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Integrating Freight and Public Transport Terminals Infrastructure by Locating Lockers: Analysing a Feasible Solution for a Medium-Sized Brazilian Cities

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Abstract: Integrating freight and public transport infrastructure can lead to providing economic feasibility to public transportation systems and reducing externalities related to urban freight transport. This can be achieved by sharing the infrastructure of freight and public transportation systems. Additionally, failed deliveries represent a major challenge in e-commerce. Lockers can address this problem and promote sustainable urban freight transport. This paper identified a locker network in a public transportation infrastructure. The framework considered scenarios built under the 15-min city concept, and the analysis is based on a case study in Jaraguá do Sul (Brazil, a mid-sized Brazilian city, and its conurbated area. The networks were found by solving a p-median problem, which minimised the maximum distance between the lockers and the population. The findings showed that, in the best scenario with 16 lockers, the population could reach the lockers within a 10-min cycling ride. Additionally, the results showed that the public transportation network provides a locker network to integrate freight and public transportation. The locker network is accessible to public transportation and micromobility users. With this solution, residents play an active role in last-mile deliveries. In addition, lockers can work as mini hubs for crowdshipping services. In addition to reducing urban delivery trips, this solution can encourage public transportation usage, which contributes to more sustainable cities.

Keywords: urban freight transport; passenger transport; integration; sharing infrastructure; e-commerce deliveries; pick-up points

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1. Introduction

Online shopping has increased significantly in recent years. For example, in Brazil, 42 million consumers made at least one online purchase in the first semester of 2021, which resulted in BRL 53.4 billion (BRL 1.00 ≅ USD 5.10 in June 2022) in online transactions [1]. The number of deliveries is directly influenced by e-commerce growth [2,3]. Furthermore, in Brazil, home delivery represents the greatest share of e-commerce delivery services [4], which clearly shows inefficiencies in the urban freight transport (UFT) system. In this case, negative externalities become even more visible when home deliveries are increased. Therefore, alternatives should be proposed to replace home deliveries, and this process might contribute to economic development and increase UFT equity [5–8].

E-commerce has greatly increased home deliveries since customers prefer this type of delivery service [9]. Moreover, one key aspect of e-commerce deliveries is the high number of failed deliveries [10–12]. Failures in the delivery process represent a problem for both consumers and carriers [4,13].

Thus, lockers are an alternative to the last-mile problem [14–16] and a solution to the problem of failed deliveries. Lockers could be used in transport policies to make freight transport more efficient [17]. Additionally, locker networks are last-mile delivery services directly linked to the SDGs (Sustainable Development Goals) 11 (Sustainable Cities and Communities) and 13 (Climate Action) and indirectly related to SDGs 8 (Decent Work and Economic Growth), 10 (Reduced Inequalities), 12 (Responsible Consumption and Production), and 17 (Partnership for the Goals).

Thus, promoting locker networks contributes to sustainable development. Although many previous studies have addressed the importance of lockers for sustainable UFT and the role of properly selecting their locations [12,18–21], few studies have effectively addressed the location problem. The location of the lockers can influence the consumer's choice of delivery service. Thus, the locker network should be accessible to all e-commerce consumers so that lockers can provide an equitable approach to on-demand home deliveries [22].

In addition, transport policies could integrate the transport of people and cargo to achieve a sustainable transportation system [23,24]. Integrating people and freight transport addresses the first-mile/last-mile problems and helps to reduce both operational and external costs [25]. This process of integrating UFT and Public Transportation (PT) to achieve sustainable goals consists of [23]: (i) improving shared road spaces between the flow of goods and the public-motorised transport of people, (ii) shifting passengers and the flow of goods from a private-motorised road-based transport mode to other urban transport modes, and (iii) introducing distribution facilities in urban areas that are already devoted to passenger use [26].

The existing literature has demonstrated the success of integrating freight into public transportation for long-haul routes [6,27], light rail systems [28], underground systems [29,30], and taxi systems [31]. For instance, the Mumbai Dabbawalas is a major example of the real operation of freight on public transportation, as the system uses the rail system for lunch box deliveries [28,32]. Although many systems share the infrastructure of both freight and public transportation, this innovative system needs to be further explored.

Lockers can be located in PT stations to integrate UFT and PT. Moreover, locating lockers in PT stations can increase PT demand and add value to transportation mode [33]. Additionally, this measure can provide liveable and equitable cities [33]. However, the population acceptability of lockers to replace home deliveries depends on the location and the market concentration [34]. For example, in Graz (Austria), the maximum accepted travel distance is 0.7 km for walking (10.3 min), 1.9 km for cycling (7.5 min), and 1.2 km for public transportation (9.1 min) [35].

Many studies have explored the population acceptability of lockers as an alternative to home deliveries [16,19,21]. However, studies relating accessibility and lockers' locations are still limited and focus only on identifying locker networks using (1) multi-objective optimisation mathematical problems [18] or (2) accessibility and equity analysis [22,36]. Therefore, the following research questions emerged: For a locker network located in bus stations, what should be the size of the network to provide equitable cities? Where should this network be located to provide an accessible service for the entire population? Thus, this paper aims to identify the size and location of a locker network to provide an accessible and equitable service. The locker network was based on the 15-min city premise, where people should access services, activities and opportunities within a maximum radius of a 15-min bicycle ride from their homes [37]. The analysis considered real data from (1) the public transportation system with electronic ticketing, (2) the shared micromobility system, and (3) the population and income of Jaraguá do Sul, which is a medium-sized city located in southern Brazil.

The contribution of this paper is twofold. First, this study designs a locker network that addresses the potential of integrating freight into the public transportation system. Most of the existing literature uses synthetic data to analyse systems that integrate UFT

with PT. Second, this study shows that locker networks have the potential to develop equitable cities for freight transport, as previously reported by Lachapelle et al. [33].

This paper is structured as follows: Section 2 reports the background of lockers as a solution for last-mile deliveries and their potential for an integrated system. Section 3 describes the study area, Section 4 explains the research approach, and Section 5 reports the results for Jaraguá do Sul. Finally, Section 6 concludes the study and proposes future research areas.

