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ISABELA KOPPERSCHMIDT DE OLIVEIRA

INTEGRATING FREIGHT AND PASSENGER MOBILITY: A comprehensive study in the Brazilian context

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ISABELA KOPPERSCHMIDT DE OLIVEIRA

INTEGRATING FREIGHT AND PASSENGER MOBILITY: A comprehensive study in the Brazilian context

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A comprehensive study in the Brazilian Context

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In loving memory of my grandfather, Siegfried Kopperschmidt, the kindest soul I've ever known.

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Life is a lot like jazz… it's best when you improvise.

George Gershwin

RESUMO

Muito se discute sobre o futuro da mobilidade urbana sustentável, a redução das emissões de gases estufa e proporcionar equidade e justiça social para as comunidades. Neste sentido, desde o início do século XXI, alguns países europeus vêm repensando o sistema de mobilidade urbana, em que o sistema de transportes de pessoas e mercadorias deve ser planejado e operado como um só. Tal mudança de paradigma só tem sido possível de ser implementada em pilotos bem sucedidos graças aos avanços tecnológicos e nas mudanças comportamentais da sociedade e sua inserção na economia das plataformas. Esta tese busca compreender como integrar o transporte de pessoas com o transporte de carga no meio urbano para o contexto brasileiro. O Brasil se encontra em uma situação ímpar para explorar tal integração, pois os planejadores enfrentam dificuldades para atrair os usuários para o transporte público coletivo, enquanto o número de entregas fragmentadas pelo comércio eletrônico só aumenta. É a partir deste contexto que esta tese explora o contexto brasileiro para (i) identificar quais os elementos que podem facilitar ou impedir a implantação de sistemas integrados de transporte de pessoas e cargas em um contexto geral e no contexto brasileiro; (ii) definir a integração, com o conceito de Mobilidade de Carga e Pessoas (MCP); e (iv) avaliar potencial soluções para o contexto brasileiro. Os especialistas brasileiros percebem como vantagens de iniciativas do tipo MCP: melhoria na eficiência do sistema de transporte, redução nos custos do transporte, redução das emissões de gases estufa e redução de congestionamentos. No entanto, eles entendem que a quantidade de atores envolvidos, a preocupação em se manter a qualidade do serviço assim como a necessidade de investimentos tanto na adaptação de veículos quanto na infraestrutura são questões que devem ser levadas em consideração ao se planejar o sistema, pois podem inviabilizar o sucesso da solução. Com isto, se percebeu que as soluções integradas de pessoas e cargas são altamente customizadas em função de sua localidade e são uma combinação de dez elementos, a saber: (i) sistema de transporte; (ii) elementos do sistema de transporte; (iii) infraestrutura urbana; (iv) nível de integração desejado; (v) stakeholders; (vi) modos de transporte disponíveis; (vii) tipos de itens/pessoas a serem transportados; (viii) integração horizontal dos serviços; (ix) integração vertical dos serviços; e (x) tecnologia. Por fim, este trabalho também avaliou a possibilidade de se instalerem lockers em terminais de transporte público e funcionarem como hubs logísticos. Tal solução se provou viável e sustentável, especialmente em municípios de pequeno e médio porte. Sendo assim, esta tese perpassou por conceitos para a integração entre pessoas e cargas em ambientes urbanos, e explorou soluções práticas para o contexto brasileiro.

Palavras-chave: Mobilidade de Carga e Pessoas. Integração. Transporte de Pessoas. Transporte Público Coletivo. Transporte Urbano de Carga. Mobilidade Urbana Sustentável.

ABSTRACT

Much has been discussed the future of sustainable urban mobility, the reduction of greenhouse gas emissions, and providing equity and social justice for communities. In this sense, since the beginning of the 21st century, some European countries have been rethinking their urban mobility systems, and the transportation system being planned and operated as one for both, people and goods. This paradigm shift has only been possible to be successfully implemented in pilot projects thanks to technological advancements and societal behavioural changes, including their integration into platform economies. In this regard, this thesis seeks to understand how to integrate the transportation of people with the transportation of goods in the urban context for Brazil. Brazil is in a unique position to explore such integration, as planners face challenges in attracting users to public transport while the number of ecommerce deliveries rise. It is within this context that this thesis explores the Brazilian context to (i) identify elements that may facilitate or hinder the implementation of integrated transportation systems for people and goods, in a general and Brazilian context; (ii) define integration between people and cargo, using the concept of Cargo and People Mobility (CPM); and (iii) assess potential solutions for the Brazilian context. Brazilian experts perceived as CPM advantages: improvement in overall transportation system efficiency, reduction in transportation costs, reduction in greenhouse gas emissions, and reduction in congestion. However, they understand that the number of actors involved, the concern to maintain service quality, as well as the need for investments in both vehicle adaptation and infrastructure are issues that must be considered when planning the system, as they can jeopardize the success of the solution. Consequently, it was realized that integrated solutions for people and goods are highly customized depending on their locality and consist of a combination of ten elements, namely: (i) transportation system; (ii) transportation system elements; (iii) urban infrastructure; (iv) desired level of integration; (v) stakeholders; (vi) available transportation modes; (vii) types of items/people to be transported; (viii) horizontal integration of services; (ix) vertical integration of services; and (x) technology. Finally, this work also evaluated the possibility of installing lockers in public transportation terminals and operating them as logistics hubs. Such a solution proved to be viable and sustainable, especially in small and medium-sized municipalities. Therefore, this thesis delved into concepts regarding the integration of people and goods in urban environments and provided practical solutions for the Brazilian context.

Keywords: Cargo-People Mobility. Integration. People Transport. Public Transport. Urban Freight Transport. Sustainable Urban Mobility.

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1 INTRODUCTION

Givoni and Banister (2010) define the transport system as “the blood system of the society and the economy”. Following the authors’ metaphor, the organs do not function as expected if the blood system does not function properly. The same can be said about the transport system; activities, services and people’s needs are severely affected if the transport system does not work efficiently. In the 21^{st} century, discussions about equity, social justice, economic development, and environmental preservation are a tonic worldwide. Worried about poverty, hunger, and the intensification of the greenhouse effect, the United Nations (UN) established 17 Sustainable Development Goals (SDG) (UNITED NATIONS, 2022), and all countries signed the 2030 Agenda as a compromise in the Paris Agreement (UNITED NATIONS, 2021). The 27th Agenda topic states:

> “We will seek to build strong economic foundations for all our countries. Sustained, inclusive and sustainable economic growth is essential for prosperity. This will only be possible if wealth is shared and income inequality is addressed. We will work to build dynamic, sustainable, innovative and people-centred economies, promoting youth employment and women’s economic empowerment, in particular, and decent work for all. We will eradicate forced labour and human trafficking and end child labour in all its forms. All countries stand to benefit from having a healthy and well-educated workforce with the knowledge and skills needed for productive and fulfilling work and full participation in society. We will strengthen the productive capacities of least-developed countries in all sectors, including through structural transformation. We will adopt policies which increase productive capacities, productivity and productive employment; financial inclusion; sustainable agriculture, pastoralist and fisheries development; sustainable industrial development; universal access to affordable, reliable, sustainable and modern energy services; sustainable transport systems; and quality and resilient infrastructure (UNITED NATIONS, 2015).“

As argued by Givoni and Banister (2010), the combination *“sustainability”* and *“transport”* is a trend in current policymaking publications, and the same can be said about *“integration” and “transport”*. The authors argue that even though integration may be easy to define and understand, achieving it is another history. Complete planning and operational integration have several layers and barriers to overcome before they become a reality. Hull (2005) considers transport integration as a ladder with eight levels, and the final step corresponds to the sustainable transport one. Integrating cargo and people’s flows is one intermediate step of this ladder as a market response to a liability of the urban dynamics.

Literature shows that urban freight transport and urban people transport are planned, operated separately, and regulated for different sectors. It creates a competitive environment for infrastructure, space and investments (TRENTINI *et al.*, 2011; TRENTINI; MALHENE, 2012; BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). As a result, the urban transport system became highly inefficient, increasing the negative externalities of transport like an increase in congestion, emissions and noise, and the reducing liveability, equity, social justice and environmental justice (CHATZIIOANNOU *et al.*, 2020).

Returning the human body metaphor, integrating cargo and people's flow demonstrated to be fundamental, as the transport system needs to function as one unit. Our veins and arteries transport gases and nutrients, and such flow is controlled by our neural system. Cargo and people move from the same urban road network; however, each flow is handled in one instance. The public sector dominates people's flow, and the private sector dominates the cargo flow (ZHOU; ZHANG, 2020). This segregation leads to inefficiency and space competition (TRENTINI *et al.*, 2011). This lead to the well-known transport negative externalities – emissions, pollution, congestion, noise, reduced liveability, and others (CHATZIIOANNOU *et al.*, 2020) – and also, deficiencies in the transport system impact economic activities, social equity, and environmental justice. Therefore, the role of an integrated and efficient transport integration at the planning and operational level has as main goals: reduce the urban transport system inefficiencies by optimizing urban infrastructure usage (BRUZZONE; CAVALLARO; NOCERA, 2021); reduce congestion, emissions and noise (MARINOV *et al.*, 2013; COCHRANE *et al.*, 2017; PTERNEA *et al.*, 2018; GHILAS *et al.*, 2018; DUIN *et al.*, 2019; OUADI *et al.*, 2021; ELBERT; RENTSCHLER, 2021); and allow transport to be a vehicle of sustainable development with social justice, environment justice and equity (KIKUTA *et al.*, 2012; BRUZZONE; CAVALLARO; NOCERA, 2021).

This thesis aims to discuss the integration of freight and passenger using the Brazilian context as a representative for the countries from the Global South Alliance as a response to the research question: *"At what extent freight and passenger integrated initiatives can be applied at the Brazilian context?"*. The motivation for choosing this geographical area and not using Europe, Japan or China – the countries where this topic is most being discussed – is to bring to light the benefits this integration can get to Brazil and countries with similar features. Additionally, considering the low-quality public transport systems in Latin American cities – including Brazil -, this thesis intends to demonstrate how freight and passenger integration can increase public transport efficiency with freight activity.

The specific goals of this research are:

- Define freight and passenger integration in a concept that includes technological trends, geographic uniqueness and areas of expertise (chapter) - thesis goal i
- Understand which factors – internal or external – for the urban transport system can boost and hinder the freight and passenger integrated solutions (chapter) -

thesis goal ii

- Understand the Brazilian experts' perceptions of freight and passenger integrated solutions in the national context (chapter 2.2) - thesis goal iii; and
- Explore solutions designs for people and freight integration (chapters and) - thesis goal iv.

This research main contribution is the conceptual design of the transport integration between people and cargo flows at planning and operational levels. The concept of Cargo People Mobility (CPM) is developed at chapter 2, as the holistic integration between freight and people flows at the planning and operational level. Integration includes private and public transport systems for cargo and people's displacement within the urban environment, both capable of using any available transportation mode in the local geography. Such integrated mobility should follow market, environmental, economic, social, and technological trends to create custom-made local solutions. This thesis delves around this concept, demonstrating not only the Brazilian experts recognize this kind of solution as a possibility for the Brazilian context, but also identifies what are the main obstacles it is needed to surpass in order to implement CPM initiatives. Such perceptions are reported at chapter 2.2. This thesis is not only theoretical but also have a practical exploratory section, that demonstrate a possible application for the Brazilian context, by using middle-sized urban areas as case studies. At chapters 3.1 and 3.2 the integration between micromobility service and terminal integration are here suggested as possible initial steps at the studied geographies.

This thesis is justified by its main contributions to the academia, environment, economy, society and policymaking. This research is following the recent trends on freight and passenger transport integration researches, especially at Europe, where funding for pilots, living labs and academic researches are being made, especially during the last five years. So, this thesis aims to start practical discussions about the transport integration theme, but translated to the Brazilian context. By discussing this theme translated to the Brazilian reality, this thesis also enables the planning of integrated initiatives to the national context. This thesis also demonstrates the applicability of the integrated solutions in Brazil by bringing some case studies with real data. The proposed solutions used simple algorithms with a few steps to be easily replicable by the public administration or the private sector.

The integrated solutions have been widely discussed in recent years, because of its potential in the fight against the climate change. The most visible benefit of integrated initiatives are the reduction in congestions and vehicle fleet, consequently, it is expected a reduction in emissions caused by the transport activity. Other recognized benefit that can be achieved with integrated solutions are a more cost-efficient transport system, and by reducing transport costs several socioeconomic benefits can be cited like (i) decrease in cargo transport costs and, consequently, decrease in products final costs; (ii) decrease in public transport fare; (iii) local economic development; and (iv) enhance liveability.

1.1 THESIS STRUCTURE

This thesis was constructed under a collection of articles. These interconnected articles serve as input/output for each other, as indicated in Figure 1. The articles of this thesis can be split into two categories: (i) theoretical and (ii) proposition, as demonstrated in Table 1. The four articles are a continuity from each other to complete the storytelling of the thesis.

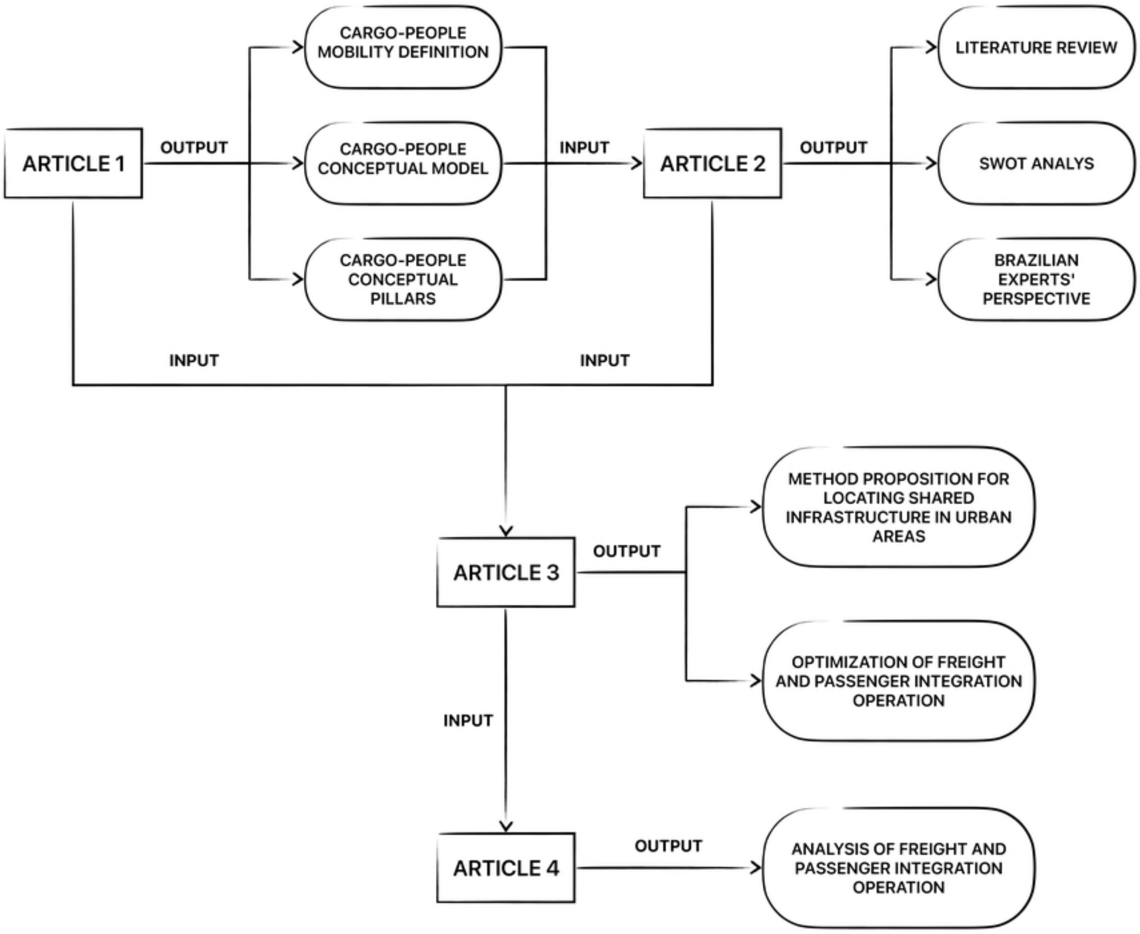
This thesis is, then, dived into four parts. The introductory and conclusion sections binds together all the four articles that composes this thesis. The second section consists on the theoretical development of the integration definition and discuss the integration success and failure components. The third section deals with practical applications of the integration between cargo and people's flow. Also, the fourth and conclusion section discuss the implications of CPM initiatives and its impact on achieving the United Nations Organization (UNO) Sustainable Development Goals (SDG).

Therefore, articles flow follows the hereafter order. The first article (section 2.1) defines this thesis theme, the integration between people and cargo transport systems. The second article (section 2.2) identifies the positive and negative factors in the process of implementation and effects of CPM initiatives, and identifies Brazilian experts' perception of such type of initiatives. The third and fourth articles (sections 3.1 and 3.2, respecteively) exemplifies the application of shared terminals and shared vehicle integration.

Table 1 – Articles Descriptions.

Article Section	2.1	2.2	3.1	3.2
Article title	Cargo and people mobility: a concept proposition for transport and urban planning	Key factors for developing freight and passenger integrated transportation systems in Brazil	Integrating freight and public transport terminals infrastructure by locating lockers: analysing a feasible solution for a medium-sized Brazilian cities	Mobility as a service for freight and passenger transport identifying a microhubs network to promote crowdshipping services
Article goals	Define Cargo-People Mobility and its elements.	Identify challenges and opportunities for freight and passenger integration solutions; Understand the challenges and opportunities for freight and passenger integrated solutions in Brazil	Propose a location method for freight and passenger integration solutions using public transport stops.	Propose an optimisation for Cargo-People Mobility operation; Analyse Cargo-People Mobility pilot operation in Brazil
Relate Specific Goal	i	ii and iii	iv	iv
Data	Literature.	Literature; Web-based questionnaire	Public transport stops (GIS); Population (GIS); E-commerce deliveries (GIS).	Public transport stops (GIS); Population (GIS); E-commerce deliveries (GIS); Company operation.
Research method(s)	Literature review; Matrix conceptual model.	Literature review; Swot analysis; LUCE model.	P-median problem.	p-median problem; Descriptive statistics.
Article type	theoretical	theoretical	proposition	proposition
Publishing Status	Submitted and in evaluation at Caderno Metrópolis (Qualis A1)	Published at Research in Transportation Economics (Qualis A1) - Annex A	Published at Sustainability (Qualis A2) - Annex B	Submitted and in evaluation at Case Studies on Transport Policy (Qualis A2

Figure 1 – Thesis flowchart.



2 THEORETICAL CONSTRUCTION OF CARGO AND PEOPLE TRANSPORT INTEGRATION

During this thesis prospection studies it was noticeable the lack of a formal theoretical framework related to cargo and people transport integration. Trentini and Mahléné (2010) were the only ones who clearly defined some elements of this kind of integration. And while Elbert and Rentschler (2021) defined the integration between public transport and freight operations, mobility solutions aside the public transport vehicles and lane infrastructure being used to transport cargo were not considered.

The section XXX of this thesis comes to fulfil the gap in the integration literature. By combining the existed theoretical definitions of integration with technological and economic trends, it is defined the integration between cargo and people' flow as Cargo-People Mobility (CPM). The concepts come accompanied by the definition of ten essential elements that need to be customized CPM combined to create customized CPM initiatives.

The prospection studies also demonstrated the lack of integrated solutions in the Brazilian context. Thus, the necessity to identify the suitability of such solution in Brazil led to the identification of the key factors of the integration. These factors can be either positive or negative and concern the transport companies and the urban dynamics. These key factors were the submitted to experts appreciation, and they ranked the factors by importance. The ranking made possible to identify the positive factors that need to be most pursued and the negative factors that need to be avoided, in the Brazilian context.

2.1 CARGO AND PEOPLE MOBILITY: A CONCEPT PROPOSED FOR TRANSPORT AND URBAN PLANNING

ABSTRACT

The environmental concern and the new mobility patterns after the COVID-19 pandemic make new solutions necessary to adapt people and environmental needs. In this context, the concept of transport integration emerged, bringing light freight and passenger integration. This article proposed the concept of cargo-people mobility (CPM) based on the holistic integration between freight and people flows. A conceptual model supports the CPM, which includes transport system, transport elements, urban infrastructure, integration levels, stakeholders, transportation mode, transported items, horizontal integration services, vertical integration services, and technology. The CPM pillars are people, public administration, partnerships, infrastructure, and technology. The CPM concept could support including freight and passenger integration projects in master plans and sustainable urban mobility plans.

Keywords: *freight and passenger integration; transport integration; urban freight*

transport; people transport; conceptual model

2.1.1 Introduction

Integration of transport is not a contemporary concept. It dates to the late 1940s in Great Britain (BUTTON, 2022). This concept depends on the political and economic scenario and has its ups and downs being a response to market failure (PRESTON, 2010). In 2007 the European Commission published the Green Paper focussing on transport integration between freight and passengers in urban environments (COMMISSION OF THE EUROPEAN COMMUNITIES, 2007). Freight and passenger transport integration focused on market failures related to sustainability issues such as greenhouse gas (GHG) emissions, congestion, urban space consumption, and urban fleet reduction vehicle (mainly private and cargo vehicles) (TRENTINI; MAHLÉNÉ, 2010; KIKUTA *et al.*, 2012; MARINOV *et al.*, 2013; ARVIDSSON; GIVONI; WOXENIUS, 2016; DUIN *et al.*, 2019; PTERNEA *et al.*, 2018; GHILAS *et al.*, 2018; BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). After the COVID-19 pandemic outbreak, the integration solution of freight and passenger transport brings new light to the efficiency benefits of integration, such as overall cost reduction, vehicle occupation optimization and the attraction of new users of public transport by reducing fares and improving reliability (BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021; ELBERT; RENTSCHLER, 2021).

Freight and passenger integration initiatives have emerged in the 1990s and are becoming more frequent since 2020. This topic is a research agenda, with several pilot tests or consolidated projects. Among the consolidated projects, some noticeable initiatives are CarGoTram in Dresden, Germany (TRENTINI; MAHLÉNÉ, 2010; MARINOV *et al.*, 2013; CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019; ZHOU; ZHANG, 2020; ELBERT; RENTSCHLER, 2021); CargoTram in Zurich, Switzerland (TRENTINI; MAHLÉNÉ, 2010; TRENTINI; MALHENE, 2012; MARINOV *et al.*, 2013; CLEOPHAS *et al.*, 2019; ELBERT; RENTSCHLER, 2021); the Monoprix project in Paris, France (TRENTINI *et al.*, 2011; ALESSANDRINI; SALUCCI, 2012; MARINOV *et al.*, 2013; STRALE, 2014; DAMPIER; MARINOV, 2015; ZHOU; ZHANG, 2020); Yamato operation in Sapporo and Kyoto, Japan (KIKUTA *et al.*, 2012; ZHOU; ZHANG, 2020); New York subway night-shift shared operation, U.S. (TRENTINI; MALHENE, 2012); Bussgods, Sweden (DUIN *et al.*, 2019; ZHOU; ZHANG, 2020); and the historical Dabbawallas in India. Among the pilot tests, the most notable are the LastMileTram in Frankfurt, Germany (ELBERT; RENTSCHLER, 2021; VGF, 2023) and the Cargo Hitching project in the Netherlands (DUIN *et al.*, 2019; CARGO HITCHING TEAM, 2023).

Most of the literature on freight and passenger integration is theoretical studies with passive data (MOTRAGHI; MARINOV, 2012; MARINOV *et al.*, 2013; REGUÉ;

BRISTOW, 2013; LI *et al.*, 2014; DAMPIER; MARINOV, 2015; SHEN *et al.*, 2015; DO *et al.*, 2016; GHILAS; DEMIR; WOENSEL, 2016a; GHILAS; DEMIR; WOENSEL, 2016c; GHILAS *et al.*, 2018; PTERNEA *et al.*, 2018; PIMENTEL; ALVELOS, 2018; OZTURK; PATRICK, 2018; BEHIRI; BELMOKHTAR-BERRAF; CHU, 2018; ZHAO *et al.*, 2018; URSAVAS; ZHU, 2018; ZHAO *et al.*, 2019; HU *et al.*, 2020b; XIE; WANG; FUKUDA, 2020; MOLENBRUCH *et al.*, 2021; MOURAD; PUCHINGER; WOENSEL, 2021; PERNKOPF; GRONALT, 2021; PIETRZAK; PIETRZAK, 2021; BRUZZONE; CAVALLARO; NOCERA, 2021; SAHLI *et al.*, 2022; JAVED *et al.*, 2022; HÖRSTING; CLEOPHAS, 2023). These works simulated the freight and passenger integration scenarios for all transportation modes: aerial, terrestrial (road and railroad), and waterway modes.

However, "*what is cargo and people transport integration?*". To answer this research question, this article aims to consolidate the literature on freight and passenger integration, creating a holistic concept called cargo-people mobility (CPM). This concept focusses on the transportation and urban planning of city authorities, even in countries with low levels of integration. This paper aims to consolidate freight and passenger integration concepts and transport trends into one accessible material.

2.1.2 TRANSPORT INTEGRATION LADDER

Several studies addressed integration as multifaceted with several stages (PRESTON, 2010). Among these concepts, Hull (2005) proposed to "climb" an eight-step ladder to take off from a scenario with no integration and reach full transport integration, called an integration ladder, as illustrated in Figure 2 and detailed in Table 2. According to Hull (2005), each horizon planning has specific steps to achieve transportation integration. The first step corresponds to the planning of short-haul horizons, where the integration of physical and operational public transportation is discussed, including fare and ticketing, multimodal integration, timetable optimization, and facility integration (HULL, 2005). The second step also comprises small-term measures, as multimodality is essential for the beginning of any sustainable transportation project.

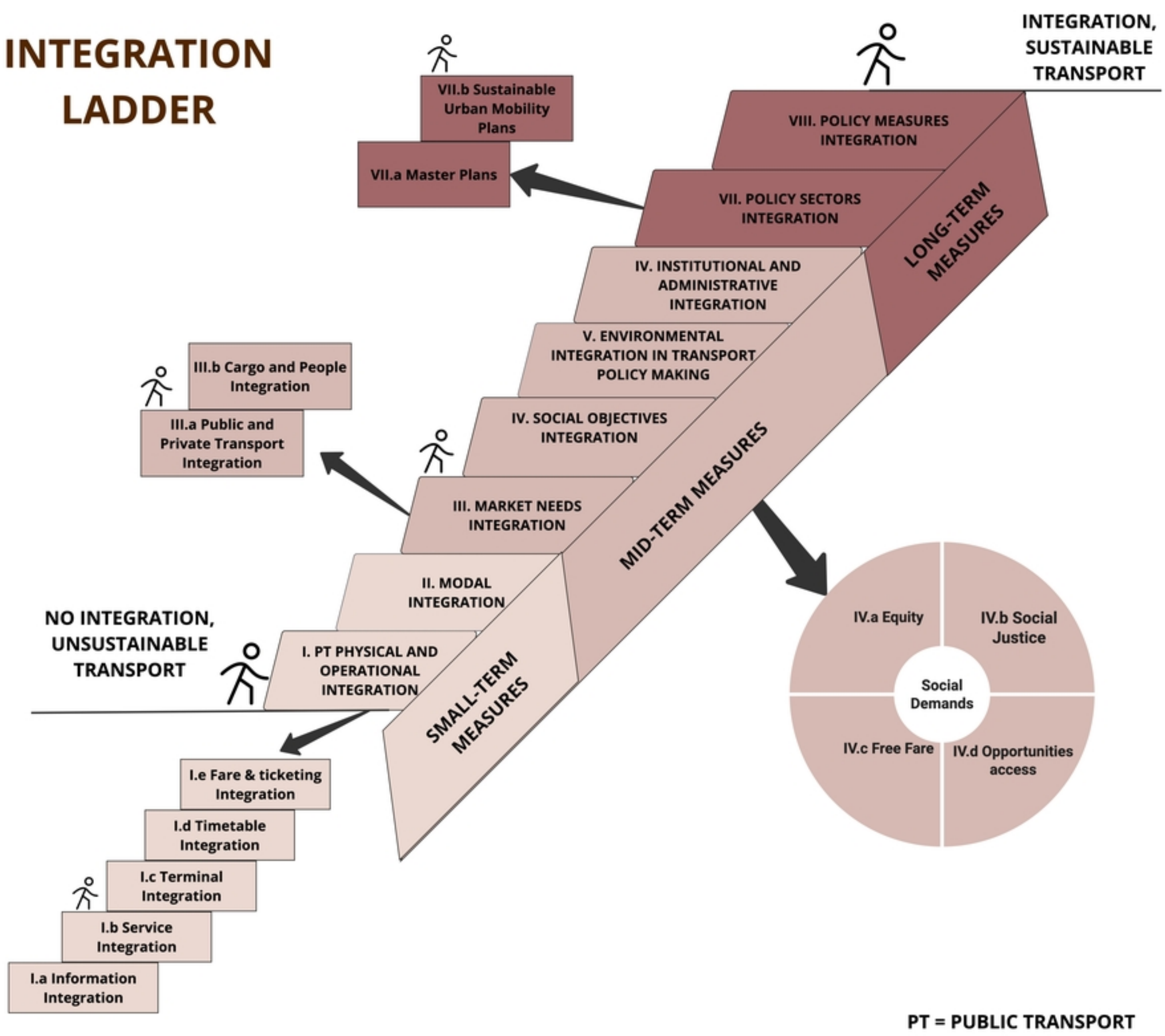
The planning of the medium-haul horizon goes from steps three to six. The third step includes the integration of cargo and people (PRESTON, 2010) and encompasses the market needs. The fourth step integrates the transportation system and social demand and includes social concerns such as equity, social justice, free public transport fare and access to opportunities and essential services (HULL, 2005). The fifth and sixth steps are related to transportation policymaking. The fifth step addresses issues related to the environment and the sixth concerns administrative integration at the regional level. And last, the long-haul horizon is related to seven and eight steps. Step seven refers to the coordination between land use and transport planning. In contrast, step eight comprehends the integration of policy measures, which is the materialization of the climbed steps into applied measures (HULL, 2005).

