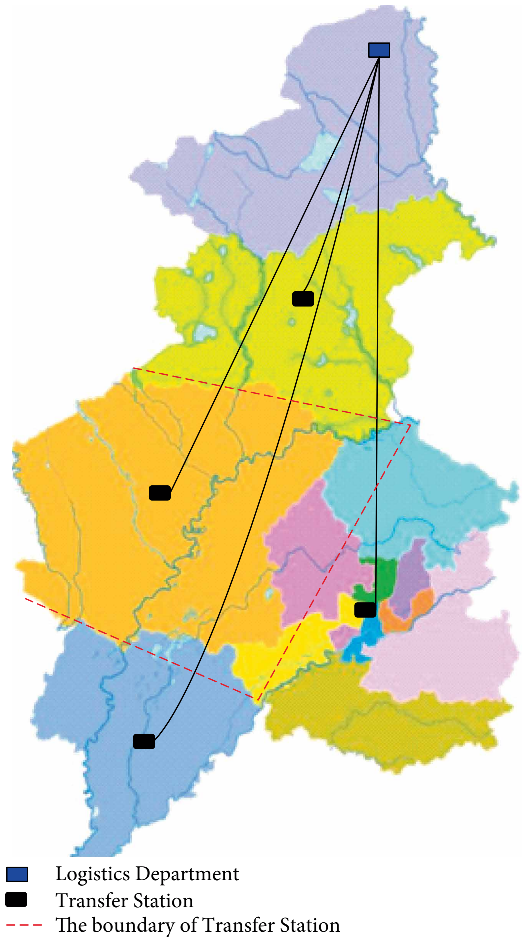

Figure 2: Distribution diagram for the last kilometer.

customers. The Courier channel starts at transfer station and ends at customers.

Experimental parameters are set as follows: $y \sim U[0.5, 1]$, $x \sim U[0, 600]$, $p_r = 20$, $p_u = 18$, $C_u = 5$, $C_c = 4$, $g_u = 5$, $g_r = 3$, $V_u = 8$, $V_c = 10$, $\theta = 0.6$, $\beta_c = 0.8$, $\beta_u = 0.8$. $\Delta E(\pi_r)$ is the relative profit change of the courier channel before and after contract coordination. $\Delta E(\pi_u)$ is the relative profit change of the UAV channel before and after contract coordination. Through calculation, the optimal decision and expected profit value of the dual channel for the last kilometer can be obtained. Table 2 shows the optimal decision results based on different contract parameters.

It can be seen from Table 2 that when the parameters satisfy $(\omega, \lambda_c, \lambda_u) = (4.705, 0.471, 0.800)$, $\Delta E(\pi_u) > 0$ and $\Delta E(\pi_c) > 0$, the improved revenue sharing contract can realize the dual-channel distribution coordination for the last kilometer.

Figures 3 and 4 show the effect in the market allocation proportion factor θ on the optimal decision and expected profit of UAV channel and courier channel respectively. It can be seen from Figure 3 that with the increase of the market allocation proportion factor, the optimal delivery quantity of DC and the optimal order quantity of DTS both increase. Figure 4 shows that with the increase of the market allocation proportion factor, the expected profit of DTS increases, while the expected profit of DC will increase first and then decrease. The overall profit of the last kilometer shows upward trend first and then downward trend. For DC, there is an optimal θ to maximize its profit.

7. Conclusion

This paper studies the dual-channel distribution coordination issue through UAV channel and courier channels for the last kilometer, considering the uncertainties of both the DC delivery and market demand. The independent optimal decision models for UAV channel and the courier channel as well as the coordination model of the two are constructed respectively. The improved bi-directional revenue sharing contract is used to coordinate the last-kilometer dual-channel distribution, and the Pareto improvement is realized. Through the case study of Jingdong Company, the following conclusions are drawn. With the increase in delivery uncertainties, UAV channel and the overall profit for the last kilometer show a downward trend, while the profit of the courier channel remains basically unchanged. With the increase in the market allocation proportion factor θ, the optimal order quantity of the courier channel and the optimal delivery quantity of the UAV channel will increase, whereas the overall profit of the last-kilometer will rise at first and then decrease. As the bi-directional revenue sharing scale factors λ_u and λ_c increase, the expected profit of the UAV channel and the courier channel can achieve Pareto improvement. In the future research, the security of the UAV distribution should be taken into consideration and the coordination of the last-kilometer dual-channel distribution with risk preference is worth further study.

Data Availability

The [Jd warehouse logistics price.xlsx] data used to support the findings of this study have been deposited in the [https://pan.baidu.com/s/1fz4M0Bjc8KJkPFSTgRXe0A (password: pm0t)] repository.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Table 2: The optimal decision results based on different contract parameters.

λ_u	λ_c	ω	$E(\pi_c)$	$E(\pi_u)$	$E(\pi_c)$	$\Delta E(\pi_c)$	$\Delta E(\pi_u)$
0.100	0.913	13.881	2615.315	171.254	2786.504	2208.441	−2110.157
0.200	0.842	12.472	2282.902	503.670	2786.532	1876.047	−1777.855
0.300	0.770	11.067	1950.696	835.815	2786.512	1543.741	−1445.572
0.400	0.701	9.645	1618.334	1168.280	2786.504	1211.442	−1113.271
0.500	0.643	8.230	1286.309	1500.573	2786.511	879.145	−780.972
0.600	0.572	6.824	953.802	1832.709	2786.568	546.875	−448.676
0.700	0.505	5.417	621.413	2165.121	2786.574	214.573	−116.270
0.800	**0.471**	**4.705**	**455.346**	**2331.203**	**2786.532**	**48.410**	**49.831**
0.900	0.429	4.983	289.226	2497.395	2786.521	−117.743	215.934

