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Sustainable E-Commerce Reverse Logistics Network Design and Evaluation: A Case Study of Melbourne

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Abstract

E-commerce growth has rapidly increased parcel returns, making reverse logistics a critical challenge for sustainable urban freight systems. While customer convenience is essential, return solutions that improve convenience without considering sustainability may increase travel demand and environmental impacts. This study focuses on the parcel retrieval stage, where customers travel to return facilities, and proposes an accessibility-based framework that jointly targets customer convenience and sustainable mobility outcomes. The model integrates production-based accessibility, representing population-driven demand, and attraction-based accessibility, representing routine activity destinations, within a bi-objective formulation to support facility placement that encourages trip chaining and reduces dedicated return trips. A classical weighting approach is applied to transform the objectives into a generalized single objective, enabling the identification of non-dominated design solutions across different trade-offs between the two accessibility dimensions. The framework is applied to two case-study suburbs in Greater Melbourne, Australia, using mesh-block population data, travel survey information, and activity locations extracted from OpenStreetMap. For evaluation, existing networks operated by Hubbed and Australia Post are benchmarked against the Pareto set by comparing their performance and deviation from non-dominated solutions. Results show that current parcel return networks are predominantly attraction-oriented, with performance varying across urban contexts and stronger alignment with Pareto-efficient designs observed in developing areas compared with mature urban regions. The findings highlight the value of accessibility-oriented planning for designing and assessing parcel return systems that balance customer convenience with sustainability objectives.

Keywords: City logistics, Reverse logistics, Parcel return; E-commerce, Accessibility.

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1 Introduction

E-commerce returns have grown rapidly in recent years, placing increasing pressure on reverse logistics systems. In 2023, online sales in the United States reached approximately USD 1.4 trillion, of which 17.6% (about USD 247 billion) were returned, compared with 13.3% for in-store purchases (NFR, 2023). Consumer expectations further intensify this trend, with 76% of customers expecting free returns and 67% avoiding retailers after poor return experiences (Shopify, 2025). In response, third-party logistics providers have expanded parcel return networks through return points such as convenience stores and parcel shops (e.g., Hubbed and Happy Returns), making reverse logistics a key component of competitive and sustainable e-commerce operations (DHL, 2024; Hubbed, 2025; Happy Returns, 2025).

From a sustainability perspective, reverse logistics can be examined through two main operational stages: (i) parcel retrieval, where customers travel to return points, and (ii) parcel collection, where professional carriers transport consolidated parcels from return points to transhipment facilities (Marriott et al., 2025). This study focuses specifically on the first stage, parcel retrieval, as its efficiency strongly depends on spatial accessibility. Improving sustainability at this stage requires minimising travel distances to return facilities, reducing induced trips made solely for parcel returns, encouraging trip chaining with existing journeys, and increasing alignment between return activities and everyday destinations (Leong et al., 2024; Mohri et al., 2021).

To address these challenges, this paper adopts an accessibility-based perspective commonly used in passenger transport planning (Mohri and Akbarzadeh, 2019). Accessibility is represented through two complementary components: origin-based accessibility, reflecting trip production associated with population distribution, and destination-based accessibility, capturing the attraction of activity locations. By integrating these components into

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a generalised spatial optimisation framework, the study aims to support both the design and evaluation of parcel return networks. The framework combines the two accessibility dimensions within a bi-objective formulation that is transformed into a weighted generalised objective, enabling the identification of non-dominated solutions representing different trade-offs between accessibility goals. This structure allows the model to be applied across different urban contexts for network design and to benchmark existing parcel return systems against Pareto-efficient configurations, supporting more sustainable reverse logistics planning.

2 Literature Review

E-commerce reverse logistics has recently emerged as an important yet still underdeveloped research area, particularly regarding the spatial design and optimisation of parcel return networks. As online retail continues to grow, efficient management of returned parcels has become increasingly critical for both operational efficiency and sustainability. Existing studies typically distinguish between returns management, reverse logistics, and waste management, where reverse logistics focuses on the physical movement of returned parcels from end customers to collection and processing facilities (Marriott et al., 2025). In practice, return networks commonly involve designated drop-off locations such as parcel lockers, post offices, or parcel shops, followed by consolidation and transport to distribution or processing centres through single- or multi-echelon systems (Difrancesco and Huchzermeier, 2020; Beh et al., 2016).

