mathematics

Article

# Parcel-Locker-Sharing Model for E-Commerce Logistics Service Providers

**King-Wah Pang [1,*], Jingyi Xu [2], Ruixuan Jiang [3] and Ruofan Liu [3]**

1 Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
2 Department of Industrial Operations Engineering, Michigan Engineering University of Michigan, Ann Arbor, MI 48109, USA; xjingyi@umich.edu
3 Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, UK; rj459@cam.ac.uk (R.J.); rl723@cam.ac.uk (R.L.)
* Correspondence: anthony.pang@polyu.edu.hk; Tel.: +852-2766-4126; Fax: +852-2330-2704

**Abstract:** In the e-commerce last-mile delivery process, the asset operators (logistics service providers who own parcel locker facilities) support their delivery service with parcel lockers, while the non-asset operators (logistics service providers without parcel lockers) perform door-to-door delivery. Due to demand fluctuation, asset operators' parcel-locker slots may be left vacant, while non-asset operators are stuck with the high-cost door-to-door service. The exclusiveness of parcel-locker usage reduces resource utilization and service efficiency in last-mile delivery. Therefore, this paper proposes a parcel-locker-sharing model in which these two parties share the parcel-locker capacity in last-mile delivery. The asset operator rents the unused parcel lockers to the non-asset operator by charging a rental fee,while the non-asset operator rents the parcel lockers for delivery to save logistics costs. The motivation of this alliance is to increase the profits of both parties and that of the total supply chain. This study establishes the supply-chain profit model for the parcel-locker-sharing framework and finds that the profit or loss depends on the comparison of the operation cost savings and delivery-cost savings. A numerical analysis is conducted to validate the final result. The research further suggests the optimal rental quantity and price interval. This paper is the first to study the operational mechanism of sharing the parcel locker between two distinct types of logistics service providers and to offer recommendations for industrial application.

**Keywords:** last-mile delivery; parcel-locker-sharing model

**MSC:** 9010



**Citation:** Pang, K.-W.; Xu, J.; Jiang, R.; Liu, R. Parcel-Locker-Sharing Model for E-Commerce Logistics Service Providers. *Mathematics* **2024**, *12*, 2802. https://doi.org/10.3390/math12182802

Academic Editor: William Wang

Received: 11 August 2024
Revised: 7 September 2024
Accepted: 9 September 2024
Published: 10 September 2024



## 1. Introduction

With the development of the global economy and the internet, an ever-increasing number of customers have decided to shop online [1,2]. In this digital age, a wide variety of global brands can be found through e-commerce, providing a profitable but challenging market for companies [3]. Knowing about e-commerce is critical to seizing the huge market and facilitating the data stream, business stream, capital stream, and coordinated factors contained in web-based business exercises [4]. The improvement of the initial three streams has been investigated to a certain extent, while terminal distribution, as an essential process, has become a bottleneck for the further improvement of e-commerce logistics. Consequently, increasing attention is attracted to working on the efficiency of the terminal distribution.

Terminal distribution, or last-mile delivery, alludes to the last segment of the distribution network, delivering the parcel from the branch office to the final customer. In most cases, organizations use door-to-door delivery to distribute the parcels, with the couriers sending the parcels to the clients individually. Door-to-door delivery is the conventional choice for last-mile delivery and is exceptionally wasteful, considering uncertainties on the customer side. Researchers noticed that the costs of last-mile delivery account for 30% of the total cost of e-commerce logistics [5]. Furthermore, the couriers cannot guarantee the client is at home during the delivery, and they need to redeliver the parcel if there is nobody in the designated location, which causes additional expenses. The traditional door-to-door delivery method has worked in the past. However, the model cannot meet the development needs brought about by boosting e-commerce [6]. Optimizing the last-mile delivery model is vital to reduce logistics and distribution costs and improve distribution efficiency and service satisfaction. Such obstacles are generally observed, requiring researchers to analyze this topic further.

This paper designs a new parcel-locker-sharing model by combining the last-mile delivery and resource-sharing models and then analyses its application and feasibility. This paper addresses the following three research problems.

1. The scenarios in which the parcel-locker-sharing model would be profitable for the asset operators, the non-asset operators, or both;
2. In the profitable scenarios of the parcel-locker-sharing model, the optimal number of locker slots that the two parties should share and the price range charged for leasing parcel-locker slots balance both parties' benefits;
3. The application of the parcel-locker-sharing model in practice to alleviate last-mile delivery problems in the e-commerce environment.

The significance and originality of this study are that this is the foundational exploration to examine the feasibility of the parcel-locker-sharing model for last-mile delivery, and the result is applicable to real-life business. The result could be directly utilized in cooperative cases in practice, and the profit for every choice is presented too. Moreover, a profitable range of rental prices could be found in the model. Every point in the interval will lead to profits for both parties and the whole supply chain. Two parties can use it as a reference for their further negotiation.

This section introduces the background of the study, research purpose, and significance of terminal distribution research in the e-commerce environment. The rest of this paper is organized as follows. First, Section 2 will summarize the current literature review and analyze the previous research on the terminal distribution mode and sharing delivery, clarifying the research opportunity. In Section 3, the research methodology presents the setting of the parcel-locker-sharing model and its associated optimization methods. Then, the profit of each party and the whole supply chain is revealed in the framework, and a numerical analysis of the parcel-locker-sharing model is presented in Section 4. The section also shows an experimental trial of the framework by using Excel SolverTM 24.0.0.0 (Frontline Systems Inc., Incline Village, NV, USA) to obtain the best result. All results are demonstrated in numerical form, further verifying the accuracy of the results in the mathematical modeling. After this, the paper will present the main findings of the parcel-locker-sharing model and discuss its significance in practical applications. Finally, Section 6 points out the limitations of the parcel-locker-sharing model, discusses future improvements, and summarizes this paper's research findings.

## 2. Literature Review

Recently, e-commerce and logistics organizations have realized the importance of terminal distribution and the existing problems and continue to explore a series of terminal distribution service modes [7]. The current service modes of terminal distribution are mainly divided into direct and indirect distribution. The direct distribution mode is a door-to-door service by the e-commerce company or logistics provider's personnel directly delivering the goods to the customer's location [8]. The indirect distribution mode is a self-help delivery operation. The delivery personnel will deliver the goods to the designated destination, and then, the customer will pick up the goods at the designated point [9].

Researchers have found ways of improving last-mile delivery from different perspectives. Researchers showed that setting an appropriate distribution center and storage spot is effective for last-mile delivery, and developing a terminal distribution mode is also critical [10]. Another researcher noted that careful investigation is needed to deliver goods to customers effectively [11]. This article provides a conceptual planning method based on the last-mile delivery system of the hierarchical structure model. Researchers proposed decision-making solutions based on the last-mile delivery's safety, convenience, and timeliness requirements [12]. It provides a basis for e-commerce platforms to increase distribution efficiency, reduce costs, and improve user satisfaction.

The research mentioned above introduces some innovative policies and attempts to streamline last-mile delivery further. Not quite the same as them, this paper focuses on optimizing the delivery method for last-mile delivery. Delivering by parcel lockers is, by all accounts, a productive and effective way. Using the parcel locker efficiently in last-mile delivery will bring about a difference in the functional, emotional, social, and financial customer value [13]. Parcel-locker delivery contributes to a lower delivery cost than door-to-door delivery, both in urban and rural areas [14]. Researchers have made significant progress by introducing the idea of parcel-locker delivery to last-mile delivery. Lately, there has been a rising number of research studies on the parcel locker, zeroing in on maximizing the profit or limiting the cost [15,16]. The problem of the optimal locations of parcel lockers either in commercial areas or in residential areas is discussed by considering the benefits both to consumers and logistics companies and supply–demand satisfaction [17–19]. Except for the parcel-locker location, the optimal size of parcel lockers is also what the researchers are interested in. It is said that before making a decision on the locker size of a building, collecting information on residents' online shopping behaviors is important [20]. Further studies on location optimization have been conducted since the new term 'movable parcel lockers' was developed. Studies combined the terms 'electric vehicle' and 'parcel lockers', introducing 'movable parcel lockers' to solve the delivery problems. Motivated by the term, researchers try to optimize the location, the size of the parcel locker, and the number of parcel lockers dynamically [21,22]. The optimal route with the shortest time is also what the current research focuses on [23].

