COMPETITIVE LOCATION OF COLLECTION DELIVERY POINTS IN LAST-MILE LOGISTICS

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ABSTRACT

Purpose: This paper focuses on the last-mile service market within an e-commerce context, involving two existing firms that operate self-collection and delivery services—pickup shops and automated parcel lockers. The analysis is conducted within a competitive location framework, where a follower firm is aware of a leader's existing facility locations and strategies. The follower's objective is to maximize profit by opening new service points. The proposed model aims to identify the optimal locations for the follower's new facilities and determine the most appropriate facility type—either a pickup shop or an automated parcel locker.
Design/methodology/approach: To model customer choice behaviour, Huff's gravity-based model is employed to estimate the probability that customers will patronise a given collection and delivery point. The problem is formulated as an integer nonlinear programming model, which is solved for a representative instance using a branch-and-bound algorithm. This approach facilitates the determination of optimal placement strategies for the follower in a dynamic urban logistics environment.
Findings: The results indicate that the follower's profit and market share can be increased significantly through strategic expansion, leading to a corresponding decline in the leader's performance. Numerical results demonstrate that the follower's profit increases by approximately 53.8%, while the leader's profit decreases by 56.2%. The follower gains a 28% share of the market, with its total share rising from 24% to 52%. From a profit-maximization perspective, the model suggests the establishment of four new pickup shops, with three located in residential areas to compete directly with the incumbent and one situated in ;a touristic area.
Originality/value: This study offers a quantitative model for market followers to optimize facility locations, capture market share, and increase profits in the burgeoning last-mile delivery sector. The research provides valuable methodological and strategic insights into competitive last-mile logistics, addressing a notable gap in the literature concerning dynamic, competitive facility location problems for modern e-commerce services.

Keywords: Competitive location, Last-mile delivery, Collection-delivery point, Huff’s rule.

1. Introduction

The rapid global increase in urbanisation, coupled with the exponential growth of the e-commerce market, has fundamentally reshaped the landscape of urban logistics. The ubiquity of smartphones and simplified online purchasing has empowered consumers, leading to a surge in frequent, small-sized online orders that challenge traditional delivery models. This paradigm shift has escalated the complexity of the "last mile" of the supply chain—the final step of the delivery process from a distribution centre to the end-user. The last mile is notoriously the most expensive and inefficient part of the delivery journey, often accounting for over 50% of total shipping costs (Lim et al., 2018). As a result, academic interest in the field has grown significantly, leading to a diverse but fragmented body of research across themes of operational optimization, emerging technologies, and sustainability (Olsson, Hellström and Pålsson, 2019).

Key challenges in last-mile logistics include high delivery costs, traffic congestion, and significant environmental and social externalities such as carbon emissions and noise pollution (Silva, Amaral and Fontes, 2023). Another major issue is the high rate of failed first-time deliveries due to recipients not being at home. The problem is compounded by a high rate of product returns, with more than half of online shoppers having returned a purchase, further strained logistics networks and increased operational costs. To mitigate these issues, logistics service providers (LSPs) have introduced alternative delivery solutions that enhance both consumer convenience and operational efficiency.

Among the most prominent solutions is the establishment of Collection and Delivery Points (CDPs), such as staffed pickup shops (PS) and automated parcel lockers (AL). These micro-consolidation platforms allow for unattended delivery, consolidating numerous individual parcels at a single location. This reduces the number of vehicle stops, mitigates the risk of failed deliveries, and offers consumers the flexibility to collect their parcels at their convenience. While home delivery remains the dominant method, consumer willingness to use CDPs is growing, evidenced by the rapid expansion of parcel locker networks globally. Major carriers like DHL, DPD, and Amazon have invested heavily in expanding their CDP networks to increase market coverage and service quality.

As the market for last-mile services matures, competition among LSPs intensifies. The strategic placement of CDPs becomes a critical factor for success, influencing not only a firm's operational efficiency but also its market share and profitability. This gives rise to a competitive facility location (CFL) problem, where one firm's decision to open a new facility directly impacts the customer base and revenue of its rivals. Most CFL research has focused on traditional retail settings (Farahani et al., 2014). However, to our knowledge, there has been limited focus on competitive location modelling specifically for last-mile CDP networks, which represents a significant and timely research area.