2. Background

Lockers may be called click and collect systems, pick-up points, or automatic delivery/parcel stations. The denomination varies according to technology and system. For example, Zurel et al. [38] describe different types of lockers. Lockers have been investigated as an alternative to consolidate end-consumer deliveries and improve the distribution efficiency of urban goods [4]. Locker networks reduce the number of deliveries, the number of failed home deliveries and, consequently, congestion and emission pollutants by reducing the distance travelled [39,40]. Additionally, locker networks increase the efficiency of supply chains [41] and of the delivery process, which promotes sustainable UFT [11,12,33,42,43]. Moreover, lockers are convenient and flexible delivery options for customers and companies [16,19,21,41,42,44].

Several factors impact the location of lockers, such as availability, accessibility, security, environmental impacts, costs and regulation [34]. Accessibility depends on the market concentration and the area served [34]. Thus, increasing accessibility increases the proximity to the end-consumer [34]. Locker networks have competitive advantages in environments with high-order density and different delivery windows [44]. Time, price, tracking, availability and location are essential elements for increasing the use of lockers [19]. In Los Angeles, the spatial distribution of Amazon lockers is influenced by population density, internet use, income, education, walkability, transit and parking [45].

PT stations are options for locating lockers, which encourages PT usage or makes them hubs for delivery services [21,33]. However, the population acceptability of lockers' locations in bus stations requires specific investigation for each context. For example, lockers in public transportation have low resident acceptability in Poland [19] and Belo Horizonte, Brazil [21]. Nonetheless, lockers are usually located in PT stations in Europe [12,16] due to their potential to increase PT efficiency and maintain a high occupancy rate [34].

Usually, lockers are used, as described in situation A (Figure 1), where the consumer has an active role in the delivery, as s/he picks up the goods in the lockers. Consumers can reach lockers in public transportation stations by bus, walking or riding a bike. These lockers are supplied by vehicles, preferably electric vehicles, to encourage sustainable transport. Additionally, lockers can also be mini hubs, as illustrated in situation B. In this case, the goods are transferred from distribution centres to lockers. From this point on, goods are delivered to their destinations by crowdshipping systems, e.g., using bicycles. Thus, locker networks in PT stations can be used by consumers and by crowdshipping.

Consumer preferences for picking goods in lockers have been previously investigated [12,19,21,46]. For example, 90% of the French population reaches a locker within a 10-min walking trip from home, while residents in Germany live on average 600 m from lockers in urban areas [16]. Kiousis et al. [47] investigated the usage of lockers instead of home deliveries in Athens, and the study showed a reduction of 82.4% in travel time, 90.9% in vehicle kilometres, and 80% in the fleet. Crowdshipping was investigated by Gatta et al. [48], who reinforced the integration of passenger and freight mobility. Additionally, most potential crowdshipping users are unwilling to modify their paths to deliver goods [48]. Thus, bus stops are suitable places for using lockers as mini hubs for last-mile deliveries using crowdshipping. Moreover, public transportation or micromobility systems could be used to deliver goods during regular home-to-work trips [48]. The environmental benefits of this delivery service have also been investigated [49].

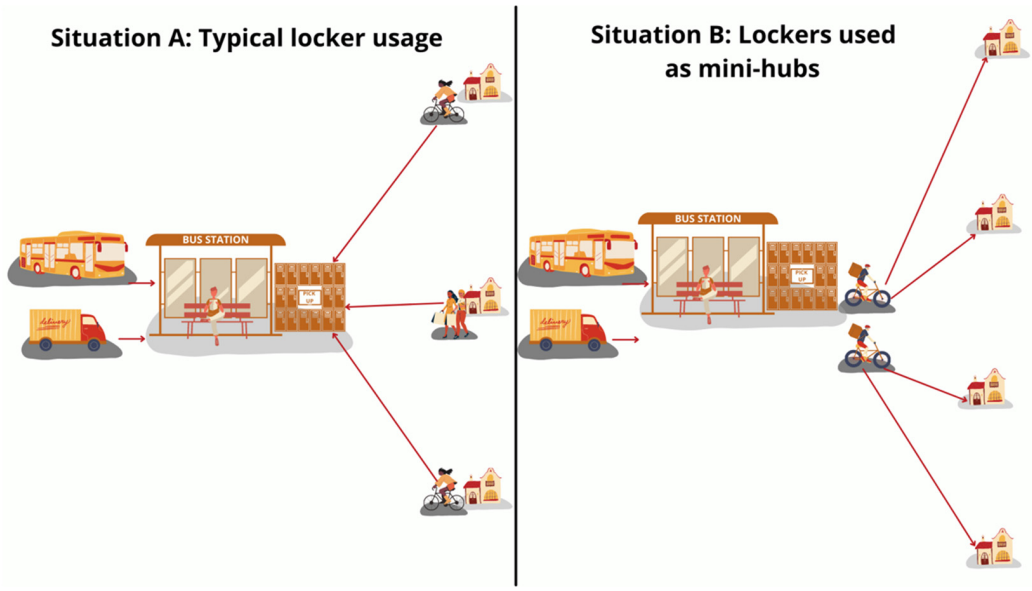


Figure 1. Scenarios for a locker network.

Despite the importance of the location of lockers [18], few studies have addressed the evaluation of their location and associated accessibility. Che et al. [18] proposed a multi-objective model solved using a combination of the Taguchi method (TA) and the non-dominant sorting genetic algorithm II (NSGA-II). The authors used the parameters found in the literature to show the effectiveness of the proposed model. Schaefer and Figliozzi [36] analysed the accessibility of Amazon lockers in Portland. The findings showed that lockers are located at the property of convenience stores, close to arterial roads, and in mixed-use commercial and residential zones. Additionally, 85% of the total number of households were within 2.4 miles of an Amazon locker, and 97% were within 5 miles. In south east Queensland (Australia), lockers are located in arterials, shopping centres, suburban streets, and commercial streets [22]. Keeling et al. [22] analysed the potential of public transportation facilities to host a locker system using a multi-criteria approach. The authors explored accessibility and equity trade-offs using real data from Portland. This trade-off must be considered to provide locker networks with high accessibility levels.