Currently, a problem has arisen in the development of parcel lockers. There is a significant amount of money invested in establishing parcel lockers, which the start-up company can hardly afford. For instance, there are 800 SF lockers in Hong Kong, each costing between USD 800 to USD 2700 [24,25]. Moreover, the company that owned the parcel lockers may not utilize all of them. Some parcel-locker slots are vacant due to the fluctuation of market demand. There is a chance for various parties to share facilities, increase benefits, and integrate the supply chain. Given that the sharing mechanisms are not applied much in the supply chain and logistics industry, the idea of parcel-locker sharing is raised. As researchers have said, very few scholars have researched parcel-locker-sharing problems [26].

Furthermore, the sharing mechanism is well known in the new business world, providing new insights into parcel lockers' operation. The sharing economy or collaborative consumption in the peer-to-peer market provides shared access to goods and services through rental, lending, and exchanging methods. This sharing mechanism creates value by making assets with low utilization accessible to the community and reducing the need for ownership [27]. The researcher framed the sharing economy as an economic opportunity; a sustainable method of consumption; a way to a decentralized, equal, and sustainable economy; and an innovation that creates unregulated marketplaces and reinforces the neoliberal paradigm [28]. This collaboration concept is increasingly popular and requires perspective modification from asset occupation to possession and usage without ownership [29]. The popularity of the sharing economy is driven by factors such as supply-chain value allocation and environmental concerns [30,31]. Customers choose the sharing option that could bring economic, environmental, and mental benefits. Consumers are motivated to participate in collaborative consumption for the resource sustainability, enjoyment, and financial gains the sharing activity brings [32]. Within the sharing economy business models, customer satisfaction is influenced by the service utility, trust in the resource providers, economic savings, and familiarity [33]. In addition, adopting the sharing economy mode has a positive effect on sustainable gain and financial motive [34].

In the field of logistics, the essence of sharing or cooperative delivery is that enterprises participate together and carry out unified planning and scheduling management. On the premise of mutual benefit, enterprises improve resource utilization and distribution efficiency through the scale of operation activities. The researcher used a traffic simulation model to study the change in carbon emissions under the city's cooperative delivery system, indicating that joint distribution can reduce environmental pollution [35]. Researchers surveyed several enterprises and summarized ten measures that enterprises use to reduce environmental pollution, including cooperative delivery [36]. The researcher analyzed the cooperative delivery application of e-commerce logistics in the common distribution service station in the center of Tokyo and established the implementation framework of joint distribution in the e-commerce environment, improving task assignment efficiency for multi-UAV collaborative package-delivery problems [37]. Researchers showed that new cooperative arrangements, in the form of a hub-and-spoke system between third-party logistics providers, were possible and applied them to the real case of an Austrian parcel service provider [38]. Researchers researched the vehicle-scheduling problem in the supply-chain management of third-party logistics enterprises [39]. They proposed a new local collaborative transportation-scheduling strategy, which planned the vehicles uniformly and delivered the goods to the end customers. Researchers suggested that the efficiency of task assignments can be improved through the collaborative package delivery of multiple UAVs [40]. Researchers presented a new idea by introducing the concept of a shared micro-depot network [41]. This new model not only increases the number of users who use a micro-depot but also decreases the individual cost and optimizes the use of urban space. Researchers also noted that crowdsourcing or crowd-shipping, which is the business model of the sharing economy, is an important trend in scientific research [42]. The above literature shows that cooperative delivery can integrate and distribute resources uniformly, which is an effective method for the sustainable development of logistics distribution.

From the summary of the current literature, we can find the advantages and disadvantages of the existing distribution mode of terminal distribution in the e-commerce environment. The distribution mode using parcel lockers is better than the traditional door-to-door delivery. As the current terminal distribution capacity makes it difficult to meet the existing demand, the terminal distribution mode must be optimized. By referring to the concept of joint delivery and clarifying the optimization principle, this paper puts forward the optimization scheme of applying the thought of joint delivery to a parcel locker. There is no research on this model and few studies on similar models, so there is a large literature gap.

## 3. Materials and Methods

The first step in the process is to build the framework. We list out the asset operator and non-asset operator's profit function separately based on the model proposed [43]. We divide the whole event into two situations, namely a sharing structure and a no-sharing structure, and define the motivation of cooperation, as the two parties' net profit will both increase [44]. In addition, we use the joint profit of the asset operator and non-asset operator to represent the profit of the total supply chain [45]. Based on this model, a new framework, called the parcel-locker-sharing framework, is constructed based on cooperative utilization.

To begin with, specific terms in the framework are defined. The expression "asset operator" refers to the company that owns the parcel locker and operates the parcel-locker delivery in their business. The term "non-asset operator" signifies a company that runs door-to-door delivery because of the limited budget for owning parcel lockers. In the parcel-locker-sharing framework, we try to motivate the collaboration between the asset operator and the non-asset operator to share the parcel lockers, which the asset operator owns. The fundamental impetus of the alliance is the profit increase for both parties and the total supply chain. Before running the sharing framework, the asset operator pays the operating cost for unused parcel-locker slots. The non-asset operator delivers parcels door-to-door, which is costly. When the sharing model is executed, the asset operator charges a rental price to the non-asset operator to cover the operating cost. The model promotes resource utilization by putting previously vacant parcel-locker slots into operations The operating cost for the delivery service of the non-asset operator also decreases. Furthermore, running the parcel-locker-sharing framework reduces the non-asset operators' requirement for owning parcel lockers. Since both parties benefit from the sharing collaboration, the total supply-chain profit can likewise increase.

After the model formulation, we need to find the optimal renting quantity. The optimal renting quantity is determined when the total supply-chain profit is maximized. The single-period model is used to find the optimal renting quantity. Many researchers have utilized the single-period model to determine the optimal order quantity to maximize the total profit in two-business operation coordination [45]. Following the mathematical analysis involving the single-period model, numerical experiments are provided to further validate the result.

## 4. Mathematical Modelling

### *4.1. Problem Description*

In the current e-commerce last-mile delivery, logistics providers operate independently. The asset operator delivers the customer packages to the parcel lockers in multiple residential or commercial areas, where customers pick up the parcels at the locker points at their convenience. To operate parcel delivery for the non-asset operators, they provide door-to-door delivery to the end customer locations. Asset operators exclusively use the locker facilities, while non-asset operators cannot access the parcel lockers for their delivery service. Under the parcel-locker-sharing framework, the asset operators will share the parcel lockers with the non-asset operators by renting or leasing. The non-asset operators can use the parcel lockers for their delivery. A summary of notations for the variables used in the problem is provided in Table 1.

**Table 1.** Summary of notations.

| | Notation | Description |
|---|---|---|
| Parameter | $P_a$ | Delivery service charge of asset operator |
| | $P_n$ | Delivery service charge of non-asset operator |
| | $c_a$ | Door-to-door delivery cost of asset operator |
| | $c_n$ | Door-to-door delivery cost of non-asset operator |
| | $f_1$ | Operating cost for used locker |
| | $f_2$ | Operating cost for unused locker |
| | $K$ | Capacity of asset operator (total number of locker slots) |
| | $c'_a$ | Delivery cost using parcel lockers of asset operator |
| | $c'_n$ | Delivery cost using parcel lockers of non-asset operator |
| | $D_a$ | Delivery demand for asset operator |
| | $D_n$ | Delivery demand for non-asset operator |
| Decision Variable | $R$ | Number of lockers rented to the non-asset operator |
| | $P_r$ | Rental price for non-asset operator |

### *4.2. Assumptions*

#### 4.2.1. Market Demand

The market demand for delivery services for both the asset and the non-asset company is assumed to follow the normal distribution. A normal distribution is suited to proposing general static solutions for problems with a fixed time period, which fits the framework of this paper [46]. Therefore, the demand for an asset operator $D_a$ follows a normal distribution ~$N(\mu_a, \sigma_a)$. The demand for the non-asset operator $D_n$ also follows a normal distribution ~$N(\mu_n, \sigma_n)$.