Table 2 – Integration ladder description. (Inspired by Hull (2005).

Integration Level	Description	Sub-levels	Planning Horizon
I	Public transport physical and operational integration	Information integration Service integration Terminal integration Timetable integration Fare and ticketing integration	Small-term
II	Modal integration		Small-term
III	Market needs integration	Public transport and private transport integration Cargo and people integration	Midterm
IV	Social needs integration	Equity Social justice Access to opportunities Social fare	Midterm

Integration Level	Description	Sub-levels	Planning Horizon
V	Environmental integration in transport planning		Midterm
VI	Institutional and administrative integration		Midterm
VII	Policy sectors integration	Master plans Sustainable Urban Mobility Plans	Long-term
VIII	Policy measures integration		Long-term

Figure 2 – Integration ladder (Inspired by Hull (2005).)



Preston (2010) evaluated the integration of transport to the United Kingdom; however, his observations can be expanded to any other country, as this ladder is not 'climbed' in the expected order. Most East European countries have consolidated the integration of small-term measures, while some midterm measures are for being a reality. However, to compensate for service failures, they managed the ladder's final steps with policy sector integration and policy measures integration (GIVONI; BANISTER, 2010).

However, the first step of the ladder is under construction in the countries of the global South. For example, Belo Horizonte (Brazil), the 6^{th} largest municipality in population, there is no ticketing integration between the bus system and the metro system. Midterm measures are also still developing, and social and environmental policies are isolated from transport policymaking. Following the example of European countries, the long-term measures are the most consolidated ones, where several countries are trying to develop integrated Master Plans and SUMPs, even though they do not translate into reality in many countries.

2.1.3 FREIGHT AND PASSENGER INTEGRATION

The Green Paper released the discussions about people and goods integration and got importance with Trentini and Mahléné (2010). According to the authors, since urban space is a limited resource and people and goods flow interact with each other, both flows can benefit from integrated resources and operational optimization. The authors define the integrated transport system as the interaction of the parts of the urban mobility system: a controlled system and a decision system. The controlled system comprises passenger and freight transport. It is worth mentioning that information must flow from one system to another (TRENTINI; MAHLÉNÉ, 2010).

Based on the integration concept, the Cargo Hitching initiative emerged in 2013. The idea is simple: *"cargo hits a ride on a vehicle transporting people, or persons hitching a ride on a vehicle transporting cargo"* (DUIN *et al.*, 2019). The evolution of the Trentini and Mahléné (2010) concept is the flexibility to use public and private transport systems. Since then, the term 'cargo hitting' has been used in many academic papers to refer to the integration of cargo and people. Elbert and Rentschler (2021) proposed the most recent concept as freight on public transportation, defined as *"the integrated and organised transportation of passengers and goods within urban areas using a system of vehicles, such as buses and trains, that operate at regular times on fixed routes and are used by the public"* (ELBERT; RENTSCHLER, 2021). The advance of their concept is the definition of the three degrees of integration: shared track, shared vehicle, and shared wagon.

It is worth mentioning that some authors consider this integration to be a crowd-based services (SAMPAIO *et al.*, 2019). Crowd logistics is becoming a reality as more communities incorporate the principles of sharing economy into their daily habits (JONGEN, 2018). It enabled people to monetize goods and services, creating new business models based on temporary access, not asset ownership (SAMPAIO *et al.*, 2019). Crowd logistics services inspired the development of transport integration technologies, such as the MaaS4PaF platform proposed by (PIRA *et al.*, 2021). MaaS4PaF unifies the traditional MaaS platform with a logistic platform creating *"a user-orientated integration of passenger and freight transport services that allows searching, booking, and payment through a single digital platform for customized door-to-door trips"* (PIRA *et al.*, 2021). Although the platform does not imply crowd-shipping solutions, crowd logistics and stakeholders' cooperation are essential to the adequate functioning of such technology.

The literature around the operation of freight and passenger integrated solutions is quite advanced, with algorithms proposition and case studies. However, themes like the policymaking process and a solid framework are lacking in the literature. This lack of solid framework makes difficult the usage, as the concept becomes too vague for policymakers. Additionally, the discussion about integrating freight and passenger is advanced in Europe, North America, Japan, and China, besides is not a reality in other parts of the world. In Latin America, for example, the integration concept is still developing. In particular at Brazil, where several public transport operators operate on the same territory, which is a barrier to achieving integrated and sustainable transport.

2.1.4 RESEARCH METHOD

This research method was designed to answer the research question *"What is people and cargo transport integration?"*. The concept of cargo-people mobility (CPM) converges with the previous concept. The CPM concept merges all idea and considers new trends on a broader picture that can be easily used by public administration in Master Plans or Sustainable Urban Mobility Plans (SUMPs).

A conceptual model was proposed to support the CPM concept. The objective of the conceptual model is to define the CPM system for public sector better application. The primary justification is that the public sector must understand the phenomenon of transport integration, so they can prioritize projects involving the CPM principles. In other words, *"If you understand it, you can use it"* (PARUSH, 2015b). A matrix approach was used to propose the CPM conceptual model, which has a nonlinear matrix shape (PARUSH, 2015a).

To complete the comprehension of the CPM, based on previous experiences of success and failures of transport integration projects related to the literature, we elaborated 5 (five) essential pillars of the CPM. First, at December 2021, with the combined keywords *"freight transport"*, *"public transport"* and *"integration"*, a literatures research at Web of

Science, Scielo and Scopus returned 17 suitable papers. This fact led the authors to use a snowball process and inclusion of the literature that was being released until August 2023, totalizing 64 papers. The papers were classified into: (i) case study, (ii) case study with simulation, (iii) concept development, (iv) simulation, (v) acceptability study, (vi) literature review, (viii) service proposition, and (ix) evaluation. The summary of the literature review and papers considered do formulate the CPM concept, conceptual model and pillars are detailed in Appendix II.

2.1.5 RESULTS AND DISCUSSIONS

2.1.5.1 Conceptualizing Cargo-People Mobility

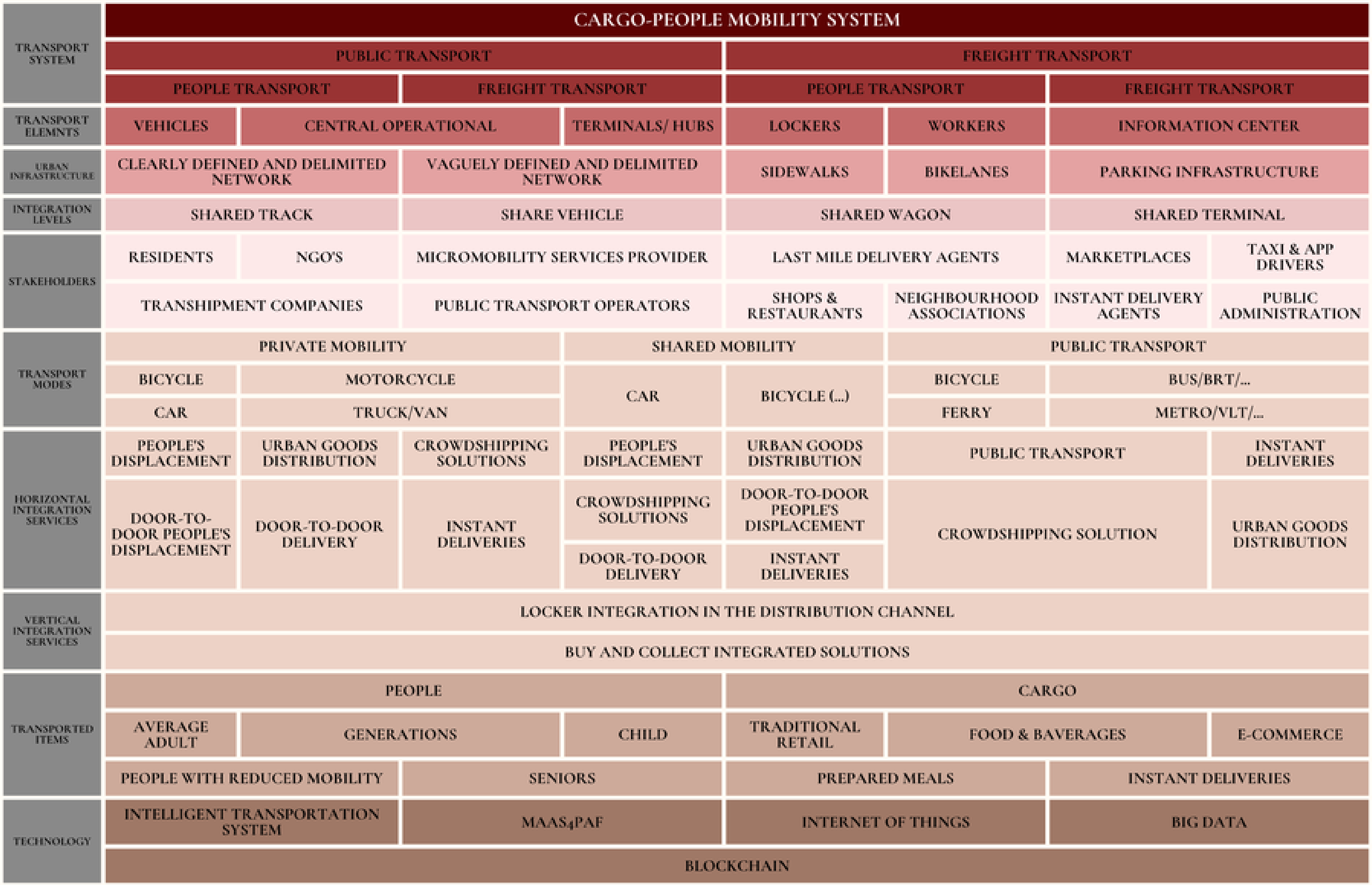
The most prominent authors who discussed theorizing freight and passenger integration are Trentini and Mahléné (2010), Duin *et al.* (2019), Elbert and Rentschler (2021). By unifying its concepts and transport trends, the following concept of cargo-people mobility (CPM) is proposed: Cargo-people mobility (CPM) is the holistic integration between freight and people flows at the planning and operational level. Integration includes private and public transport systems for cargo and people's displacement within the urban environment, both capable of using any available transportation mode in the local geography. Such integrated mobility should follow market, environmental, economic, social, and technological trends to create custom-made local solutions.

The high level of customization of CPM initiatives is explicitly noted by Marinov *et al.* (2013), who argue that each municipality has a unique transportation system, with different transport offers and urban interactions. The CPM initiatives should be smoothly mimetic at each context requiring extra funding for marketing and stakeholder consulting and awareness.

2.1.5.2 Cargo-people Mobility Conceptual Model

Software designers use conceptual models to make applications understandable for users (JOHNSON, 2008). Here, the objective of the conceptual model is to abstractly define the functioning of the CPM system by the public sector. If the public administration can understand the phenomenon of transport integration, they can prioritize projects involving the CPM principles. The idealized cargo-people mobility conceptual model has ten tiers with the essential elements the public sector or private agents needs to consider when conceptualizing such an integration project. Figure 3 summarizes the elements in a matrix conceptual model. The tiers are (i) transport system; (ii) transportation modes; (iii) transport elements; (iv) urban infrastructures; (v) stakeholders; (vi) transported items; (vii) integration levels; (viii) horizontal integration services; (ix) vertical integration services; and (x) technology. Each tier is composed by different elements, which its presence and descriptions combined are what will define the CPM initiative to be planned out.

Figure 3 – Cargo-People Mobility conceptual model.



The first tier that needs an extensive demand-offer study is the transport system, that is composed of all available transportation choices for public and private transport in people and freight transport. The second tear in the conceptual model is the transport elements. This level identifies all components necessary to develop the people transport system and the freight transport system, but also the required modifications at each of these elements to create physical and operational integration, as detailed by Trentini and Mahléné (2010). Other authors also highlight the importance of modifications to terminal / hub infrastructure and vehicles to ensure security and service quality (TRENTINI; MALHENE, 2012; KELLY; MARINOV, 2017; BEHIRI; BELMOKHTAR-BERRAF; CHU, 2018; OUADI *et al.*, 2021). The stakeholders of CPM are directly or indirectly influenced by urban freight transport, people transport, and the joint system. Therefore, stakeholders include users of the transportation system, transportation service providers, lawmakers, and influential organizations such as neighbourhood associations and nongovernmental organizations (NGOs).

The CPM system requires urban infrastructure for all modes of transport. According to (RODRIGUE; DUCRUET, 2017), there are two essential kinds: clearly or vaguely defined and delimited. The first one is most common in the urban environment, corresponding to road and rail networks. Still, the vague kind is also present depending on the municipality's reality with maritime or aerial networks. We cannot exclude the active modes of the transportation network or the parking infrastructure. All these components must be mapped and understood before we consider implementing the CPM system. Transport modes must provide resources for private, shared, and public mobility. It should include private modes such as cars, bicycles, trucks, vans, and motorcycles and public modes such as buses, metros, ferries, and others. Depending on the geographical context and the goal of the service, the service could be idealized into three levels of integration, as established by (ELBERT; RENTSCHLER, 2021). The levels include sharing the infrastructure or the same vehicle space.

A CPM system must transport people and cargo. However, there are several possibilities for it. From the people's perspective, their desires should be known to adjust the offer to demand, since each group has its notion of social justice(JAFINO, 2021). It is also essential to map the demand for this service from millennials because they have a different mobility pattern than the elderly generation (DELBOSC *et al.*, 2019) and are the ones who are more eager to be crowd force (GIUFFRIDA *et al.*, 2021b). For the displacement of the cargo, it is also essential to understand what is being transported because each segment requires suitable packing and has different delivery times.

Depending on the service offered, there are two possible integration types, according to (CLEOPHAS *et al.*, 2019). Services included in horizontal collaboration are those with parts of the transport network that overlap, where multiple providers can offer the same route. The horizontal integration solutions are those that most embrace the potential of the crowd as they answer the questions *"who"*, *"what"* and *"when"* the cargo or people is being transported. On the other hand, vertical integration services are composed of different parts of the network serving different mobility demands. In vertical collaboration services, residents become active in the last mile displacement, especially for freight deliveries.

This complex environment requires information technology (IT) for a suitable functioning. IT should support transport management, urban infrastructure, and transportation modes resources. Moreover, IT allows matching the resources to help stakeholders' demands and crowd availability. Therefore, technological advances should provide the proper functioning of the services offered at both levels of integration. For example, the IT is crucial for the development and implementation of MaaS4PaF, idealized by (PIRA *et al.*, 2021), is crucial when considering crowd solutions. This MaaS application should be able to match the demands of people with the transportation offer and the demands for transport of cargo. MaaS4PaF can also increase crowd-shipping solutions.

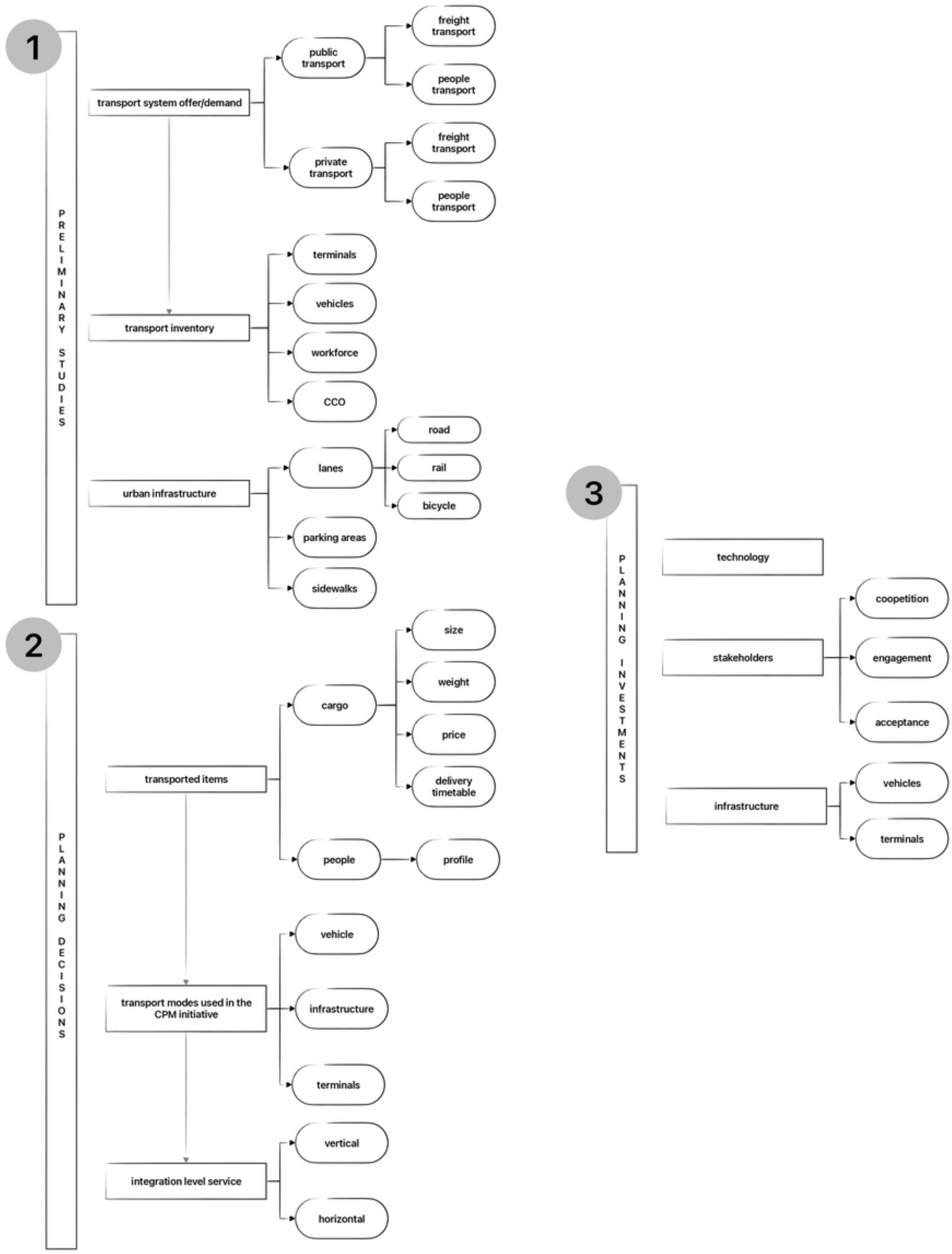
Blockchain technology is the glue that holds all this information together, managing assets, and guaranteeing privacy and data integration among all stakeholders. Creating integrated networks connected to an Internet of Things (IoT) environment that allows collecting and analysing a large amount of city data (big data) is fundamental to customizing flows in real time and distributing people and cargo across the city network. Blockchain technology should allow the administration to manage all the 'smart' aspects of the city (FIORENTINO; BARTOLUCCI, 2021). Such technology provides communication within the sensor network, platform communications, 'smart' devices functioning, well-functioning controlled systems, real-time data analytics, and cloud services (BAGLOEE *et al.*, 2021). However, it still has some barriers that need to be fixed for the full functioning of all these functionalities, like interoperability between different systems, high operational costs, scalability, lack of regulation, and cybersecurity (BAGLOEE *et al.*, 2021).

To implement CPM initiatives and apply the aforementioned conceptual model it is suggested a three-step approach, as demonstrated in Figure 4. The first step includes the preliminary studies. This phases main goal is to make a diagnosis of transport services and infrastructures. With the diagnosis it will be possible to identify the underutilized infrastructure and service gaps. This step is essential at the CPM initiatives design, as one principle of the integration lies on the utilization of the entire transport system, optimizing occupation and routes.

With the diagnosis it is possible to design the CPM initiative. In phase two, decisions related to the CPM service will be defined. Aspects like what kind of cargo can be transported – size, weight, value –, what kind of delivery – door-to-door, just in time, etc –, and what social group will be involved. This decision also comes with choosing the adequate integration solution – shared lane, shared vehicle, shared wagon or shared terminal. And finally, the decision process is only competed when defining if the integration will be vertical or horizontal, which defines the kind of service offered.

And finally, the final step is related to investments needed to implement the designed CPM initiative. Such investments are related to technology, infrastructure adaptation and effort to engage stakeholders and create a heath coopetition environment for companies. The last investment, related to stakeholder engagement, is as important as the structuring investments. Without marketing campaigns, public sections and stakeholders meeting, the implementation of the initiative may not achieve the planned results.

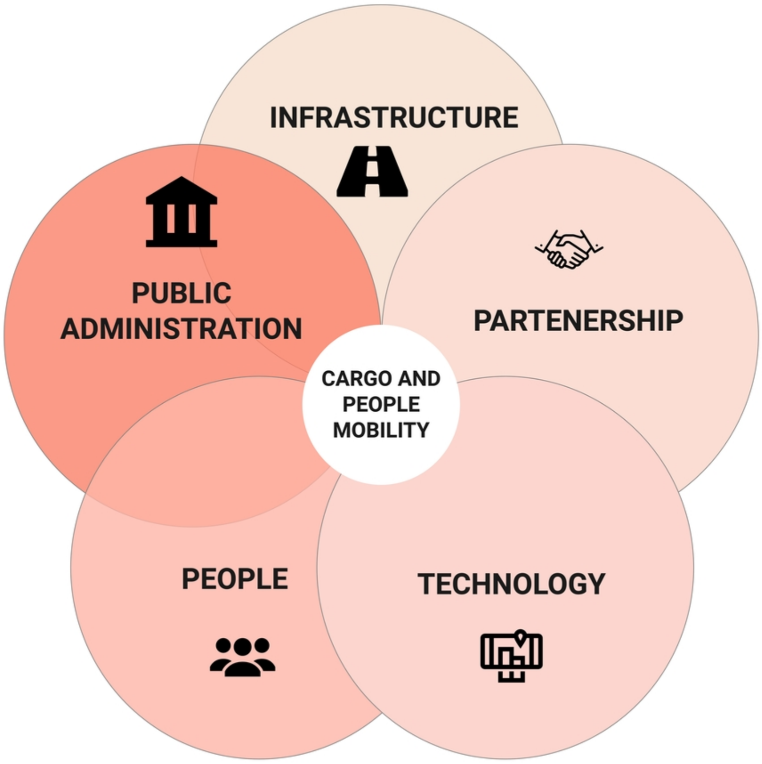
Figure 4 – Cargo-People Mobility planning flowchart.



2.1.5.3 Pillars of Cargo-People Mobility

Although the CPM is well mapped and understandable with the conceptual model, experiences and academia are necessary for successful CPM projects. The components found in the literature were summarized into five pillars (Figure 5) infrastructure, partnership, technology, people, and public administration.

Figure 5 – Cargo-People Mobility pillars.



Connectivity, integrity, resilience, and accessibility of the urban infrastructure are required to function properly in CPM initiatives. Moreover, the transhipment terminals for people and goods are one of the essential principles of integrated mobility defined by the (COMMISSION OF THE EUROPEAN COMMUNITIES, 2007). Properly designed, shared terminals/hubs optimize urban space consumption and allow freight transport and public transport providers to share operational costs (GHILAS; DEMIR; WOENSEL, 2016a). The lockers can also enhance the CPM initiatives, especially offering vertical integration services or serving as temporary storage units. Some authors have explored this solution (WANG *et al.*, 2016; OLIVEIRA *et al.*, 2022b). Ouadi *et al.* (2021) suggested Physical Internet with shared storage units are fundamental for CPM initiatives. Some scholars cite the importance of vehicle adaptation to receive goods and people simultaneously. Kelly and Marinov (2017) argue that most parts of public transport vehicles are not prepared to receive cargo, even in segregated spaces, which requires studies to guarantee transport security. Despite weight capacity, the literature suggests a layout reconfiguration inside public transport vehicles (KELLY; MARINOV, 2017; BURGGRAAF; JOVANOVA, 2021) or installing lockers inside them (KELLY; MARINOV, 2017). Multimodality is even more crucial to the CPM projects and a goal of many SUMPs (OUADI *et al.*, 2021). As discussed above, multimodality is required before the CPM initiatives on the integration ladder. The micromobility system plays an essential role in this process, guaranteeing the connection between different modes of transport and assisting the last mile route.

The CPM solutions are based on the principles of sharing and platform economy. In this context, cooperation between multiple stakeholders is essential for the success of CPM initiatives. However, a trusty and a collaborative environment has been proven to be one of the biggest challenges facing existing initiatives. To a successful coopetition environment companies should be willing to share operational information, vehicles, and infrastructure assets in order to make a more efficient transport system. However, Khakdaman, Rezaei and Tavasszy (2020) demonstrated that even though transshipment companies are willing to give control to third parties, they tend to not allow access to their database, which difficulties the integration process. Data sharing and confidentiality remain among the most significant issues in collaborative projects. The creation of a healthy coopetition environment seems, yet, to be challenging. As long as companies do not allow data sharing, the transport operation will not become more efficient.

A trusty environment is necessary for CPM initiatives and could influence the user's perception of the service. Therefore, CPM systems are possible if people rely on the offered service and engage with the new proposition. Shops, restaurants, and marketplaces must be willing to use this service instead of their own. Residents must be ready to serve as a crowd workforce for horizontal integration solutions. For it, a good marketing strategy must demonstrate and explain to all stakeholders the benefits of using a CPM system.

CPM initiatives come with a high complexity level of coopetition (competition and cooperation between companies). To provide secure financial transactions, protect data, allocate flows, match scales and meet offer/demand transport services are a difficult match. The use of adequate technology tools facilitates the integration process and allows matching offers and demand, allowing the solutions to connect with the crowd. Also, Blockchain technology and MasS4PaF are essential to secure and distribute flows, perform monetary transactions, and protect and collect data.

Although CPM solutions are not exclusively the responsibility of the public administration, they have a crucial role in the development of new policies and regulations. Historically, the private sector has all control over urban freight flow (ZHOU; ZHANG, 2020), leading to a highly unregulated sector. However, the public transport sector became overregulated due to the role of public sector. This regulation mismatch presents a problem for CPM projects. The public sector can foster CPM initiatives by including its principles in their master plans and CPM-related goals in their SUMPs. In addition, the public sector must regulate the new transportation system. Regulation is required to guarantee security, priority of displacement of people, quality service, and data confidentiality.

2.1.6 Conclusions

The importance of freight and passenger integration is an emerging topic in the academic and private sectors. However, few works can help its application in the planning process. This manuscript fills this gap by consolidating the knowledge, experiences, and research and translating it into a suitable framework for anyone, public sector, or private investors.

This paper aims to answer the following research question: *"What is cargo and people transport integration?".* The integration of freight and passenger could be provided by the concept of cargo-people mobility (CPM). In a few words, it is a holistic way of seeing public and private transport unifying people and cargo flows. This concept came with a conceptual model of a ten-tier matrix that helps map all elements of the CPM system. The tiers are re;ated to transport system, transport elements, urban infrastructure, integration levels, stakeholders, transportation mode, transported items, horizontal integration services, vertical integration services, and technology.

CPM projects are complex and require detailed analysis prior to implementation. After analysing several papers, the five essential pillars for CPM projects are identified: infrastructure, people, technology, public administration, and partnership. No pillar is more important than another. How each pillar interacts with the other in the geographic context could determine the success or failure of the CPM project. This paper summarizes many others to promote the discussion of freight and passenger integration.

2.1.6.1 Future Research Agenda

Starting from a clear definition of the integration of cargo and people, it is possible to create a wide research agenda. First, explore the challenges and opportunities for each type of integration, shared lanes, shared vehicles, and shared wagons, and its suitability for each geography and transport structure of transport. Second, this work can inspire research from other countries, such as Latin America ones, to develop their own simulated solutions. A third possibility this article shows is the lack of policymaking research that now can be developed under a clear framework. Finally, the next step to this research is the construction of a guide of possible solutions, based on the CPM conceptual model.

Concerning the stakeholder's role in the success of CPM solutions, it was noticed that a lack of feasibility studies to the implementation of CPM solutions, this gap needs to be fulfilled for such solutions receive public and private investments. Furthermore, no work explored the engagement of stakeholders, which should be investigated in further works.

2.2 KEY FACTORS FOR DEVELOPING FREIGHT AND PASSENGER INTEGRATED TRANSPORTATION SYSTEMS IN BRAZIL

ABSTRACT:

The intensification of e-commerce increases freight movements in urban areas, which negatively contributes to promoting sustainable cities. Conversely, the spare capacity of the public transport system could reduce the externalities of urban freight transport and then promote sustainable cities. This article identifies and evaluates key factors for developing integrated freight and public transport systems. Key factors were identified with a literature review and then classified into benefits and barriers related to the urban environment, and challenges and strengths related to the transport operation. Subsequently, these factors were evaluated by experts and classified by estimating a Luce model. The results indicate that benefits are related to the fight against climate change by optimizing urban space and reducing the movements of freight vehicles. Barriers are associated with the lack of a collaborative culture and the need to change consumer behaviour, which helps to promote collaboration and reduce just-in-time demand. For the transport operation, the integration of people and freight systems can reduce operational costs, increase the efficiency of the transport system, and improve the accessibility for people and goods, while promoting economic development by decentralising economic activity. To achieve these benefits, the main challenges concern the logistic activity and the cooperation of stakeholders.

***Keywords*:** public transportation freight, urban freight transport, public transport, sustainable development.

2.2.1 Introduction

Transportation systems (TS) are vital in cities as they contribute to the movement of goods and people. TS, which include both people transportation systems (public and private) and freight transportation systems, allow access to essential services, goods, leisure, work, and study. However, these systems fail to achieve cost efficiency (MARINOV *et al.*, 2013) because of low-quality public transportation services and low coverage of freight transportation.

The inefficiency of urban freight transport (UFT) leads to negative externalities, such as congestion, pollution, noise, emissions, increasing inequality, and reduced economic development (REGUÉ; BRISTOW, 2013; KELLY; MARINOV, 2017; MASSON *et al.*, 2017; CLEOPHAS *et al.*, 2019). Meanwhile, having a low-quality public transport increases car use levels, congestion, and inequalities (FRIMAN; LÄTTMAN; OLSSON, 2020; GORI; MANNINI; PETRELLI, 2020). Despite their negative externalities, freight and public transport are crucial to creating sustainable and liveable cities that require appropriately planning both systems.