The growing adoption of parcel return infrastructures by third-party logistics providers has increased interest in the efficient design of reverse logistics networks. Early studies mainly focused on cost minimisation through optimisation-based network design. For example, XiaoYan et al. (2012) formulated a mixed-integer linear programming model to determine facility locations and routing decisions while minimising system costs under capacity and operational constraints. Similarly, Das et al. (2020) examined the allocation of customer areas to initial collection centres in fashion-related returns, aiming to reduce operational expenditure. More recent research has expanded beyond purely economic objectives. Nanayakkara et al. (2022) proposed a data-driven framework combining spatial clustering and optimisation to improve facility placement, demonstrating substantial cost reductions compared with conventional planning approaches. Luong et al. (2024) further extended reverse logistics network design by introducing multi-objective optimisation that balances economic efficiency with social outcomes, highlighting trade-offs between cost and broader sustainability considerations.

Despite these advances, existing studies remain limited in addressing accessibility-based perspectives in reverse logistics network design, particularly the balance between population-driven demand and activity-based attraction patterns. Most formulations focus primarily on cost or flow optimisation, while spatial accessibility and service coverage dimensions remain underexplored. This gap motivates the present study, which investigates reverse logistics facility placement through a spatial accessibility framework that integrates both trip production and trip attraction components to better capture urban demand dynamics.

3 Problem Definition and Methodology

Parcel return retrieval represents the first operational stage of e-commerce reverse logistics, where customers transport returned items to designated return facilities. Since parcel returns are often integrated with routine activities rather than performed as dedicated trips, focusing solely on residential population is insufficient for facility location decisions. In this study, facility placement is formulated by considering both trip production and trip attraction, allowing return facilities to align with everyday travel patterns and support trip chaining behaviour. Each spatial unit, defined precisely in Subsection 3.1, is therefore modelled simultaneously as a source of trip production and a potential destination of routine travel. The proposed framework combines these components within a gravity-based accessibility formulation, encouraging facility placement along highly commutable corridors where parcel return activities can be embedded into existing travel chains, thereby reducing induced travel and supporting sustainability objectives.

3.1 Spatial Representation and Demand Components

The study area is partitioned into a set of small spatial polygons, denoted by I, each representing a demand origin, demand destination, and a potential area for placing parcel return facilities. Fig. 1 illustrates an example of this spatial representation, where activity facilities belonging to three different categories (e.g., C_1, C_2, and C_3) are shown to represent locations that attract routine travel activities. While these facilities are visualised here to illustrate the spatial structure of the problem, their role in constructing the trip-attraction component is described in the following subsection.

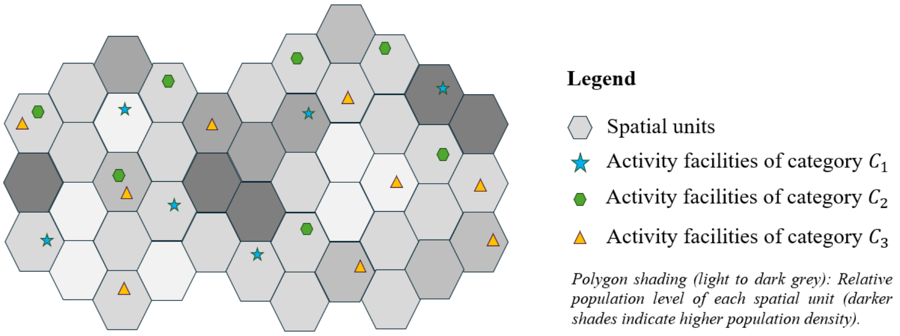

Fig. 1. Spatial representation of the study area.

To incorporate both trip production and trip attraction within the studied area, two complementary attributes are defined for each polygon: a trip production component and a trip attraction component.

Trip Production Component: This reflects the residential demand associated with parcel returns. Let p_i denotes the population of polygon $i \in I$. To obtain a comparable measure across spatial units, population values are normalised by Equation (1).

$$\bar{p}_i = \frac{p_i}{\max\limits_{k \in I} p_k} \qquad \forall i \in I \tag{1}$$

where $\bar{p}_i \in [0,1]$ represents the normalised production score.