#### 4.2.2. Cost Index

It is assumed that costs, including the parcel-locker operating costs and the delivery costs of using parcel locker and door-to-door delivery, can be measured and estimated. While both used and unused lockers share the operating cost of utility, such as electricity, used lockers require more maintenance costs because of usage depreciation. Therefore, the operating costs for used lockers are assumed to be higher than for unused ones, i.e., $f_1 > f_2$. In addition, when couriers adopt parcel-locker delivery, they only need to travel to the locker points and store parcels in specific lockers. The delivery cost using parcel lockers $c_a, c_n$ will, therefore, be lower than door-to-door delivery costs $c'_a, c'_n$. So, the operating cost for parcel lockers is assumed to be lower than the door-to-door delivery cost, i.e., $c_a > c'_a$, $c_n > c'_n$, $c_a > c'_n$, $c_n > c'_a$.

#### 4.2.3. Locker Capacity

It is assumed that the asset operator's locker capacity is sufficient to satisfy its own demand, i.e., $K > D_a$. Since the asset operator will only consider sharing its locker facilities with the non-asset operator when its locker capacity exceeds its service needs, the assumption of sufficient locker capacity is credible. It serves as a premise for the feasibility of the mechanism.

### *4.3. Profit Model*

The model expressing the profits of asset and non-asset operators under both original non-sharing operations and the proposed parcel-locker-sharing operations is established. The profits of the sharing mechanism for the two parties and the total supply-chain profit of implementing the sharing mechanism are then computed. The detailed model expressions are shown as follows.

#### 4.3.1. No-Sharing Operations

For non-asset operator profit,

$$P_n D_n - c_n D_n \tag{1}$$

For asset operator profit,

$$P_a D_a - c_a D_a - f_1 D_a - f_2(K - D_a) \tag{2}$$

The profit model can be described as follows.

(1) The profit of the non-asset operator is comprised of the revenue of the delivery service, $P_n D_n$, minus the costs of door-to-door delivery, $c_n D_n$;
(2) The profit of the asset operator is comprised of the revenue of the delivery service, $P_a D_a$, minus the costs of delivery using a parcel locker, $c_a D_a$, and the operating cost for both used lockers, $f_1 D_a$, and unused lockers, $f_2(K - D_a)$.

#### 4.3.2. Sharing Operations

For non-asset operator profit,

$$P_n D_n - P_r R - c'_n Min(R, D_n) - c_n Max(D_n - R, 0) \tag{3}$$

For asset operator profit,

$$\begin{aligned} P_a D_a + P_r R - c'_a Min(K-R, D_a) - c_a Max[D_a - (K-R), 0] - f_1[Min(R, D_n) + Min(K-R, D_a)] \\ - f_2[Max(R - D_n, 0) + Max(K - R - D_a, 0)] \end{aligned} \tag{4}$$

The profit model is explained as follows.

(3) The profit of the non-asset operator under the sharing operations is comprised of the revenue of delivery service, $P_n D_n$, minus the rental costs for using the parcel locker, $P_r R$, the costs of delivery using parcel locker, $c'_n Min(R, D_n)$, and the costs of door-to-door delivery when the delivery demand is larger than the locker supply, $c_n Max(D_n - R, 0)$;

(4) The profit of the asset operator under the sharing operations is composed of the revenue of the delivery service, $P_a D_a$, together with the parcel-locker rental revenue, $P_r R$, minus the costs of delivery using the parcel locker, $c'_a Min(K - R, D_a)$, the costs of door-to-door delivery in case the unrented locker capacity is not enough to satisfy the delivery demand, $c_a Max[D_a - (K - R), 0]$, and the operating costs of used lockers, $f_1[Min(R, D_n) + Min(K - R, D_a)]$ and the operating costs of unused lockers, $f_2[Max(R - D_n, 0) + Max(K - R - D_a, 0)]$.

4.3.3. Sharing Benefit: Sharing Profit–No-Sharing Profit

For non-asset operator benefits,

$$c_n D_n - P_r R - c'_n Min(R, D_n) - c_n Max(D_n - R, 0) \tag{5}$$

For asset operator benefit,

$$\begin{gathered} c_a D_a + f_1 D_a + f_2(K - D_a) + P_r R - \left(c'_a + f_1\right) Min(K - R, D_a) - c_a Max[D_a - (K - R), 0] \\ - f_1[Min(R, D_n) - f_2[Max(R - D_n, 0) + Max(K - R - D_a, 0)] \end{gathered} \tag{6}$$

For the total supply-chain benefit,

$$\begin{gathered} c_n D_n + f_2 K + \left(c'_a + f_1 - f_2\right) D_a - \left(f_1 + c'_n\right) Min(R, D_n) - \left(f_1 + c'_a\right) Min(K - R, D_a) \\ - c_a Max[D_a - (K - R), 0] - c_n Max(D_n - R, 0) - f_2[Max(R - D_n, 0) + Max(K - R - D_a, 0)] \end{gathered} \tag{7}$$

The computation of the sharing mechanism profit is explained as follows.

(5) The profit brought by adopting a sharing mechanism for the non-asset operator is computed by subtracting the profit under the parcel-locker-sharing operations (3) from the profit under the no-sharing operations (1) of the non-asset operator;

(6) The profit brought by adopting a sharing mechanism for the asset operator is computed by subtracting the profit under the parcel-locker-sharing operations (4) from the profit under the no-sharing operations (2) of the asset operator;
The total supply-chain profit is calculated by adding the profit of the two participating parties of the sharing mechanism, including the non-asset operator (5) and the asset operator (6).

(7) The positive difference represents that the sharing mechanism increases the profit for a particular party or the total supply chain. In contrast, a negative result means a profit decrease is incurred, and the sharing model is unprofitable.

### *4.4. Mathematical Analysis*

Mathematical Model and Computation

The profit model of the total supply chain is built into mathematical formulas of expected profits for derivative-based optimization analysis. The market demands for the delivery are presented using a normal distribution. The maximum and minimum functions are presented using the integrals below.

For the expected total supply-chain benefit,

$$\begin{aligned} P(R) = {} & E[\text{Profit}(D_a,\ D_n,\ R)] = \\ & c_n \int_0^\infty \varepsilon_n \varphi_{D_n}(\varepsilon_n) d\varepsilon_n + f_2 K + \left(c_a' + f_1 - f_2\right) \int_0^\infty \varepsilon_a \varphi_{D_a}(\varepsilon_a) d\varepsilon_a \\ & + \left(f_1 + c_n'\right) \left[ \int_0^R \varepsilon_n \varphi_{D_n}(\varepsilon_n) d\varepsilon_n + \int_R^\infty R \varphi_{D_n}(\varepsilon_n) d\varepsilon_n \right] \\ & + \left(f_1 + c_a'\right) \left[ \int_0^{K-R} \varepsilon_a \varphi_{D_a}(\varepsilon_a) d\varepsilon_a + \int_{K-R}^\infty (K-R) \varphi_{D_a}(\varepsilon_a) d\varepsilon_a \right] \\ & + c_a \int_{K-R}^\infty [\varepsilon_a - (K-R)] \varphi_{D_a}(\varepsilon_a) d\varepsilon_a - c_n \int_R^\infty (\varepsilon_n - R) \varphi_{D_n}(\varepsilon_n) d\varepsilon_n \\ & + f_2 \left[ \int_0^R (R - \varepsilon_n) \varphi_{D_n}(\varepsilon_n) d\varepsilon_n + \int_0^{K-R} (K - R - \varepsilon_a) \varphi_{D_a}(\varepsilon_a) d\varepsilon_a \right] \end{aligned} \tag{8}$$

where $\varphi_{D_a}(\varepsilon_a) : p.d.f.of D_a$, $\varphi_{D_n}(\varepsilon_n) : p.d.f.of D_n$.

To analyze the profitability of the parcel-locker-sharing mechanism and identify the optimal renting quantity that will maximize the total supply-chain profit brought by the mechanism adoption, the first derivative of the expected total supply-chain profit P(R) (8) is computed:

$$\boldsymbol{P'(R)} = \left(f_1 + c_a' - c_a\right)[1 - \phi_a(K-R)] + \left(c_n - f_1 - c_n'\right)[1 - \phi_n(R)] - f_1 \phi_n(R) + f_2 \phi_a(K-R) \tag{9}$$

where $\phi_a(\varepsilon_a) = c.d.f.of D_a$, $\phi_n(\varepsilon_n) = c.d.f.of\ D_n$.