Synergies between UFT and people transport, especially public transport, can promote liveability and economic development (KELLY; MARINOV, 2017; MASSON *et al.*, 2017). Trentini and Mahléné (2010) were the first to define essential elements to integrate people and freight infrastructure, while Duin *et al.* (2019) explored the concept of cargo hitching, where "*cargo hits a ride with people, and people hit a ride with cargo*". Elbert and Rentschler (2021) provided a definition of the synergy between public transport and UFT as freight on public transportation (FPT): FPT refers to an "*integrated and organized transportation of passengers and goods within urban areas using a system of vehicles such as buses and trams that operate regularly on fixed routes and are used by people* (ELBERT; RENTSCHLER, 2021)".

The European Commission first encouraged this integration in 2007 (KELLY; MARINOV, 2017) to promote sustainable cities. The Green Paper suggested rethinking urban mobility by (i) optimizing the use of all transportation modes and promoting co-modality between them, including individual transport; (ii) achieving shared objectives for economic prosperity by guaranteeing mobility, quality of life, and environmental protection; and (iii) integrating the interests of freight transportation and public transportation regardless of the mode of transport used (COMMISSION OF THE EUROPEAN COMMUNITIES, 2007).

The motivation to consider the integration of these types of transportation arises from the same urban infrastructure that freight transportation and public transportation share to meet their travel needs (TRENTINI; MAHLÉNÉ, 2010). However, due to historical issues, UFT and public transport are usually treated as separate agents in the urban environment with conflicting interests and goals; therefore, they are considered independent (TRENTINI *et al.*, 2011; TRENTINI; MALHENE, 2012; BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). The fragmentation of planning and operational processes resulted in stressful environments, where agents in both systems have conflicting interests that increase the inefficiency of urban transportation systems.

The principles of the sharing economy (JONGEN, 2018) justify and support idealizing new solutions that integrate public and freight transport resources. Public transport systems could move goods during off-peak hours with a spare capacity (OUADI *et al.*, 2021), which increases the efficiency of both systems while reducing freight vehicle movements and costs. Furthermore, following the principles of sharing economy, these spare capacities and resources can help the operation of the other system, as proposed by the cargo hitching research group (CARGO HITCHING TEAM, 2023). Thus, FPT solutions imply considering UFT and public transport as one system that seeks cost efficiency and operational efficiency together.

Elbert and Rentschler (2021) proposed three integration levels: (i) shared track transportation systems, where cargo and passengers share the same route; (ii) shared vehicle transportation systems, where cargo and passengers share both the same route and vehicle; and (iii) shared wagon transportation systems, which represent the complete integration between cargo and passengers, where they share the route and the same space in the vehicle. These integration levels vary from geographical, TS, and socioeconomic contexts.

The literature reported some successful examples of these three integration levels. Examples of shared track transportation systems include CarGo Tram in Dresden (Germany) for the Volkswagen Transparent Factory (ARVIDSSON, 2010; MARINOV *et al.*, 2013; CLEOPHAS *et al.*, 2019; ELBERT; RENTSCHLER, 2021; DUIN *et al.*, 2019; ZHOU; ZHANG, 2020); the Cargo Tram in Zurich (Switzerland) to transport recycling goods (ARVIDSSON, 2010; TRENTINI *et al.*, 2011; TRENTINI; MALHENE, 2012; MARINOV *et al.*, 2013; CLEOPHAS *et al.*, 2019; ELBERT; RENTSCHLER, 2021); and the Monoprix railway transport in Paris (France) (ALESSANDRINI; SALUCCI, 2012; TRENTINI; MALHENE, 2012; MARINOV *et al.*, 2013; STRALE, 2014; DAMPIER; MARINOV, 2015; ZHOU; ZHANG, 2020). Shared vehicle transportation systems can be represented by goods being transported underground in Sapporo (Japan), with the Yamato operator as an example (ZHOU; ZHANG, 2020) . Finally, examples of shared wagon transportation systems include the underground delivery system in Kyoto (Japan) with the Yamato operator (ZHOU; ZHANG, 2020), the Bussgoods in Sweden (DUIN *et al.*, 2019; ZHOU; ZHANG, 2020), and the Dabbawalla delivery system in India (DUIN *et al.*, 2019; BAINDUR; MACÁRIO, 2013).

In Brazil, the integration of freight and passengers is still in the early stages, and integration solutions are mainly pilots in the private sector. A private micromobility company (GoMoov) provided the most recent successful solution for medium and small cities (GOMOOV, 2022). However, the urge for integration arises from the decrease in public transport demand due to low quality of service and high prices, among other reasons (RABAY *et al.*, 2021). At the same time, e-commerce deliveries increase and modify urban dynamics (OLIVEIRA *et al.*, 2022a). Therefore, finding ways to both ensure the efficiency of last-mile e-commerce deliveries and increase the quality of public transport service could balance the weaknesses of these systems and promote sustainable transportation. As a result, this work seeks to answer the following question: *'What are the key factors in the development of freight and passenger integration projects in Brazil?'*

To answer the research question, this paper has two distinct parts. First, the literature was classified into challenges, barriers, opportunities, and benefits of integrated freight and passenger systems. This was done to obtain a clear overview of the key factors (KF) to integrate freight and passengers. Subsequently, Brazilian experts ranked the critical factors in terms of the potential transferability to Brazil. The Plackett-Luce model estimated the importance of each KF for the respondents.

The contribution of this paper is twofold. First, identifying and classifying key factors (such as challenges, barriers, strengths, and benefits) provides a detailed analysis of the integrated freight and passenger systems around the world. Second, the qualitative approach to evaluate key factors enables identifying potential features of the FPT system in the Brazilian context. This is a starting point to base policymaking procedures. To the best of the authors' knowledge, this is the first paper focused on Brazilian experts on integrated passenger and freight systems.

This paper has six sections. After this introductory section, Section 2.2.2 presents a brief review of the literature of works that analysed the success of the integration initiative. Section 2.2.3 describes the research method. Section 2.2.3.3 presents the key factors that were classified into challenges, barriers, opportunities, and benefits for the FPT system. Section 2.2.4 reports the results of the evaluation from the Brazilian experts. Finally, Section 2.2.6 concludes this paper.

2.2.2 Literature Review

Trentini and Mahléné (2010) stated that, to create a friendly environment for shared urban mobility, passengers and goods should have access to and be able to tranship through all available transportation modes in a city. The authors proposed an integrated urban mobility network and transhipment points, which were supported by both control and pilot systems (TRENTINI; MAHLÉNÉ, 2010). The authors also highlighted the importance of cross-docking stations and cargo consolidation centres for freight transport (TRENTINI; MALHENE, 2012). Moreover, it is essential to build an architecture that identifies (1) freight flows, (2) the residual capacity of public transport, and (3) the best combination of goods and passengers. This procedure should consider the capillarity of TS, the scheduled time of public transport, and consumer satisfaction (TRENTINI; MALHENE, 2012). Also, within the difficulties of implementing FPT solutions, (TRENTINI; MALHENE, 2012) mention problems with cargo loading due to strict regulations and time schedules. To overcome regulatory issues, a concentric diversification for transport operators may be the legal solution. Therefore, public transportation operators should consider cargo delivery as a new service (TRENTINI *et al.*, 2011).

Ouadi *et al.* (2021)conducted a comprehensive review of the literature on the integration process. The authors emphasized that a warehouse network is essential for the success of cargo operations. This includes facilities for crowd-shipping, which should use a Physical Internet network, and the cooperation between logistics agents. To facilitate cargo operation and maintain PT quality of service, it is crucial to establish a standardised procedure to pack or container, which reduces repacking and restoring activities when dealing with a shared track or shared vehicles in integrated systems. Standardizing containerization and packing are linked to the proper selection of cargo that can be transported in the FPT-designed solution. The use of technology, with real-time routing sharing information, is essential not only for consumer/user satisfaction but also to improve management, safety, security, infrastructure maintenance, and transport operation efficiency. As transport networks should be accessible for goods and passengers, multimodality should be encouraged, which creates a more connected city. Finally, the success of the FPT system is related to the demand for both freight and passengers. The increase in population density encourages mixed-use and increases the scale of both passenger and goods transportation.

Arvidsson (2010) highlighted the importance of adequate sizing of the integrated systems. They should start small to ensure financing, overcome political and social resistance, and finally encourage stakeholder cooperation. Cleophas *et al.* (2019) emphasized the importance of stakeholders' engagement and acceptance of the FPT system, especially for policymakers and legislators.

Operational aspects include providing storage space at strategic stations, in addition to financial incentives and efficient time schedules (BEHIRI; BELMOKHTAR-BERRAF; CHU, 2018; URSAVAS; ZHU, 2018). Furthermore, it is crucial to account for the capacity of public transport vehicles, as they should carry extra weight due to transporting goods (KELLY; MARINOV, 2017).

Recent literature also highlights the importance of crowdshipping in reducing costs and scaling integrated initiatives. Sampaio *et al.* (2019) include freight as passenger integration in crowd logistics solutions. Marcucci *et al.* (2017), Serafini *et al.* (2018), Gatta *et al.* (2019b), Giuffrida *et al.* (2021a), Tapia *et al.* (2023), Cebeci *et al.* (2023) addressed the issue of crowd-shipping in the context of integration. To help organize flows and match supply and demand, Pira *et al.* (2021) proposed an integrated MaaS system called MaaS4PaF.

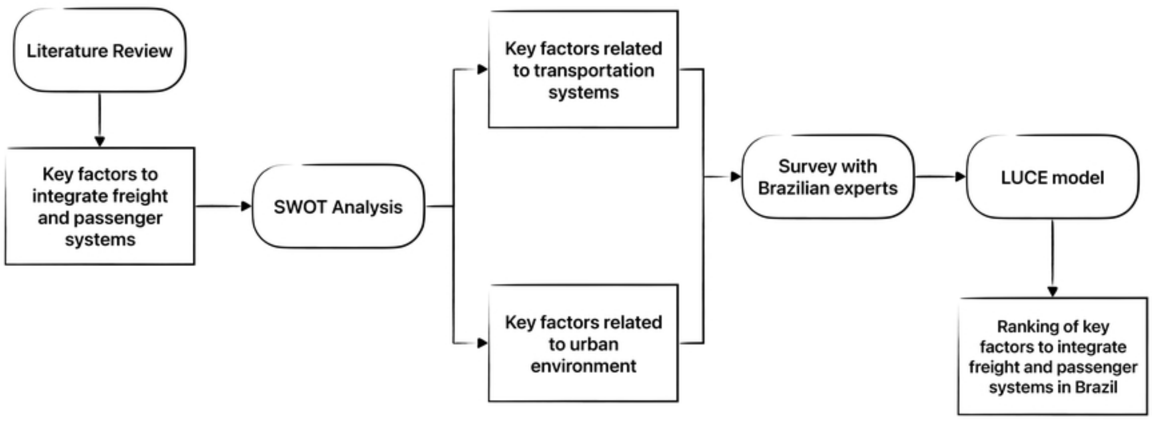
Baindur and Macário (2013), Duin *et al.* (2019), He, Liu and Zhao (2022) present a literature review focussing on megacity regions. The authors showed that the main benefit of such integration is reducing land use conflicts. In addition to identifying the lack of studies for megacities, the authors also demonstrated that rail transport is the leading mode of transportation for integration, followed by taxi sharing. Bjørgen and Ryghaug (2022) explored the role of the public administration in implementing integrated systems into urban planning in Norway. They demonstrated the essential role of early stakeholder participation in the success of policymaking and highlighted that the traditional planning approach may face difficulties in implementing integrated projects.

This literature review has shown that the lack of real data played a major role in analysing the performance of existing projects. Most of the identified factors to evaluate integrated systems resulted from each author's observations and perspectives. Additionally, we observed limited documents on the planning process and on the legal framework for integrated passenger and freight systems. The idea of identifying KF emerged as an attempt to group the conclusions of each author to assist future freight and passengers integrated systems designers. This research fills the gap identified by Elbert and Rentschler (2021): it highlights the opportunities for freight and passenger integration initiatives and understands the caveats and barriers of such initiatives. Finally, it aims to prevent failure and allow the policy to achieve its full potential.

2.2.3 Research Method

This paper followed three steps to answer the research question, *'What are the key factors in the development of freight and passenger integration projects in Brazil?'*: (i) identifying key factors (ii) classifying key factors, and (iii) ranking key factors based on experts' evaluation. Figure 6 shows the research steps described in this section.

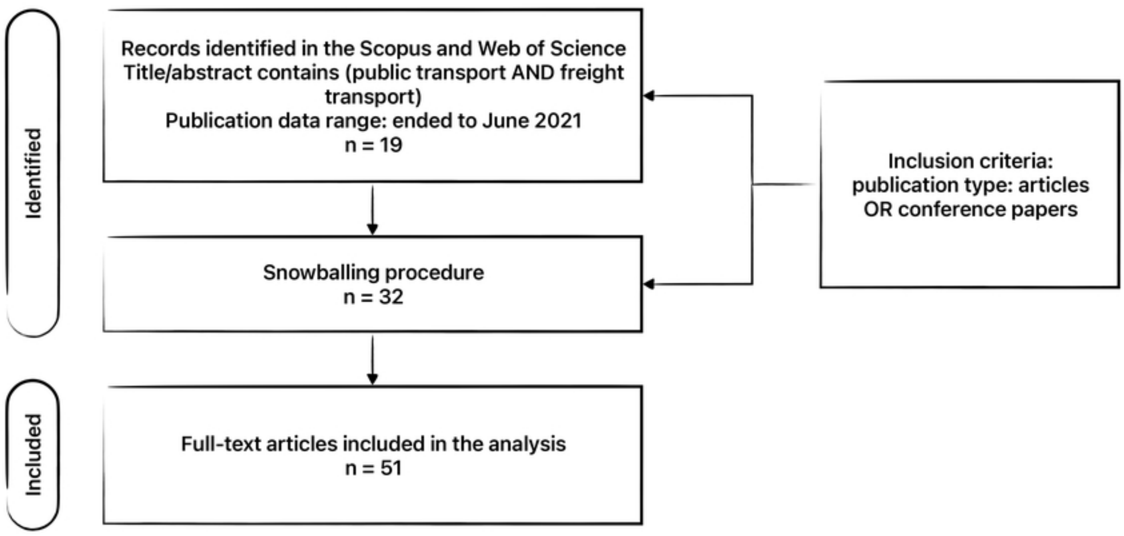
Figure 6 – Research steps.



2.2.3.1 Identifying key factors

The key factors for an FPT system were identified using a literature search with the combined keywords *"public transport"* and *"freight transport"* in the Scopus and Web of Science databases. The investigation considered papers published in peer-reviewed journals up to June 2021 with no additional considerations for the year of the publication. The research found 19 documents and, with the snowballing procedure, additional 32 documents. Therefore, we observed that no systematic literature review protocol was conducted due to the lack of papers published at that time. Thus, all articles that could contribute to identifying key factors (KFs) in integrated freight and passenger systems were included in the analysis, as shown in Figure 7. Manuscripts dealing with freight and people transport were included in the review, while manuscripts with only one of them were excluded. This selection included literature reviews, conceptual frameworks, case studies, and modelling papers.

Figure 7 – Literature review procedure.



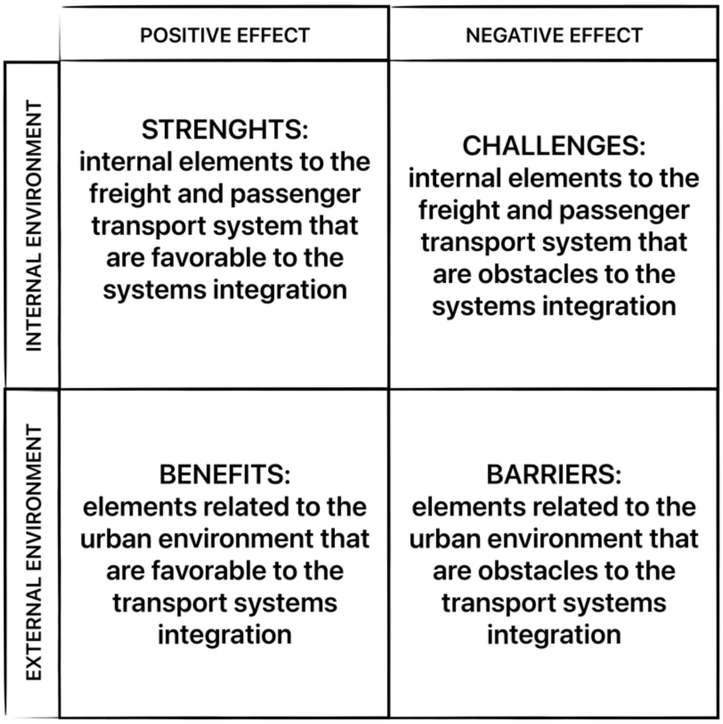
2.2.3.2 Classifying key factors

The identified key factors were classified into a SWOT analysis. This analysis identified the KFs that influence (negatively or positively) the internal operation and the external environment of the project. SWOT analyses comprise four elements: strengths, weaknesses, opportunities, and threats. Strengths are the internal elements that positively influence the project development. Weaknesses are the internal elements that can damage the project development. Opportunities are the external elements that help the development of the project. Finally, threats are external elements that must be anticipated because they can damage project development (HELMS; NIXON, 2010).

Adapting the SWOT analysis by defining the internal and external environments of the integrated system is one of the main contributions of this paper. Therefore, modifying the SWOT technique described by Helms and Nixon (2010), (1) the internal environment is associated with the operational and technical aspects of UFT and PT transport companies and (2) the external environment of the system is the dynamic urban environment.

This article adapted the SWOT analysis to identify positive and negative effects to the urban environment and the integration of freight and passengers. The strengths are KFs of UFT or PT systems to drive the implementation of integrated initiatives. The *challenges* represent the KFs of UFT and PT systems that become more complex the integrated initiatives. The *benefits* are the KFs related to the urban environment that can encourage the implementation of integrated initiatives because of the positive effects that these projects can bring to cities. The *barriers* are the KFs related to the urban environment that can retard the implementation of integrated initiatives. Figure 8 exemplifies the SWOT elements for integrated freight and passenger projects.

Figure 8 – SWOT analysis to integrate freight and passenger systems.



SWOT analyses are widely used in transport planning due to their effortless ability to communicate conclusions to a broad audience. Scholars have used SWOT analyses to introduce mobility as a service system (WOłEK, 2018; DANILINA; MAJORZADEHZAHIRI, 2020; CRUZ; SARMENTO, 2020), to describe the usage of digital technologies applied to transportation systems (DANILINA; MAJORZADEHZAHIRI, 2020; JOVIć *et al.*, 2020; MAHAJAN *et al.*, 2022), to support literature review for strategic planning (BENZAGHTA *et al.*, 2021), and to analyse transportation and mobility projects (WOłEK, 2018; CAVALLARO; SOMMACAL, 2019; KRAMAR; DRAGAN; TOPOLšEK, 2019; GIUFFRIDA *et al.*, 2021a). This application for other studies to map innovative solutions makes the SWOT method suitable for investigating the integration of freight and passengers. The results of this part of the method are detailed in Section 2.2.4.

2.2.3.3 RANKING KEY FACTORS

The KFs were classified into SWOT analysis supported by the expert questionnaire. The questionnaire aims to answer the questions: *'What are the key factors in developing freight and passenger integration projects in Brazil?'* This question was split into two parts depending on the perspective that was analysed. (1) *"What could be improved/avoided in PT or/and UFT operations to develop freight and passenger transport integrated systems?"*; (2) *"What are the main benefits/barriers of freight and passenger integrated systems to the urban environment?"* Appendix I presents the questionnaire.

The questionnaire was emailed to Brazilian transport experts using a web-based survey. Experts were selected from the public transport or freight transport sectors. They should also be members of academia, of the private sector, or of the public sector. The survey was conducted in December 2021 and received 37 responses. In addition to ranking the KFs, respondents could contribute with additional factors not identified in the literature. In this questionnaire, the respondents classified the importance of each KF (strength, challenges, benefits, and barriers) from 1 to 10, where 1 is the most important and 10 is the least important for the cases of strengths and benefits; and from 1 to 16, where 1 is the most important and 16 is the least important for the cases of challenges and barriers.

A Luce model was used to provide the importance ranking of the questionnaire responses. The Plackett-Luce package (TURNER *et al.*, 2020) was chosen to build the model in the R environment. The Luce axiom (LUCE, 1977) states that the odds of picking one item (i_1) over another item (i_2) over disconnected or weakly connected networks do not depend on the available items (TURNER *et al.*, 2020). The Luce model is defined by Equations 2.1, 2.2 and 2.3. Equation 2.1 defines the universe S of a set of J items to be chosen. Equation 2.2 describes the probability of selecting an item i_j from the universe S, where $\alpha_i \geq 0$ is the value of item i, which is a latent characteristic of the item that makes it more likely to receive a higher score. Finally, Equation 2.3 defines which item is expected to be ranked higher out of an A_j set of alternatives (TURNER *et al.*, 2020).

$$S = i_1, i_2, \ldots, i_J \tag{2.1}$$

$$P(i_j|S) = \frac{\alpha_{i_j}}{\sum_{i \epsilon S} \alpha_i} \tag{2.2}$$

$$\prod_{j=1}^{J} \frac{\alpha_{i_j}}{\sum_{i \epsilon A_j} \alpha_i} \tag{2.3}$$

The Plackett-Luce package estimates the parameters based on maximum likelihood and computes standard errors for the item parameters, which allows inferring the importance ranking of these parameters (TURNER *et al.*, 2020). Turner *et al.* (2020) provide further information about the Luce model. The higher the probability obtained by the KFs, the higher the importance of the factors for the respondents. These results are presented in Section 2.2.5.

2.2.4 Key Factors for Developing Freight and Passenger Integrates Systems

Figure 9 summarizes the KFs identified in the literature, which were classified in the proposed SWOT matrix. KFs were classified into strengths (10) and challenges (16) for public and freight transport companies; and benefits (10) and barriers (16) for the integrated freight and passenger system to the urban environment.

Figure 9 – Summary of KFs to promote FPT systems

	POSITIVE EFFECT	NEGATIVE EFFECT
PT AND FT COMPANIES	• reduce circulating freight vehicles • share trip costs • reduce overall operation costs • reduce the transport system complexity • reduce PT fare • reduce energy waste • reduce energy consumption • increase operation scale • increase PT vehicles occupancy • increase transport system efficiency	• PT fixed routes • PT fixed stops • PT fixed scheduled time • PT awkward ticketing • maintain quality service for PT and FT • limited capacity of the services • failed deliveries • cargo packing • cargo manipulation • matching scales and routes • network infrastructure adequacy (select shared-facilities location) • deliver goods to their final destination • adapted vehicles and stations investments • investments in shared infrastructure (cross docking platforms and distribution centres) • companies' cooperation • stakeholders' cooperation
URBAN ENVIRONMENT	• reduce congestion • reduce emissions • reduce air pollution • better usage of urban space • better usage of infrastructure • increase peripheral areas accessibility • reduce competition • promote economic growth • increase policy financial benefits • contribute to sustainable goals achievement	• home deliveries • on-demand deliveries • just-in-time deliveries • congestion in peak hours • cargo manipulation parking area • lack of multimodal network • insuficient warehouse infrastructure • need for behaviour change • PT and FT integration lack of knowledge • PT strong regulation • numerous stakeholders • lack of collaboration culture • financing • political barriers • lack of integration in the planning process • lack of policy integration

LEGEND: PT = people transport; FT = freight transport

2.2.4.1 Key Factors: Strengths

Strengths are KFs related to the operational elements of PT and/or freight companies that would be improved, benefited from, or would help develop the integrated freight and passenger system. Caution should be exercised with the reduction of freight vehicle movements in urban areas due to cargo and people sharing the same vehicles (ARVIDSSON, 2010; TRENTINI; MALHENE, 2012; OUADI *et al.*, 2021). Goods could increase vehicle occupancy by using PT spare capacity during off-peak hours (ARVIDSSON, 2010). Consequently, sharing vehicles to transport both goods and people increases the overall efficiency of the transportation system by reducing vacant space inside the vehicles (OUADI *et al.*, 2021). Furthermore, by minimizing the number of freight vehicles, integrated systems can also contribute to reducing energy consumption (OUADI *et al.*, 2021), energy waste (BRUZZONE; CAVALLARO; NOCERA, 2021), and loading/unloading conflicts (KIKUTA *et al.*, 2012).

Independently of the business model adopted to consolidate integration and collaboration between companies, operational costs are expected to be reduced overall (COCHRANE *et al.*, 2017; GHILAS *et al.*, 2018; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021) due to resource optimization. As a consequence of sharing operational transportation costs by freight transport and public transportation companies (OUADI *et al.*, 2021), the integrated solution has the potential of reducing PT fares and attracting new PT demand (KIKUTA *et al.*, 2012; COCHRANE *et al.*, 2017; OUADI *et al.*, 2021). This shared system would have efficiency and reliability, which would attract new users and provide the needed scale to maintain systems of good quality (BRUZZONE; CAVALLARO; NOCERA, 2021). Finally, such a design could reduce complexity, bureaucracy, and management compartmentalization as cargo and people move together (BRUZZONE; CAVALLARO; NOCERA, 2021).

2.2.4.2 Key Factors: Challenges

Challenges can slow or stop the development of integrated passenger and freight systems. These challenging operational elements must be identified and addressed *a priori* during the system planning process. Mapping and overcoming these challenges at early stages is essential to increase the success of any project.

PT systems have several constraints, such as fixed routes, stops, and schedules (BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). These operational constraints should be considered to match the demand for the successful integration with goods. Furthermore, PT ticketing without fare integration could make the shared system cost more expensive and the charging process more complex (BRUZZONE; CAVALLARO; NOCERA, 2021). Also, it could make the system less transparent to PT users about how much freight companies are charged for using PT.

The demand for transport services for both passengers and cargo is not always compatible (COCHRANE *et al.*, 2017). As PT vehicles and routes have limited capacity, matching freight and people demand is an operational challenge for integrated transportation systems (COCHRANE *et al.*, 2017), but it can be overcome, as shown by several authors (MOTRAGHI; MARINOV, 2012; LI *et al.*, 2014; FATNASSI; CHAOUACHI; KLIBI, 2015; GHILAS; DEMIR; WOENSEL, 2016a; GHILAS; DEMIR; WOENSEL, 2016c; GHILAS; DEMIR; WOENSEL, 2016b; GHILAS *et al.*, 2018; BEHIRI; BELMOKHTAR-BERRAF; CHU, 2018; OZTURK; PATRICK, 2018; ZHAO *et al.*, 2019; HU *et al.*, 2020b). Therefore, two main objectives should be compatible: maintaining PT service quality and cargo delivery time windows However, these integrated systems should always prioritize people's transport (TRENTINI; MAHLÉNÉ, 2010; ARVIDSSON; BROWNE, 2013; CLEOPHAS *et al.*, 2019; OUADI *et al.*, 2021).

Integrating PT and UFT cannot be a reason for low-quality service for either people or cargo. Cargo packing directly influences cargo manipulation, integrity, and service quality (OUADI *et al.*, 2021). Therefore, planning and conceptualizing the integrated freight and passenger system should include package sizing and standardization. At the initial stages of the decision process, other operational decisions are worth mentioning, such as failure deliveries and how active consumers would be in the delivery process (OUADI *et al.*, 2021). These factors should aim for improving cargo quality of service.

Implementing a new transportation system requires adapting existing stations and vehicles. Choosing appropriate stations to operate cargo and passengers simultaneously is essential to reduce the initial costs of the system (ARVIDSSON; BROWNE, 2013; OUADI *et al.*, 2021). In general, the PT sector invests in vehicles and stations (KELLY; MARINOV, 2017), while logistics companies invest in physical Internet, cross-dock platforms, and distribution centres (TRENTINI; MALHENE, 2012; STRALE, 2014). The Physical Internet in the integrated freight and passenger system should create a collaborative distribution network, which allows additional integration between sharing spaces (warehouses) and trip (vehicles and routes) identification. This collaborative distribution network using Physical Internet should enhance the reduction of travelled distances and movements of freight vehicles.

Finally, a major challenge is the cooperation between logistic actors to develop a collaborative distribution network using the Physical Internet network (ARVIDSSON; BROWNE, 2013; COCHRANE *et al.*, 2017; CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021). This collaboration is required for the efficiency of the system. Additionally, cooperation must be at all levels (strategic, tactical, and operational) and involve freight and PT companies; otherwise, implementing a freight and passenger integrated system may not be possible (STRALE, 2014).

2.2.4.3 Key Factors: Benefits

Benefits are elements of the urban environment that positively contribute to implementing integrated freight and passenger transport systems due to their potential positive. The most cited benefit is the improved use of urban space, which is achieved with shared infrastructure (BRUZZONE; CAVALLARO; NOCERA, 2021) and reduces both urban and logistical sprawl. It also promotes better usage of infrastructure and resources from passenger transport (e.g., vehicles, exclusive lanes, or stations) as cargo would also be able to use such infrastructure. Finally, it reduces competition in infrastructure demand between goods and passengers by decreasing (i) parking conflicts, (ii) competition in lane spaces, and (iii) accidents due to reducing the number of vehicles circulating (ARVIDSSON; GIVONI; WOXENIUS, 2016).

Integration can assist city authorities in mitigating negative environmental consequences of transportation, which contributes toward achieving the goals of the 2030 Agenda. Reducing movement of freight vehicles in urban areas can potentially reduce congestion (COCHRANE *et al.*, 2017; GHILAS *et al.*, 2018; PTERNEA *et al.*, 2018; DUIN *et al.*, 2019; ELBERT; RENTSCHLER, 2021) and emissions (COCHRANE *et al.*, 2017; GHILAS *et al.*, 2018; PTERNEA *et al.*, 2018; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). In other words, integrated transport systems can contribute to sustainable cities (OUADI *et al.*, 2021). Finally, integrating goods and people can increase the capillarity of PT (BRUZZONE; CAVALLARO; NOCERA, 2021) due to the destination of freight demand and to the additional associated revenue. Consequently, integrated systems increase accessibility and promote economic development (KIKUTA *et al.*, 2012; BRUZZONE; CAVALLARO; NOCERA, 2021).