Trip Attraction Component: Trip attraction captures the ability of a location to draw routine travel activities. Activity locations are cate`gorised into a set C, including shopping, social, recreational, and other non-work purposes, indexed by c. Work-related trips are excluded because they are typically schedule-constrained and less flexible for integrating parcel return behaviour. Let n_{ic} denotes the number of activity locations of category $c \in C$ within polygon i, and let w_c denote the proportion of trips associated with activity category c, derived from travel survey data. Therefore, the weighted attraction intensity is defined by Equation (2), which is subsequently normalised by Equation (3).

$$a_i = \sum_{c \in C} w_c \, n_{ic} \qquad \forall i \in I \tag{2}$$

$$\bar{a}_i = \frac{a_i}{\max\limits_{i \in I} a_i} \qquad \forall i \in I \tag{3}$$

where $\bar{a}_i \in [0,1]$ represents the attraction score.

Combined Spatial Score: To jointly account for trip production and attraction, a weighted combination ($\bar{s}_i$) is introduced for polygon i as shown by (4).

$$\bar{s}_i = \alpha \bar{p}_i + (1 - \alpha)\bar{a}_i \qquad \forall i \in I \tag{4}$$

where $\alpha \in [0,1]$ controls the relative emphasis between residential proximity and destination attractiveness. The parameter serves a dual purpose. First, it enables sensitivity analysis to explore the trade-off between origin-oriented and destination-oriented facility placement. Second, it provides a behavioural interpretation framework for evaluating whether existing parcel return networks implicitly prioritise population-based demand or activity-based travel alignment.

3.2 Gravity-Based Accessibility Measure

Accessibility between demand locations and candidate facilities is evaluated using a gravity-based formulation widely adopted in transportation analysis. Let d_{ij} denote the Manhattan travel distance between polygons i and j. Accessibility increases with the spatial importance of the origin and decreases with travel impedance according to a distance-decay function. Hence, the accessibility contribution between origin i and return facility j is defined by Equation (5).

$$g_{ij} = \frac{\bar{s}_i}{d_{ij}^{\beta}} \qquad \forall\, i \in I \tag{5}$$

where $\beta > 0$ is the distance-decay parameter controlling the rate at which accessibility decreases with distance. Higher values of β represent stronger behavioural sensitivity to travel distance and reduced willingness to undertake detours.

3.3 Facility Location Optimisation Model

The optimisation model identifies facility locations that maximise system-wide accessibility while ensuring consistent assignment of demand polygons to selected facilities. The notation used in the model is summarised in Table 1.

Table 1. Summary of notation

Type	Notation	Description
Set	I	Set of spatial polygons representing demand locations and candidate facility sites.
Parameters	$\bar{s}_i$	Combined spatial score of polygon i.
	d_{ij}	Travel distance between polygons i and j.
	β	Distance-decay parameter.
	K	Number of facilities to be selected.
Decision variables	Y_j	Binary variable equal to 1 if a facility is located at polygon j, 0 otherwise.
	Z_{ij}	Binary variable equal to 1 if polygon i is assigned to facility j, 0 otherwise.

The closed-form mathematical formulation of the model is presented as follows:

$$Max \sum_{i \in I} \sum_{j \in I} Z_{ij} g_{ij} \tag{6}$$

subject to

$$\sum_{j \in I} Z_{ij} = 1 \qquad \forall\, i \in I \tag{7}$$

$$Z_{ij} \leq Y_j \qquad \forall\, i, j \in I \tag{8}$$

$$\sum_{j \in I} Y_j = K \tag{9}$$

$$Y_j \in \{0,1\} \qquad \forall\, i \in I \tag{10}$$

$$Z_{ij} \in \{0,1\} \qquad \forall\, i, j \in I \tag{11}$$

Objective (6) maximises gravity-based accessibility by favouring facility locations that combine high spatial attractiveness with shorter travel distances. Constraints (7) ensures that each demand polygon (i) is assigned to exactly one selected facility (j). Constraints (8) links assignment decisions (Z_{ij}) to facility selection (Y_j), preventing allocation to locations (j) where no facility is established (i.e., $Y_j = 0$). Constraints (9) fixes the total number of facilities to the predefined value K, while Equations (9) and (10) enforces binary decisions for both facility selection and demand assignment.