Let the first derivative of the expected total supply-chain profit $\boldsymbol{P'(R)}$ (9) equals 0, then

$$c_a' - c_a + c_n - c_n' = \left(c_a' - c_a + f_1 - f_2\right)\phi_a(K-R) + \left(c_n - c_n' + f_2 - f_1\right)\phi_n(R) \tag{10}$$

When the sharing mechanism is profitable, the optimal renting quantity that maximizes the total supply-chain profit can be computed through this equation.

To analyze the profitability of the mechanism, the second derivative of $\boldsymbol{P(R)}$ in Equation (8) is computed:

$$\boldsymbol{P''(R)} = \left(c_a' - c_a + f_1 - f_2\right)\varphi_{D_a}(K-R) + \left(c_n' - c_n + f_1 - f_2\right)\varphi_{D_n}(R) \tag{11}$$

**For Case 1**, when $\begin{cases} f_1 - f_2 < c_a - c_a' \\ f_1 - f_2 < c_n - c_n' \end{cases}$, then $\boldsymbol{P''(R)} = \left(c_1 - c_a + f_1 - f_2\right)\varphi_{D_1}(K-R) + \left(c_2 - c_b + f_1 - f_2\right)\varphi_{D_2}(R) < 0$.

The negative second derivative implies that the expected total supply-chain profit $\boldsymbol{P(R)}$ is a concave function. When $R = 0$, no sharing mechanism is implemented, and no profit will be generated, i.e., $\boldsymbol{P(R)}$ equals 0 when $R = 0$. When $R$ increases, the benefit $\boldsymbol{P(R)}$ will increase from zero to a maximum point and then decrease. The profit maximization will be achieved at the quantity $R$ when $\boldsymbol{P'(R)} = 0$.

**For Case 2**, when $\begin{cases} f_1 - f_2 > c_a - c_a' \\ f_1 - f_2 > c_n - c_n' \end{cases}$, then $\boldsymbol{P''(R)} = \left(c_a' - c_a + f_1 - f_2\right)\varphi_{D_a}(K-R) + \left(c_n' - c_n + f_1 - f_2\right)\varphi_{D_n}(R) > 0$.

The positive second derivative implies that the expected total supply-chain benefit $\boldsymbol{P(R)}$ is a convex function. Similarly, $\boldsymbol{P(R)}$ equals 0 when $R = 0$. When $R$ increases, the benefit $\boldsymbol{P(R)}$ will decrease from zero to a minimum point and then increase. The maximum will be achieved at the endpoints either when $R = 0$ or $K$.

**For Case 3**, when $c_a - c_a' \le f_1 - f_2 \le c_n - c_n'$, then $\boldsymbol{P'(R)} \ge (c_a' - c_a + c_n - c_n')[1 - \phi_n(R)] \ge 0$.

The positive first derivative implies that $\boldsymbol{P(R)}$ is a monotonic increasing function. Since $\boldsymbol{P(R)} = 0$, the profit will constantly increase from 0 when the renting quantity $R$ increases. Therefore, the maximum will be reached at endpoint $K$.

**For Case 4**, when $c_n - c_n' \le f_1 - f_2 \le c_a - c_a'$, then $\boldsymbol{P'(R)} \le (c_a' - c_a + c_n - c_n')[1 - \phi_n(R)] \le 0$.

The negative first derivative implies that $\boldsymbol{P}(\boldsymbol{R})$ is a monotonic decreasing function. Therefore, the profit will continuously decrease from zero when the renting quantity increases.

Additional to the total supply-chain benefit, the profitability of the two participating parties, including the asset operator and non-asset operators, is also considered to justify their willingness to join the sharing model. To ensure the profitability of model adoption for the two parties, the profit brought by the sharing operations should be positive, i.e., Equations (5) and (6) should be larger than zero. The profit balance between the two parties can be achieved and adjusted by setting the rental price (i.e., $P_r$).

### *4.5. Numerical Analysis*

A numerical example is used to illustrate the applications of the proposed model. Four specific numerical examples are used to demonstrate each case.

#### 4.5.1. Parameter Setting

Based on the assumptions about market demand, cost index, and locker capacity, the basic parameter setting is as follows (Table 2).

**Table 2.** Parameter setting value.

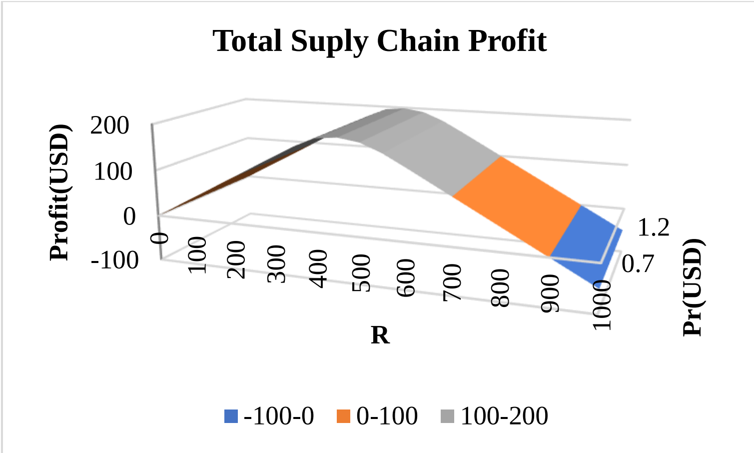
| **Parameter** | **Value** |
|---|---|
| Delivery service charge of asset operator, $P_a$ | USD 15 |
| Delivery service charge of non-asset operator, $P_n$ | USD 13 |
| Operating cost of used parcel locker, $f_1$ | USD 2 |
| Operating cost of unused parcel locker, $f_2$ | USD 1 |
| Delivery cost using parcel lockers for asset operator, $c_n'$ | USD 1.5 |
| Delivery cost using parcel lockers for non-asset operator, $c_n'$ | USD 1.5 |
| Locker capacity, $K$ | 1000 |
| Delivery demand for asset operator, $D_a$ | ~$N$ (600, 30) |
| Delivery demand for non-asset operator, $D_n$ | ~$N$ (500, 40) |

#### 4.5.2. Computational Experiments and Discussion

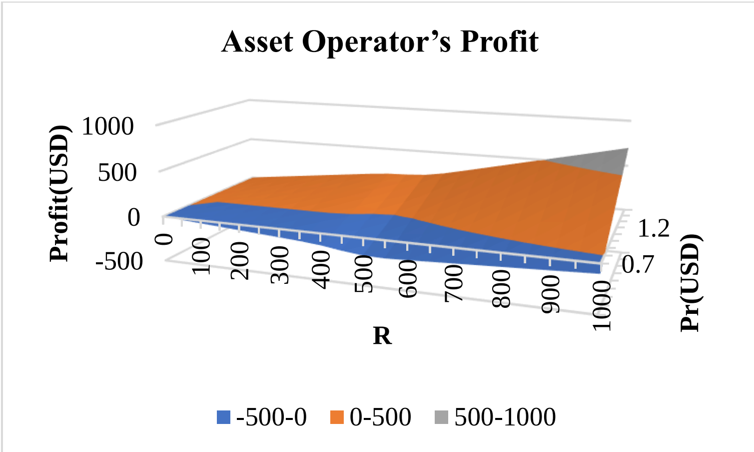
The costs for door-to-door delivery for the asset and non-asset operators are set under each case scenario to fulfill the different cost-structure conditions. The renting quantity $R$ is set from 0 to $K$. (i.e., 1000), and the rental price, $P_r$ is set from 0.2 to 1 for computing the total supply-chain benefit, asset operator's profit, and non-asset operator's profit. The results are demonstrated in the 3D plots shown in Figures 1–4.

**Scenario 1.** *The delivery-cost saving on using the locker is greater than the operating-cost difference between using and not using the locker,*$c_a = USD\ 3,\ c_n = USD\ 3$.