Previous studies have identified preferences for the location of the lockers [16,19,21], the factors that influence the location of the lockers [45], and the accessibility of the lockers [35,36]. However, the existing literature exploring the usage of PT stations for locker locations is limited to Keeling et al. [22]. This study advances the literature by identifying a locker network solving a facility location model. Moreover, this study evaluates the accessibility of public transport users, micromobility users and the general population. This study then identifies networks that can be used by e-commerce consumers and crowdshipping.

3. Study Area and Data Description

This study uses data from Jaraguá do Sul conurbated area, located in the south of Brazil. More specifically, it is located in the Santa Catarina State and integrates the metropolitan region of the north of the state, as shown in Figure 2. Jaraguá do Sul, the main city of the studied region, presented a high Human Development Index (0.803), which is in the first positions of the national ranking (34th in Brazil and 8th in Santa Catarina). The city hosts several industries in the metal and mechanical sectors. In addition, clothing sectors and both technology and service companies are present in Jaraguá do Sul, which influences regional and national economies.

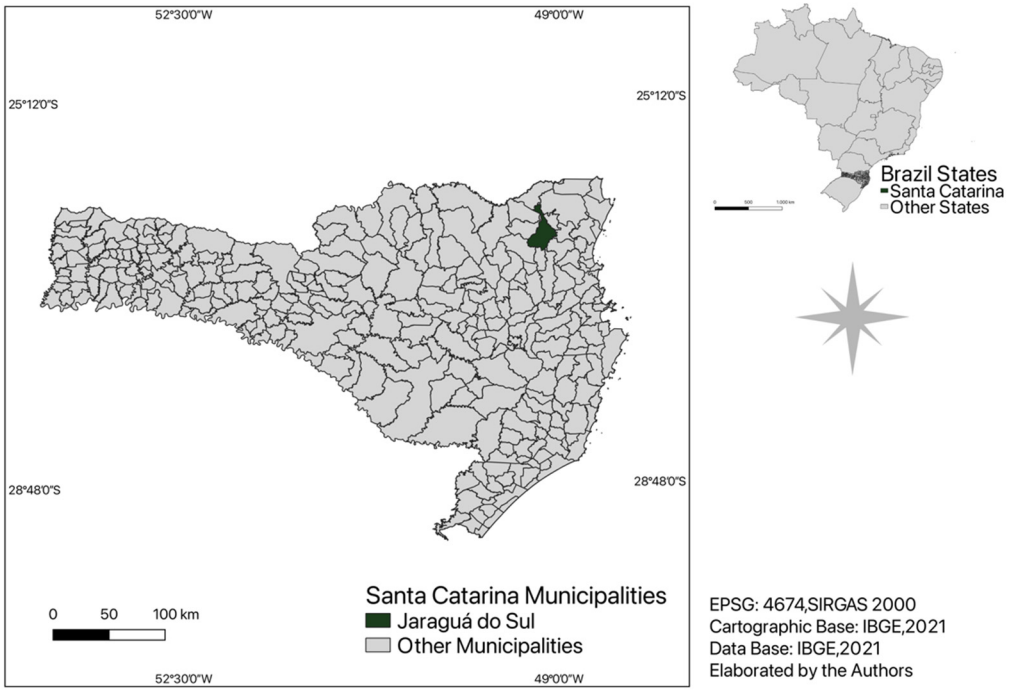


Figure 2. Location of Jaraguá do Sul.

The conurbated area has 1820 km^2, and most of the territory is rural, which characterises the region with large farms (Figure 3a). Jaraguá do Sul is a medium-sized city with 201,445 residents, of which 93% live in urban areas (Figure 3b) and 90% live in Jaraguá do Sul. The demographic density is 271 inhabitants per square kilometre, and the mean income is BRL 3157.40 (USD 700 in January 2022), which is 2.2 times higher than the average in Brazil (Figure 3c). The Gross Domestic Product (GPD) per capita is BRL 38,563.00 (USD 7140). The vehicle fleet comprises 77,212 private vehicles, 19,617 motorcycles, 462 buses, and 3414 trucks. Additionally, the trip generation hubs are also concentrated in urban areas, mainly in Jaraguá do Sul, including factories, universities and shopping malls (Figure 3d). The downtown area of each city has many small businesses. We used the conurbated area as our study because the municipalities have a high level of integration and a high number of commuting trips. The bus operator service is also the provider of the bus services of all the cities in this area. The conurbated area is composed of Guaramirim, Jaraguá do Sul e Massaranduba.

The road infrastructure is shown in Figure 4a, and the public transportation system comprises 70 routes (Figure 4b) and 2485 bus stations (Figure 4c), which cover all urban areas. A fleet of 55 buses is destined for public transportation. The micromobility system consists of a bike-sharing system provided by a private company with 83 micromobility stations located in the city centre (Figure 4d). The bike-sharing system offers trips for people and goods, and these trips are charged in minutes. In addition, Jaraguá do Sul has 94 km of cycle paths.