2.2.4.4 Key Factors: Barriers

Barriers are elements of the urban environment that reduce the probability of success or slow the implementation of freight and passenger systems. Barriers must be addressed carefully, which requires the cooperation of stakeholders, a change of habits, and effective policymaking. Stakeholder participation is the most significant barrier as any considerable modification in transport systems needs the acceptance and participation of all to succeed (ARVIDSSON; BROWNE, 2013; COCHRANE *et al.*, 2017; CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021). For example, conflicting goals between stakeholders, such as market demands and just-in-time delivery culture, can prevent sustainable delivery solutions (FATNASSI; CHAOUACHI; KLIBI, 2015; CLEOPHAS *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021). The conflict of interest between the passenger and freight sectors is another barrier that should be considered in FPT projects (COCHRANE *et al.*, 2017).

Funding for disruptive systems is always difficult (CLEOPHAS *et al.*, 2019), especially for uncertain aspects such as freight and passenger integrated systems, which have a limited number of successful pilot projects and lack real-time information (LI *et al.*, 2014). The lack of a clear network, such as Physical Internet or multimodal, is another barrier that requires high investments. Many countries do not have an integrated facility infrastructure that is close to a Physical Internet network, and many locations do not have a multimodal network (CLEOPHAS *et al.*, 2019; OUADI *et al.*, 2021). Parking spaces for loading and unloading activities represent another barrier. In general, cities restrict freight operation and circulation, which increases negative externalities related to UFT (FATNASSI; CHAOUACHI; KLIBI, 2015).

Moreover, the traditional structure of splitting freight and passengers at the political and planning levels leads to limited integration and communication between policymakers (LI *et al.*, 2014; ARVIDSSON; GIVONI; WOXENIUS, 2016; CLEOPHAS *et al.*, 2019), which makes integration difficult at these levels. Also, PT is strongly regulated (TRENTINI; MALHENE, 2012), while freight activity has minor or no regulation in some countries.These identified barriers provide two main conclusions. First, a collaborative culture is mandatory for FPT projects (CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019). Second, behaviour changes of all stakeholders are required to embrace this collaboration, which reduces just-in-time needs (ARVIDSSON; GIVONI; WOXENIUS, 2016) and space consumption.

2.2.5 Key Factors' Evaluation of Freight and Passenger Systems by Brazilian Experts

Brazilian transport experts evaluated the KFs, which were identified and classified after an extensive literature review, using a web-based survey. As mentioned before, 37 experts answered the survey. Respondents were academics (32.4%), from the public sector (51.4%), and from the private sector (16.2%). In addition, 35.1% of the respondents were in the freight sector and 64.9% were in the public transportation sector.

The integrated freight and passenger approach is very novel for Brazilian experts, and only 29.7% of the respondents confirmed that they had previous knowledge about integrated freight and passenger initiatives. To overcome this limitation, a text and a cartoon were included in the questionnaire, which helped to illustrate how integrated freight and people transport systems work. After responding to the survey, 83.8% of the respondents stated that these systems could be suitable for developing sustainable transportation in Brazil.

2.2.5.1 Evaluation of key strengths and challenges in freight and passenger systems

After applying the Luce model, not all coefficients per group had statistical significance, which shows that the respondents do not consider some KFs as potentialities for freight and passenger systems. Based on the estimated coefficients (Table 3), the probability of strong key factors was calculated and illustrated in Figure 10. Most of the groups considered economic benefits to be the most important factors, which is consistent with previous research that pointed out the importance of monetary benefits of shared systems as strong factors (KIKUTA *et al.*, 2012; COCHRANE *et al.*, 2017; GHILAS *et al.*, 2018; BRUZZONE; CAVALLARO; NOCERA, 2021). However, the private sector also considers reducing the system's complexity because legal requirements are not standardized. With integrated freight and passenger systems, more straightforward regulations are needed. In these cases, the core issues must be addressed for all transport agents, independently of the nature of the transport. Also, the private sector does not consider the PT fare reduction as a core strength of the system mainly because this KF is not essential for this type of business.

Figure 10 – Probabilities of key strengths per group.

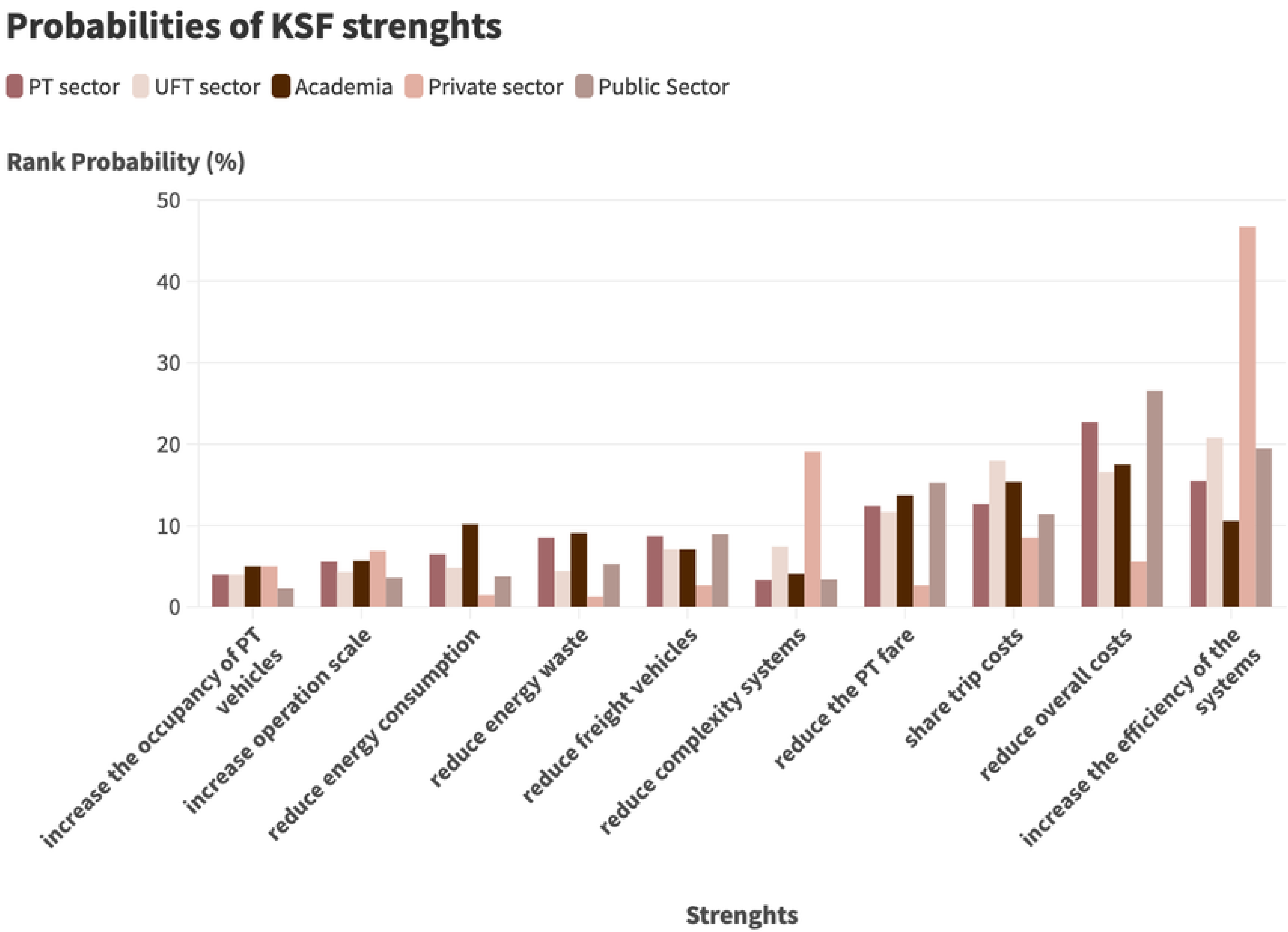


Table 3 – Estimated coefficients of key strengths.

KFs	Public Transport Sector	Urban Freight Transport Sector	Academia	Private Sector	Public Sector	All Respondents
reduce circulating freight vehicles	6.349***	2.026*	1.337	4.911	11.186**	4.119***
share trip costs	6.728***	2.956**	2.114*	6.047.	11.424**	4.748***
reduce overall operation costs	7.304***	2.875**	2.240**	5.637	12.273**	5.054***
reduce the complexity of the transport system	5.376**	2.073*	0.784	6.859	10.205**	3.578***
reduce PT fare	6.704***	2.521**	1.997*	4.899	11.719**	4.563***
reduce energy waste	6.323***	1.539	1.584.	4.177	10.659**	3.863***
reduce energy consumption	6.062***	1.626.	1.698*	4.321	10.318**	3.762***
increase operation scale	5.913***	1.529.	1.115	5.836	10.259**	3.668***
increase PT vehicles occupancy	5.568***	1.450	0.993	5.523*	9.812*	3.425***
increase transport system efficiency	6.924***	3.100**	1.739*	7.755*	11.963**	4.907***

Significance codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.

Table 4 and Figure 11 present the coefficients of the Luce model and the probabilities of key challenges. Respondents considered the operational aspects of PT, especially UFT, as the main challenges to overcome. The literature reported that these challenges can be easily overcome with properly matching route algorithms and technical assistance. However, as automating and robotizing PT seem far for Brazil and other developing countries, operational issues are more difficult to overcome. While the PT sector and the public sector ranked higher in the operational aspects of UFT, the private sector and the UFT sector ranked higher in the operational aspects of the PT. This difference is expected due to the traditional separation of UFT and PT at the planning, operational and research levels (LI *et al.*, 2014; ARVIDSSON; GIVONI; WOXENIUS, 2016; CLEOPHAS *et al.*, 2019). The need for shared infrastructure is an essential challenge for the PT sector (1^{st} ranking with a 12.8% probability rank) and academia (1^{st} ranking with a 13.81% probability rank), but it is an intermediate challenge by UFT respondents (10^{th} ranking with a 5.89% probability rank), private sector respondents (5^{th} ranking with an 8.49% probability rank) and public sector respondents (8^{th} ranking with a 5.69% probability rank). This difference may have occurred due to the bad infrastructure of Brazilian PT terminals that already struggle with current demand.

Another crucial challenge is the quality of service. It received a higher ranking as an overall KF and was considered a priority for the academia, PT, UFT, and public sectors. However, each sector may present its own focus when talking about quality of service. For freight providers, quality of service can be translated into security, delivery time, loading/unloading activities, and cargo accessibility. For PT providers, quality of service is related to reliability, time travel, accessibility, comfort, safety, and trip cost. Quality of service was also a highly mentioned factor in the existing literature (TRENTINI; MALHENE, 2012; COCHRANE *et al.*, 2017; CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021).

Previous research pointed out that stakeholders' integration is one of the main challenges to consider when planning integrated solutions (ARVIDSSON; BROWNE, 2013; STRALE, 2014; COCHRANE *et al.*, 2017; CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021). However, in the Brazilian context, only the UFT sector (2^{nd} position with a probability rank of 10.22%) and the private sector (2^{nd} position with a probability rank of 11.48%) considered it as a significant challenge. Other groups presented a lower rank for this challenge, which made the overall importance of Brazilian experts less important than in developed countries (9^{th} position with a probability rank of 5.88%). Due to data privacy concerns and market competition, the private sector may be more concerned with this cooperation.

Figure 11 – Probabilities of key challenges per group.

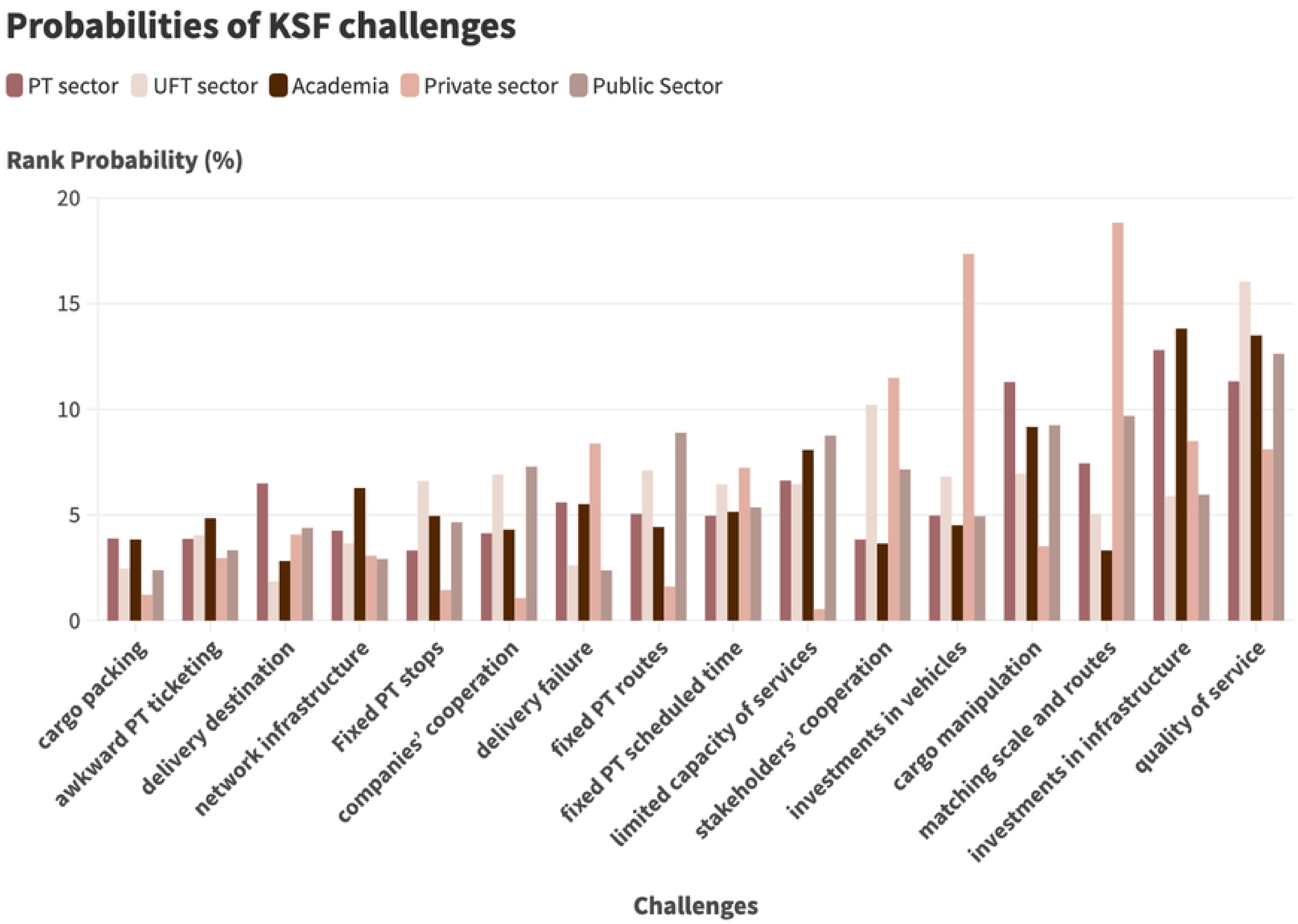


Table 4 – Estimated coefficients of key challenges.

KFs	Public Transport Sector	Urban Freight Transport Sector	Academia	Private Sector	Public Sector	All Respondents
PT fixed routes	3.295***	2.115**	0.865	0.979	5.576***	2.694***
PT fixed stops	2.872***	2.041**	0.978	0.873	4.928***	2.440***
PT fixed scheduled time	3.277***	2.019**	1.015	2.484	5.070***	2.688***
PT ticketing	3.030***	1.550*	0.956	1.588	4.590**	2.326***
maintain quality service for PT and FT	4.102***	2.929***	1.981*	2.595	5.927***	3.524***
limited capacity of the services	3.566***	2.020**	1.466.	-0.087	5.561***	2.833***
failed deliveries	3.397***	1.116	1.084	2.629	4.258**	2.270***
cargo packing	3.033***	1.060**	0.720	0.702	4.263**	2.030***
cargo manipulation	4.100***	2.093*	1.594*	1.761	5.616***	3.137***
matching scales and routes	3.683***	1.774	0.575	3.440*	5.662***	2.732***
network infrastructure (selecting shared-facilities location	3.123***	1.448	1.215	1.627	4.461**	2.309***
deliver goods to their final destination	3.546***	0.776	0.412	1.907	4.870***	2.195***
investments in adapted vehicles and stations	3.278***	2.075*	0.885	3.358*	4.988***	2.653***
investments in shared infrastructure (crossdocking platforms and distribution centres)	4.255***	1.928*	2.003*	2.643.	5.176***	3.115***
companies' cooperation	3.094***	2.088**	0.835	0.568	5.377***	2.572***
stakeholders' cooperation	3.018***	2.479**	0.669	2.945.	5.358***	2.654***
Significance codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.						

2.2.5.2 Evaluation of Key Benefits and Barriers in Freight and Passenger Systems

The coefficients of the key benefits of the Luce model and their respective probability ranks are shown in Table 5 and Figure 12, respectively. The overall evaluation converged with the literature, i.e., the main benefits are congestion reduction (1^{st} ranking with a 16.2% probability rank), better use of urban space (2^{nd} ranking with a 15.5% probability rank), and the increase in accessibility at peripheral areas (3^{rd} ranking with a 13% probability rank). The PT sector is also considered as relevant to the economic growth the integration can bring (2^{nd} ranking with a 10.99% probability rank) and the air pollution reduction (3^{rd} ranking with a 10.74% probability rank). Meanwhile, UFT respondents value some factors almost equally, such as accessibility in peripheral areas (1^{st} ranking with a 19.98% probability rank) and better use of urban space (2^{nd} ranking with a 19.97% probability ranking).

Air pollution is another main benefit pointed out by the literature (COCHRANE *et al.*, 2017; GHILAS *et al.*, 2018; PTERNEA *et al.*, 2018; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). However, Brazilian experts consider it as a secondary benefit, which was ranked lower for all groups except for the PT sector. This also emphasizes the different contexts that developed and developing countries face. Depending on the location, air pollution may be a concern, but it is normally not a major goal in developing countries. The reduction in space competition was considered to be the most important factor only in the private sector (with a 16.54% probability rank). This result is related to the nature of the operation, where most freight vehicles need to *"fight"* for parking spaces. The other groups consider this variable as a secondary benefit as most groups do not experience this conflict for parking spaces. Economic growth was also considered secondary, except for PT and public sectors. The importance of these factors may arise from implementing the goals of the Agenda 2030 in Master Plans and Sustainable Urban Mobility Plans.

Figure 12 – Probabilities of key benefits per group.

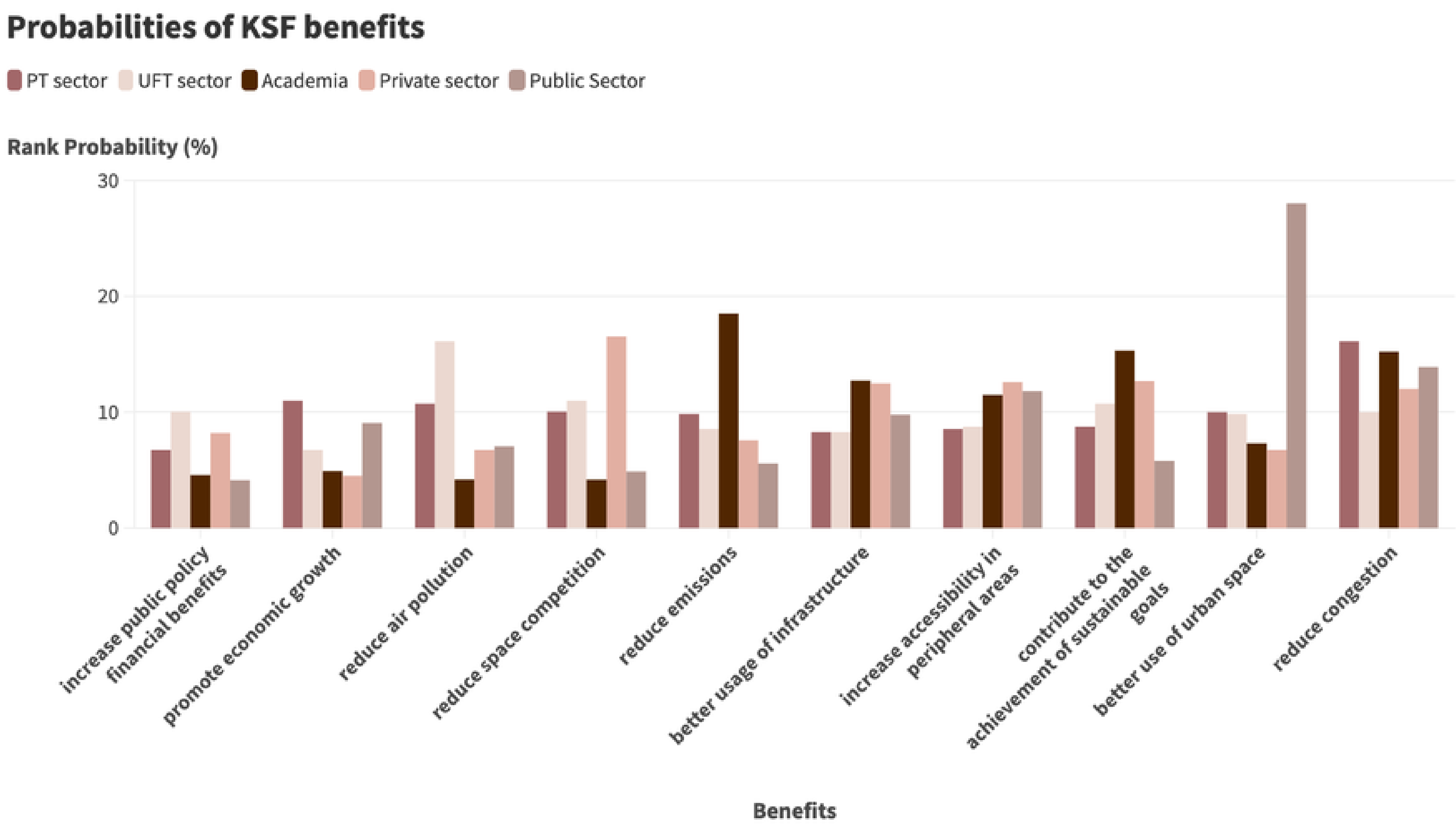


Table 5 – Estimated coefficient of key benefits.

KFs	Public Transport Sector	Urban Freight Transport Sector	Academia	Private Sector	Public Sector	All Respondents
reduce congestion	6.903***	3.616***	2.204*	5.558.	10.529**	4.863***
reduce emissions	6.411***	3.617***	2.400**	5.093	9.611**	4.353***
reduce air pollution	6.497***	3.274***	0.913	4.978	9.850**	3.938***
better use of urban space	6.426***	2.742**	1.468	4.978	11.230***	4.818***
better usage of infrastructure	6.237***	3.452***	2.026*	5.595.	10.178**	4.573***
increase accessibility in peripheral areas	6.267***	2.751**	1.922	5.604.	10.366**	4.642***
reduce space competition	6.430***	1.745.	0.910	5.878	9.482**	3.877***
promote economic development	6.520***	1.680.	1.076	4.574	10.100**	3.982***
increase public policy financial benefits	6.028***	1.604.	0.998	5.175.	9.312**	3.698***
contribute to the achievement of sustainable goals	6.291***	1.724.	2.210*	5.613.	9.655**	4.301***

Significance codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.

Table 6 and Figure 13 show the estimated coefficients of barriers and their respective probabilities. On-demand and just-in-time deliveries were the main barriers to the success of the integration (with 8.91% and 8.62% probability ranks, respectively). Academics considered KFs related to recent consumer habits as barriers to implement successful freight and passenger integration systems (i.e., the importance of the change in people behaviour was in 4^{th} ranking with a 9.48% ranking probability). Similarly, the UFT sector valued the importance of behaviour change (1^{st} ranking with a 15.24% probability rank). The academic sector (3^{rd} ranking with a 14.18% ranking probability) and the UFT sector (2^{nd} ranking with a 10.11% ranking probability) shared the same worry about congestion during peak hours to maintain service quality.

Against the findings of the existing literature (ARVIDSSON; BROWNE, 2013; LI *et al.*, 2014; CLEOPHAS *et al.*, 2019), the lack of policy integration, the political barriers and the financing struggle were ranked lower for almost all groups, especially for the private sector. This result may be a consequence of the lack of integrated initiatives in Brazil, which leads to experts perceiving some factors as more challenging than others. Moreover, the UFT and the private sector emphasize the lack of integration. These sectors have a hard time with unclear legislation, leading the UFT and the private sectors to think that political and legal factors are essential as well. The literature pointed out the presence of multiple stakeholders with different demands as one of the main challenges (ARVIDSSON; BROWNE, 2013; COCHRANE *et al.*, 2017; CLEOPHAS *et al.*, 2019; DUIN *et al.*, 2019; BRUZZONE; CAVALLARO; NOCERA, 2021). This factor was considered crucial to the public sector (1^{st} ranking with a 16.79% probability rank) and the private sector (2^{nd} ranking with a 24.32% probability rank). This may be a consequence of dealing with multiple perspectives and service demands.

Overall, academia considered conflicting interests as easier barriers to overcome, and the experts gave higher importance to barriers related to consumer habits. However, respondents from the private and public sectors considered both consumer habits and aspects related to the political and legal framework to be significant barriers to achieving integrated systems.

Figure 13 – Probabilities of key barriers per group.

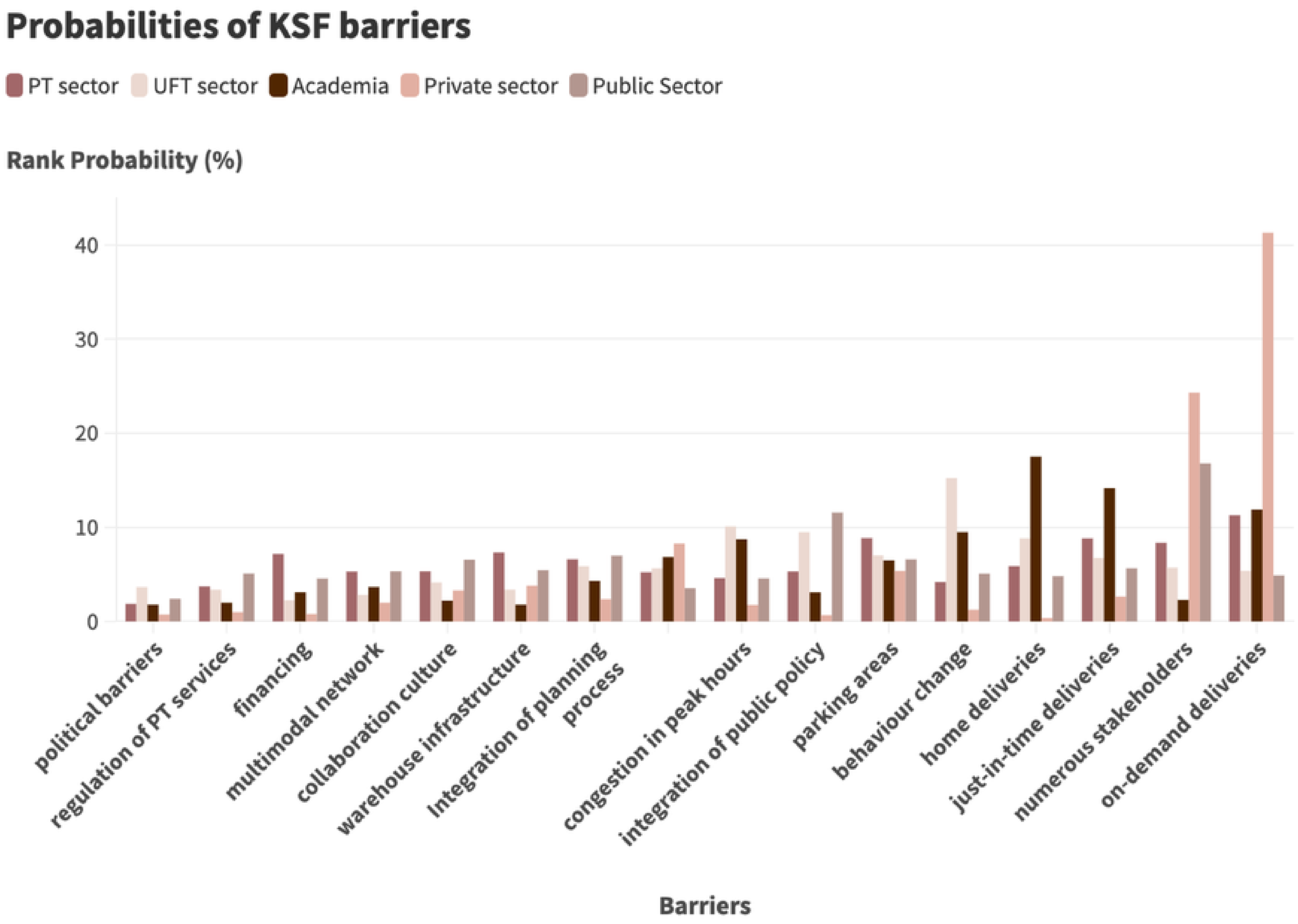


Table 6 – Estimated coefficient of key barriers.