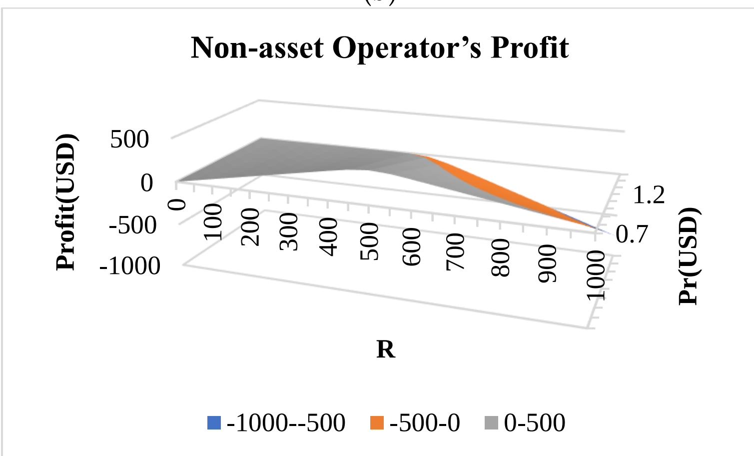
The total supply-chain benefit increases from 0 to a maximum of USD 198.80 at a renting quantity of 443 units and then decreases. The rental price does not influence the total supply-chain benefit because it only balances the profits between the two parties, as shown in Figure 1a. Considering the two parties separately, there is an interval of rental price, $P_r$. Between USD 1.046 and USD 1.495 generates positive profits for both the asset and non-asset operators, as shown in Figure 1b,c. It is noted that the savings in the delivery cost exceed the operating-cost difference between using and not using the lockers, making sharing a profitable option for the supply chain. If the two parties can set the costs within a specific interval, they can adopt the sharing model to maximize the total supply-chain benefit.




(**a**)



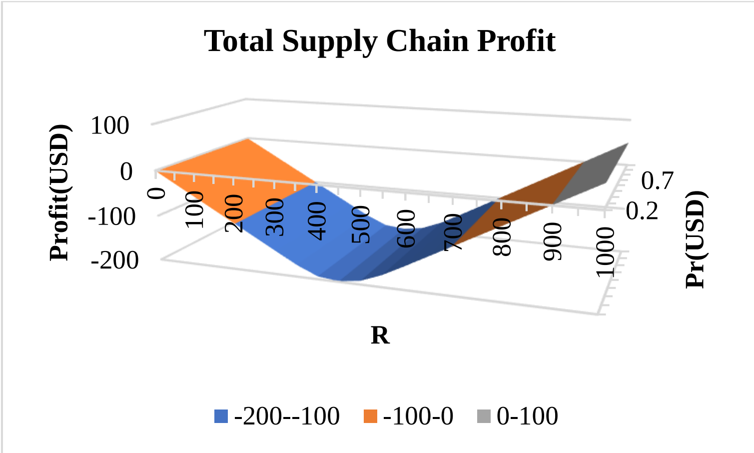

(**b**)



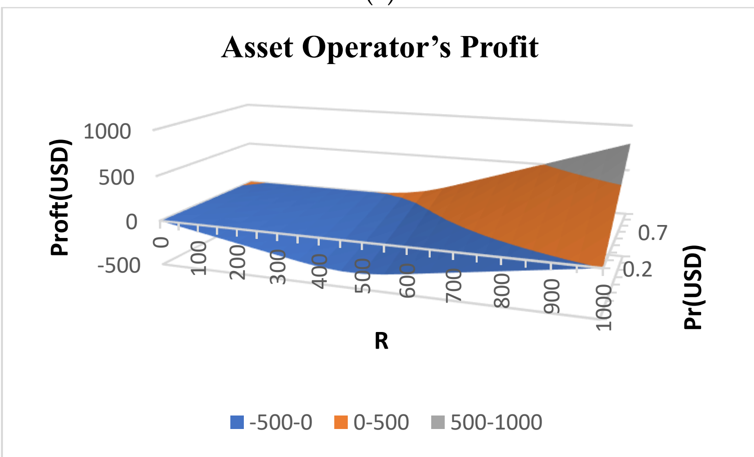

(**c**)

**Figure 1.** (**a**) Total supply-chain profit under scenario 1. (**b**) Asset operator's profit under scenario 1. (**c**) Non-asset operator's profit under scenario 1.

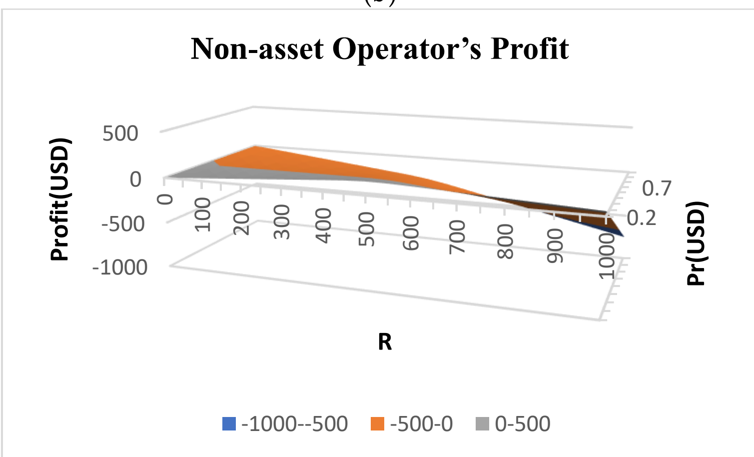
**Scenario 2.** *The delivery-cost benefit of using the locker is smaller than the operating-cost difference between using and not using the locker, i.e.,*$c_a = USD\ 2,\ c_n = USD\ 2$.




(**a**)




(**b**)

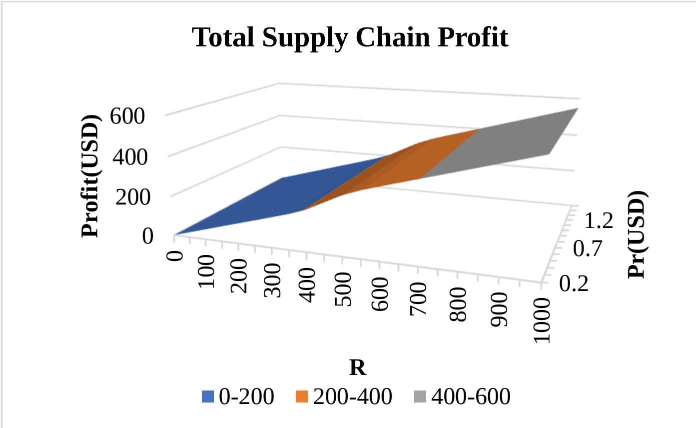



(**c**)

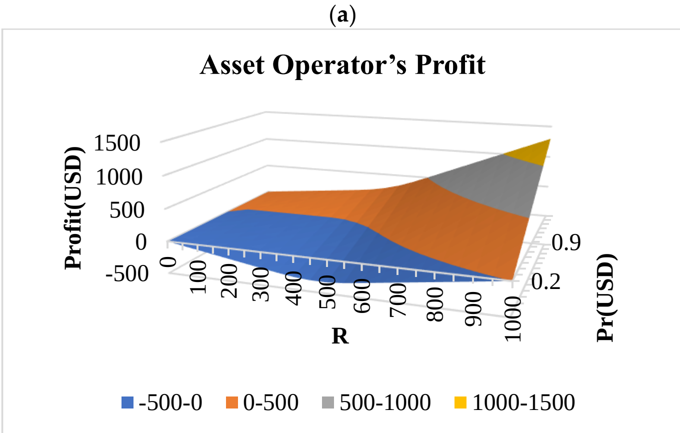
**Figure 2.** (**a**) Total supply-chain profit under scenario 2. (**b**) Asset operator's profit under scenario 2. (**c**) Non-asset operator's profit under scenario 2.

The total supply-chain benefit decreases from 0 to the minimum and bounces back to a maximum of USD 50 in Figure 2a at the endpoint $K$. The positive profit for both parties is achieved when the rental price is between USD 0.2 to USD 0.25, as shown in Figure 2b,c. Under this scenario, the operating-cost difference between using and not using the lockers is larger than the savings by using parcel-locker delivery. As a result, the usage of a locker will incur higher costs to the asset operator, which implies that renting out the unused capacity is not profitable for the whole supply chain. Therefore, the sharing mechanism should not be implemented. However, there is a case when the asset operator rents out the full capacity to the non-asset operator, such that the rental price can cover the operating-cost difference between using and not using the lockers. As a result, there would be a positive total supply-chain benefit in the expenses of the non-asset operator.

