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An urban freight transport information system: The OTUC-Lima observatory

Claudio Ortega, *École supérieure d'ingénieurs Léonard-de-Vinci (ESILV),* *claudio.ortega@edu.devinci.fr*
Michelle Rodríguez-Serra, *Universidad del Pacífico,* *rodriguez_m@up.edu.pe*

Abstract

Urban freight transport in emerging megacities is characterized by high operational complexity, fragmented data sources, and significant information asymmetries between public authorities and private operators. In cities such as Lima, these challenges are intensified by the rapid expansion of e-commerce, which increases demand for fast, traceable deliveries while amplifying congestion and environmental externalities.

This paper presents the design and implementation of the Urban Freight Transport Observatory of Metropolitan Lima (OTUC-Lima), a data-intensive decision-support information system developed to support urban freight governance. OTUC-Lima integrates heterogeneous data sources—including high-frequency GPS traces from freight vehicles, operational logistics data, census information, and land-use datasets—through an Extract–Load–Transform architecture combined with spatial–temporal processing.

Using a 14-month dataset covering 652 freight vehicles, the study demonstrates how the system enables descriptive and diagnostic analytics through interactive dashboards that reveal freight mobility patterns and operational dynamics across the metropolitan area. From an Information Systems perspective, the paper conceptualizes urban freight observatories as socio-technical infrastructures that transform fragmented logistics data into actionable intelligence for data-driven urban freight governance in complex metropolitan contexts. Specifically, OTUC-Lima extends the conceptualization of IS information infrastructures to the urban freight domain, demonstrating how data-intensive IS artifacts can generate governance value under conditions of high institutional fragmentation and data scarcity.

Keywords: Urban Freight Transport, Decision-Support Systems, Information Infrastructure, Urban Analytics, Data-Driven Governance

Introduction

Latin America and the Caribbean is one of the world's most urbanized regions, with more than 81% of its population living in urban areas (World Bank, 2018). This rapid and often uncoordinated urbanization has created significant challenges in urban planning and freight logistics infrastructure, particularly in megacities such as Lima, where spatial expansion has outpaced the development of adequate logistics systems (Calatayud & Constance, 2022). As Latin American cities continue to grow in density and logistical complexity, urban freight systems face increasing pressure from rising delivery demand and e-commerce expansion. However, infrastructure, coordination mechanisms, and integrated freight data systems remain insufficiently developed, limiting cities' ability to support efficient and sustainable logistics operations

(Calatayud et al., 2021; Galkin et al., 2025). Beyond physical infrastructure and planning constraints, these challenges increasingly reflect limitations in data availability, integration, and use, underscoring the need for information systems that support evidence-based decision-making in urban freight transport.

At the same time, the rapid growth of e-commerce has reshaped consumer expectations, increasing demand for fast, reliable, and traceable delivery services. These trends have significantly altered freight movement patterns, contributing to rising congestion, emissions, and operational inefficiencies in urban centers (World Economic Forum, 2024). Addressing these challenges requires not only physical or regulatory interventions but also logistics intelligence and decision-support capabilities that can transform large volumes of heterogeneous data into actionable insights (Gutierrez-Franco et al., 2021). However, the expansion of e-commerce and just-in-time distribution practices has further fragmented freight flows and amplified information asymmetries among stakeholders, limiting the capacity of both private operators and public authorities to effectively monitor, analyze, and manage urban freight activity.

This growing atomization of shipments exacerbates the fragmentation of data sources and reduces the visibility of freight activity at the urban scale. From an Information Systems perspective, prior research emphasizes the importance of explicitly conceptualizing the IT artifact as a socio-technical construct embedded in organizational and institutional contexts, rather than treating technology as a neutral or purely technical element (Orlikowski & Iacono, 2001). In the context of urban freight transport, the absence of integrated information systems capable of capturing, processing, and sharing freight-related data across stakeholders constrains the generation of comprehensive and reliable representations of the urban freight transport system, which varies across cities according to social, economic, cultural, and regulatory conditions.

These limitations have been widely documented in the urban logistics literature. Orji et al. (2019) identify three major technological challenges facing sustainable urban logistics: the lack of integrated systems and robust databases, weak data-sharing protocols and standards, and insufficient infrastructure. In practice, urban freight transport systems are characterized by high operational complexity and institutional fragmentation, making it difficult for any single actor to obtain a comprehensive, timely view of freight activity. Private operators typically rely on data to address localized operational needs, while public authorities often depend on territorially limited, aggregated, or low-resolution information.

As a result, persistent information asymmetries constrain coordinated decision-making and limit the capacity to design, implement, and evaluate effective urban freight policies. Data scarcity is further reinforced by private-sector concerns about privacy and competitive sensitivity, as well as by the absence of governance frameworks that enable secure, trusted data sharing. Consequently, transport policies are frequently formulated on the basis of incomplete or biased information, and post-implementation evaluation of urban freight initiatives remains limited (Janjevic et al., 2019a).