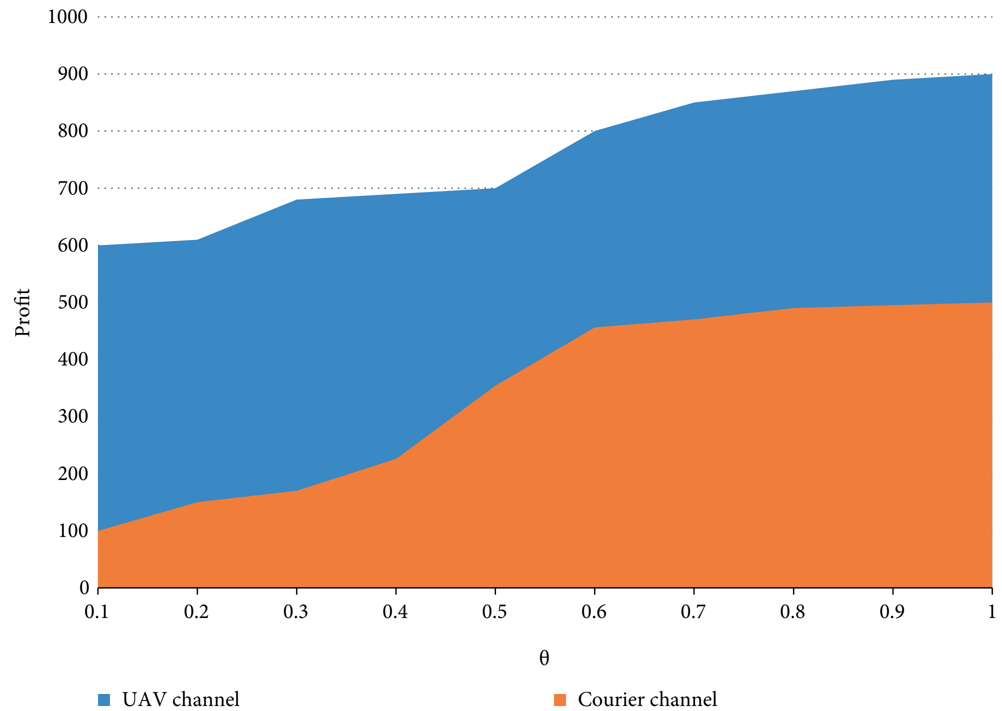

Figure 3: The impact of the market allocation proportion factor θ on the distribution quantity of UAV channels and courier channels.

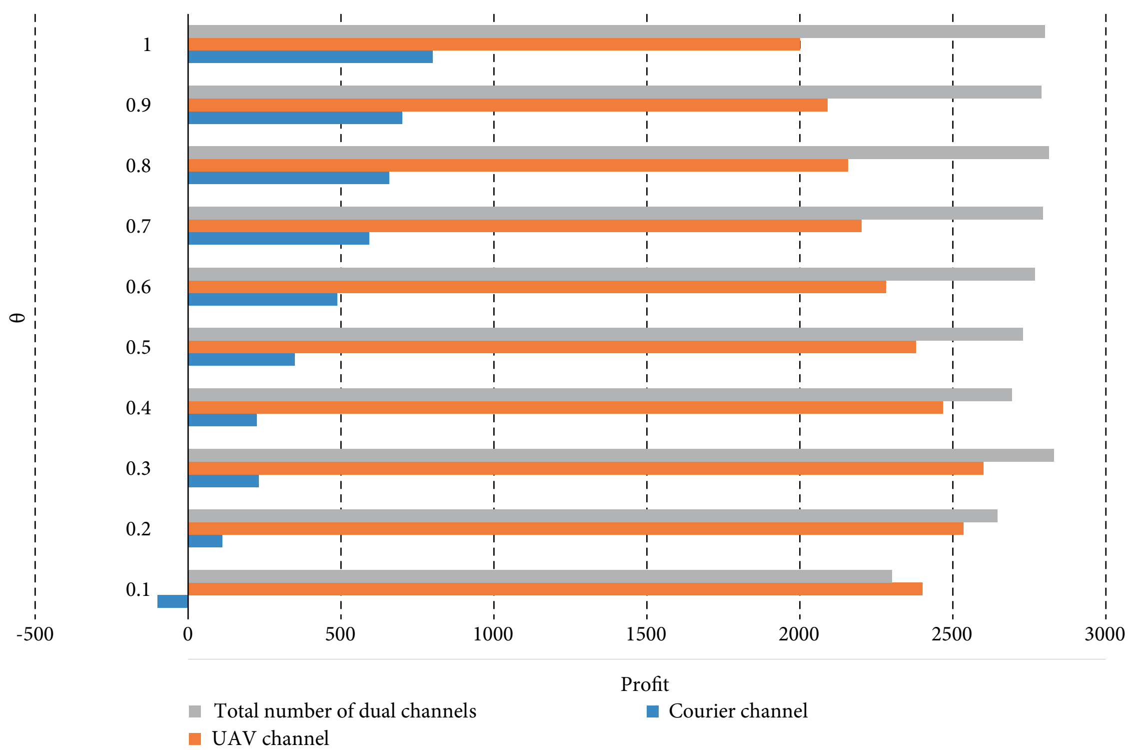

Figure 4: The impact of the market allocation proportion factor θ on UAV channels, courier channels and the total expected profit.

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