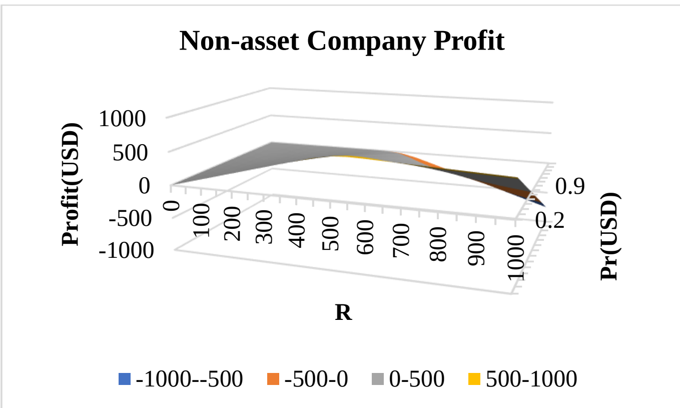
**Scenario 3.** *The cost savings for the non-asset operator using the locker is larger than the operating cost difference between using and not using the locker and larger than the cost saving for the asset operator,*$c_a = USD\ 2,\ c_n = USD\ 3$.




(**a**)




(**b**)




(**c**)

**Figure 3.** (**a**) Total supply-chain profit under scenario 3. (**b**) Asset operator's profit under scenario 3. (**c**) Non-asset operator's profit under scenario 3.

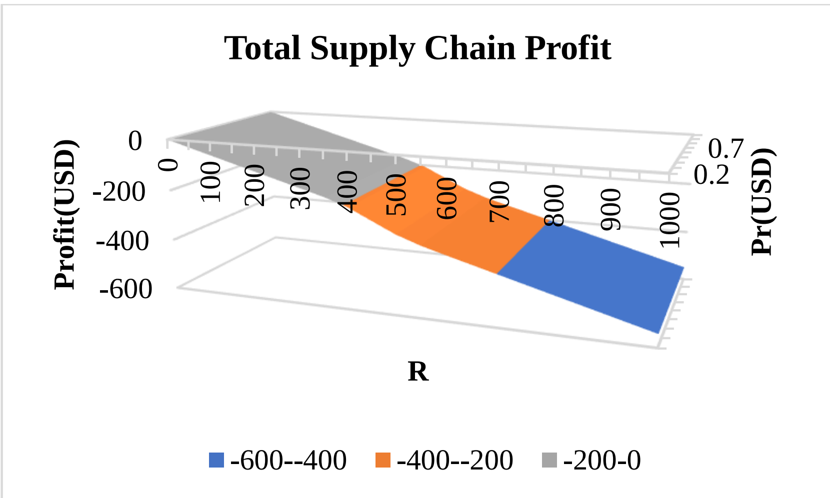
The total supply-chain benefit continuously increases from 0 to the maximum of USD 550 at the endpoint $K$, as shown in Figure 3a. The positive profits for both parties are achieved when the rental price is between USD 0.2 to USD 0.75, as shown in Figure 3b,c. Under this scenario, the savings from using the lockers for the non-asset operator exceed the additional cost of operating the lockers and the savings achievable by the asset operator. On the other hand, if the non-asset operator solely uses the locker to fulfill its demand, the total supply chain can achieve more cost savings. Therefore, the asset company should rent out its full capacity to maximize the total supply-chain benefit.

**Scenario 4.** *The cost savings for the asset operator using the locker is larger than the operating-cost difference between using and not using the locker and larger than the cost saving for the non-asset operator,*$c_a = USD\,3,\ c_n = USD\,2$.

There is no positive benefit for the total supply chain, as shown in Figure 4a, indicating the unprofitability of the sharing mechanism under this cost scenario. Under this scenario, the asset operator can save more money by using the parcel locker for delivery. In contrast, the additional cost of operating the used locker cannot be covered by the non-asset operator's savings on the delivery cost. Therefore, renting lockers to the non-asset operator is not profitable to the supply chain. Thus, the sharing mechanism should not be adopted.

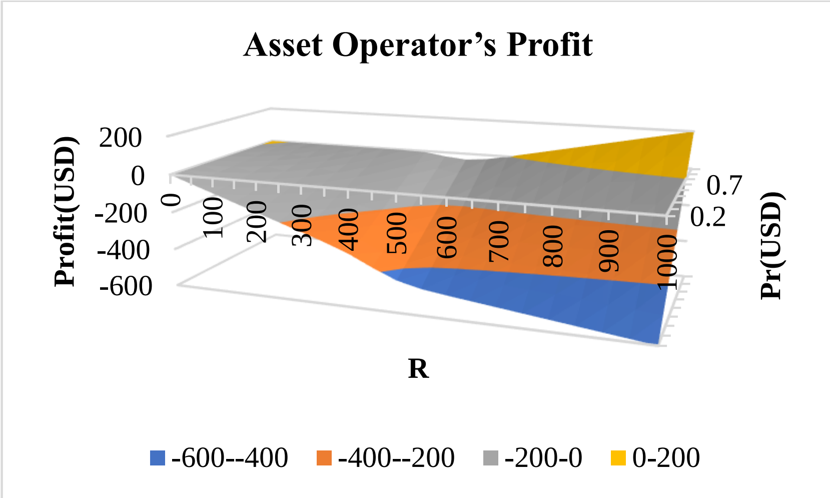
In addition to the total supply-chain benefit, the profitability of the two participating parties should also be fulfilled for model implementation by adjusting the rental price. The rental price can be determined within the price interval computed using Equations (5) and (6) and depends on the bargaining power of the two parties.

The value we set in numerical analysis was picked under the assumption of the market demand, cost index, and locker capacity. To show the result significantly in different scenarios, we enlarge the differences between the service revenue and the delivery cost. It is believed that the whole case will earn profit or lose money, even though the price of the delivery service is a little greater than the cost of delivery by door to door and the cost of delivering by parcel locker. The difference will only be seen in terms of the value and not the final strategy and decision. Overall, the focus of picking the cost values is on size relationships rather than specific differences. The final decision will always be the same under the assumption.

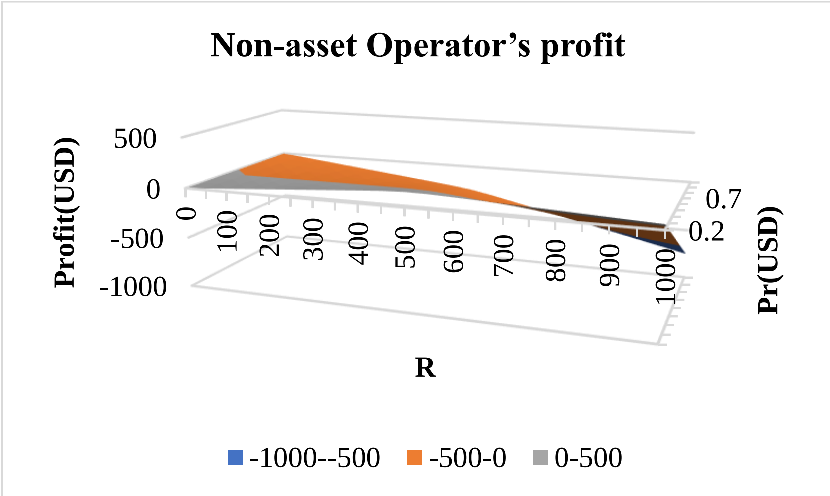



(**a**)

**Figure 4.** *Cont.*




(**b**)




(**c**)

**Figure 4.** (**a**) Total supply-chain profit under scenario 4. (**b**) Asset operator's profit under scenario 4. (**c**) Non-asset operator's profit under scenario 4.

## 5. Discussions

The result (Table 3) shows that we can determine the profitability of the framework by comparing the locker operating-cost difference and the savings of the delivery costs from using the locker. There are four scenarios for running the framework. The sharing is profitable when the increase in operating cost is smaller than the delivery-cost savings for both operators. When the increase in the operating cost is between the delivery-cost savings of the two operators, if the cost savings for the non-asset operator is larger, the sharing framework brings profit and reaches the optimum when the total locker capacity is rented. If the cost savings for the asset operator is larger, the sharing of the locker should not be implemented. The profitability is undetermined if the increase in operating cost is larger than the delivery-cost savings for both parties. It requires further analysis to decide whether to abandon the sharing framework or rent all the lockers. The rental price will be determined based on the bargaining power of the two parties to agree on a price, ensuring mutual profits. These outcomes can be directly applied to real-life cases when companies collect related data.