This paper addresses this gap by focusing on a competitive scenario between two firms in the last-mile market: an established market "leader" and a "follower" aiming to expand its presence. We consider a single-level competitive problem where the follower, knowing the leader's existing facility locations, seeks to maximize its profit by strategically opening new CDPs. The leader is assumed not to react in this initial stage. The core objectives are to determine (1) the optimal locations for the follower's new service points and (2) the optimal type of service (PS or AL) for each location. The remainder of this paper is structured as follows: Section 2 reviews the relevant literature. Section 3 details the problem formulation and mathematical model. Section 4 presents the numerical study and its results. Section 5 discusses the implications of the findings. Finally, Section 6 provides conclusions and outlines directions for future research.

2. Literature Review

This research is situated at the intersection of three main streams of literature: last-mile logistics, consumer behaviour regarding CDPs, and competitive facility location models.

2.1 Last-Mile Logistics and Collection Delivery Points (CDPs)

The operational and environmental benefits of CDPs are well-documented. By consolidating deliveries, LSPs can significantly improve vehicle routing efficiency, reduce fuel consumption, and lower carbon emissions (Vakulenko, Hellström and Hjort, 2018). From the consumer's perspective, CDPs offer flexibility and security, eliminating the need to wait at home for a delivery and reducing the risk of parcel theft. However, consumer adoption is contingent on several factors. Recent research indicates that consumer trust in the technology and concerns over the security of packages are significant drivers of adoption intention for parcel lockers (An et al., 2022). Furthermore, consumer characteristics, such as gender, can influence preferences, with males being more likely to adopt parcel lockers when presented with information about their security and environmental benefits.

Location remains a primary factor. Iwan, Kijewska and Lemke (2016) found that the ideal locations for parcel lockers are "hot spots" like shopping centres and transport hubs. Their survey of consumers revealed a strong preference for lockers located close to home, followed by locations on their daily commute. Similarly, Yuen et al. (2018) identified shopping centres and transport hubs as preferred locations. These studies underscore that the "attractiveness" of a CDP is heavily influenced by its accessibility and integration into a consumer's daily routine.

2.2 Competitive Facility Location (CFL) Models

The field of CFL is extensive, with models designed to capture the strategic interactions between firms competing for market share. Early seminal work includes Hotelling's (1929) model of two vendors on a linear market, which assumes that customers patronise the nearest facility. While foundational, this deterministic "all-or-nothing" approach is often unrealistic in complex markets.

To address this, gravity-based models, most notably the one proposed by Huff (1964), were developed. The Huff model posits that a customer's probability of visiting a particular facility is proportional to its attractiveness and inversely proportional to some function of the distance to it. This probabilistic framework provides a more nuanced representation of market share allocation and has been widely applied and validated in retail location analysis.

Many CFL problems are structured as leader-follower or Stackelberg games, where one firm (the leader) acts first, and a second firm (the follower) observes and then makes its own optimal move. These scenarios are often formulated as bi-level programming problems, a framework that has been successfully applied to CFL for decades (Aras and Küçükaydın, 2017). Küçükaydin, Aras and Altınel (2011) applied a Huff-based gravity model to a leader-follower problem, transforming a bi-level program into a single-level equivalent to find the optimal locations for the follower. They later extended this work to consider various competitive reactions from the leader (Küçükaydin, Aras and Altınel, 2012). This body of work provides the theoretical foundation for our study.

Despite the extensive literature on both last-mile logistics and CFL, there is a distinct lack of research that integrates these two areas. While studies have explored optimal non-competitive locations for CDPs or have analysed consumer preferences, the strategic competitive placement of CDP networks remains an underexplored area. This paper contributes by formulating and solving a CFL problem tailored specifically to the last-mile market, providing a decision-support model for a follower firm seeking to expand its network.

3. Model Description

This study models a competitive market for last-mile delivery services involving a leader and a follower firm. The follower's objective is to determine the optimal number, locations, and types of new CDPs to open to maximize its total profit. The model assumes the follower has complete information about the leader's existing facility locations and that the leader does not react to the follower's expansion in this stage.