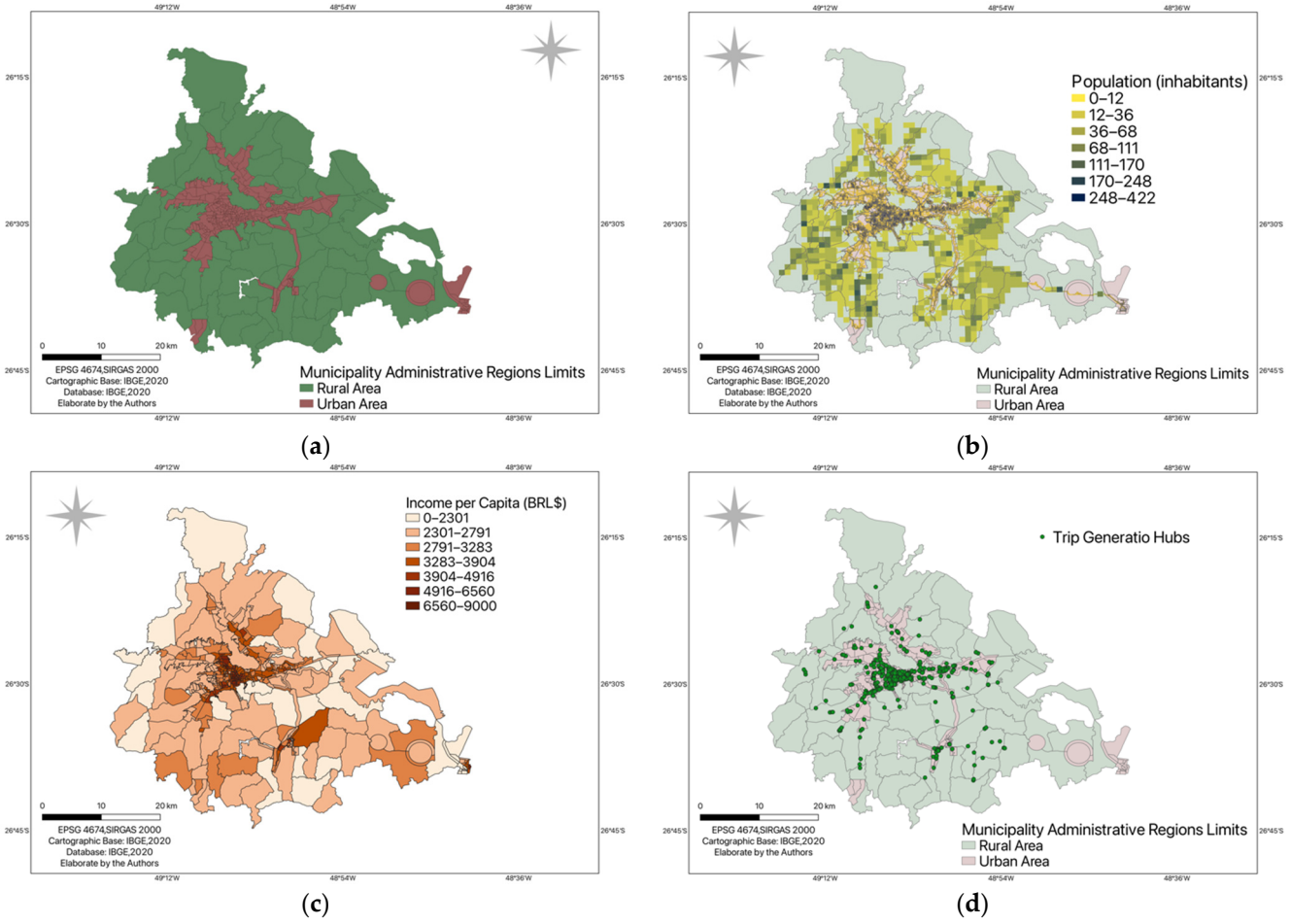


Figure 3. Characterisation of the study area. (**a**) Urban area; (**b**) Population; (**c**) Income; (**d**) Trip generation hubs.

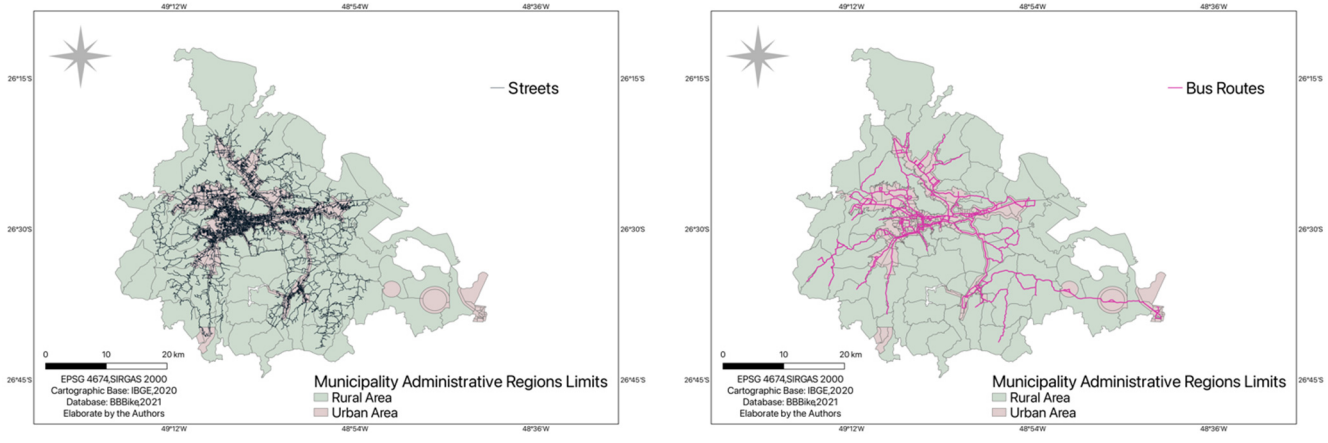
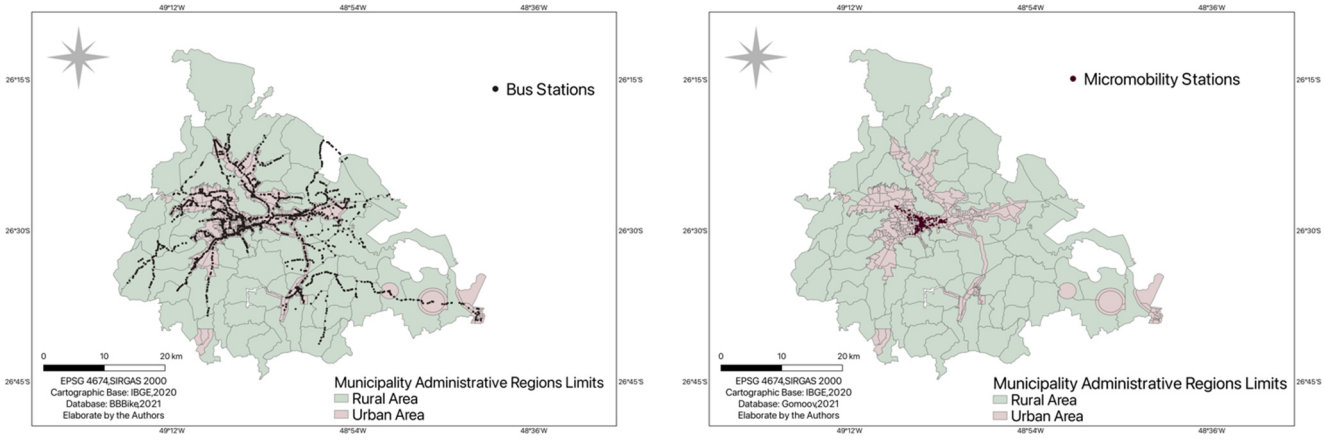