4 Data and Case Study

This study focuses on the Greater Melbourne metropolitan area, Australia as the case study region. The analysis is based on parcel return facility data obtained from two major return network operators currently active in Melbourne: Hubbed, whose return facilities are branded as ParcelPoint locations, and Australia Post, where return activities are conducted through post offices. These networks represent the primary organised parcel return infrastructure available to customers in the study area. Figure 2 illustrates the spatial distribution of these facilities across Greater Melbourne.

Spatial Scope: The proposed framework is designed to be applicable at both metropolitan and local scales, allowing implementation across Greater Melbourne or within specific districts. For computational analysis, this study focuses on two representative suburbs within Greater Melbourne: Brighton (population ≈ 23,2501; area ≈ 8.3 km^2) and Point Cook (population ≈ 66,781; area ≈ 38.9 km^2), representing a highly developed inner-urban region and a rapidly developing suburban area, respectively (Market Report, 2025). Within these areas, spatial units ($i \in I$) are represented using mesh blocks, which are the smallest statistical units defined by the Australian Bureau of Statistics (ABS, 2021). Mesh blocks serve as the base modelling units, to which population data are assigned and later enriched with trip production and trip attraction components for the optimisation analysis.

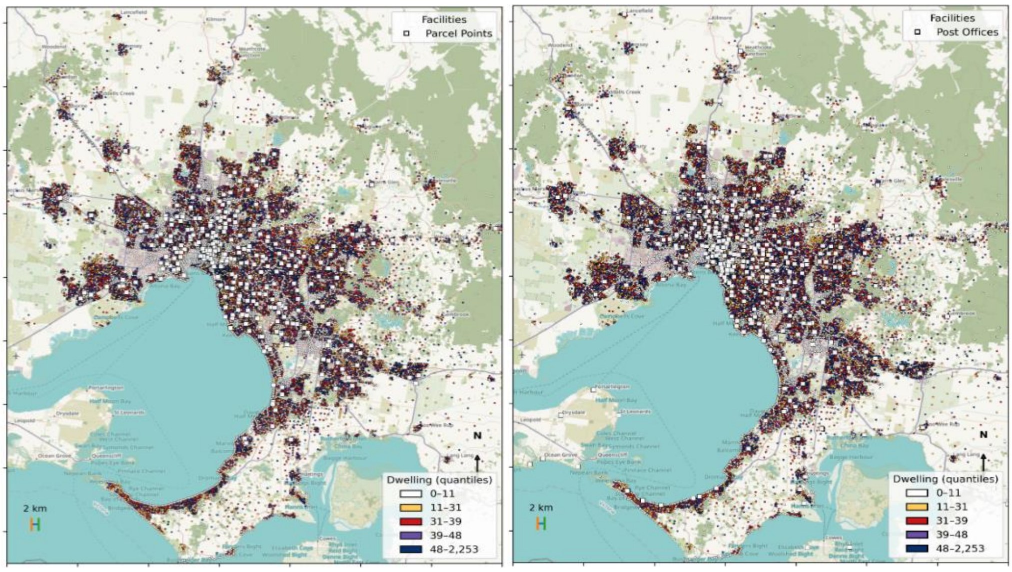

Fig. 2. Networks of Hubbed and Australia Post return points

Trip Production Component data: Population values (p_i) for each mesh block are extracted from the 2021 Australian Census and used to represent the spatial distribution of trip production in the study area.

Table 2. OSM keys and values used to extract facilities for trip-attraction categories.

Trip purpose category	OSM keys and (values)	Description
Shopping	Shop (all values)	Retail and commercial facilities
Social	Amenity (Community centre, social centre, arts centre, conference centre, events venue, theatre, cinema, nightclub, townhall, marketplace, library, social facility); Social facility (all values)	Food, hospitality, social gathering, and entertainment facilities
Recreation	Leisure (sports centre, fitness centre, stadium, playground, swimming pool); tourism (attraction, museum, and zoo)	Recreational, sports, and leisure destinations
Personal business	Amenity (bank, post office, doctors, clinic, hospital, pharmacy)	Service-oriented destinations related to personal and administrative activities
Pick-up / drop-off / accompany	Amenity (school, childcare, kindergarten, hospital, clinic); public transport (station); railway (station); highway (bus stop)	Proxy locations representing escort and pick-up/drop-off activities
Education	Amenity (school, university, college, kindergarten, and childcare)	Educational facilities