**Table 3.** Profitability summary of the sharing mechanism and suggested strategies.

| Scenario | | Profitability | Strategy |
|---|---|---|---|
| 1 | $f_1 - f_2 < c_a - c'_a, f_1 - f_2 < c_n - c'_n$ | Profitable | Rent $R$ at $\boldsymbol{P}'(\boldsymbol{R}) = 0$ |
| 2 | $f_1 - f_2 > c_a - c'_a, f_1 - f_2 > c_n - c'_n$ | Undetermined | Do not rent or rent K |
| 3 | $c_a - c'_a \leq f_1 - f_2 \leq c_n - c'_n$ | Profitable | Rent K |
| 4 | $c_n - c'_n \leq f_1 - f_2 \leq c_a - c'_a$ | Unprofitable | No-sharing |

The computational experiment results provide significant insights into the operational and economic dynamics of such a locker-sharing collaborative model. By examining four distinct scenarios based on the cost differentials between operating used and unused lockers versus the cost differences between s door-to-door service and a parcel-locker delivery service, the study elucidates the conditions under which sharing parcel lockers can be mutually beneficial.

From a managerial perspective, this study provides actionable insights into how logistics operators can strategically adopt a locker-sharing model. Managers should conduct a thorough cost–benefit analysis to understand their specific cost structures and identify the scenarios where sharing would be advantageous. For instance, if the operating costs of unused lockers are significantly high, sharing these lockers with non-asset operators can help distribute these costs more effectively, leading to overall cost reductions. Additionally, managers should consider the demand patterns and delivery preferences of their customers to optimize the use of the shared lockers. By leveraging these insights, logistics operators can make informed decisions about when and how to engage in locker-sharing agreements, ultimately enhancing their service offerings and operational efficiency. This study, thus, contributes to the broader understanding of collaborative logistics and provides a framework for implementing shared locker systems in real-world scenarios.

Implementing this framework in real life can also significantly contribute to environmental protection, particularly by reducing carbon emissions through a decrease in the number of door-to-door deliveries. This reduction aligns with the growing emphasis on sustainability within supply-chain operations. As businesses increasingly prioritize environmental concerns, the model's ability to lower emissions through optimized delivery routes offers substantial advantages. It presents a valuable solution, not only in terms of cost-efficiency but also in promoting sustainability, thereby addressing both economic and environmental objectives.

## 6. Implications and Limitations

With the continuous growth of the e-commerce market, last-mile delivery is the terminal link of supply-chain activities, and the level of its logistics costs largely affects the operational efficiency of the entire supply chain. The parcel-locker network emerges as a promising contributor to solving the last-mile delivery problem. This paper contributes to the research on parcel-locker utilization for last-mile delivery by providing a novel and systematic analysis of the profitability of the parcel-locker-sharing framework and the optimization of the framework. The research results suggest the profitability of the sharing framework, the optimal renting quantity, and the rental price. Furthermore, the sharing parcel-locker framework has established a logistics market in which companies cooperate and integrate the resources of enterprises, building a new era of last-mile delivery. The key to whether a company can successfully integrate last-mile delivery resources lies in the feasibility of its operations, which is the trade-off of changes in operating costs and delivery costs in the model. It is believed that the use of shared parcel lockers will soon become inevitable, and this research will help companies pursue this collaborative model.

The current work has limitations, and there is room for further progress by considering relaxation on the setting of demand and variable delivery charges. Future research can consider introducing dynamic variables into the framework. Fluctuations in the demand and delivery price will make the framework more practical. In addition, the framework could expand and be broader regarding allocating customer orders so that the operators can assign customer orders for door-to-door or parcel-locker delivery. The customer's preference for door-to-door or parcel-locker delivery can also be involved, influencing the customer's perceived value and selection of different last-mile delivery modes. Another cogitation includes that door-to-door delivery services may charge a higher price than parcel-locker delivery in particular situations for better services, such as heavy items or parcels for the elderly with mobility problems. By incorporating these factors, future studies could empirically validate or simulate to offer a more comprehensive understanding of the parcel-locker-sharing framework. Future research can also consider the relaxation of some assumptions and involve customer preferences, making this model more practical.

## 7. Conclusions

The increased customer demand for e-commerce activities has attached importance to managing last-mile delivery. The parcel locker is one of the rising solutions to improve efficiency in last-mile delivery, and the sharing economy catalyzes logistics companies to consider cooperation. The parcel-locker-sharing framework that promotes the collaboration between the asset and non-asset logistics operators for using parcel lockers for last-mile delivery can be implemented to improve operational efficiency and resource utilization. Asset operators may have a surplus of unused lockers without sharing, and non-asset operators must provide expensive door-to-door services. Under the parcel-locker-sharing framework, the asset operator rents out a specific number of parcel lockers to the non-asset operator. The asset operator gains revenue from renting the lockers but faces a higher chance of insufficient lockers for themselves and may end up paying a higher cost for additional door-to-door delivery service. Non-asset operators will have some parcel lockers for delivery service, lowering their operations costs. There will be mutual benefits to both parties if the parcel-locker-sharing framework is implemented.

**Author Contributions:** Conceptualization, K.-W.P., J.X., R.J. and R.L.; methodology, K.-W.P., J.X., R.J. and R.L.; validation, K.-W.P., J.X., R.J. and R.L.; writing—original draft preparation, J.X., R.J. and R.L.; writing—review and editing, K.-W.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no funding.

**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Alfonso, V.; Boar, C.; Frost, J.; Gambacorta, L.; Liu, J. E-commerce in the pandemic and beyond. *BIS Bull.* **2021**, *36*. Available online: https://www.bis.org/publ/bisbull36.htm (accessed on 12 January 2021).
2. Zhang, X.; Huang, G. Research on Urban Logistics Distribution Based on Dynamic Demand. In Proceedings of the 2018 2nd International Conference on Economic Development and Education Management (ICEDEM 2018), Dalian, China, 29–30 December 2018; Atlantis Press: Amsterdam, The Netherlands, 2018; pp. 234–237.
3. Hoque, M.; Bashaw, R.E. (Eds.) *Cross-Border E-Commerce Marketing and Management*; IGI Global: Hershey, PA, USA, 2020.
4. Tian, L.; Vakharia, A.J.; Tan, Y.; Xu, Y. Marketplace, Reseller, or Hybrid: Strategic Analysis of an Emerging E-Commerce Model. *Prod. Oper. Manag.* **2018**, *27*, 1595–1610. [CrossRef]
5. Yu, Y.; Yu, C.; Xu, G.; Zhong, R.Y.; Huang, G.Q. An operation synchronization model for distribution center in E-commerce logistics service. *Adv. Eng. Inform.* **2020**, *43*, 101014. [CrossRef]
6. Janjevic, M.; Winkenbach, M.; Merchán, D. Integrating collection-and-delivery points in strategic design of urban last-mile e-commerce distribution networks. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *131*, 37–67. [CrossRef]
7. Zhou, J.; Yang, M.; Zhou, X.; You, K.; Zhang, M. Distribution Service Mode of the Express Terminal Outlets. In Proceedings of the First International Symposium on Management and Social Sciences (ISMSS 2019), Wuhan, China, 13–14 April 2019; Atlantis Press: Amsterdam, The Netherlands, 2019; pp. 1–5.
8. Islam, D. Barriers to and enablers for European rail freight transport for integrated door-to-door logistics service. *Transp. Probl.* **2014**, *9*, 5–13.