Figure 4. *Cont.*



(**c**) (**d**)

Figure 4. Characterisation of the transportation infrastructure. (**a**) Road infrastructure (streets); (**b**) Bus routes; (**c**) Bus stations; (**d**) Micromobility stations.

Table 1 summarises the data from Jaraguá do Sul conurbated area. Grid square (200 × 200 m) statistics were used in this study. This geographical unit was used to provide more details about the study area. Socioeconomic data were obtained from IBGE [50]). The public transportation data were made available by two companies: Mobilibus and Senhora dos Campos. Finally, the micromobility data were made available by GoMoov. The data were compiled and organised using GIS tools.

Table 1. Data description.

Variable	Description
Population	201,445 inhabitants
Mean income	BRL 3157.40
Number of PT routes	70 routes
Number of bus stations	2485 stations
Number of micromobility stations	83 stations

4. Research Approach

A p-median problem was used to identify the size of the lockers and to map their locations. The population was set as the demand point, and the PT and micromobility stations were potential locations for the lockers.

Thus, set I = {1, . . . , n} of potential locations for p lockers, a set J = {1, . . . , m} of customers (i.e., population), and an n x m matrix (g_{ij}) of transportation distance between the demands of the customers from the facilities [51]. The p-median problem is to locate the *p* facilities at locations where *I* minimise the distance between the lockers and customers. Each customer is supplied by the closest open locker.

The distances between the lockers and the customer were evaluated considering different distance ranges, as described in Table 2. Five scenarios were investigated, considering that lockers must be reached by non-motorised modes to promote more sustainable transport. Scenarios I and II focus on walking. The maximum distances between lockers and customers are 400 m and 1200 m, and the lockers are reached by 5-min and 15-min walking trips, respectively. Scenarios 3, 4 and 5 focus on cycling. The distances between the lockers and the customer are 1200, 3200 and 4800 m, which leads to reaching lockers by 5-min, 10-min, and 15-min cycling trips, respectively.

Table 2. Distance scenarios' description.

Scenario	Distance (m)	Transportation Mode	Description
Scenario I	400	Walking	5-min walking
Scenario II	1200	Walking	15-min walking
Scenario III	1600	Cycling	5-min cycling
Scenario IV	3200	Cycling	10-min cycling
Scenario V	4800	Cycling	15-min cycling

A Geographic Information Systems for Transportation (GIS-T) software (TransCAD®) was used to solve the p-median problem. For more information about the location problem, interested readers are referred to [51–54].

Additionally, for each scenario, the influence area of each locker was measured for different coverage ranges. This process was based on the 15-min city concept. Thus, given the number of lockers identified for each scenario, a coverage range was measured by buffer using distances in the network. The following situations were considered: 5-min walking, 15-min walking, 5-min cycling, 10-min cycling and 15-min walking. For each case, different metrics were calculated in the buffer, including population, public transportation and micromobility users.

Since different scenarios for various situations were estimated, the final analysis identified the most suitable locker network for the case under study. Considering that the locker purchase costs do not vary until 1000 units and that the purchase cost is inversely proportional to the number of lockers, the results were normalised to evaluate the efficiency of the scenarios. This process considered the population served, transportation users, micromobility users and purchase costs.

5. Results and Discussion

Figure 5 illustrates the location of the lockers by solving the p-median problem, and the results are summarised in Table 2. Scenario I requires 465 lockers at a maximum distance of 400 m so that residents can reach the lockers by a 5-min walking trip. Scenario II requires 45 lockers at a maximum distance of 1200 m so that residents can reach the lockers by a 15-min walking trip. Scenario III requires 29 lockers at a maximum distance of 1600 m so that residents can get to the lockers by a 5-min cycling trip. Scenario IV requires 15 lockers at a maximum distance of 3200 m so that residents can reach the lockers by a 10-min cycling trip. Scenario V needs six lockers at a maximum distance of 4800 m so that residents can reach the lockers by a 15-min cycling trip. The required number of lockers decreases as the distance increases. Thus, the trade-off between the distance and the number of lockers is crucial for obtaining a locker network that is equitable for residents and profitable for carriers.

Figure 6 shows the influence area of each scenario for the following buffers: 5-min walking trip, 15-min walking trip, 5-min cycling trip, 10-min cycling trip, and 15-min walking trip. Except for Scenario V, the other scenarios cover all urban areas. Table 3 describes the demand for each buffer, considering the different scenarios.

Scenarios I and II refer to the potential to reach the lockers by walking. In Scenario I, the locker network covers 77% of the population, 97.09% of the PT users, and 97.91% of the micromobility users. The locker network identified in Scenario II covers 75.46% of the population, 91.27% of the PT users, and 99.94% of the micromobility users. The size of the locker network estimated for Scenario I is somewhat unrealistic for a medium-sized city because of the large number of units. In addition, the buffer analysis did not cover all residents, despite covering almost all PT users. The number of lockers was reduced significantly from Scenario I (465) to Scenario II (45).