KFs	Public Transport Sector	Urban Freight Transport Sector	Academia	Private Sector	Public Sector	All Respondents
home deliveries	3.598***	3.5113**	3.3033***	1.610	4.804**	3.777***
on-demand deliveries	4.250***	3.0113**	2.9154**	6.317*	4.819**	3.942***
just-in-time deliveries	4.005***	3.2426**	3.0908**	3.569	4.965**	3.909***
congestion in peak hours	3.357***	3.6441**	2.6059**	3.153	4.753**	3.677***
parking areas	4.009***	3.2798**	2.3076*	4.275*	5.120***	3.905***
multimodal network	3.492***	2.3668*	1.7405.	3.281	4.900**	3.242***
warehouse infrastructure	3.817***	2.554*	1.0174**	3.930	4.928**	3.421***
behaviour change	3.257**	4.055***	2.6885*	2.828	4.855**	3.686***
knowledge about PT and UFT	3.476***	3.065**	2.3657	4.707	4.928**	3.465***
regulation of PT services	3.143**	2.5512*	1.1231	2.566	4.856	3.112***
numerous stakeholders	3.948***	3.0768**	1.2722	5.786*	6.052***	3.776***
collaboration culture	3.495***	2.7503*	1.2269	3.791.	5.115***	3.402***
financing	3.796***	2.1403.	1.5674	2.348	4.751**	3.265***
political barriers	2.447*	2.6283*	1.0174	2.279	4.115**	2.701***
integrating of planning process	3.716***	3.1**	1.9014*	3.462.	5.175***	3.653***
integration of public policy	3.494***	3.5803**	1.5645	2.183	5.679***	3.663***
Significance codes: '***' 0.001; '**' 0.01; '*' 0.05; '.' 0.						

2.2.5.3 Implications to the Brazilian Context

This paper seeks to answer the question: *'What are the key factors in the development of freight and passenger integration projects in Brazil?'* The findings highlighted some differences between the Brazilian context and other environments where most of the integration experiences occur. Operational aspects and quality of service are main concerns in Brazil. Conversely, most of the literature focuses on the participation of stakeholders in implementing solutions, policies, and legal frameworks. Additionally, previous studies report cases in developed countries.

For the internal environment of transport providers, respondents were asked *"What could be improved/avoided in the PT or UFT operations to develop integrated freight and passenger transport systems?"*. Most of the respondents were concerned about the operational aspects, i.e., the quality of service of PT must be improved to transport cargo and people. The second aspect is the investment in shared infrastructure as current PT infrastructure is bad. To address these concerns around the UFT operation, solutions should address issues like cargo space and failed deliveries before implementation. Therefore, investing in embedded technologies and vehicle adaptations is essential to maintain service quality by matching scales and routes. These investments are needed to achieve the benefits identified by the respondents. Finally, creating a trustful corporative environment is vital for improved efficiency and cost reduction.

For the urban environment of Brazilian cities, respondents were asked *"What are the benefits/barriers of integrated freight and passenger systems to the urban environment?"*. The most concerning point was related to Brazilian consumer behaviour. This issue is not simple to address because it evolves deep changes in habits that could be overcome with effective marketing strategies. Another solution is investing in a Physical Internet network, which allows the regional distribution to be more efficient. This is important as Brazil has continental dimensions. Additionally, to achieve benefits such as reduced congestion, increased accessibility, and reduced use of urban spaces, this solution must be included in National Transport Plans, Master Plans, and Sustainable Urban Mobility Plans.

2.2.6 Conclusions

The urban environment is becoming more complex each day. Technological advances help UFT companies in their objectives to quickly meet the desire of the population. Transportation systems are reaching unsustainable levels due to the desire for fast deliveries and/or movements. On the other hand, awareness of climate change is rising worldwide, and initiatives to fight it are being encouraged. For example, the European Commission in 2007 proposed integrated freight and passenger transport systems to address people's and cargo needs.

Based on the literature, this paper identified the strengths, challenges, benefits, and barriers of freight and passenger transportation systems. The key strength is reducing the cost of the transportation system. The main challenge is maintaining the quality of service for cargo and passengers. In addition, considering most of the literature, the benefits are related to reducing emissions and pollution and contributing to the fight against climate change. Conversely, experts consider congestion reduction to be a primary benefit of the integrated freight and passenger system. Finally, the literature highlights the cooperation and acceptance of the various stakeholders as barriers in the planning process.

The integrated passenger and freight system has many obstacles to overcome in the urban environment, and it also has several operational challenges to reconcile freight and public transportation companies. Experts referred to operational freight barriers as the most challenging factor in integrated systems, ranking it first in the responses. Infrastructure investments were also considered relevant to the PT sector (1^{st} ranking with a 12.8% probability rank) and academia (1^{st} ranking with a 13.81% probability rank). Meanwhile, the main barriers were related to consumer behaviour. Behavioural change is crucial according to the UFT sector (1^{st} ranking with a 15.24% probability rank) and academics (5^{th} ranking with a 9.48% probability ranking). The benefits to the urban environment and the business opportunities for freight and public transport are considerable, especially in terms of fighting climate change. Brazilian experts considered this solution essential to reduce congestion, to promote better use of urban space, and to increase accessibility in peripheral areas. Only the members of the academia consider reducing emissions as the main benefit of urban space (1^{st} ranking with an 18.5% probability ranking). The primary strengths were related to cost-efficiency factors and sharing both costs and resources.

This survey focused on Brazil, where integrated transportation system solutions for freight and passengers are developing and literature is scarce. We could observe different perspectives among academia, the public transport sector, the freight transport sector, the private sector, and the public sector. Each of these sectors has a different view related to critical or challenging KFs that should be addressed first. Therefore, this demonstrates how this integrated solution, which deals with multiple stakeholders, needs to consider different needs and goals to develop more inclusive and acceptable transportation systems.

2.2.6.1 Study Limitations

This study was conducted during the COVID-19 pandemic and 39 experts answered the questionnaire. Although the Luce model had statistical significance for the sample, some fields had few respondents when divided into groups. However, despite the low number of respondents for some groups, this study can be considered valid for the Brazilian context as it reflects the dynamics of transport in Brazil.

2.2.7 Suggestions for further studies

The findings showed that the literature on integrated freight and passenger transportation systems is under development. Therefore, further studies are required, especially to design integrated passenger and freight transportation systems, which was explored by Kelly and Marinov (2017). Furthermore, an advanced and collaborative logistic distribution system is important for developing integrated freight and passenger transportation environments, which could also benefit from the Physical Internet network (OUADI *et al.*, 2021).

The findings inspired a new research agenda. The context in developing countries differs from other countries that have already been studied (e.g., developed countries); it is suggested to extend the research worldwide to support the integrated solution in developing countries. We also observed a lack of studies related to selecting the location of shared facilities, as proposed by (OLIVEIRA *et al.*, 2022b), the design of shared vehicles, as analysed by Kelly and Marinov (2017), and how to develop an urban Physical Internet network, as proposed by (OUADI *et al.*, 2021). We suggest exploring the challenges of FPT systems in different localities, especially in developing countries, showing their differences for further work. Even though most studies mention the acceptance and participation of stakeholders as a critical aspect of the success of integrated mobility, only (CLEOPHAS *et al.*, 2019) explored this topic. Therefore, exploring stakeholder engagement and the acceptability of the proposed mobility solution is another research opportunity. Most of the literature focused on developing quantitative algorithms to solve routing problems of integrated passenger and freight transportation systems. This can be achieved by analysing pilot projects or operating systems. However, since most integrated freight and passenger transportation systems are small-scale prototypes, most quantitative routines use artificial data, making it difficult to evaluate the real benefits of the system. Thus, analysing real-scale projects that integrate freight and passenger transport projects is another research opportunity for future work.

3 CARGO PEOPLE MOBILITY INITIATIVES APPLIED TO MID-SIZED BRAZILIAN MUNICIPALITIES

After the theoretical construction of CPM in section XXX, this section illustrates how it can be applied in Brazil. This section focus on two different geographies: Jaraguá do Sul conurbated area and Joinville. The choice of mid-sized urban areas to develop the case studies differs from the traditional researches being made in Brazil. Traditionally, small and mid-sized municipalities are frequently ignored by the academia because they lack quality data information and have less impact as metropolitan studies. However, the CPM initiatives have high complexity, making smaller urban areas less complex and more suitable to implement such initiatives.

Both regions, at the moment this research was being developed, were introducing a CPM service using electric micromobility, operated by GoMoov. At the stage of the operation, the company had a MaaS4PaF platform that integrated their vehicle renting app with occasional couriers and marketplace company. Their operation was not optimized and it was small.

The solution proposed by GoMoov were a shared vehicle solution-type. The micromobility vehicles were used occasional couriers to deliver e-commerce small-sized cargo at off-peak hours. This research then, proposed an optimization of this service by including a shared terminal solution, combining public transport stops with lockers creating minihubs.

The minihubs location solved a p-median problem using 15-Minute City buffers as threshold. It is important to highlight that the usage of such thresholds could only be applied at such geographies because the topography is flat, and both municipalities already have a robust cycleable network.

3.1 INTEGRATING FREIGHT AND PUBLIC TRANSPORT TERMINALS INFRASTRUCTURE BY LOCATING LOCKERS: ANALYSING A FEASIBLE SOLUTION FOR A MEDIUM-SIZED BRAZILIAN CITIES

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 minimized 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

3.1.1 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 (EBIT|NIELSEN, 2021). The number of deliveries is directly influenced by e-commerce growth (BORSENBERGER *et al.*, 2014; GHAJARGAR; ZENEZINI; MONTANARO, 2016). Furthermore, in Brazil, home delivery represents the greatest share of e-commerce delivery services (OLIVEIRA *et al.*, 2019), 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 (REGUÉ; BRISTOW, 2013; MASSON *et al.*, 2017; KELLY; MARINOV, 2017; CLEOPHAS *et al.*, 2019).

E-commerce has greatly increased home deliveries since customers prefer this type of delivery service (RAI; VERLINDE; MACHARIS, 2019). Moreover, one key aspect of e-commerce deliveries is the high number of failed deliveries (SONG *et al.*, 2009; DUIN *et al.*, 2016; KEDIA; KUSUMASTUTI; NICHOLSON, 2017). Failures in the delivery process represent a problem for both consumers and carriers (OLIVEIRA *et al.*, 2019; RAI; VERLINDE; MACHARIS, 2021a).

Thus, lockers are an alternative to the last-mile problem (DELL'AMICO; HADJIDIMITRIOU, 2012; MORGANTI; DABLANC; FORTIN, 2014; SCHNIEDER; WEST, 2020) and a solution to the problem of failed deliveries. Lockers could be used in transport policies to make freight transport more efficient (SCHRÖDER; LIEDTKE, 2017). 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 (IWAN; KIJEWSKA; LEMKE, 2016; KEDIA; KUSUMASTUTI; NICHOLSON, 2017; OLIVEIRA *et al.*, 2017; SCHWERDFEGER; BOYSEN, 2020; CHE; CHIANG; LUO, 2022), 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 (KEELING; SCHAEFER; FIGLIOZZI, 2021).

In addition, transport policies could integrate the transport of people and cargo to achieve a sustainable transportation system (COMMISSION OF THE EUROPEAN COMMUNITIES, 2007; ELBERT; RENTSCHLER, 2021). Integrating people and freight transport addresses the first-mile/last-mile problems and helps to reduce both operational and external costs (BRUZZONE; CAVALLARO; NOCERA, 2021). This process of integrating UFT and Public Transportation (PT) to achieve sustainable goals consists of (COMMISSION OF THE EUROPEAN COMMUNITIES, 2007): (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 (TRENTINI; MALHENE, 2012).

The existing literature has demonstrated the success of integrating freight into public transportation for long-haul routes (MARINOV *et al.*, 2013; KELLY; MARINOV, 2017), light rail systems (DUIN *et al.*, 2019), underground systems (KIKUTA *et al.*, 2012; DAMPIER; MARINOV, 2015), and taxi systems (LI *et al.*, 2014). 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 (BAINDUR; MACÁRIO, 2013; DUIN *et al.*, 2019). 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 (LACHAPELLE *et al.*, 2018). Additionally, this measure can provide liveable and equitable cities (LACHAPELLE *et al.*, 2018). However, the population acceptability of lockers to replace home deliveries depends on the location and the market concentration (LAGORIO; PINTO, 2020). 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) (HOFER *et al.*, 2020).

Many studies have explored the population acceptability of lockers as an alternative to home deliveries (MORGANTI *et al.*, 2014; IWAN; KIJEWSKA; LEMKE, 2016; OLIVEIRA *et al.*, 2017). However, studies relating accessibility and lockers' locations are still limited and focus only on identifying locker networks using (1) multi-objective optimization mathematical problems (CHE; CHIANG; LUO, 2022) or (2) accessibility and equity analysis (KEELING; SCHAEFER; FIGLIOZZI, 2021; SCHAEFER; FIGLIOZZI, 2021). 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 (CARLOS MORENO *et al.*, 2021). 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.* (2018).

This paper is structured as follows: Section 3.1.2 reports the background of lockers as a solution for last-mile deliveries and their potential for an integrated system. Section 3.1.3 describes the study area, Section **??** explains the research approach, and Section 3.1.5 reports the results for Jaraguá do Sul. Finally, Section 3.1.6 concludes the study and proposes future research areas.

3.1.2 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.* (2018) 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 (OLIVEIRA *et al.*, 2019). Locker networks reduce the number of deliveries, the number of failed home deliveries and, consequently, congestion and emission pollutants by reducing the distance travelled (MCLEOD; CHERRETT; SONG, 2006; ALLEN *et al.*, 2018). Additionally, locker networks increase the efficiency of supply chains (BROWNE; ANDERSON; ALLEN, 2001) and of the delivery process, which promotes sustainable UFT (DUIN *et al.*, 2016; KEDIA; KUSUMASTUTI; NICHOLSON, 2017; WANG *et al.*, 2018; YUEN *et al.*, 2018). Moreover, lockers are convenient and flexible delivery options for customers and companies (BROWNE; ANDERSON; ALLEN, 2001; DING, 2014; MORGANTI *et al.*, 2014; IWAN; KIJEWSKA; LEMKE, 2016; OLIVEIRA *et al.*, 2017; YUEN *et al.*, 2018).

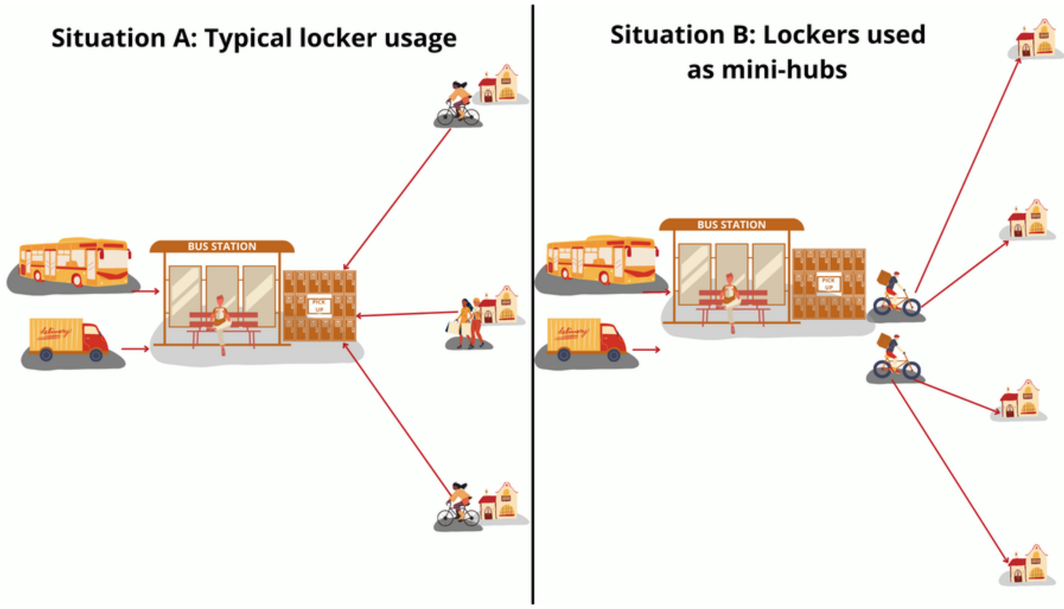
Several factors impact the location of lockers, such as availability, accessibility, security, environmental impacts, costs and regulation (LAGORIO; PINTO, 2020). Accessibility depends on the market concentration and the area served (LAGORIO; PINTO, 2020). Thus, increasing accessibility increases the proximity to the end-consumer (LAGORIO; PINTO, 2020). Locker networks have competitive advantages in environments with high-order density and different delivery windows (DING, 2014). Time, price, tracking, availability and location are essential elements for increasing the use of lockers (IWAN; KIJEWSKA; LEMKE, 2016). In Los Angeles, the spatial distribution of Amazon lockers is influenced by population density, internet use, income, education, walkability, transit and parking (FANG; GIULIANO; WU, 2019).

PT stations are options for locating lockers, which encourages PT usage or makes them hubs for delivery services (OLIVEIRA *et al.*, 2017; LACHAPELLE *et al.*, 2018). 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 (IWAN; KIJEWSKA; LEMKE, 2016) and Belo Horizonte, Brazil (OLIVEIRA *et al.*, 2017). Nonetheless, lockers are usually located in PT stations in Europe (MORGANTI *et al.*, 2014; KEDIA; KUSUMASTUTI; NICHOLSON, 2017) due to their potential to increase PT efficiency and maintain a high occupancy rate (LAGORIO; PINTO, 2020).

Usually, lockers are used, as described in situation A (Figure 14), 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 (IWAN; KIJEWSKA; LEMKE, 2016; KEDIA; KUSUMASTUTI; NICHOLSON, 2017; OLIVEIRA *et al.*, 2017; IANNACCONE; MARCUCCI; GATTA, 2021). 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 (MORGANTI *et al.*, 2014). Kiousis, Nathanail and Karakikes (2019) 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.* (2019b), who reinforced the integration of passenger and freight mobility. Additionally, most potential crowdshipping users are unwilling to modify their paths to deliver goods (GATTA *et al.*, 2019b). 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 (GATTA *et al.*, 2019b). The environmental benefits of this delivery service have also been investigated (GATTA *et al.*, 2019a).

Figure 14 – Scenarios for a locker network.



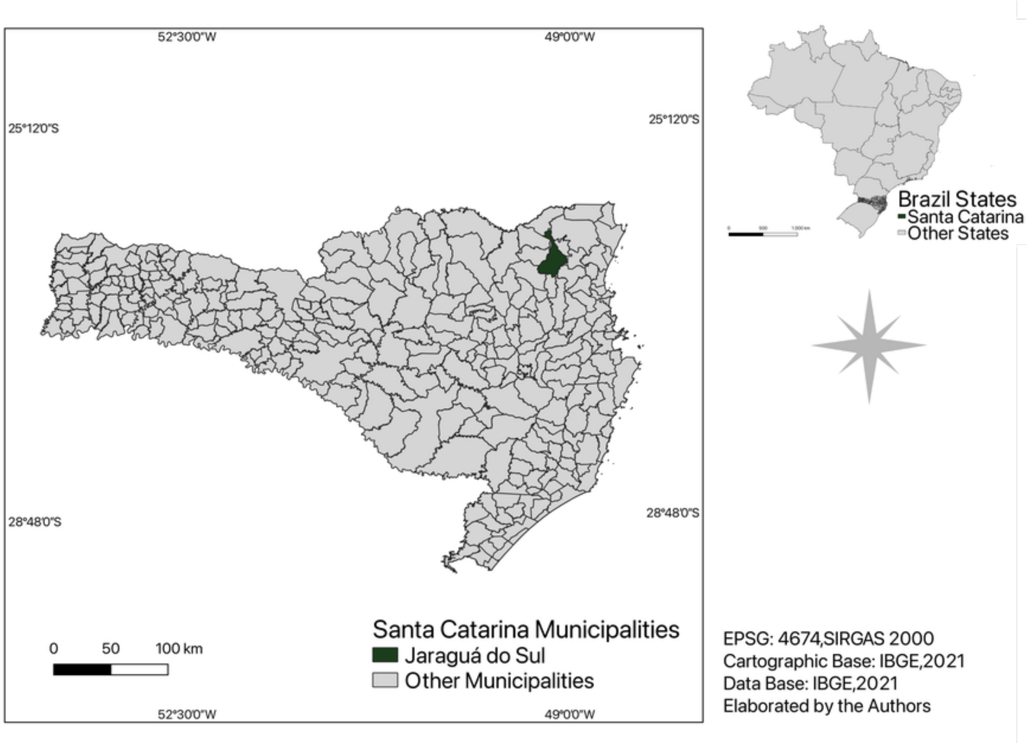
Despite the importance of the location of lockers (CHE; CHIANG; LUO, 2022), few studies have addressed the evaluation of their location and associated accessibility. (CHE; CHIANG; LUO, 2022) proposed a multi-objective model solved using a combination of the Taguchi method (TA) and the non-dominant sorting 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 (2021) 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 (KEELING; SCHAEFER; FIGLIOZZI, 2021). Keeling, Schaefer and Figliozzi (2021) 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 (MORGANTI *et al.*, 2014; IWAN; KIJEWSKA; LEMKE, 2016; OLIVEIRA *et al.*, 2017), the factors that influence the location of the lockers [45], and the accessibility of the lockers (HOFER *et al.*, 2020; SCHAEFER; FIGLIOZZI, 2021). However, the existing literature exploring the usage of PT stations for locker locations is limited to Keeling, Schaefer and Figliozzi (2021). 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.

3.1.3 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 15. 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 15 – Location of Jaraguá do Sul.



The conurbated area has 1820 km2, and most of the territory is rural, which characterises the region with large farms (Figure 16). Jaraguá do Sul is a medium-sized city with 201,445 residents, of which 93% live in urban areas (Figure 17) 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 18). 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 19). 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 20, and the public transportation system comprises 70 routes (Figure 21) and 2485 bus stations (Figure 22), 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 23). 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.

Table 7 summarizes the data from Jaraguá do Sul conurbated area. Grid square (200 x 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, 2022a). 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 organized using GIS tools.

Table 7 – Data description.

Variable	Description
Population	201,445 inhabitants
Mean Income	BRL3157.40
Number of public transport routes	70 routes
Number of bus stations	2485 stations
Number of micromobility stations	83 stations

Figure 16 – Study area: urban area.

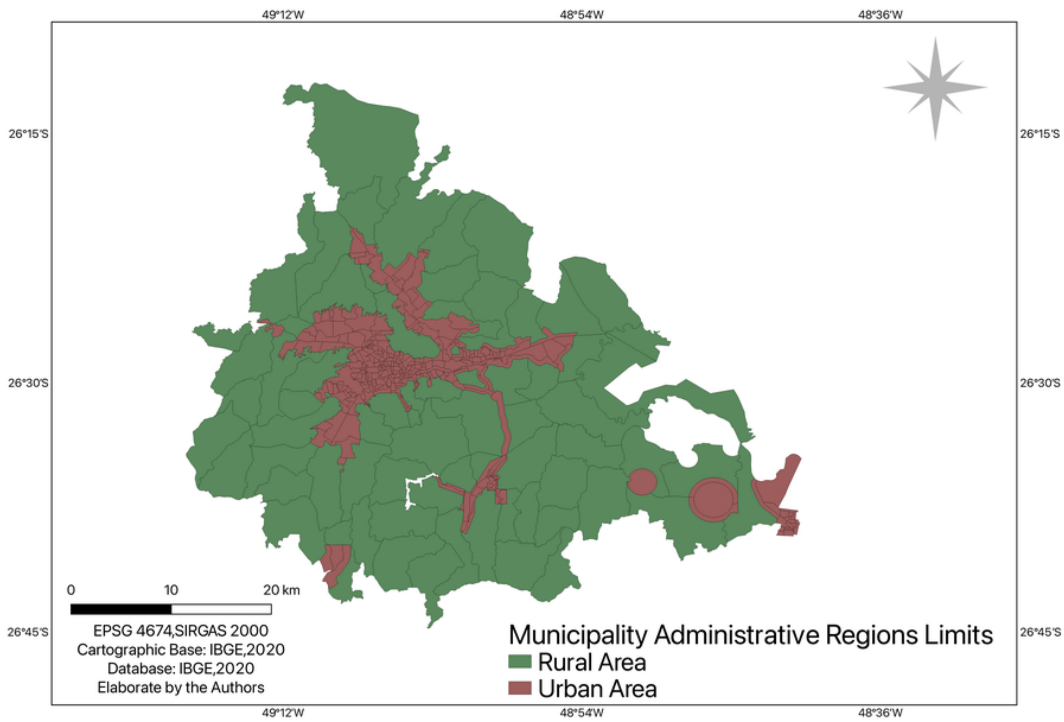


Figure 17 – Study area population.

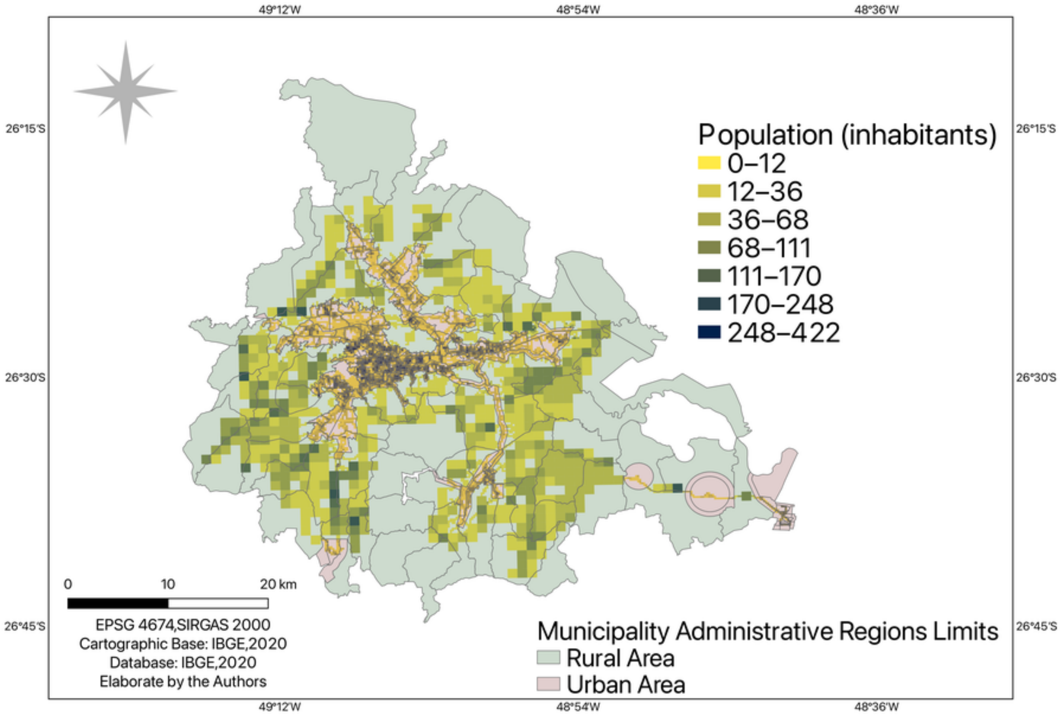


Figure 18 – Study area income per capita.

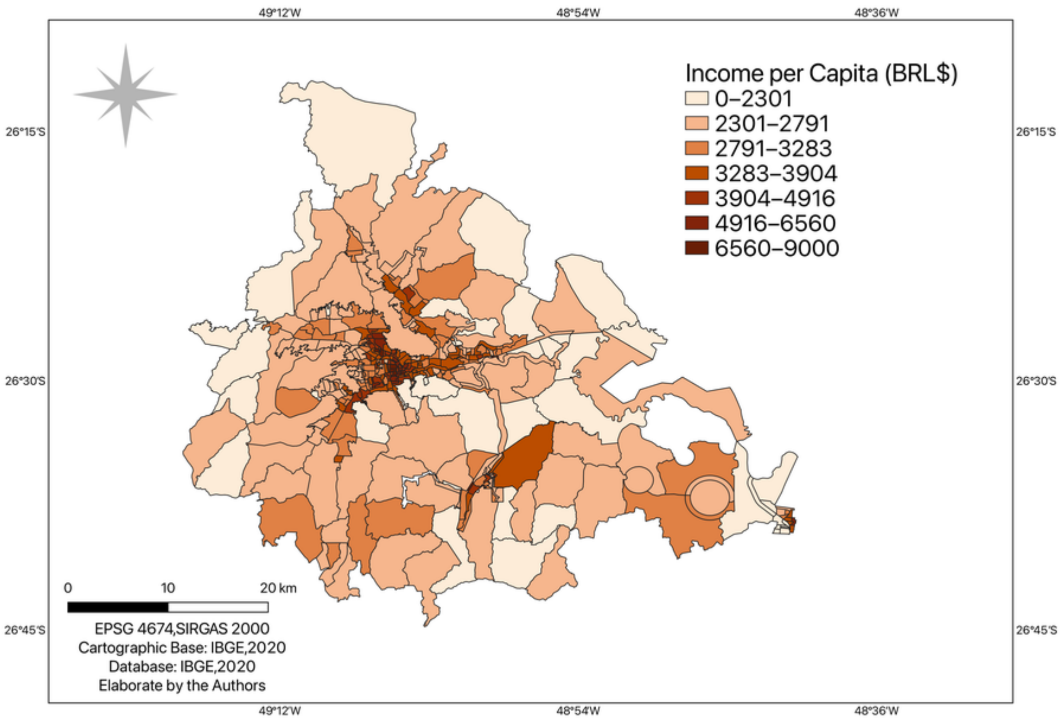


Figure 19 – Study area trip generation hubs

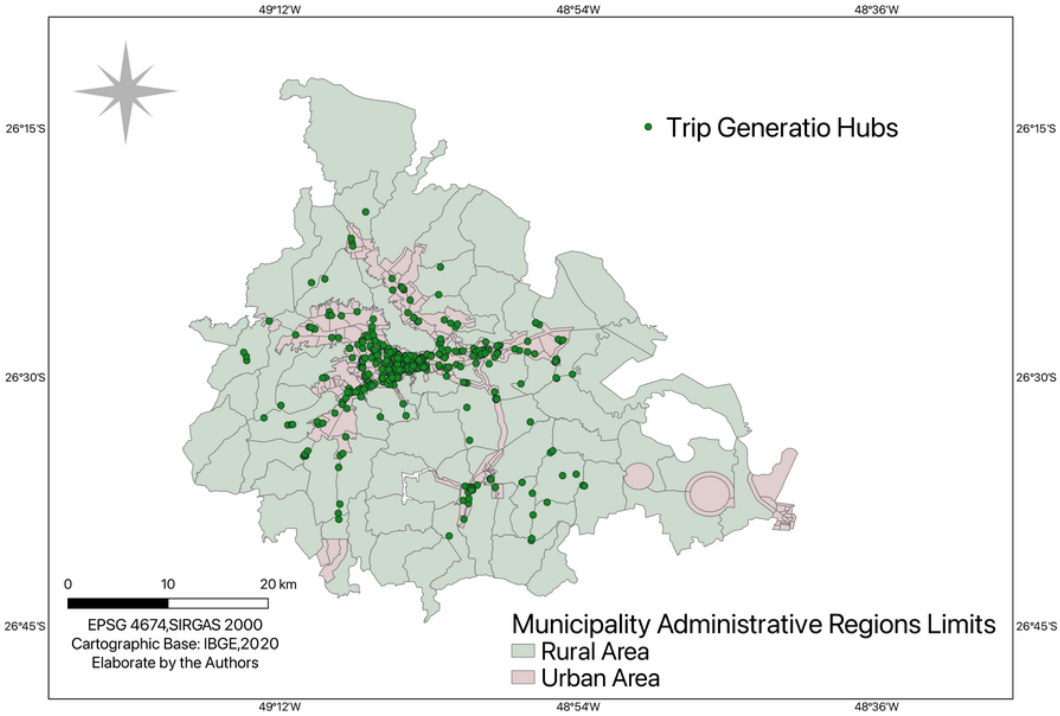


Figure 20 – Study area streets infrastructure.