3.1 Customer Choice Modelling

We employ Huff's gravity-based rule to model the probabilistic nature of customer choice. The probability that a customer at a given demand point will choose a specific facility is determined by the relative utility of that facility compared to all other available options. The utility of a facility is a function of its attractiveness and the distance from the customer. In this study, we consider three key attractiveness attributes, based on findings in the literature:

- Location Type: The community and specific site of the facility (e.g., residential area, bus station, supermarket).
- Operating Hours: The accessibility of the service (e.g., 24/7 for lockers vs. standard business hours for shops).
- Retrieval Time: The time it takes a customer to collect a parcel, which depends on the service type.

Each attribute is assigned a utility value, and a weight is used to reflect its relative importance to consumers.

3.2 Mathematical Model

The problem is formulated as an integer nonlinear programming (INLP) model. We assume that the customers are at n demand points, the number of existing service points of the leader is p, the number of existing service points of the follower is r, and the number of candidate service points of the follower is m. The demand points are indexed by j = 1,2,…, n ; the leader's existing facilities by l = 1,2,…, p; the follower's existing facilities by k = 1,2,…, r; and the follower's candidate facilities by i = 1,2,…, m. In addition, attractiveness utility and type of service are defined as index u = 1,2,…, U and s = 1,2,…, S, respectively.

Parameters:

h_j	annual revenue occurs at point j,
f_{is}	set up and operating costs of service type s of firm's candidate facility i,
c_k	current set up and operating costs of firm's existing facility k,
q_{isu}	attractiveness utility u of service type s at facility node i,
d_{ij}	Euclidean distance between facility at node i and customer point j,
w_u	weight adjustment of utility u.

Decision variable:

X_{is}	binary variable which is equal to one if a service point type s is opened at node i.

Considering Huff's rule, the probability P_{ij} that customer at point j visits a new self-collection point of the follower' firm is express as

$$P_{ij} = \frac{\sum_{s=1}^{S}\sum_{u=1}^{U} w_u q_{isu} X_{ij} \Big/ d_{ij}^2}{\sum_{i=1}^{m}\left(\sum_{s=1}^{S}\sum_{u=1}^{U} w_u q_{isu} X_{ij} \Big/ d_{ij}^2\right)+\sum_{k=1}^{r}\left(\sum_{u=1}^{U} w_u q_{ku} \Big/ d_{kj}^2\right)+\sum_{l=1}^{p}\left(\sum_{u=1}^{U} w_u q_{lu} \Big/ d_{lj}^2\right)} \tag{1}$$

thus, the revenue of this facility is $\sum_{j=1}^{n} h_j P_{ij}$. Then the total revenue captured by the new facilities of the follower is

$$\sum_{i=1}^{m}\sum_{j=1}^{n} h_j P_{ij} = \sum_{j=1}^{n} h_j \frac{\sum_{i=1}^{m}\left(\sum_{s=1}^{S}\sum_{u=1}^{U} w_u q_{isu} X_{ij} \middle/ d_{ij}^2\right)}{\sum_{i=1}^{m}\left(\sum_{s=1}^{S}\sum_{u=1}^{U} w_u q_{isu} X_{ij} \middle/ d_{ij}^2\right) + \sum_{k=1}^{r}\left(\sum_{u=1}^{U} w_u q_{ku} \middle/ d_{kj}^2\right) + \sum_{l=1}^{p}\left(\sum_{u=1}^{U} w_u q_{lu} \middle/ d_{lj}^2\right)}. \tag{2}$$

However, we consider both leader (competitor) and follower (firm) have had existing facilities, and the firm plans to expand his service network by opening the new facilities and simultaneous maximizing his profit. During this stage, we consider that the competitor does not react and does not change or improve his facilities. Therefore, we can formulate our model as the following integer nonlinear programming:

$$\text{Max} \quad \sum_{j=1}^{n} h_j \frac{\sum_{i=1}^{m}\left(\sum_{s=1}^{S}\sum_{u=1}^{U} w_u q_{isu} X_{ij} \middle/ d_{ij}^2\right) + \sum_{k=1}^{r}\left(\sum_{u=1}^{U} w_u q_{ku} \middle/ d_{kj}^2\right)}{\sum_{i=1}^{m}\left(\sum_{s=1}^{S}\sum_{u=1}^{U} w_u q_{isu} X_{ij} \middle/ d_{ij}^2\right) + \sum_{k=1}^{r}\left(\sum_{u=1}^{U} w_u q_{ku} \middle/ d_{kj}^2\right) + \sum_{l=1}^{p}\left(\sum_{u=1}^{U} w_u q_{lu} \middle/ d_{lj}^2\right)} - \sum_{i=1}^{m}\sum_{s=1}^{S} f_{is} X_{is} - \sum_{k=1}^{r} c_k, \tag{3}$$