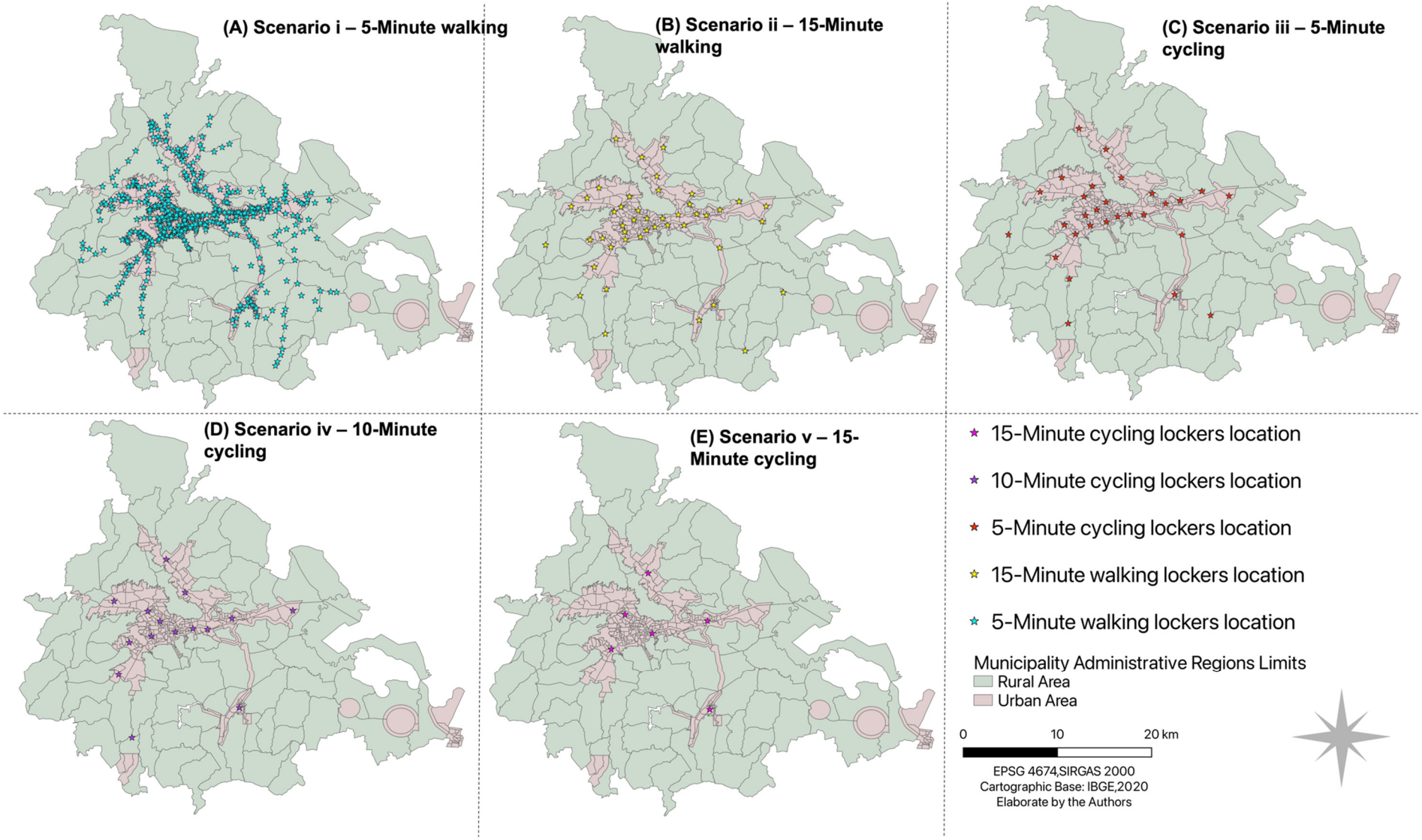


Figure 5. Location of the lockers.