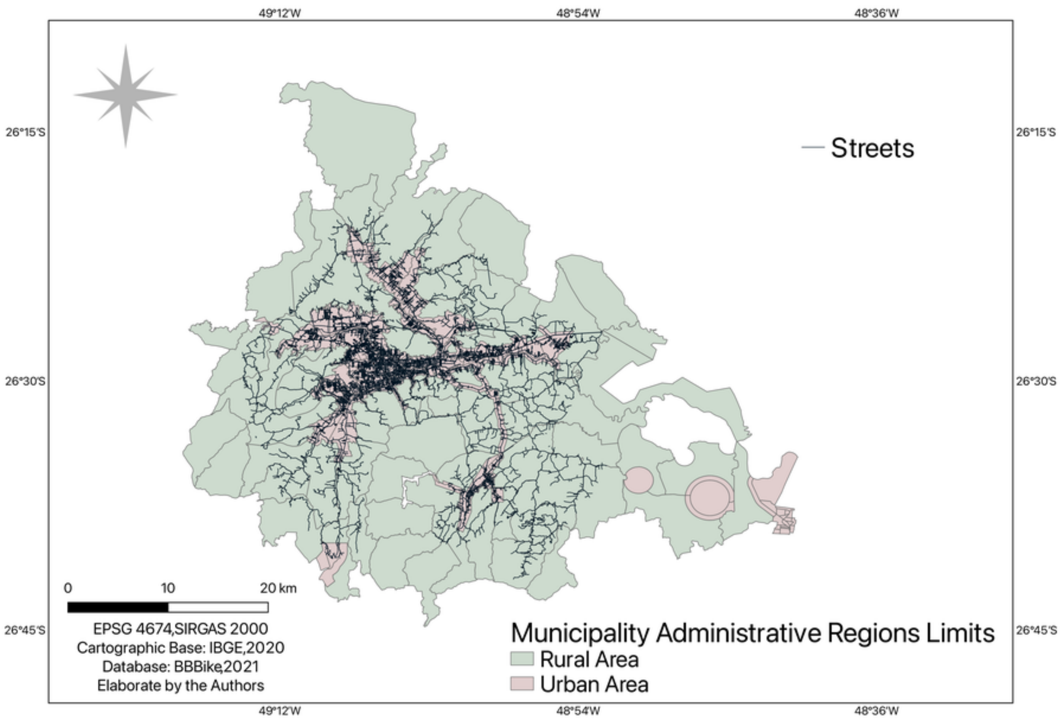


Figure 21 – Study area bus routes.

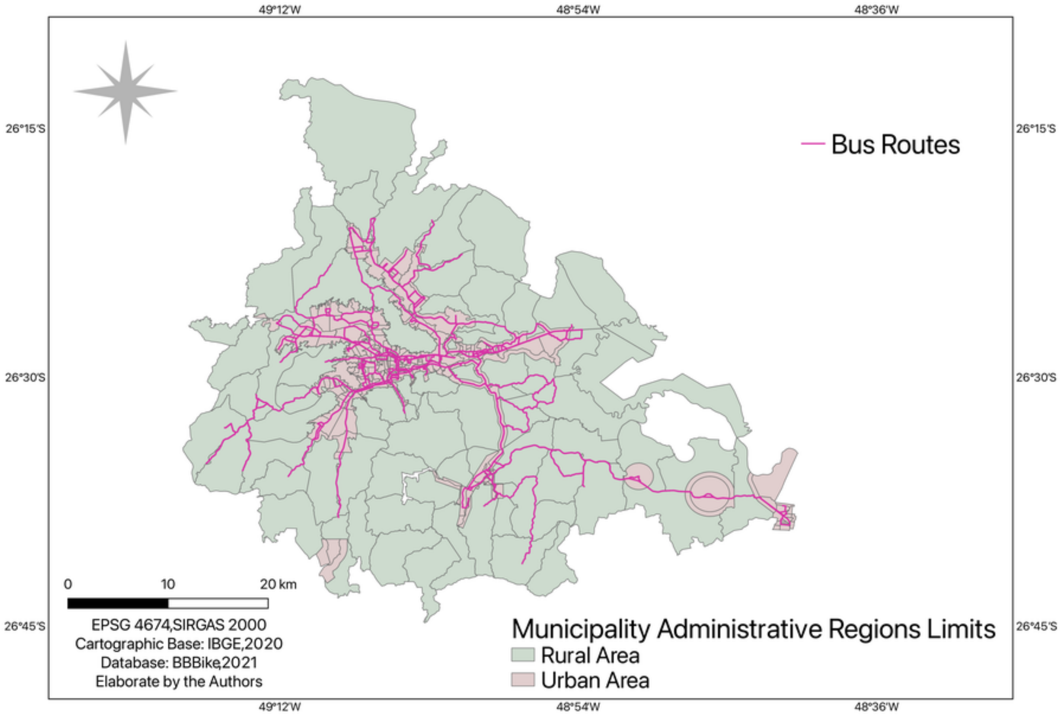


Figure 22 – Study area bus stations.

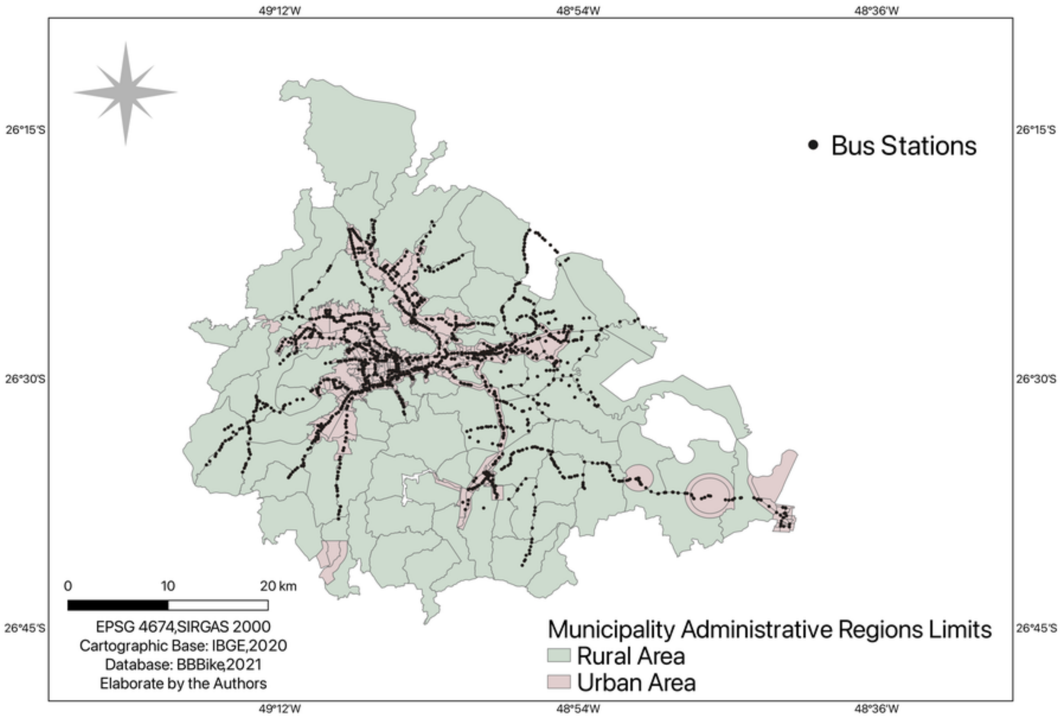
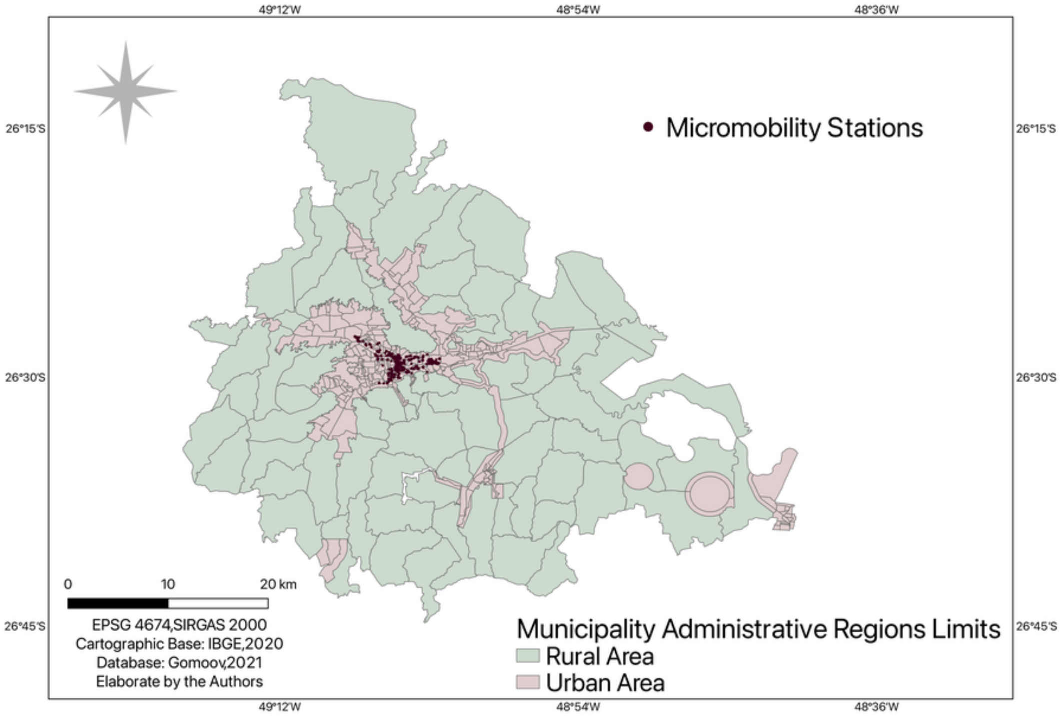


Figure 23 – Study area micromobility stations.



3.1.4 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 (gij) of transportation distance between the demands of the customers from the facilities (COOPER, 1963). 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 11. 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 III, IV and V 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.

A Geographic Information Systems for Transportation (GIS-T) software

(TransCAD®, (CALIPER, 2021)) was used to solve the p-median problem. For more information about the location problem, interested readers are referred to (COOPER, 1963; CHURCH; ROBERTS, 1983; DREZNER; MEHREZ; WESOLOWSKY, 1991; MAPA; LIMA, 2014); .

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 normalized to evaluate the efficiency of the scenarios. This process considered the population served, transportation users, micromobility users and purchase costs.

3.1.5 Results And Discussions

Figure 24 illustrates the location of the lockers by solving the p-median problem, and the results are summarized in Table 8. Scenario I require 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 25 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 12 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).

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 provide more equitable access to all residents, whereas Scenario V provide 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 8 – 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%

Figure 24 – Location of the lockers.

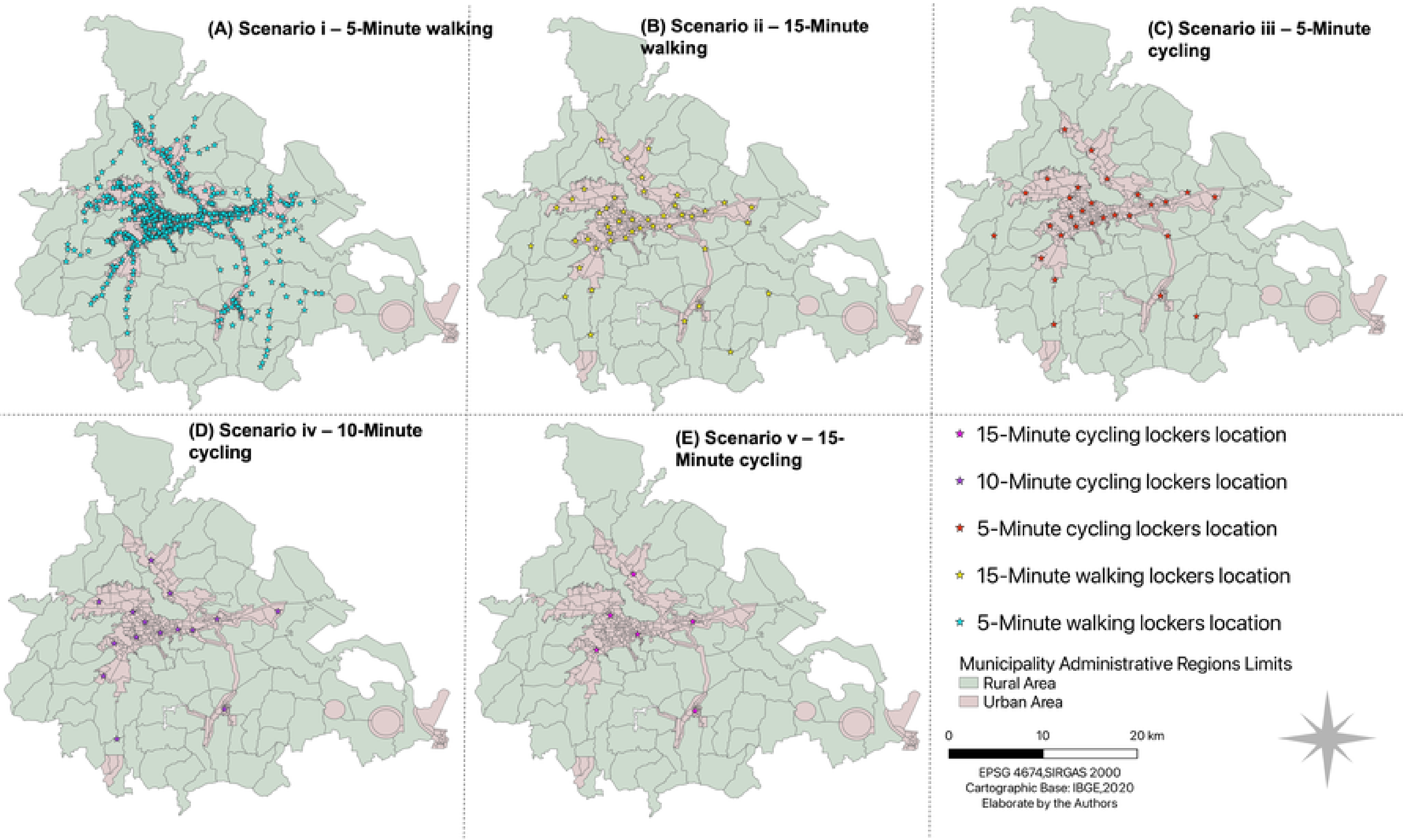


Figure 25 – Influence area for the location of the lockers.

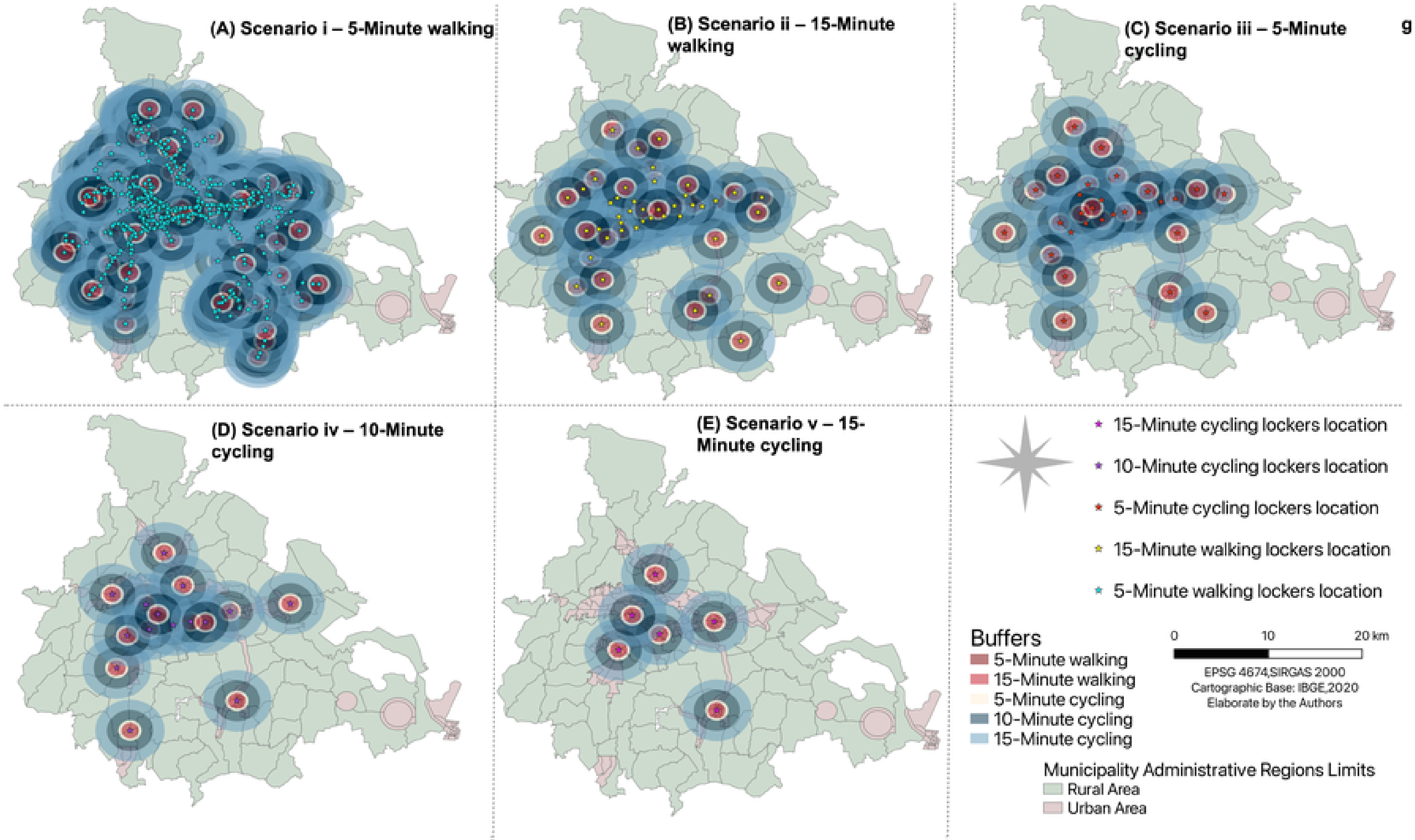


Table 9 shows a comparison of the results, including the unity purchase cost. Scenario IV with buffer IV (3200-m maximum distance and 10-min cycling trip) provides the best efficiency among the evaluated scenarios, since all standardized parameters have positive values. Micromobility users have more advantages with implementing a locker network, except in Scenario I, which has a negative standardized 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 standardized purchase unit cost value is positive. The influence of each parameter can be evaluated by summing all the standardized 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.

Table 9 – 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

3.1.5.1 Discussions

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 (MORGANTI *et al.*, 2014) to 2.4 km in Portland (KEELING; SCHAEFER; FIGLIOZZI, 2021). In Paris, half of the total number of pick-up points is located within 300 m of a railway station (MORGANTI; DABLANC; FORTIN, 2014). The travel time varies from

5 min in Graz (HOFER *et al.*, 2020) to 10 min in Paris (MORGANTI *et al.*, 2014). In addition, considering the distance travelled, the tolerable distances to walk and cycle are 1.7 km and 2.33 km, respectively (KEDIA; KUSUMASTUTI; NICHOLSON, 2017). 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.*, 2019b; GATTA *et al.*, 2019a).

Locker networks integrated into the PT network contribute to developing sustainable cities (RAI; VERLINDE; MACHARIS, 2021a). 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.

3.1.6 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 popularizing e-commerce when lockdowns forced the closure of traditional commercial services (OLIVEIRA *et al.*, 2022a).

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 Magalhães (2021), Leyerer *et al.* (2020), Gatta *et al.* (2020)). 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 Pira *et al.* (2017) 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 transport, 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.

3.2 MOBILITY AS A SERVICE FOR FREIGHT AND PASSENGER TRANSPORT IDENTIFYING A MICROHUBS NETWORK TO PROMOTE CROWDSHIPPING SERVICES

ABSTRACT

Mobility as a service platform for freight and passenger transport has the potential to promote sustainable cities. However, most of the contributions in the literature on mobility as a service platform explicitly focus on passenger mobility only. This paper describes the operational characteristics of mobility as a service platform for freight and passenger transport operated by GoMoov in Joinville, Brazil. Moreover, we also describe a microhub network for e-commerce deliveries using the e-shared vehicle and a crowdshipping workforce. Besides describing the platform, the findings indicate that ten microhubs are sufficient to cover the urban area of Joinville (98.96% of residents and 98.99% of dwellings). The solution investigated shows both economic and environmental benefits. However, marketing strategies and active engagement of involved companies are crucial for the scheme's success.

Keywords: Urban freight transport; Freight and passenger transport; Mobility as a Service; Crowdshipping services; Microhubs

3.2.1 Introduction

Passenger and goods movements share the same infrastructure in cities however they are typically conceived, considered, and treated as separate issues notwithstanding their evident and substantial interactions and, sometimes, conflicting interests (TRENTINI *et al.*, 2011; TRENTINI; MALHENE, 2012; BRUZZONE; CAVALLARO; NOCERA, 2021; OUADI *et al.*, 2021). Passengers and goods integration are built upon a widely accepted vision, aligned with the European Union's (EU) aim of developing a sustainable urban mobility policy. This vision foresees and incorporates the development of efficient public transport systems with good connectivity, improving the quality of life in cities.

Connected mobility solutions play a vital role in reducing transport-related negative externalities (MARCUCCI *et al.*, 2017). Many digital platforms providing door-to-door services and connecting users to transport service providers are progressively emerging and taking a central place in the urban mobility panorama (PANGBOURNE *et al.*, 2020; PIRA *et al.*, 2021). In the case of passengers, these platforms go under the name of Mobility as a Service (MaaS) (PANGBOURNE *et al.*, 2020; SANTOS; NIKOLAEV, 2021; VIJ; DÜHR, 2022). MaaS has become a reality due to the ubiquitous development of digital technology and the subsequent societal changes it induces (HASSELWANDER *et al.*, 2022). MaaS platforms can potentially alter urban mobility patterns (PANGBOURNE *et al.*, 2020) and help cities achieving sustainable development goals.

Despite the positive perception, the scientific literature has an emphasis concern with the capability that MaaS might have in tackling transportation problems (HASSELWANDER *et al.*, 2022), since most of the contributions explicitly focus on passenger mobility. This implies limited exploitation of the potential benefits that might materialize whenever integrating passenger and freight movements is technically possible and financially convenient. Pira *et al.* (2021, p. 5) define MaaS for passenger and freight (Maas4PaF) as "*a user-oriented integrator of passenger and freight transport services enabling searching, booking and payment through a single digital platform for customized door- to-door trips. The users are both passengers and shippers, and those who perform the delivery (i.e., MaaS carriers) could be passengers, passenger transport operators, and freight transport operators*".

A MaaS platform for freight and passenger transport allows promoting sustainable cities, creating environmental awareness could increase the sharing schemes (STORME *et al.*, 2021), as crowdshipping services. Moreover, improved use of urban infrastructure (BRUZZONE; CAVALLARO; NOCERA, 2021) might promote economic growth and social equity by creating new business opportunities for companies (VIJ; DÜHR, 2022), and new consumer e- markets for transport service operators (VIJ; DÜHR, 2022). As a new consumer market, MaaS4FaP stimulates consumer demand. Finally, MaaS4FaT contributes to creating trip awareness (BUTLER; YIGITCANLAR; PAZ, 2021), increases users' travel responsibility (ALYAVINA; NIKITAS; NJOYA, 2020), changes in travel behaviour (ALYAVINA; NIKITAS; NJOYA, 2020; BUTLER; YIGITCANLAR; PAZ, 2021), and reductions of urban space use by diminishing parking areas (BUTLER; YIGITCANLAR; PAZ, 2021).

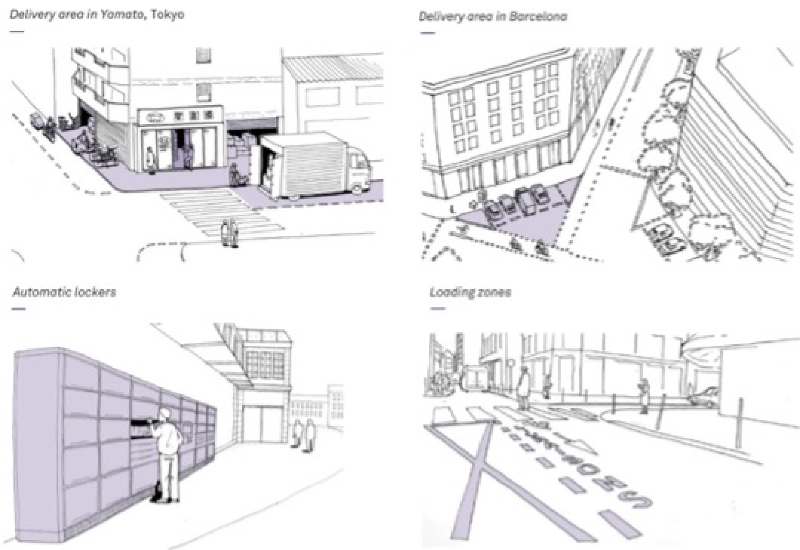
Recently, some scholars have been investigating how to introduce UFT in MaaS. For example, Casady (2020) illustrates the integration of freight and people in a MaaS framework; Pira *et al.* (2021) identify opportunities and schemes for Maas4PaF and conceptualize its framework; Brach (2019) discusses the benefits and costs associated with MaaS for freight transport; and Monios and Bergqvist (2020) propose a business model for using autonomous electric vehicles in a sharing system for freight transport. Jittrapirom *et al.* (2017) cite the Tuup app as a MaaS platform including both passengers (public transportation, bike sharing, car sharing, car rental, taxi and shared taxi, parking rent) and freight services (crowdshipping). The authors cite this case, developed in Helsinki, as an example of MaaS for other transport-related services.

Concerning freight services in MaaS, crowdshipping represents an emerging trend accelerated by app-based platforms connecting supply with demand (LE *et al.*, 2019). The crowd offers the free capacity concerning time and/or space to perform deliveries voluntarily and is compensated (RAI *et al.*, 2017). The selection of couriers to the delivery route is based on the closest voluntary courier, who asks for the lowest delivery fee, or the best reputation on the platform (LE *et al.*, 2019). The crowd could use the transport modes available on the MaaS platform to perform deliveries.

Much has been published on crowdshipping business in the literature. Most of the articles look into supply side, i.e., commuters that can act as a crowdshippers and look into on the willingness of a commuter to act as a crowdshipper (NEUDOERFER; MLADENOW; STRAUSS, 2021). From the operations and management side of the service (i.e., crowdshipping companies) including the sustainable aspects of the service (DAI; JIA; LIU, 2020) optimizations of the services and facilities used (PUNEL; ERMAGUN; STATHOPOULOS, 2019), supply and demand matching derived problems (ERMAGUN; SHAMSHIRIPOUR; STATHOPOULOS, 2020; MARCUCCI *et al.*, 2017). The demand side investigates consumers' preferences for crowdshipping use (PUNEL; ERMAGUN; STATHOPOULOS, 2019) and their willingness to accept a parcel via a crowdshipping delivery service (RAI; VERLINDE; MACHARIS, 2021b). The acceptance and the positive behaviour of the consumers toward the crowdshipping service are crucial to maintaining the profit of this business model. Thus, despite an increase in the literature regarding crowdshipping (POURRAHMANI; JALLER, 2021), no paper reports the benefits one can obtain using a MaaS platform for freight service integrated with passenger transport

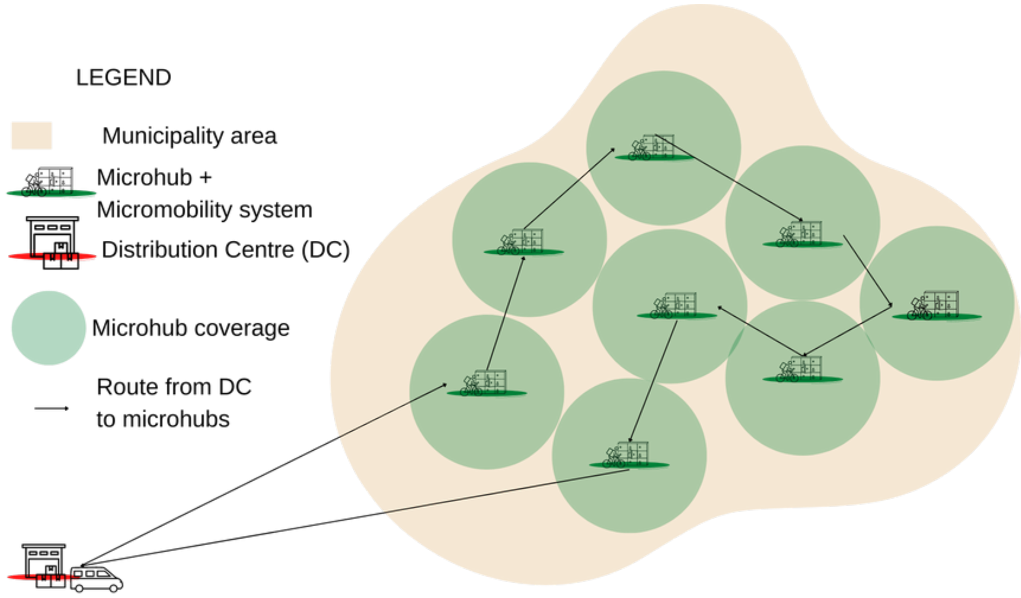
Based on this gap, this paper describes the operation of a MaaS4PaF platform operated by GoMoov in Joinville, Brazil. The platform offers shared micromobility and delivery services by crowdshipping. The company started its operation in December 2020 as an e- shared micromobility company and in October 2021 started to expand its activities by offering e-commerce deliveries using its e-shared vehicle and a crowdshipping workforce. In this paper, we also identified a microhubs network to serve this purpose to increase delivery efficiency and increase crowdshipping options. Microhubs, micro-fulfilment centres, delivery microhubs or micro-distribution hubs that are logistics facilities typically located nearby the final delivery destination. They are urban logistics spaces that link distribution centres to the final delivery destinations. Microhubs can contribute to the use of eco-friendly vehicles for last-mile distribution. Moreover, microhubs have also the potential to reduce motorized trips in dense areas, improve customer experience by reducing delivery time and has the potential to reduce delivery costs. This solution is being implemented by the City of Hamburg to provide a flexible solution for the last mile (HAMBURG INVEST, 2022). Figure 26 illustrates the main types of urban logistics spaces.