$$\text{s.t.} \quad \sum_{s=1}^{S} X_{is} \le 1, \qquad \forall i \in m \tag{4}$$

$$X_{is} \in \{0,1\}. \qquad \forall i \in m, s \in S \tag{5}$$

The objective function (3) of the firm consists of three terms. The first term represents total revenue captured by the firm after the new service facilities are opened. The second term is setup and operating cost of the new facilities while the third term is current costs of the existing facilities of the firm, respectively. Constraint (4) ensures that, at each candidate location, at most one type of the service is opened and constraint (5) is the binary restriction.

Each attractiveness utility q_{isu} is assigned by consumers to alternative location i and service type s, so it is not possible that certain alternative will be selected by different customers. Therefore, we employ perceived utility function as follow into our study:

$$q_{isu} = v_{isu} + \varepsilon_{isu}, \qquad \forall i \in m, s \in S, u \in U \tag{6}$$

where, v_{isu} is a systematic utility expected value of utility u perceived by consumers and ε_{isu} represents a random residual value. At the initial stage, however, we assume the random residual is very small and the residual variance tends to be zero, so the utility model tends to be a deterministic model.

The attractiveness attributes that considered in this study are (1) type of community and location to place the service, e.g. residential area, high traffic pedestrian area, bus/train station, supermarket, etc. This attribute is weighted by information from carriers accompanied with consumer perception towards different locations of the service. (2) Operating hours of the self-collection shop or locker and (3) retrieval time for customers which depends on type of the service facility. Both utilities are weighted by consumer perception towards the two different services.

3.3 Solution Approach

The resulting INLP model is complex due to the fractional and nonlinear objective function. For the scope of this initial study, a specific problem instance was generated and solved using a standard branch-and-bound algorithm, a complete enumeration method capable of finding the global optimum for small to medium-sized problems.

4. Numerical Study and Results

To test the proposed model and gain strategic insights, a numerical experiment was conducted on a representative instance.

4.1 Experimental Setup

The study area was defined as a square of 10x10 distance units. It was divided into 100 grids, with a demand point located at the center of each, assuming an even distribution of demand for simplicity. The area was categorised into three community types: residential, business center, and touristic, and six different types of location are considered, as shown in Table 1 and 2, respectively. The market initially consists of 5 CDPs operated by the leader (2 PS, 3 AL) and 2 CDPs operated by the follower (2 PS). The follower considers opening new CDPs from a set of 10 candidate locations. Two service types are available: pickup shops (PS) and automated lockers (AL). The initial state of the market is depicted in Figure 1.

No.	Community
1	Residential area
2	Business center
3	Touristic area

Table 1: Type of community

No.	Type of service location
1	Close to consumer home
2	High traffic pedestrian area
3	bus/train station
4	Shopping center
5	Supermarket
6	Gas station

Table 2: Type of location of a service point

4.2 Parameterisation

Attractiveness utility values, ranging from 1 to 10, were assigned based on the location type, service type, operating hours, and retrieval time, as detailed in the Table 3 and 4. For example, a location "close to consumer home" has the highest attractiveness of 10, while a "gas station" has a value of 4. ALs are given a higher utility for operating hours (24/7 access), while PSs receive a higher utility for retrieval time (assuming efficient service). In terms of cost, the setup and operating costs for an AL were assumed to be higher than for a PS, as PSs are often co-located with existing businesses like convenience stores, reducing overheads. The relative importance of the attractiveness attributes was weighted, with location being the most influential factor for consumers.

Table 5 provides information of the existing facilities along with attribute values which are generated for the initial study. Then, 10 candidate nodes of the follower are randomly generated and characteristics of the locations shown in Table 6.