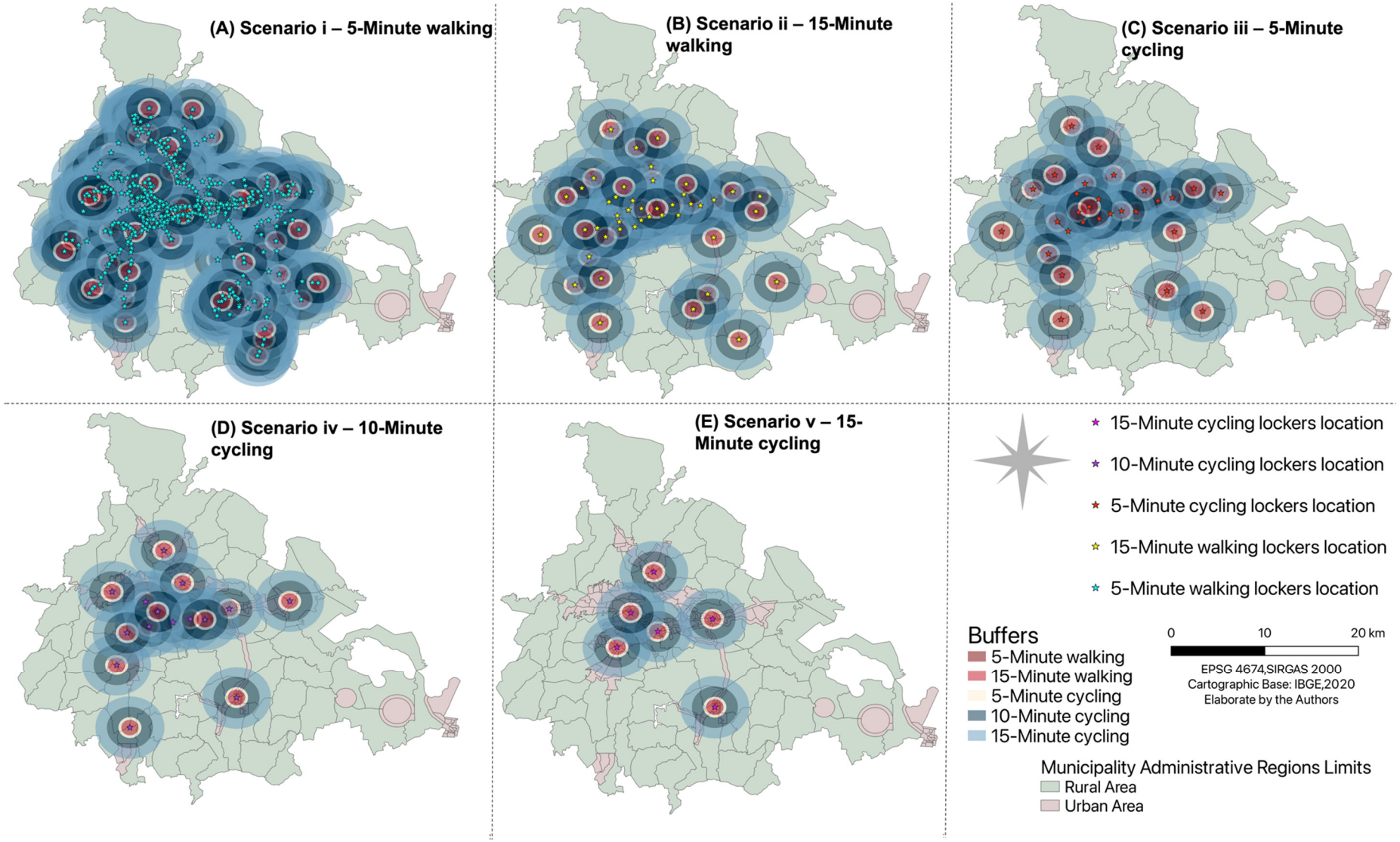


Figure 6. Influence area for the location of the lockers.

Table 3. Demand for different scenarios and associated buffers.

Scenario	Demand	Buffer 5-min. Walking	Buffer 15-min. Walking	Buffer 5-min. Cycling	Buffer 10-min. Cycling	Buffer 15-min. Cycling
Scenario I	Population	77.11%	93.30%	94.51%	96.54%	97.45%
	PT users	97.09%	99.58%	99.64%	99.73%	99.94%
	Micromobility users	97.91%	100.00%	100.00%	100.00%	100.00%
Scenario II	Population	20.99%	75.46%	83.32%	93.84%	96.72%
	PT users	45.02%	91.27%	95.20%	99.22%	99.70%
	Micromobility users	27.85%	99.94%	100.00%	100.00%	100.00%
Scenario III	Population	13.34%	62.93%	75.19%	91.57%	95.43%
	PT users	11.57%	72.81%	90.08%	98.51%	99.39%
	Micromobility users	21.39%	88.35%	100.00%	100.00%	100.00%
Scenario IV	Population	8.12%	42.98%	58.32%	83.36%	92.13%
	PT users	7.46%	31.06%	55.03%	95.11%	98.32%
	Micromobility users	16.08%	81.01%	96.96%	100.00%	100.00%
Scenario V	Population	2.96%	18.35%	27.69%	65.29%	78.23%
	PT users	1.60%	10.46%	18.55%	71.64%	83.62%
	Micromobility users	4.87%	18.99%	43.92%	99.18%	100.00%

Nonetheless, the coverage area is similar for both scenarios, considering the walkability in 15-min cities. The coverage area for reaching lockers during a 5-min walking trip was reduced significantly. In contrast, the cycling mode presents high coverage, with more than 90% of PT and micromobility users and at least 75% of the population. The results from Scenario II converge with the previously presented literature.

Scenarios III, IV and V refer to the potential to reach the lockers by cycling. Scenario III covers 75% of the population by a 5-min cycling trip, 90% of the PT users and 100% of the micromobility users. This same scenario allows 62% of the population to reach a locker by a 15-min walking trip and 95% of the population by a 15-min cycling trip. Scenario IV's influence area covers 83% of the population, 95% of the PT users and 100% of the micromobility users. Finally, Scenario V's influence area covers 78% of the population, 84% of the PT passengers and 100% of the micromobility users.

Scenarios I and II are suitable for typical locker usage, where customers walk short distances to pick up goods. Conversely, Scenarios III, IV and V are more useful for cycling or PT users. Scenario I provides more equitable access to all residents, whereas Scenario V provides an unequal locker network since less than 50% of the population reaches a locker by a walking trip. Moreover, based on the 15-min city concept, the 6-locker network offers the lowest accessibility and the lowest equity for last-mile deliveries. Therefore, Scenario V is the least favourable for a locker network.

In all scenarios, at least one locker was located in a rural area. Given the importance of agricultural activity in this city, large land properties and family farms make rural areas highly populated. However, a relevant share of residents in rural areas do not have a postal code, which makes it challenging to use e-commerce. Thus, providing freight infrastructure for last-mile deliveries using the locker network might increase e-commerce access for rural residents.

Table 4 shows a comparison of the results, including the unity purchase cost. Scenario IV with buffer IV (3200-m maximum distance and 10-min cycling trip) provides the best efficiency among the evaluated scenarios, since all standardised parameters have positive values. Micromobility users have more advantages with implementing a locker network, except in Scenario I, which has a negative standardised result. This indicates the negative contribution of this scenario to the efficiency of the network. In contrast, Scenarios I and IV are the most efficient for PT users, while Scenarios IV and V are efficient for all residents. Considering the unity purchase cost, small locker networks provide low purchase costs,

and consequently, they are more attractive to investors. This benefit is obtained in Scenarios IV and V, where the standardised purchase unit cost value is positive.

Table 4. Comparison of scenarios—standardised results.