Figure 26 – Types of urban logistics spaces (Source: AFLOG (2023))



Considering these concept, the company could use the microhubs network to deliver goods using crowdshipping. Since the system is integrated, the crowd use the micromobility vehicles to perform the last mile deliveries, as illustrated in Figure 27. These facilities can play an important role in system functioning since it can offer a better level of service to the crowdshipper, increasing its accessibility to the parcels and, consequently, boosting their probability (willingness to) to perform the delivery. This also can diminish their total detour to pick up the parcel, making the delivery more sustainable. This is even more important when the location of these facilities is closer to the main public transport terminals.

Figure 27 – Crowdshipping service using microhubs and micromobility vehicles.



In this paper we present the case of (GOMOOV, 2022), the company that offers e-shared mobility system integrated with Maas4PaF platform that operates the delivery module based on the crowdshipping principles. Based on the actual operation, we propose an improvement on the delivery network by creating microhubs strategically located within the public transport network. Based on the results, we discuss the importance of crowdshipping services for MaaS4PaF.

3.2.2 Study Area and Data Description

GoMoov is operating the e-mobility sharing system in the Brazilian cities of Barra Velha, Penha, Balneário Piçarras, Jaraguá do Sul and Joinville, all of them located in the province of Santa Catarina. This study focused on the operation in Joinville (Figure 28), the municipality where the company started the integration of freight and passengers. In 2021, Joinville had 604,708 inhabitants (Figure 29), being the most populous city in Santa Catarina State. The density population is 536,1 hab/km2. The municipality has a high Human Development Index (0.809) among Brazilian municipalities, occupying the 21st national position, and has one of the highest incomes per capita in the country. Industrial and commercial activity is the basis of the city's economy, which has a per capita GDP of BRL 58,476.90 in 2019 (about 11,457.30 euros).

Figure 28 – Location of Joinville in Brazil.

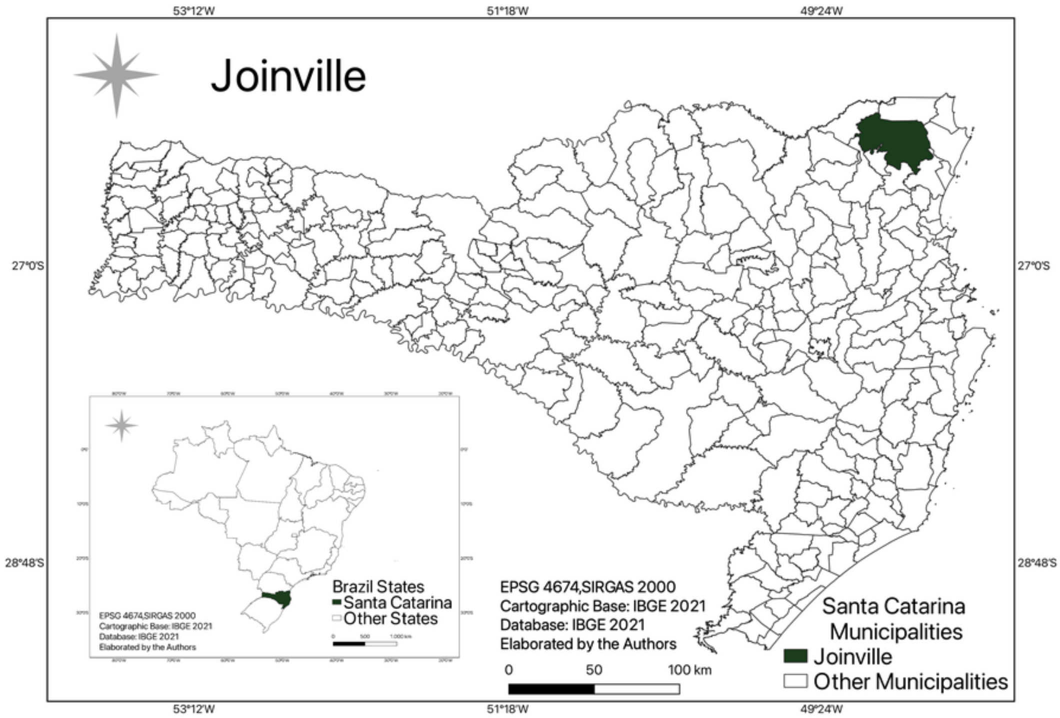
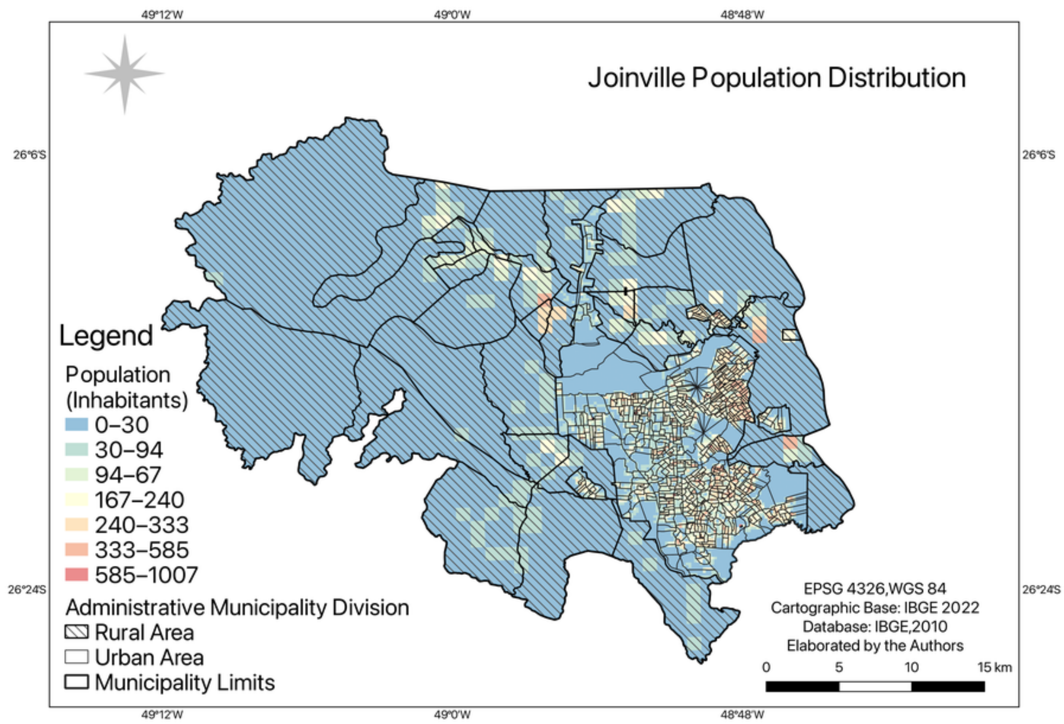


Figure 29 – Spatial distribution of population.

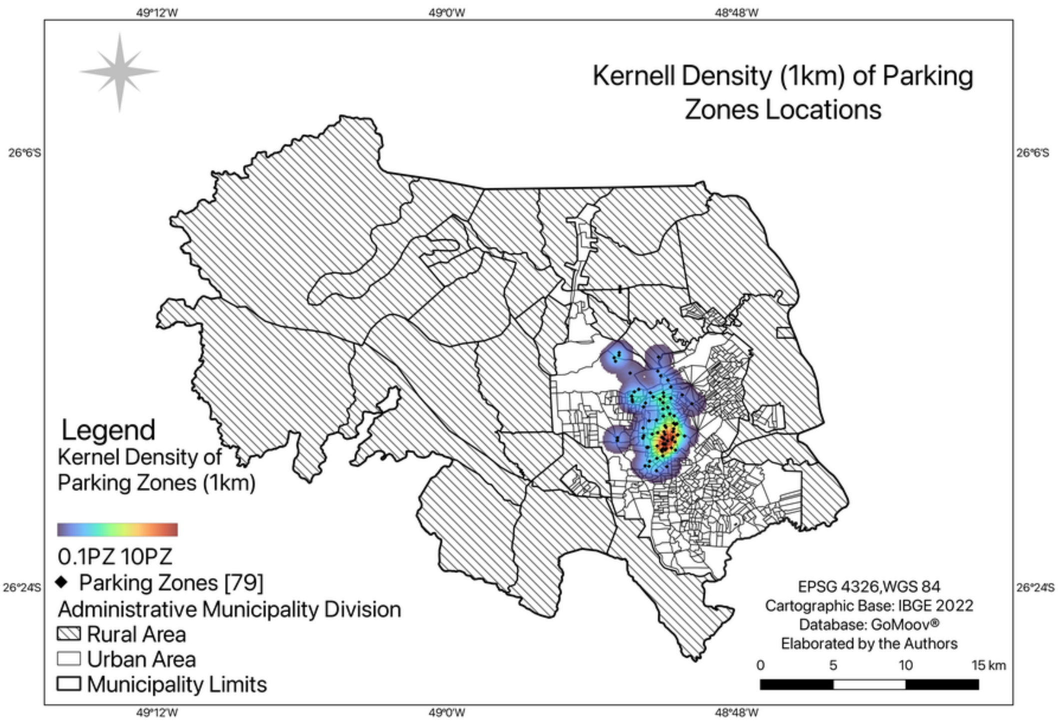


Beyond being Brazil's third-largest industrial area, Joinville also promotes many international cultural events every year, has an intense industrial activity and is an important tourist and commercial activity's location. The city has a very smooth topography, and it is well-endowed with good cycling routes and infrastructure. On the other hand, the public transportation system and the micromobility infrastructure do not cover all the city territory and, consequently, all population. Joinville has a high motorization rate compared to Brazil average, while Brazil has a 25% proportion car per inhabitants, Joinville's is 50% (IBGE, 2022).

The technology park in Joinville hosts several startup companies. One of them being GoMoov, which launched the shared micromobility service in 2020 by mobile application. The GoMoov is a subsidiary startup of ALLmobility, a Brazilian startup that is responsible for developing: 1) MaaS app of GooMoov, 2) e-micromobility vehicles with Brazilian technology and 3) tracking system installed on these vehicles. GoMoov offers e-scoters and e-bike services as options for micromobility displacements. Initially, the service was charged per minute (BRL 1.00 + BRL 0.50 per minute, 0.20€ + 0.10€/minute, on September 13, 2022). From August 2022, customers can buy service packages: 60 minutes per day cost BRL 8.90 (1.74€) and 800 minutes per month cost BRL 29.90 (5.86€). The total fleet is 300 e-bikes and 30 e-scoters.

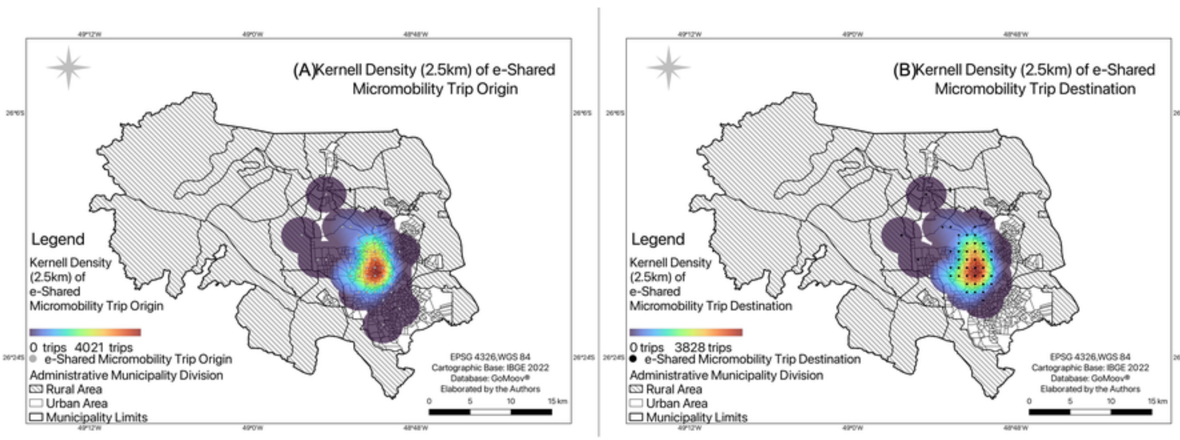
The system adopts a free flow strategy. However, for improving public space management, vehicles can be parked only in designated parking zones that are signalled with a small totem or a banner. They partnered with local businesses, located close to public transport stops, to use the space in front of the property to accommodate parking zones. The number of vehicles that can be parked in each parking zone depends on the negotiated space availability. The company allows in-app advertising in exchange for space. Figure 30 illustrates the location of 79 parking zones (PZ) in Joinville. The most concentrated region has a density of 10 PZ/km. Parking the vehicle outside the application's coverage area or parking zone results in a fine for the user. Most parking zones are located close to public transport stations or bus stops, to allow integration with this mode, although the system is not integrated because there is no partnership either with the municipality or the public transport operator company. Among the travel options suggested to users, there are options that integrate the use of the system e- micromobility system offered by GoMoov using public transport.

Figure 30 – Location of parking zones in Joinville and coverage area.



The operational data from December/2020 to February/2022 showed that 10,180 trips were performed using the system. Most trips occur in the main core of Joinville (Figure 60). Using a Kernel distribution function to obtain the density of the distribution of the origin and destination of the trips, we observed a similar pattern of distribution. A piece of evidence that the main offer of e-vehicles needs to be located in the red area of Figure 31. We can also notice that there is still a part of the municipality that has no coverage of the e-micromobility system, which needs to be addressed when promoting the creation of an equitable micromobility system and efficient distribution system.

Figure 31 – Concentration of origin and destination of trips.



The number of users is similar during the weekdays and increase at the weekends (Figure 32). Most trips are performed by e-bike (67%) during the weekdays. The use of e-scooters is more frequently at the weekends (Figure 33).

Figure 32 – Number of users per weekday.

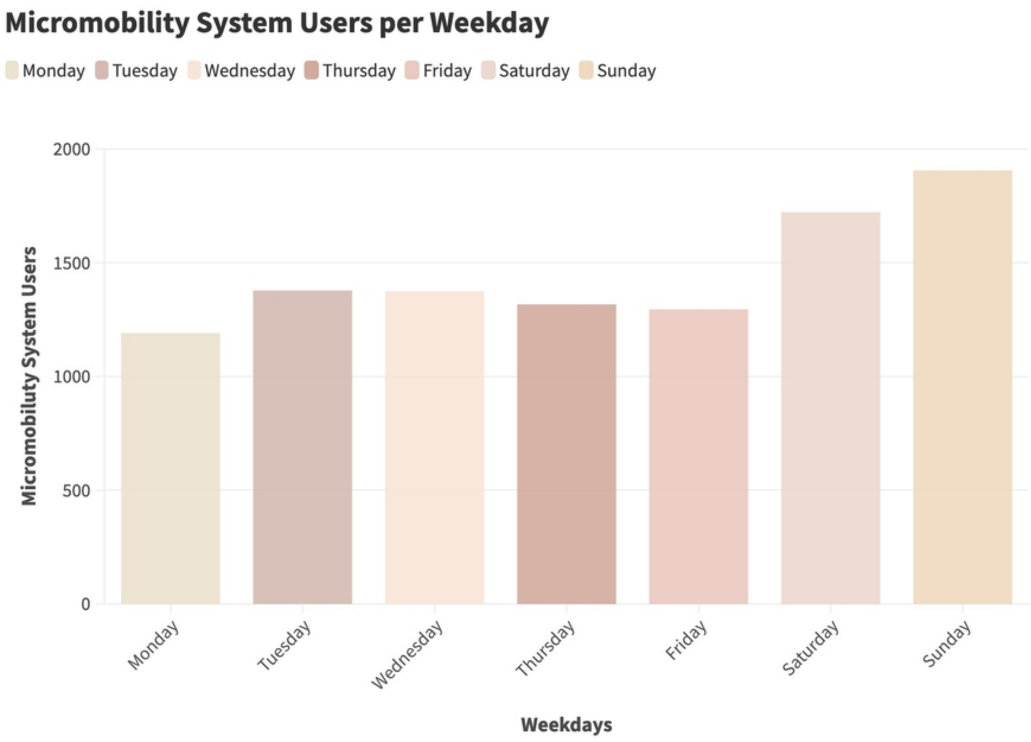
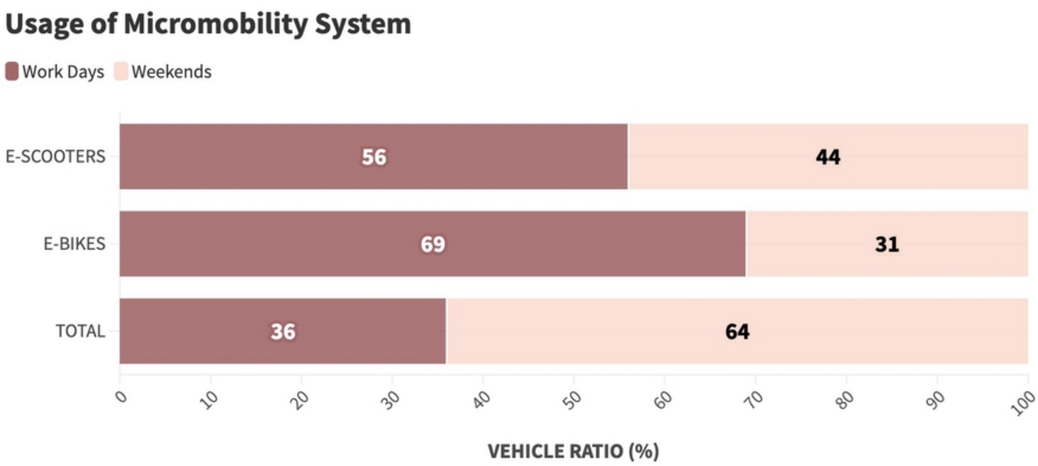


Figure 33 – Percentage usage of micromobility system.



To increase visibility and rentability, the business model included the delivery module in the application. Among the motivations for incorporating deliveries using e-bikes one can include: a) increase in agility in deliveries, b) reduction of the impact of fuel value in the product delivery, c) reduction of gas emissions pollutants and other environmental impacts, d) provision and improvement of customer experience, e) reduction of traffic accidents, f) overall traffic reduction in the city, g) strengthen company's brand. Currently, the micromobility users can be associated as crowdshippers in the delivery. When a delivery needs to be performed in the coverage area, the system offers the delivery to those making journeys with the app and available for the delivery. The nearest available person accepts delivery, picks up the order at the establishment and delivers it using the system. The delivery operation is tracked by the app.

The integrated experience analysed in this section, is a pilot GoMoov made in partnership with a big marketplace in the municipality, which has been up-and-running since October 2021. They developed a zero-emission last-mile delivery inside Joinville, where the goods are picked up in the local distribution centre using an electric vehicle and are delivered in a GoMoov microhub, located in a central are inside Joinville. From there, the crowdshippers can collect their assigned packages and perform the deliveries, being paid for each delivery. Meanwhile, the marketplace pays for the e-vehicle used for the deliveries. As reported by the company, the deliveries that previously used to take more than 8 hours, now, using the proposed system, are made in less than 4 hours. The fulfilment of logistics microhub is made by a courier company, partner of GoMoov.

The improvement in the operations could also be seen from the perspective of the micromobility company. In an analysis of the operational activity of the micromobility system before the implementation of the delivery module, we have observed two different patterns (Figure 35). On weekdays the lower e-vehicles demand suggests their high predominant use for leisure purposes. The peak demand for its services did not correspond to the traditional commuting travel hours, instead, the peak demand corresponds to the period when people used to make small displacements to go shopping or express any other demand during the day. The company started its operation during COVID-19, which may have affected some of the commuting travels in this period due to smart working, which may have induced them to start the integration quickly, so to maintain their vehicles operating all day. The drastic change in the demand curve due to the start of the operations can be observed in Figure 64. On weekdays, the demand is similar to that of weekends, suggesting that a change in user behaviour when compared to Figure 63. Moreover, we notice an improved distribution of trips throughout the day.

In addition, during five months of the company's operation (Figure 34) and before the implementation of the delivery module 6,571 trips were performed. The five months after the implementation of the delivery module, only 3,610 trips were made mainly due to the December to February holiday period in Brazil. This drastically reduced the trips travels performed during weekends for leisure purposes. The next module to be implemented by the application is the integration with public transport. When this module is complete, the GoMoov application can be considered a full MaaS4PaF according to Pira *et al.* (2021).

Figure 34 – GoMoov activity before the integration with freight activity.

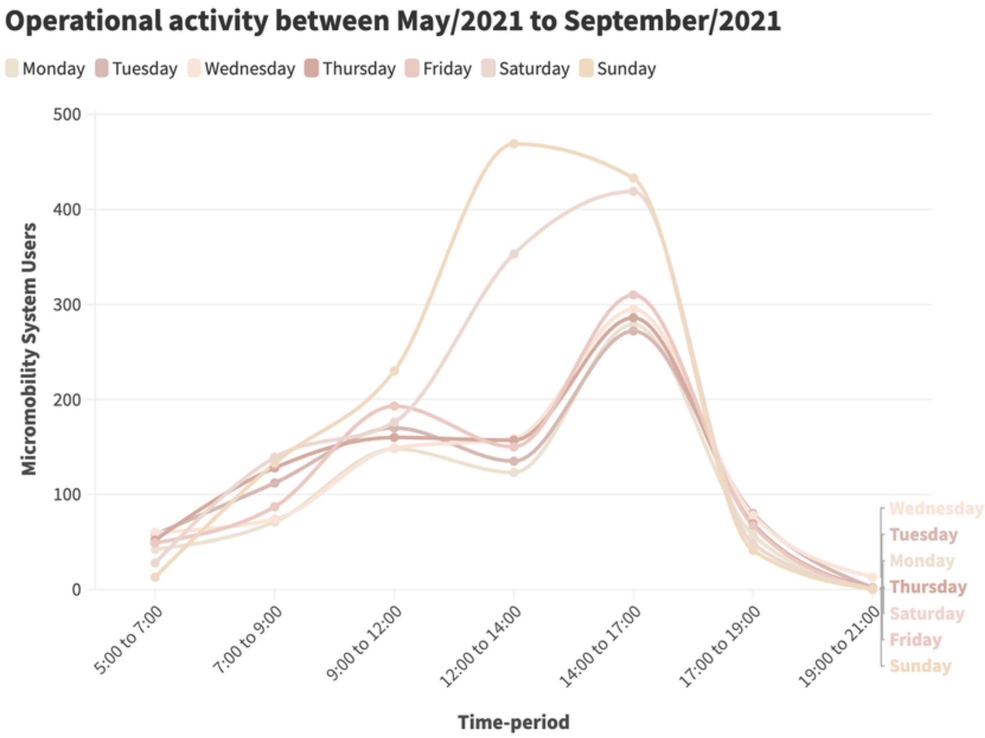
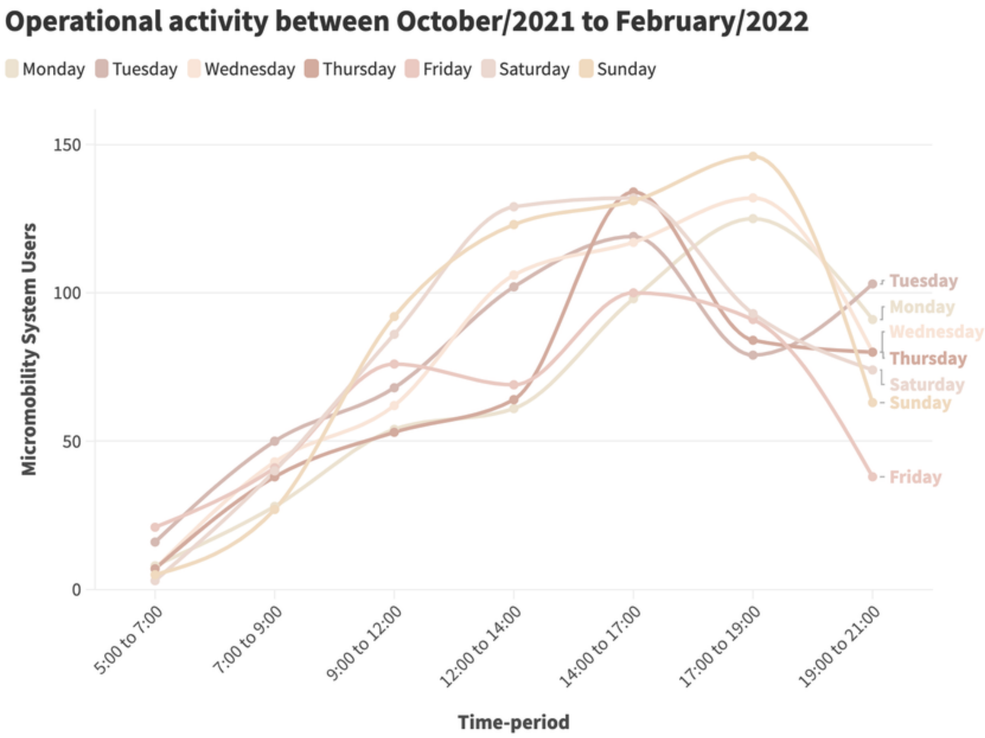


Figure 35 – GoMoov activity after the integration with freight activity.



3.2.3 Research Steps

Based on the description, this paper identifies a last-mile hub network for e-commerce last-mile deliveries. The fundamental assumption is that microhubs are located at parking zones close to public transport stations or bus stops. Thus, we set parking zones and bus stops as candidates. The population was set as the demand point since the population is the final customer of e-commerce. Still, any resident is equally likely to perform an online purchase.

To identify the location of microhubs, we solve a p-median problem. Set I = {1, 2, . . . , i] of the potential location of microhubs, i.e., the parking zones and bus stations; J = {1, 2, . . . , j} of the location of e-commerce customers, i.e., the residents; d_{ij} distance matrix between the potential location of microhubs and e-commerce customers. The p-median problem identifies p facilities, where p , minimizing the distance for satisfying the demand of the customers (BEASLEY, 1985). In this paper, the distance matrix is given by real distance. Based on the results, we discuss the operational, economic, and environmental implications of the MaaS4PaF platform.

3.2.4 Results and Discussions

Figure 36 shows the location of microhubs for the case under study and Figure 37 shows the influence area of each microhub. The network is composed of 10 microhubs and covers almost the whole urban area of Joinville. This network covers 98.96% of residents and 98.99% of dwellings. However, the company must include 4 additional parking zones, since 4 facilities are located at bus stops. The other 6 microhubs are located in pre-existing parking zones.

Pre-existing parking zones that been turned into microhubs must allow a few meters for storage and the building must preserve delivery bays (AFLOG, 2023). For HAMBURG INVEST (2022), an area of 15–20 m^2 serves a delivery area for approximately 120–150 items per day. Engaging partners has strong practical implications determining either success or failure of the initiative. Business relationships need to be fair and account for everyone's preferences of the various partners involved. In addition, considering the economic and environmental benefits of the solution for the city, as in Hamburg, the municipality could provide and/or facilitate the installation of microhubs in urban areas.

The economic benefits might derive from the improvements impacting on the main stakeholders involved: GoMoov company (the MaaS4PaF provider), e-micromobility users, crowdshippers and courier marketplace company. First, for GoMoov, the introduction of the delivery module provoked an increase in the revenue due to the growth of trip demand. Moreover, it increased the usage of the vehicles contributing to improved distribution of its e-vehicles in the city, reducing the necessity of their forced distribution to match supply-demand. Second, e-micromobility users benefit from the innovation since delivery demand can allow for a fare reduction, making the e-shared micromobility more accessible. Third, the installation of the new parking zones equipped with lockers also expands the e-shared micromobility network, increasing the accessibility and intermobility with the public transport potential.

For the crowdshippers, the implementation of the lockers and the microhubs has the potential to reduce the detour travel distance, making the system more attractive and accessible. For the marketplaces, even with the increase in the number of stops inside Joinville (from 1 to 10), the last mile tends to be faster and cheaper as the crowdshippers are closer to their destination.

Figure 36 – Location of microhubs for last mile e-commerce delivery.