No.	Type of service location	Attractiveness utility
1	Close to consumer home	10
2	High traffic pedestrian area	8
3	bus/train station	8
4	Shopping center	5
5	Supermarket	6
6	Gas station	4

Table 3: Attractiveness utility values

No.	Type of service	Operating hours	Retrieval time
1	PS	6	10
2	AL	8	6

Table 4: Service operating time

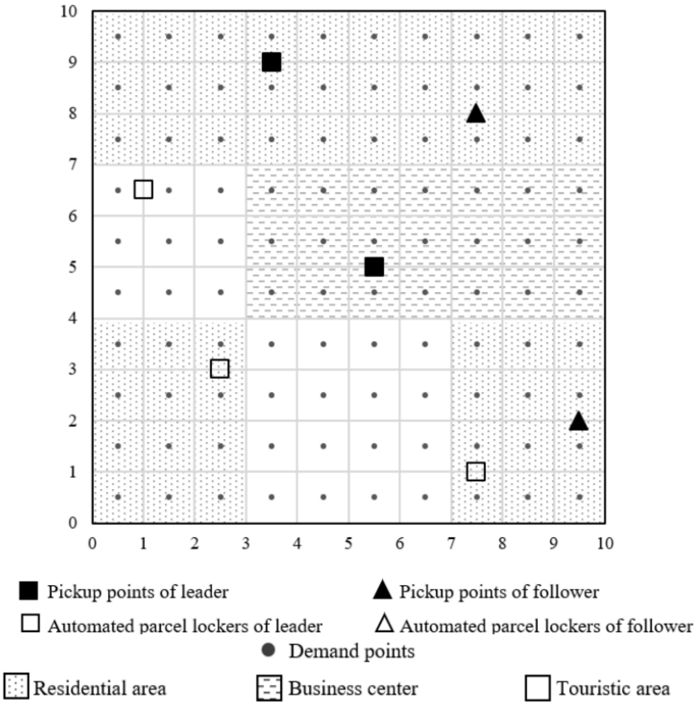

Figure 1: Locations of existing service points and demand points

Firm	Service point	Location		Type of service	Type of community	Type of location	Attractiveness utility		
		x	y				Service location	Operating hours	Retrieval time
Leader	1	7.5	1.0	AL	1	1	10	8	6
	2	5.5	5.0	PS	2	3	8	6	10
	3	2.5	3.0	AL	3	4	5	8	6
	4	1.5	9.0	PS	1	3	8	6	10
	5	1.0	5.5	AL	3	2	8	8	6
Follower	1	9.5	2.0	PS	1	1	10	6	10
	2	7.5	8.0	PS	1	6	4	6	10

Table 5: Existing locations of leader and follower and their attractiveness utilities

Firm	Candidate service point	Location		Possible of service	Type of community	Type of location
		x	y			
Follower	1	5.0	2.0	PS or AL	3	3
	2	7.0	3.5	PS or AL	2	4

Firm	Candidate service point	Location		Possible of service	Type of community	Type of location
		x	y			
	3	2.0	5.0	PS or AL	3	5
	4	6.0	9.0	PS or AL	1	3
	5	1.0	9.0	PS or AL	1	6
	6	9.0	9.0	PS or AL	1	1
	7	1.0	1.0	PS or AL	1	1
	8	8.0	5.5	PS or AL	2	5
	9	5.0	6.0	PS or AL	2	4
	10	4.0	8.0	PS or AL	1	2

Table 6: Candidate locations of follower's new self-collection service

4.3 Computational Results

The INLP model was solved using a branch-and-bound algorithm. The results of the optimization demonstrate a significant strategic advantage for the follower.

Profit and Market Share: The follower's total profit increased by 53.8%. This gain came at the direct expense of the incumbent, whose profit decreased by 56.2%. The follower's market share grew substantially from an initial and 24% to 52%, capturing 28% of the market previously held by the leader.

Optimal Location Strategy: The profit-maximizing solution for the follower was to open four new service points, all of which were pickup shops (PS). The strategic placement of these new facilities is shown in Figure 2 and can be summarised as follows:

- Three pickup shops were located in residential areas. This is a direct competitive move, designed to intercept market share from the leader's existing facilities, which are also present in or near these high-demand zones.
- One pickup shop was located in the touristic area, a part of the market where neither the leader nor the follower previously had a presence. This represents a market expansion strategy, capturing an entirely new customer segment without direct initial competition.