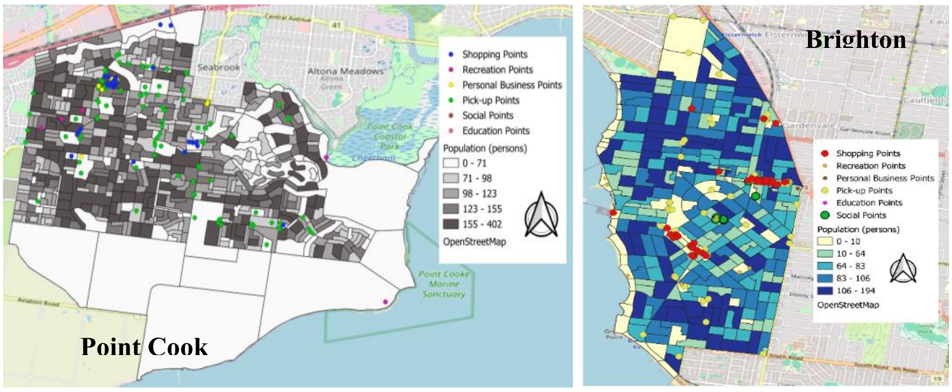

Fig. 3. Mesh blocks, population distribution, and existing return facilities in Brighton and Point Cook.

Trip Attraction Component data: First, the Victorian Integrated Survey of Travel and Activity (VISTA, 2024) data (2021–2024) is used to identify the distribution of non-work travel purposes based on observed sample trips. Based on these data, five activity categories are defined to represent major non-work trip purposes, including shopping (22%), social (14%), recreational (11%), pick-up/drop-off (11%), personal business (11%), and education (5%), others[1] (26%) activities. Using the frequency and distribution of trips associated with each

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[1] Other trip purposes, including work-related trips, are not included in the weight estimation.

category, corresponding weights (w_c) are derived to reflect their relative importance in the attraction component of the model. For each activity category, relevant facilities are then identified from OpenStreetMap (OSM) using appropriate keys and values, Table 2, and extracted through OSM-based plugins in QGIS. The extracted facilities are spatially mapped to mesh blocks and subsequently used to compute the trip-attraction component following the methodology described in the Section 3. For visual reference, Figure 3 shows the spatial configuration of the study areas, including mesh blocks, population distribution, and existing parcel return facilities.

Additional model parameters are specified as follows. The distance-decay parameter is fixed at $\beta = 1$. The weighting parameter α, controlling the balance between trip production and trip attraction components, is varied within the range $[0,1]$ with a step size of 0.1 to enable sensitivity analysis. Travel distance between spatial units is approximated using the Manhattan distance metric, which provides a reasonable proxy for movement along urban road networks. Furthermore, the number of facilities to be selected in each case study area is fixed according to the existing return networks to allow consistent comparison with current practice. Specifically, in Point Cook, the number of facilities is set to 3 for the Hubbed scenario (Mesh Block IDs: 20632320000, 20633291000, and 20632874000) and 1 for the Australia Post scenario (Mesh Block ID: 20632874000), while in Brighton the number of facilities is set to 3 for Australia Post (Mesh Block IDs: 20042542000, 20632005400, and 20631935240) and 1 for Hubbed (Mesh Block ID: 20042901000), reflecting their observed facility distributions in the study area.

5 Results

The optimisation problem is solved using a GRASP-based heuristic procedure, which is well suited to the p-median–type structure of the proposed facility-location model (Resende and Werneck, 2002). The algorithm combines a greedy-randomised construction phase with a local improvement search to efficiently explore the solution space while avoiding purely deterministic selections. In each iteration, candidate facility locations are first generated using a restricted candidate list (RCL), after which a swap-based local search refines the solution by iteratively replacing selected facilities when improvements in the objective function are identified. The algorithm is implemented using 100 multi-start iterations and an RCL size of 5.