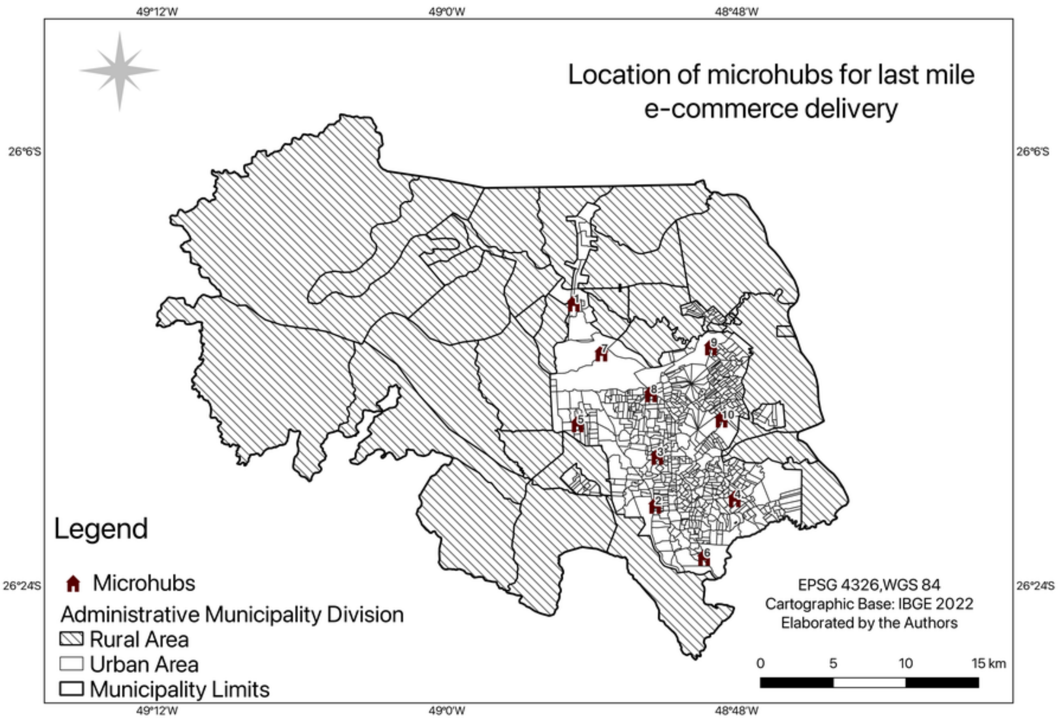
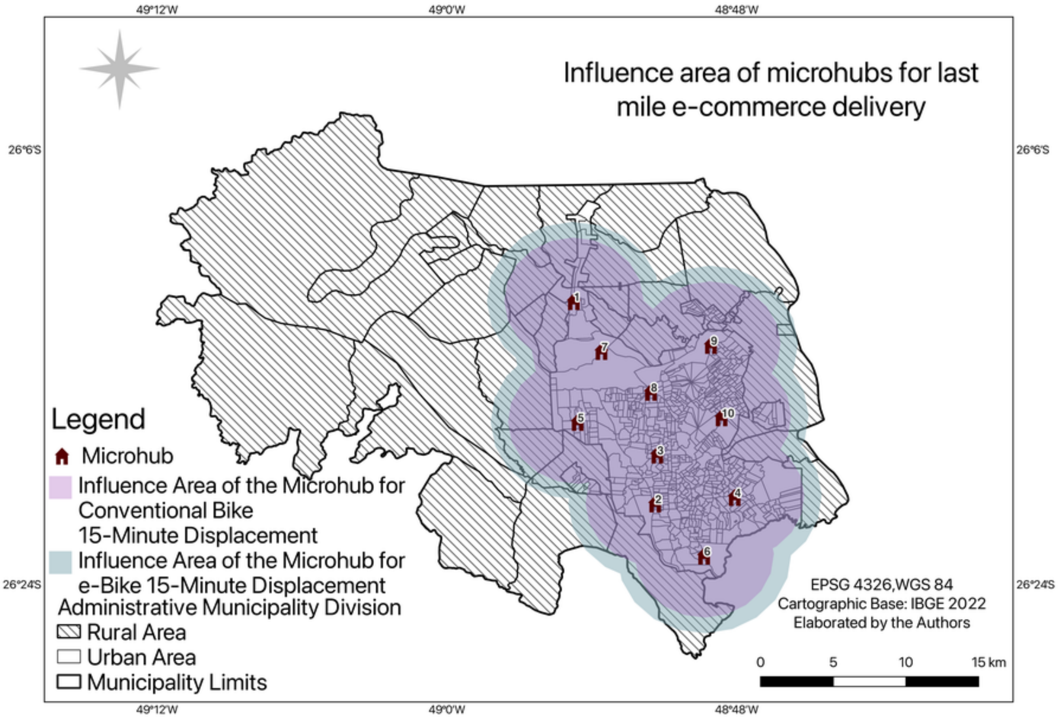


Figure 37 – Influence area of microhubs for last mile e-commerce delivery.



Taking an environmental perspective, crowdshipping can promote the sustainability of deliveries when the trip is performed using cleaner vehicles and by a non-dedicated nature of the trip. This solution canters on e-mobility and non-dedicated trips thus making the last-mile chain much more sustainable compared to the one characterising traditional deliveries. In addition, most of Brazil's electric energy comes from renewable hydroelectrical sources making all this even greener. Additionally, using the e- micromobility system for e-commerce deliveries contribute to a reduction in the number of vehicles circulating in the municipality, thus also reducing the congestion due to e- commerce-related activities.

A marketing strategy could be crucial to attracting crowdshippers and establishments to use the e-shared micromobility to deliver the goods and allow the company to use their space as parking zones. From an economic perspective, a MaaS4PaF stimulates the use of micromobility and public transportation system thus guaranteeing its overall financial viability. However, some business challenges must be addressed and overcome as well as technological ones. The binomial discussion of data-sharing versus data-confidentiality makes the vertical and horizontal integration between the stakeholders a hard-to-fulfil task, even considering a financially viable business model. This solution contributes to improving urban mobility and economic development. Since the parking zones are in commercial establishments, using these spaces for microhubs allows for an increase in the profitability of the partner establishment. These issues have not been addressed in the current paper and represent stimulating research topics for future research endeavours.

3.2.5 Conclusions

One can interpret cargo and passenger integration as a promising solution for the last-mile distribution and asset sharing (vehicles, network, and facilities). This is even more true for the last-mile distribution of parcels combined with a crowdshipping service. Despite a growing attention paid, in the literature, to crowdshipping (POURRAHMANI; JALLER, 2021), no research, to the best of our knowledge, discusses the potential benefits of using a MaaS platform for freight service integrated with passenger transport. This paper has tried to address this research gap, first, by describing the operation of a MaaS4PaF platform operated by GoMoov in Joinville, Brazil, and subsequently by analysing the pilot implementation test performed thanks to a delivery module development implemented in partnership with a local marketplace. Then, using the demand from the pilot, the paper identifies the best microhubs network location to increase the delivery efficiency and crowdshipping options by solving a p-median problem.

In total, 10 microhubs are needed in the network to cover the urban area of Joinville (98.96% of residents and 98.99% of dwellings). However, the company must include more 4 parking zones, since 4 facilities are located at bus stops, the other 6 microhubs are in already parking zones.

In addition, for a good success of this type of platform, the engagement of the stakeholders is crucial, especially considering the partnership between involved. In order to have a good functioning system, the information sharing needs to follow a good path to ensure productivity of the system. For it, we suggest for further works develop a business model considering all stakeholders involved in the scheme, the flow of information, money, and value. Also, it is necessary to identify the key performance indicators to measure and monitor the MaaS4FaP.

4 FINAL REMARKS

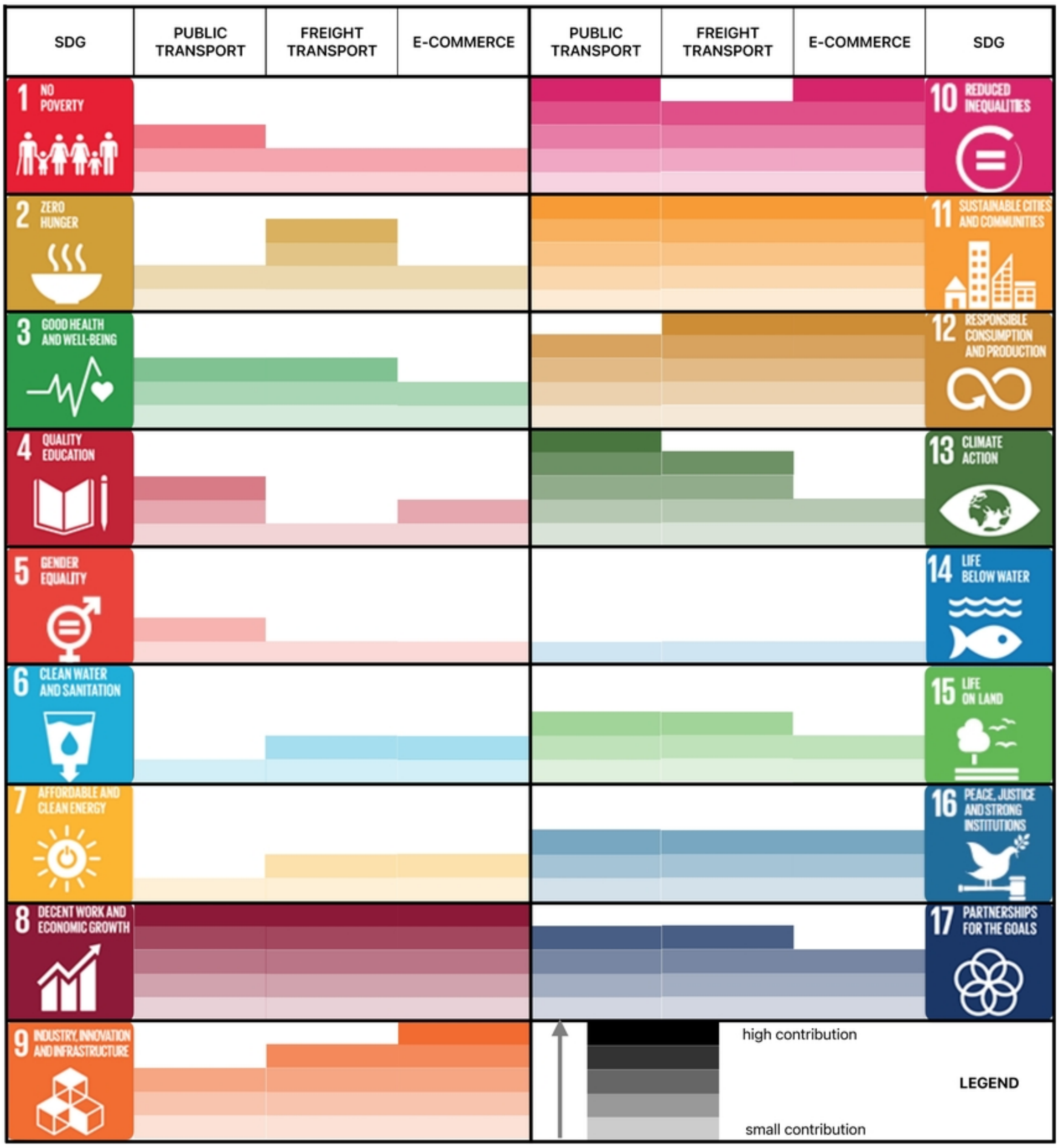
Some considerations around the potential contributions of CPM initiatives need to be pointed out. Each day, evidence of the role of the transport activity in the Fight Against the Climate Change and achieving the Sustainable Development Goals (SDG) and the 2030 Agenda become clearer. The role of the Sustainable Urban Mobility Plans to guide the transport as an inductor for the SDGs (MAGALHÃES; SANTOS, 2022) shows the importance to consider the transport solution potential to reach these goals when prioritizing actions and policies.

Transport systems play a vital role in facing recent changes and enabling sustainable development of the cities. After the COVID-19 pandemic, people's travel behaviour changed, and public transport saw decreased investments and demand. The pandemic also changed people's working habits, education, teaching tools and methods and directly impacted the energy sector as the world faced an increase in automotive (NUNDY *et al.*, 2021). The 2030 Agenda even recognised that the goals once established for the World temperature should be redefined, as it would be impossible to achieve (UNITED NATIONS, 2015). Pieces of evidence of the benefits of transportation systems on achieving the Sustainable Development Goals (SDG), especially SDG 11, SDG 9 and SDG 3, can be observed in studies for Mexico (OCHOA-COVARRUBIAS; GRINDLAY; LIZARRAGA, 2021), Nairobi (FRIED *et al.*, 2020), India (TIWARI; PHILLIP, 2021), and Brazil (MOREIRA *et al.*, 2018; NOBREGA *et al.*, 2021). Fried *et al.* (2020) identified that the inequalities need to be surpassed for a sustainable city, as sustainability has as pillars of the economy, environment, and society. In Brazil, the main concerns are related to the safety and security (MOREIRA *et al.*, 2018).

However, it is needed a shift in traditional planning that sees people and cargo flows as separate institutions. This conventional vision reinforces transport-related negative externalities and intensifies network inefficiencies. Using freight and passenger integration seems a suitable solution to reduce urban space competition and increase transport efficiency. By sharing resources, this solution can reduce vehicle fleets, especially freight-related ones, thus lowering congestion, emissions, and pollution. Therefore, freight and people integration can be seen as a solution that improves liveability and life quality.

These benefits of freight and passenger integration solutions, or CPM initiative, evidences the importance of an integrated and efficient transportation system in achieving a better society regarding equity, liveability, and sustainability. The United Nations (UN) clearly states that transportation systems benefit people's daily lives and the environment. Considering the results of this thesis, some conclusions could be made about the role of CPM in achieving the SDG. Figure 68 demonstrates the impact level CPM solutions may have on achieving the SDG. The contributions to CPM initiatives contributions to SDGs are related to tree main activities: (i) public transport; (ii) freight transport; and (iii) e-commerce. Figure 38 illustrates how each one of these activities included in the CPM initiatives can help municipalities on achieving SDG.

Figure 38 – Cargo-People Mobility contributions to Sustainable Development Goals.



The CPM solution contribution to SDG 8 (decent work and economic growth) achievement is due to the increment in opportunities' accessibility, where people and cargo can reach places, they were excluded, like low-income communities. The accomplishment of SFG 9 (industry, innovation, and infrastructure) is related to the technological development of what CPM needs to function, such as the creation of MaaS4PaF and the routing algorithms. SDG 11(sustainable cities and society) is the goal the CPM solutions can have more impact. This type of solution enables the financial and environmental sustainability of the transport activity, leading to more sustainable cities. It also increases equity and social justice in urban environments as it can reduce transport costs and positively impact low-income communities with more opportunity accessibility.

The CPM solutions' contributions to SDG 12 (responsible production and consumption) are related to the central concept behind the solutions, the shared economy. Principles of the shared economy also merge with the circular economy principles, and by doing this, it is possible to create a more efficient network and surpass people's awareness of their consumption habits. CPM solutions to achieve SDG 13 (climate action) are related to the vehicle's potential reduction, especially cargo ones. Doing this is expected to reduce emissions related to transport activity and vehicle production. Finally, the CPM solution can boost the SDG 17 (partnership for the goals) achievement by the created environment that allows the implementation of CPM solutions, as a cooperation environment between society, government, and private and public sectors is essential to developing the CPM solution.

The CPM solution is also based on the five (5) pillars of sustainability proposed by the UN: (i) people, (ii) peace, (iii) partnership, (iv) planet, and (v) prosperity (UNITED NATIONS SYSTEM STAFF COLLEGE, 2016). People because the solution is intended to increase accessibility and reduce transportation costs. Peace because the solution needs a friendly and cooperative environment to work. Partnership, as this solution, cannot go on without engagement, acceptability and effort from all stakeholders involved. Planet, because this solution aims to reduce energy consumption, circulating fleet and emissions. And finally, prosperity, as this solution aims to reduce transport costs for people and companies.

4.1 Conclusions

In the urge to achieve a sustainable community, policy-makers and researchers are seeking innovative transport solutions. Transport plays a vital role in society as it is at the centre of people's daily lives, being an essential feature for liveability, equity, and environmental justice. One solution that is regaining focus is integrating freight, and passenger flows at operational and planning levels. The European Communities again highlighted this concept in the 2007 Green Book (COMMISSION OF THE EUROPEAN COMMUNITIES, 2007), and several pilots, studies and initiatives have had successful results (ARVIDSSON; BROWNE, 2013).

However, this reality is far in the Global South Alliance countries, which are still facing issues of public transport, poor quality of service and deep inequalities in the spatial distribution of it. In Brazil the inefficiency of the urban transport system increases, while e-commerce practices increases (OLIVEIRA *et al.*, 2022a) without being considered in the Urban Mobility Plans. This context makes the integrated solutions a good opportunity to reduce operation costs and increase sustainability.

This thesis translated the integration between freight and people's flows into the Cargo-People Mobility (CPM) framework. Cargo-people Mobility (CPM) was defined as the holistic integration between cargo and people's flows at a planning and operational level. The integration includes private and public transport systems for freight and people's displacement within the urban environment, both being able to use any available transportation mode in the local geography. This solution should follow the market, environmental, economic, social, and technological trends to create local-customized solutions. The ten tiers that compose the CPM conceptual model (3) that should be considered during the planning activity are transport system, transport elements, urban infrastructure, integration levels, stakeholders, transportation mode, transported items, horizontal integration services, vertical integration services, and technology. By clearly defining the CPM phenomena, this thesis delimitates theoretically the integrated planning approach.

Even though Brazil is not a country known for integrated solutions, the local experts demonstrated that CPM could be applied to the country's reality to create a better mobility system. Their biggest concern was the integration of operational aspects like ticketing, infrastructure investments and matching operation scales. Meanwhile, the recognized positive aspects of the CPM initiatives include accessibility-related factors and operational efficiency gains.

This work also demonstrated that integration is possible with the current Brazilian scenario, even without the necessary integration requirements detailed at the integration ladder. With minor modifications on terminal infrastructure, a design of shared terminal CPM initiative can be implemented in mid-sized municipalities. A combined share vehicle and shared terminal solution have been proved to be infrastructure adaptation affordable, executable and profitable. By turning public transport stops into shared infrastructures and integrating people micromobility service with e-commerce deliveries, this thesis demonstrated public transport can work in synergy with the freight transport activity. The example of GoMoov in Jonville and Jaraguá do Sul proved that integration could be done in the Brazilian context, bringing financial and operational gains for both people and cargo transport. The case studies demonstrated that even the same solution cannot be replied at different geographies. A condensed area would need less integrated microhubs concentrated at key centralities, a sprawled urban area would need a more complex integrated microhub network, even having less inhabitants.

Finally, it is noteworthy the implementation of CPM initiatives in Brazil may face some extra challenges not considered in this thesis, such as (i) low qualification of public sector techicians; (ii) low integration level between academia and public sector; (iii) little number of living labs initiatives in Brazil; and (iv) transport initiatives funding and business model. This thesis does not deal with these themes, and they can be explored in future studies.

This thesis is a starting point for a broader research agenda that can be developed, especially for the Brazilian reality, which is far from the truth of other initiatives. Pilot studies of the operational aspects of the CPM initiatives must be adapted to correspond to the Brazilian dynamic. Also, studies concerning public transport operations and urban logistic operations must be done to understand the business opportunities in the country. Studies to subsidize the law-making process to regulate the activity is also essential. Understanding stakeholders' engagement and acceptability of the CPM initiative also should be investigated.

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Appendix

APPENDIX I

Table 1 – Experts perspective questionnaire on integrated freight and passengers systems.

Question	**Answer**
Do you work in which sector?	• Academia • Public sector • Private sector
What is your field of expertise?	• Public transport • Freight transport
Rank 1 to 10 factors, 1 being the most important for integrated freight and passenger systems, and 10 the least important, with respect to the strengths.	• Reduction in the number of vehicles • Increase in the occupancy of public transportation • Shared trip costs • Increasing the overall efficiency of the transportation system (both freight and public transportation) • Reduce the overall cost • Reduce overall system complexity • Reduce public transportation fare • Reduce energy waste • Reduce energy consumption • Increase operation scale

Question	Answer
Have you considered other factor(s) that can be strength(s) in the freight and passengers integrated systems?	-
Rank 1 to 16 factors, 1 being the most challenging for the integrated freight and passenger systems, and 16 the least challenging, regarding the weakness.	• Fixated scheduled time for public transport • Fixed public transportation routes • Fixed stops of public transportation • Awkward ticketing of public transportation • Maintain quality of service for both systems • Investments in cross-dock platforms and distribution centres • Manipulation of cargo (loading/unloading) • Limited capacity of public transport • Investments in adapted vehicles and stations • Strategical, tactical, and operational cooperation between public transportation operations and carrier companies • Match scale and route of goods and passengers • Choose the appropriate cargo packing • Cooperation between logistics actors • Select the appropriate number of nodes that will be an FPT station • Decide whether the goods will be delivered directly to the final destination. • Solve failure delivery

Question	Answer
Have you considered other factors that can be weakness(s) in the integrated cargo and passenger systems?	-
Rank the factors from 1 to 10, with 1 being the most important for integrated freight and passenger systems and 10 the least important, with respect to opportunities.	• Better use of urban space • Increase accessibility of public transport and goods to peripheral areas • Reduce congestions • Reduce emissions • Better use of installed public infrastructure • Help achieve sustainable goals • Promote economic growth • Increase public policy financial gains associated with sustainability • Reduce space competition between goods and passenger vehicles • Reduce air pollution

Question	Answer
Have you considered other factors that can be opportunities in the integrated freight and passenger systems?	-
Rank 1 to 16 factors, 1 being the most challenging for the integrated freight and passenger systems, and 16 the least challenging, regarding the weakness.	• Numerous stakeholders • Home deliveries • Instant delivery • Congestions during peak hours • Just-in-time deliveries • Parking spaces for loading and unloading activities • The traditional institutional separation between freight and passenger planning activities • Lack of policy integration • Need for behavioural change • Ignorance of the phenomenon • Nonexistence of a multimodal network • Nonexistence of a collaborative culture • Strong regulation for the public transportation sector • Nonexistence of integrated facility location • Financing • Political barriers

Question	Answer
Have you considered other factors that may be threats to the integrated passenger and freight systems?	-
Have you ever heard of the solution addressed in this research or something similar to it?	• Yes • No
In your country, do you know of any initiative, project, research group, or prototype being developed in this field?	• Yes • No
an this solution be one potential solution to urban mobility in your country?	• Yes • No

APPENDIX II

Table 2 – Literature review summary.

ID	Reference	Classification
01	Arvidsson (2010)	Case study
02	Trentini and Mahléné (2010)	Concept development
03	Trentini *et al.* (2011)	Concept development
04	Trentini and Malhene (2012)	Concept development
05	Alessandrini and Salucci (2012)	Service proposition
06	Kikuta *et al.* (2012)	Service proposition
07	Motraghi and Marinov (2012)	Service proposition
08	Arvidsson and Browne (2013)	Case study
09	Marinov *et al.* (2013)	Literature review
10	Regué and Bristow (2013)	Case study with simulation
11	Li *et al.* (2014)	Case study with simulation
12	Strale (2014)	Case study
13	Dampier and Marinov (2015)	Case study with simulation
14	Shen *et al.* (2015)	Case study
15	Fatnassi, Chaouachi and Klibi (2015)	Case study with simulation
16	Ducret, Lemarié and Roset (2016)	Case study
17	Do *et al.* (2016)	Simulation
18	Ghilas, Demir and Woensel (2016a)	Case study with simulation
19	Ghilas, Demir and Woensel (2016c)	Case study with simulation
20	Ghilas, Demir and Woensel (2016b)	Case study with simulation
21	Arvidsson, Givoni and Woxenius (2016)	Literature review
22	Masson *et al.* (2017)	Simulation
23	Cochrane *et al.* (2017)	Acceptability study
24	Kelly and Marinov (2017)	Concept development
25	Ursavas and Zhu (2018)	Simulation

ID	Reference	Classification
26	Behiri, Belmokhtar-Berraf and Chu (2018)	Case study with simulation
27	Ghilas *et al.* (2018)	Case study with simulation
28	Cheng *et al.* (2018)	Case study with simulation
29	Dong *et al.* (2018)	Case study with simulation
30	Ozturk and Patrick (2018)	Case study with simulation
31	Pimentel and Alvelos (2018)	Case study with simulation
32	Pternea *et al.* (2018)	Case study with simulation
33	Zhao *et al.* (2018)	Case study with simulation
34	Beirigo, Schulte and Negenborn (2018)	Evaluation
35	Cieplińska (2019)	Concept development
36	Cleophas *et al.* (2019)	Concept development
37	Zhao *et al.* (2019)	Case study with simulation
38	Duin *et al.* (2019)	Concept development
39	Galkin *et al.* (2019)	Case study
40	Sampaio *et al.* (2019)	Concept development
41	Ji *et al.* (2020)	Case study with simulation
42	Xie, Wang and Fukuda (2020)	Case study with simulation
43	Zhou and Zhang (2020)	Literature review
44	Hu *et al.* (2020a)	Case study with simulation
45	Hu *et al.* (2020b)	Service proposition
46	Ouadi *et al.* (2020)	Case study with simulation
47	Pernkopf and Gronalt (2021)	Case study with simulation
48	Bruzzone, Cavallaro and Nocera (2021)	Case study
49	Pietrzak, Pietrzak and Montwiłł (2021)	Case study
50	Elbert and Rentschler (2021)	Concept development
51	Nocera, Pungillo and Bruzzone (2021)	Concept development
52	Mourad, Puchinger and Woensel (2021)	Case study with simulation
53	Ouadi *et al.* (2021)	Concept development
54	Giuffrida *et al.* (2021b)	Service proposition
55	Kiba-Janiak, Thompson and Cheba (2021)	Concept development
56	(GIUFFRIDA *et al.*, 2021a)	Concept development

ID	Reference	Classification
57	Molenbruch *et al.* (2021)	Case study with simulation
58	Neudoerfer, Mladenow and Strauss (2021)	Service proposition
59	Pietrzak and Pietrzak (2021)	Case study
60	Musolino, Rindone and Vitetta (2022)	Case study
61	Bjørgen and Ryghaug (2022)	Case study
62	Galkin, Sirina and Zubkov (2022)	Concept development
63	He, Liu and Zhao (2022)	Concept development
64	Hörsting and Cleophas (2023)	Case study with simulation

Annex

ANNEX A

KEY FACTORS FOR DEVELOPING FREIGHT AND PASSENGER INTEGRATED TRANSPORTATION SYSTEMS IN BRAZIL:Research in Transportation Economics publishing front page

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Research paper

Key factors for developing freight and passenger integrated transportation systems in Brazil

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A R T I C L E I N F O

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A B S T R A C T

The intensification of e-commerce increases freight movements in urban areas, which negatively contributes to promoting sustainable cities. Conversely, the spare capacity of the public transport system could reduce the externalities of urban freight transport and then promote sustainable cities. This article identifies and evaluates key factors for developing integrated freight and public transport systems. Key factors were identified with a literature review and then classified into benefits and barriers related to the urban environment, and challenges and strengths related to the transport operation. Subsequently, these factors were evaluated by experts and classified by estimating a Luce model. The results indicate that benefits are related to the fight against climate change by optimising urban space and reducing the movements of freight vehicles. Barriers are associated with the lack of a collaborative culture and the need to change consumer behaviour, which helps to promote collaboration and reduce just-in-time demand. For the transport operation, the integration of people and freight systems can reduce operational costs, increase the efficiency of the transport system, and improve the accessibility for people and goods, while promoting economic development by decentralising economic activity. To achieve these benefits, the main challenges concern the logistic activity and the cooperation of stakeholders.

1. Introduction

Transportation systems (TS) are vital in cities as they contribute to the movement of goods and people. TS, which include both people transportation systems (public and private) and freight transportation systems, allow access to essential services, goods, leisure, work, and study. However, these systems fail to achieve cost efficiency (Marinov et al., 2013) because of low-quality public transportation services and low coverage of freight transportation.

The inefficiency of urban freight transport (UFT) leads to negative externalities, such as congestion, pollution, noise, emissions, increasing inequality, and reduced economic development (Cleophas et al., 2019; Kelly & Marinov, 2017; Masson et al., 2017; Regué & Bristow, 2013). Meanwhile, having a low-quality public transport increases car use levels, congestion, and inequalities (Friman et al., 2020; Gori et al., 2020). Despite their negative externalities, freight and public transport are crucial to creating sustainable and liveable cities that require appropriately planning both systems.

Synergies between UFT and people transport, especially public transport, can promote liveability and economic development (Kelly & Marinov, 2017; Masson et al., 2017). Trentini and Mahléné (2010) were the first to define essential elements to integrate people and freight infrastructure, while Van Duin et al. (2019) explored the concept of cargo hitching, where *'cargo hits a ride with people, and people hit a ride with cargo'*. Elbert and Rentschler (2021) provided a definition of the synergy between public transport and UFT as freight in public transportation (FPT): FPT refers to an 'integrated *and organised transportation of passengers and goods within urban areas using a system of vehicles such as buses and trams that operate regularly on fixed routes and are used by people* (Elbert & Rentschler, 2021, p. 2).

The European Commission first encouraged this integration in 2007 (Kelly & Marinov, 2017) to promote sustainable cities. The Green Paper suggested rethinking urban mobility by (i) optimising the use of all transportation modes and promoting co-modality between them, including individual transport; (ii) achieving shared objectives for economic prosperity by guaranteeing mobility, quality of life, and environmental protection; and (iii) integrating the interests of freight transportation and public transportation regardless of the mode of transport used (Commission of the European Communities, 2007).

The motivation to consider the integration of these types of

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ANNEX B

INTEGRATING FREIGHT AND PUBLIC TRANSPORT TERMINALS INFRASTRUCTURE BY LOCATING LOCKERS: ANALYSING A FEASIBLE SOLUTION FOR A MEDIUM-SIZED BRAZILIAN CITIES: Sustainability publishing front page

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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].