Variable	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V
Number of units	465	45	29	15	6
Population	−0.25	−0.81	−0.90	1.85	0.12
PT users	1.21	−0.03	−0.29	0.79	−1.67
Micromobility users	−1.99	0.44	0.51	0.51	0.51
Unity purchase costs	−0.97	−0.62	−0.41	0.14	1.86
Efficiency	−2.01	−1.03	−1.09	3.31	0.83

The influence of each parameter can be evaluated by summing all the standardised values per scenario. From this analysis, Scenario IV provides the best efficiency based on the parameters evaluated in this paper, i.e., coverage area and purchase cost. Identifying the scenario with the greatest efficiency shows that accessing lockers by bicycle is enough to create an efficient locker network.

Discussion

The findings showed that the public transportation network could provide locker networks to integrate freight and public transportation. Additionally, the 15-min city concept allows the identification of locker networks that are accessible for public transportation and micromobility users. Thus, they provide accessibility and equity for freight transport.

Existing studies mention that the distance range varies from 600 m in Germany [16] to 2.4 km in Portland [22]. In Paris, half of the total number of pick-up points is located within 300 m of a railway station [55]. The travel time varies from 5 min in Graz [35] to 10 min in Paris [16]. In addition, considering the distance travelled, the tolerable distances to walk and cycle are 1.7 km and 2.33 km, respectively [12]. Our analysis showed that the size of the locker network varies from 45 units for 1200 m to 15 units for 3600 m. From an operational perspective, a 15-unit network size may be a viable starting point to implement a network (1) focused on crowdshipping deliveries and (2) aiming to change consumer behaviour related to home deliveries. The authors believe that behaviour change is achievable if the service is available in short distances, such as in Paris or Poland. Thus, increasing the size of the network is essential for successfully implementing this initiative.

Additionally, the PT system plays a vital role in locating the locker network. An efficient PT system includes reaching all residents, including those living in rural areas. Consequently, using the PT infrastructure for last-mile deliveries implies covering all residents despite their preferred transportation modes. In addition, a micromobility system complementary to the transport system allows for more sustainable crowdshipping deliveries, as stated by Gatta et al. [48,49].

Locker networks integrated into the PT network contribute to developing sustainable cities [13]. Moreover, locker networks reduce failed deliveries, freight vehicle movements in the city and the overall number of deliveries (because they consolidate the deliveries in the lockers). Furthermore, by integrating locker networks with the PT infrastructure, locker networks can increase the attractiveness of the PT system. This occurs because this system increases people's movements.

Locker networks located in PT stations directly contribute to reducing congestion and emissions. Thus, they contribute to achieving the targets of SDGs 11 and 13. When consumers move to pick up goods, this delivery system stores the goods, reduces the distance travelled and reduces the number of failed deliveries. Crowdshipping associated with lockers does not alter the delivery service for consumers. However, it is more sustainable since either micromobility or PT can be used to deliver goods.

Implementing this solution benefits small and medium cities, such as our study area. First, this solution provides more accessibility to goods. Moreover, lockers accessible by bicycles or by the public transport system may improve the quality of life by improving the accessibility of goods. The second potential effect of this solution for small and medium cities is the increase in public transportation usage, as the stations start to receive more visitors. Finally, from the carriers' perspective, lockers reduce delivery failure and optimise operations.

Although this study was applied to a medium-sized city, the approach could be used in other situations, including larger cities. Moreover, in large cities, delivery failure is even more of a problem, requiring alternative systems to address this issue. It is important to mention that lockers are not a usual solution in Brazil, although their use is well established in Europe. However, sharing infrastructure to establish a locker network could benefit both freight and public transportation.

6. Conclusions

The increase in urban population has also increased the complexity of urban dynamics. The flow of people became more intense, and the flow of urban goods became more complex, intense and pulverised with e-commerce growth. In addition, the COVID-19 pandemic contributed to popularising e-commerce when lockdowns forced the closure of traditional commercial services [56].

This paper identified the size of the locker network and its location to provide accessible and equitable services. For the research question "for a locker network located in bus stations, what should be the size of the network to provide equitable cities?" the network size varies from 45 to 15 units, whereas the maximum distance varies from 1200 to 3600 m. These units, which are located in PT stations, provide accessible and equitable services for the entire population by walking or cycling. The most suitable scenario indicates that the locker network is accessible by a 10-min cycling trip. A 10-min cycling service area reaches both urban and rural residents in Jaraguá do Sul conurbated area.

This analysis was conducted in a Brazilian city, but the method could be used to identify locker networks in other cities by solving the p-median problem. The main challenges are related to defining the maximum distances accepted by users. However, previous studies suggest that considering the 15-min city concept contributes to developing more sustainable cities. The results of this study can be used by policymakers or companies that wish to offer services. For policymakers, using the public transport infrastructure for urban freight helps to reduce operating costs, increases the flow of people and encourages public transport usage. Therefore, locker networks in PT stations contribute to a sustainable city by reducing delivery vehicles, congestion and emissions. In addition, they enhance the public transportation system by incentivising its use, which potentially contributes to improving the system. Furthermore, involving all agents in the discussion of such solutions can minimise problems not addressed in this paper, which may be specific to each system.

From an operational point of view, logistics companies can use crowdshipping services for e-commerce delivery. Since lockers can be used as mini hubs for last-mile deliveries, crowdshipping could use public transportation or micromobility services to deliver goods. In this proposal, locker delivery systems contribute even more to sustainable development, as they can be used for different types of goods, including groceries. Locker systems are the usual designs for e-commerce products. Home deliveries are consumers' preferred service for e-groceries, and previous studies have investigated sustainable alternative delivery services for this purpose (see [57–59]). Thus, identifying product types that are suitable for this system is crucial and recommended for future research.

The system identified in this research has not been validated by companies operating in the city. Therefore, assessing the acceptability of the proposal by stakeholders is recommended, and the method proposed by Le Pira et al. [60] is proposed.

Additionally, this research opens up a research agenda to integrate public and urban freight transportation. As this paper suggests the use of PT infrastructure for freight trans-

port, it is essential to assess the acceptability of the involved stakeholders. Additionally, the acceptability of lockers in PT stations should be investigated. In addition, the environmental benefits of lockers for crowdshipping services should be explored and compared to home deliveries.

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