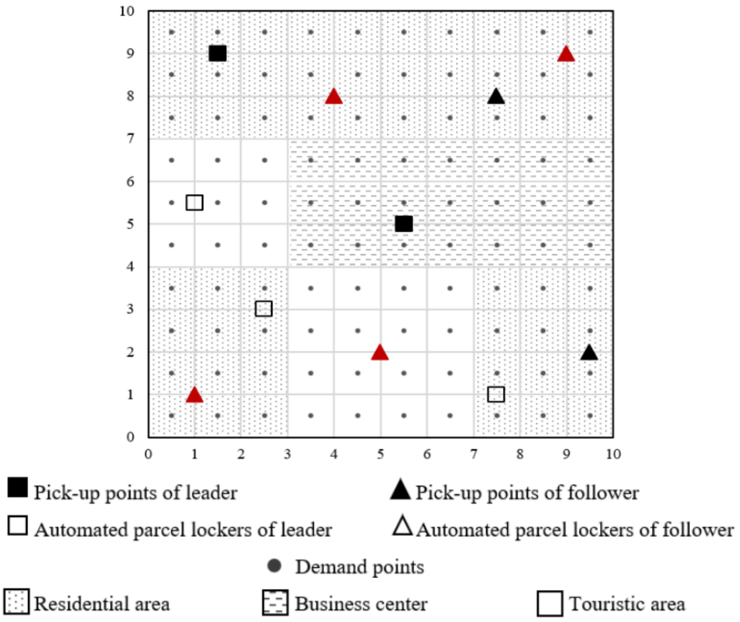

Figure 2: Optimal Locations of the Follower's New Service Points

5. Discussion

The results of the numerical study offer several important strategic insights for challenger firms in the last-mile logistics market.

5.1 Interpretation of the Optimal Strategy

The model's choice of opening four pickup shops over any automated lockers is a direct consequence of the cost-attractiveness trade-off defined in the parameters. This suggests that for a profit-maximizing follower, a cost-effective expansion using a co-location model (PS within existing shops) can be superior to a capital-intensive one (installing new ALs).

The dual nature of the location strategy—combining direct competition with market expansion—is particularly noteworthy. Placing three facilities in residential areas is an aggressive move to erode the incumbent's core customer base. Simultaneously, establishing a presence in the untapped touristic area is a classic "blue ocean" move. This balanced approach is consistent with recent findings by Risberg, Jafari and Sandberg (2023), who argue that competitive advantage in last-mile logistics is achieved through specific configurations of practices. The optimal solution found here, a configuration of both competitive and expansionist placements, supports the idea that a single strategy is insufficient; rather, a bundled approach tailored to the market landscape is required for success.

5.2 Implications for Market Followers

This research provides a clear message for follower firms: strategic, data-driven location planning can dramatically alter market dynamics. A proactive expansion, guided by an optimization model like the one presented, can enable a smaller player to leapfrog the competition. The study highlights that a follower's strategy should not be monolithic. It must be adapted to the specific competitive landscape, considering where to compete, where to expand, and what type of service offering provides the best return on investment.

6. Conclusion and Future Research

This paper investigated the competitive facility location problem for a follower firm in the last-mile e-commerce market. By formulating an integer nonlinear programming model based on Huff's gravity rule, we determined the optimal number, type, and locations of new collection and delivery points to maximize the follower's profit. The results demonstrated that a well-designed expansion strategy allowed the follower to more than double its market share and significantly increase its profitability.

This research lays the groundwork for several promising avenues for future investigation:

- Dynamic Competition with Leader Reaction: The most critical next step is to model the problem as a bi-level leader-follower game. In such a model, the leader would react to the follower's decisions, creating a more realistic, dynamic competitive model.
- Real-World Application and Validation: The model should be tested and validated using real-world data from a specific urban area. This would involve using actual demographic data, GIS mapping, real cost data, and consumer surveys to determine attractiveness weights more accurately.
- Advanced Solution Techniques: While the branch-and-bound algorithm is effective for small instances, solving large-scale problems will require more advanced metaheuristics such as Tabu Search, Simulated Annealing, or Genetic Algorithms.

By addressing these areas, future research can build upon this study's foundation to develop even more powerful and realistic tools for strategic decision-making in the competitive world of last-mile logistics.

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