9. Kawa, A. Out-of-Home Delivery as a Solution of the Last Mile Problem in E-commerce. In *Smart and Sustainable Supply Chain and Logistics–Trends, Challenges, Methods and Best Practices*; Springer: Cham, Switzerland, 2020; pp. 25–40.
10. Chen, C.T. A fuzzy approach to select the location of the distribution center. *Fuzzy Sets Syst.* **2001**, *118*, 65–73. [CrossRef]
11. Aized, T.; Srai, J.S. Hierarchical modelling of Last Mile logistic distribution system. *Int. J. Adv. Manuf. Technol.* **2014**, *70*, 1053–1061. [CrossRef]
12. Jiang, X.; Wang, H.; Guo, X.; Gong, X. Using the FAHP, ISM, and MICMAC approaches to study the sustainability influencing factors of the last mile delivery of rural E-commerce logistics. *Sustainability* **2019**, *11*, 3937. [CrossRef]
13. Vakulenko, Y.; Hellström, D.; Hjort, K. What's in the parcel locker? Exploring customer value in e-commerce last-mile delivery. *J. Bus. Res.* **2018**, *88*, 421–427. [CrossRef]
14. Seghezzi, A.; Siragusa, C.; Mangiaracina, R. Parcel lockers vs. home delivery: A model to compare last-mile delivery cost in urban and rural areas. *Int. J. Phys. Distrib. Logist. Manag.* **2022**, *52*, 213–237.
15. Deutsch, Y.; Golany, B. A parcel locker network as a solution to the logistics last mile problem. *Int. J. Prod. Res.* **2018**, *56*, 251–261. [CrossRef]
16. Wang, Y.; Bi, M.; Lai, J.; Chen, Y. Locating movable parcel lockers under stochastic demands. *Symmetry* **2020**, *12*, 2033. [CrossRef]
17. Yang, G.; Huang, Y.; Fu, Y.; Huang, B.; Sheng, S.; Mao, L.; Huang, S.; Xu, Y.; Le, J.; Ouyang, Y.; et al. Parcel Locker Location Based on a Bilevel Programming Model. *Math. Probl. Eng.* **2020**, *2020*, 5263689. [CrossRef]
18. Lin, Y.H.; Wang, Y.; He, D.; Lee, L.H. Last-mile delivery: Optimal locker location under multinomial logit choice model. Transportation Research. *Part E Logist. Transp. Rev.* **2020**, *142*, 102059. [CrossRef]
19. Ding, M.; Song, Y.; Hu, Y. Supply–Demand Matching of Smart Parcel Lockers in a Residential Area: Insights from Tianjin. *Buildings* **2023**, *13*, 2088. [CrossRef]
20. Ranjbari, A.; Diehl, C.; Dalla, C.G.; Goodchild, A. *What Is the Right Size for a Residential Building Parcel Locker? Transportation Research Record*; SAGE Publications: Los Angeles, CA, USA, 2023.
21. Wang, Y.; Bi, M.; Chen, Y. A scheduling strategy of mobile parcel lockers for the last mile delivery problem. *Promet* **2020**, *32*, 875–885. [CrossRef]
22. Schwerdfeger, S.; Boysen, N. Optimizing the changing locations of mobile parcel lockers in last-mile distribution. *Eur. J. Oper. Res.* **2020**, *285*, 1077–1094. [CrossRef]
23. Vukićević, M.; Ratli, M.; Rivenq, A.; Zrikem, M. *Covering Delivery Problem with Electric Vehicle and Parcel Lockers: Variable Neighborhood Search Approach*; Computers & Operations Research; Elsevier Ltd.: Amsterdam, The Netherlands, 2023.
24. SF Express (n.d). About SF Locker. Available online: https://htm.sf-express.com/hk/en/other_services/intelligent_cabinet/marketing_services/ (accessed on 10 August 2024).
25. Kistler.K (n.d). Electronic Parcel Lockers: Are They the Best Package Management System for Your Property? Available online: https://butterflymx.com/blog/electronic-parcel-lockers/ (accessed on 10 August 2024).
26. Rohmer, S.; Gendron, B. *A Guide to Parcel Lockers in Last Mile Distribution: Highlighting Challenges and Opportunities from an OR Perspective*; CIRRELT-2020-11; Cirrelt: Montreal, QC, Canada, 2020.
27. Stephany, A. *The Business of Sharing: Making It in the New Sharing Economy*; Palgrave MacMillan: London, UK, 2015.
28. Martin, C.J. The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism? *Ecol. Econ.* **2016**, *121*, 149–159. [CrossRef]
29. Belk, R. You are what you can access: Sharing and collaborative consumption online. *J. Bus. Res.* **2014**, *67*, 1595–1600. [CrossRef]
30. Gansky, L. *The Mesh: Why the Future of Business Is Sharing*; Portfolio Penguin: New York, NY, USA, 2010.
31. Schor, J.B.; Fitzmaurice, C.J. Collaborating and connecting: The emergence of the sharing economy. In *Handbook of Research on Sustainable Consumption*; Edward Elgar Publishing: Northampton, MA, USA, 2015; pp. 410–425.
32. Hamari, J.; Sjöklint, M.; Ukkonen, A. The sharing economy: Why people participate in collaborative consumption. *J. Assoc. Inf. Sci. Technol.* **2016**, *67*, 2047–2059. [CrossRef]
33. Möhlmann, M. Collaborative consumption: Determinants of satisfaction and the likelihood of using a sharing economy option again. *J. Consum. Behav.* **2015**, *14*, 193–207. [CrossRef]
34. Chatterjee, S.; Chaudhuri, R.; Vrontis, D.; Mahto, R. *Bright and Dark Sides of Adopting a Platform-Based Sharing Economy Business Model*; R & D Management: Stockholm, Sweden, 2023.
35. Yamada, T.; Taniguchi, E.; Noritake, M.; Horie, A. Attitudes of companies towards introducing cooperative freight transport systems. In Proceedings of the International Conference on City Logistics, Cairns, Australia, 12–14 July 1999.
36. Hayashi, K.; Yano, Y. Future City Logistics in Japan from the Shippers' and Carriers' View–Prospects and Recent Measures to Develop them. In *Logistics Systems for Sustainable Cities*; Emerald Group Publishing Limited: Leeds, UK, 2004.
37. Nemoto, T. An experimental cooperative parcel pick-up system using the internet in the central business district in Tokyo. In *Logistics Systems for Sustainable Cities*; Emerald Group Publishing Limited: Leeds, UK, 2004.
38. Zäpfel, G.; Wasner, M. Planning and optimization of hub-and-spoke transportation networks of cooperative third-party logistics providers. *Int. J. Prod. Econ.* **2002**, *78*, 207–220. [CrossRef]
39. Xu, S.; Liu, Y.; Chen, M. Optimization of partial collaborative transportation scheduling in supply chain management with 3PL using ACO. *Expert Syst. Appl.* **2017**, *71*, 173–191. [CrossRef]
40. Oh, G.; Kim, Y.; Ahn, J.; Choi, H.L. Task allocation of multiple UAVs for cooperative parcel delivery. In *Advances in Aerospace Guidance, Navigation and Control*; Springer: Cham, Switzerland, 2018; pp. 443–454.

41. Rosenberg, N.; Balouka, N.; Herer, T.; Dani, E.; Gasparin, P.; Dobers, K.; Rüdiger, D.; Pättiniemi, P.; Portheine, P.; van Uden, S. Introducing the Shared Micro-Depot Network for Last-Mile Logistics. *Sustainability* **2021**, *13*, 206. [CrossRef]
42. Kiba-Janiak, M.; Marcinkowski, J.; Jagoda, A.; Skowrońska, A. Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. Literature review. In *Sustainable Cities and Society*; Elsevier Ltd.: Amsterdam, The Netherlands, 2023.
43. Abad, P.L. Determining Optimal Selling Price and Lot Size When the Supplier Offers All-Unit Quantity Discounts. *Decis. Sci.* **1988**, *19*, 622–634. [CrossRef]
44. Esmaeili, M.; Aryanezhad, M.-B.; Zeephongsekul, P. A game theory approach in seller–buyer supply chain. *Eur. J. Oper. Res.* **2009**, *195*, 442–448. [CrossRef]
45. Li, J.; Liu, L. Supply chain coordination with quantity discount policy. *Int. J. Prod. Econ.* **2006**, *101*, 89–98. [CrossRef]
46. Liao, C.-J.; Shyu, C.-H. An Analytical Determination of Lead Time with Normal Demand. *Int. J. Oper. Prod. Manag.* **1991**, *11*, 72–78. [CrossRef]