The results analysis is structured in two stages: ***design*** and ***evaluation***. In the design stage, the model is solved separately for each operator (Hubbed or Australia Post) within each suburb (Brighton or Point Cook), resulting in four scenarios. To ensure comparability, the number of facilities (K) in each scenario is fixed to the observed number currently operated by the corresponding operator. The Pareto fronts are generated by varying the weighting parameter (α) from 0 to 1 with a step size of 0.1, allowing exploration of the trade-off between production-oriented and attraction-oriented accessibility outcomes. The resulting non-dominated solutions are plotted using two accessibility-based objective components: the Production Accessibility Index (PAI), defined as $\sum_i \bar{p}_i / d_{ij^*}^{\beta}$, and the Attraction Accessibility Index (AAI), defined as $\sum_i \bar{a}_i / d_{ij^*}^{\beta}$, where j^*denotes the selected facility assigned to polygon i.

In the evaluation stage, the existing facility networks of each operator are assessed through a reverse-engineering procedure by calculating the same accessibility indices for their observed facility locations. This enables a fair assessment of performance under equivalent resource levels, where each operator is benchmarked against its own Pareto frontier rather than against other operators. The analysis therefore captures both the deviation of current configurations from Pareto-efficient solutions and their relative position along the frontier, providing insight into whether existing networks are more aligned with production-oriented or attraction-oriented accessibility trade-offs.

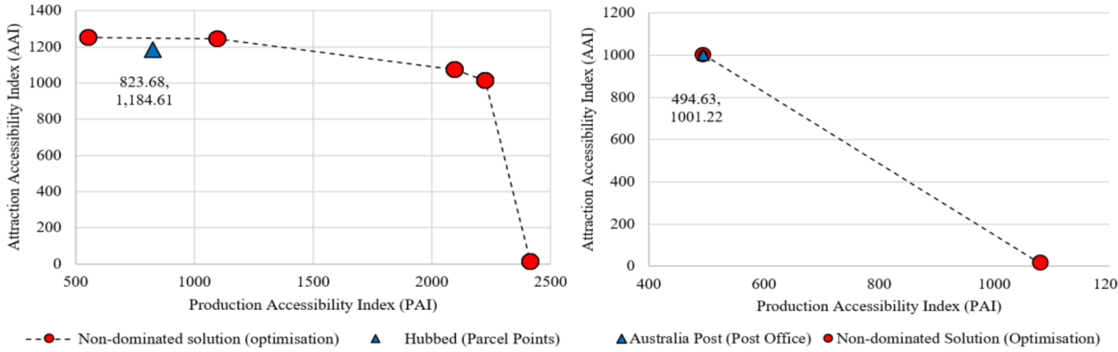

Fig. 4. Pareto front and existing operator performance for Point Cook

Figure 4 presents the resulting Pareto fronts for both operators, together with the performance of their existing facility networks, which are evaluated through a reverse-engineering procedure by calculating the same accessibility indices for the currently observed facility locations. The results for Point Cook, a rapidly developing suburban area, reveal two key findings. First, the existing facility configurations of both operators are positioned close to the attraction-oriented end of the Pareto front, indicating that current network designs implicitly prioritise attraction-based accessibility rather than production-based accessibility. This suggests that facility locations are largely aligned with destinations that attract routine activities, consistent with trip-chaining behaviour. Second, the existing operator configurations demonstrate strong performance, as their observed facility locations lie very close to, and in some cases overlap with, the non-dominated solutions obtained from the optimisation model. This indicates that the current networks already operate near the optimal trade-off frontier for this region, leaving limited room for further improvement under the proposed accessibility framework.

Figure 5 presents the corresponding Pareto front for the Brighton suburb, together with the evaluated performance of the existing facility networks of both operators. Similar to the Point Cook analysis, the figure illustrates the trade-off between production-based and attraction-based accessibility and enables direct comparison between optimised solutions and current operational configurations.

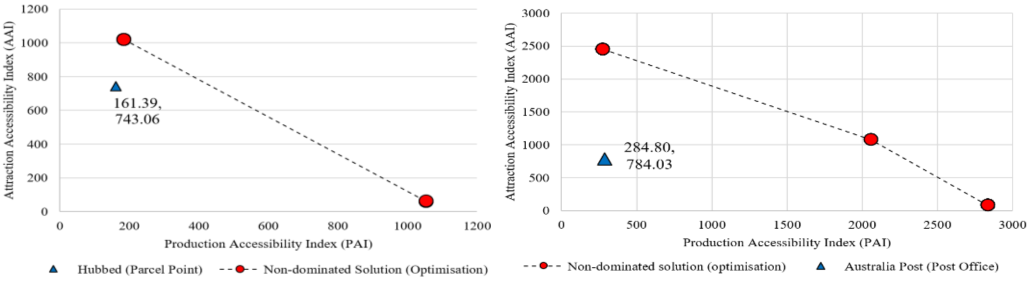

Fig. 5. Pareto front and existing operator performance for Brighton

The results for Brighton, a highly developed inner-urban area with a mature distribution of facilities and amenities, reveal a different pattern compared with Point Cook. First, both operators exhibit lower performance relative to the Pareto-optimal frontier, indicating that their existing facility configurations are less aligned with the optimal accessibility trade-offs identified by the model. Second, similar to the previous case, the observed solutions remain attraction-oriented, suggesting that facility placement continues to prioritise destination-based accessibility rather than production-based accessibility. Third, a notable difference emerges between operators: Hubbed achieves comparatively stronger performance with only a single facility, positioning its solution closer to the non-dominated frontier, whereas Australia Post, despite operating three facilities, remains substantially farther from the optimal solutions. This indicates lower network efficiency and reduced accessibility performance for the Australia Post configuration within this highly developed urban context.

Discussion: Comparing the optimal solutions with the existing operator performance across the two case-study suburbs reveals several key insights. First, both cases consistently show that current facility configurations are primarily aligned with maximising attraction-based accessibility rather than production-based accessibility, indicating a stronger focus on trip destinations and activity concentrations than population distribution. Second, differences in operational flexibility appear to play a critical role. Hubbed, as a third-party logistics provider relying on contracted retail partners, benefits from higher locational flexibility, enabling facilities to adapt more easily to evolving spatial patterns of activities and demand. In contrast, Australia Post relies on fixed, capital-intensive post office infrastructure, which limits relocation potential and may reduce performance over time as population and attraction patterns change. This effect is particularly evident in the developed Brighton area, where Hubbed performs closer to the optimal solutions, while Australia Post's long-established network shows reduced alignment with current spatial demand. Conversely, in the rapidly developing Point Cook suburb, where both operators have relatively recently established facilities, existing configurations remain close to the non-dominated frontier. However, the results suggest that maintaining such performance over time may be more challenging for fixed infrastructure systems compared with flexible, partnership-based networks. This highlights the importance of incorporating forward-looking planning and forecasting of future suburban development when designing long-term fixed return infrastructures to maintain customer convenience and sustainability benefits.

6 Conclusion

This study developed an accessibility-based optimisation framework to support the sustainable design of parcel return networks by balancing customer convenience with urban sustainability objectives. The model integrates production-based accessibility, representing population-driven demand, and attraction-based accessibility, representing routine activity destinations, to identify facility locations that encourage trip chaining and reduce dedicated return trips. The framework was tested in two contrasting suburbs in Greater Melbourne, Point Cook as a developing area and Brighton as a mature, highly developed area, and the resulting non-dominated solutions were compared with existing operator configurations.

The results indicate that current parcel return networks are predominantly attraction-oriented, demonstrating strong alignment with activity destinations. However, performance relative to the optimal solutions varies across urban contexts, with developing areas showing closer alignment to the optimal frontier than mature urban regions. The findings also suggest that flexible, low-investment networks (e.g., partnership-based facilities) are better able to adapt to changes in activity patterns and population distribution, whereas fixed, high-investment infrastructures, such as post-office-based systems, may gradually lose convenience and sustainability performance over time if future spatial changes are not anticipated. These results highlight the importance of accessibility-oriented planning and long-term forecasting of population and activity dynamics to ensure sustained customer convenience and system-level sustainability in reverse logistics networks.

Nevertheless, several limitations remain. Although the model is scalable, analysing isolated suburbs may overlook interactions with surrounding areas, suggesting that future studies should adopt larger and spatially continuous study regions. In addition, behavioural evidence on customers' willingness to integrate parcel returns with different trip purposes is needed to better inform attraction weighting and facility prioritisation. Incorporating such behavioural insights would further strengthen the practical applicability of accessibility-based reverse logistics planning.

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