In response to these challenges, urban freight observatories can be conceptualized as information systems designed to support integrated analysis and decision-support processes in data-scarce and highly fragmented urban contexts. Within the Information Systems discipline, design-oriented research highlights the role of purposeful artifacts—such as models, methods, and instantiated systems—as central contributions for addressing relevant organizational problems (Hevner et al., 2004). Building on this perspective, the Urban Freight Transport Observatory of Metropolitan Lima (OTUC-Lima) was developed to systematically capture, process, and analyze large volumes of heterogeneous data related to urban freight activity, integrating private-sector operational data with public and open-source information.

By transforming raw data into actionable information through analytical dashboards and spatial–temporal indicators, OTUC-Lima supports a more comprehensive understanding of urban freight dynamics and their evolution over time. This study documents the design and implementation of OTUC-Lima as a data-intensive decision-support information system, outlines its main analytical capabilities, and examines the challenges of data integration, governance, and collaboration among public and private stakeholders in an emerging megacity context.

The study contributes to Information Systems research by illustrating how data-intensive urban observatories can function as socio-technical decision-support infrastructures in fragmented metropolitan environments. In contrast to European urban freight observatories, which typically build upon pre-existing logistics data infrastructure and regulatory frameworks (e.g., CITYLAB, ENCLOSE), OTUC-Lima demonstrates how an integrated freight observatory can be constructed from scratch in a data-scarce emerging megacity context by combining private-sector operational data with open-source public datasets under a collaborative governance model. This advances IS knowledge by establishing design principles for socio-technical information infrastructures in resource-constrained and highly fragmented institutional environments.

Literature Review

Urban Freight Transport: Global and Latin American Challenges

Urban freight transport (UFT) has become a critical component of contemporary urban systems, especially in densely populated and rapidly urbanizing regions, including Latin America. The growth of e-commerce, just-in-time deliveries, and fragmented shipping practices has heightened the complexity of freight flows within cities, contributing to congestion, pollution, noise, and traffic incidents (Fransoo et al., 2017). Cities face mounting pressures to reconcile logistical demands with livability and sustainability goals (Sorichetta et al., 2015).

However, many Latin American cities lack integrated urban logistics planning and infrastructure, exacerbating these negative externalities.

The Role of Data in Urban Freight Governance

From an Information Systems perspective, urban freight governance depends not only on transportation infrastructure but also on the capacity to collect, integrate, process, and transform heterogeneous data into actionable knowledge for decision-making. In highly fragmented metropolitan environments, information systems play a central role in enabling visibility, coordination, and analytics capabilities across multiple stakeholders.

In the field of urban freight transport (UFT), data has become both a critical asset and a persistent challenge. Effective freight planning relies on accurate, granular, and timely information about vehicle flows, delivery patterns, and spatial demand. In practice, however, this planning capacity remains constrained by the data fragmentation and information asymmetries already described in the Introduction (Orji et al., 2019).

Recent research emphasizes the strategic role of logistics data governance in enabling more sustainable, efficient, and equitable freight systems. This includes building institutional capacity for data collection, establishing clear data-sharing protocols, and designing participatory platforms for multi-stakeholder collaboration (Taniguchi & Thompson, 2018; Yoshizaki et al., 2021).

Key Barriers to Sustainable Urban Freight Systems

Despite growing academic and policy interest in sustainable urban logistics (SUL), structural barriers continue to hinder progress. These barriers correspond to the technological challenges already described in the Introduction (Orji et al., 2019).

In addition, private-sector actors often use data solely for operational purposes and are reluctant to share it due to privacy concerns and a lack of legal protection. Public authorities, in turn, lack comprehensive visibility into urban freight systems and often must make decisions based on incomplete, outdated, or low-quality data (Janjevic et al., 2019a). This leads to suboptimal policy design and limited capacity for evaluation of implemented measures.

Freight Observatories: Concepts, Functions, and Global Experiences

Urban freight observatories have emerged as strategic institutional mechanisms that enable the systematic collection, analysis, and application of logistics data for planning and policymaking. These observatories vary in scope, from basic data repositories to advanced platforms that support descriptive, diagnostic, and predictive analytics. Their primary functions include monitoring freight flows and vehicle activity, generating key performance indicators (e.g., congestion, emissions, delivery reliability), and informing the design, implementation, and evaluation of urban freight policies (Taniguchi & Thompson, 2015; National Academies of Sciences, Engineering, and Medicine, 2015; Janjevic et al., 2019b).

In Europe, freight observatories have been incorporated into broader sustainable urban mobility strategies, often focusing on last-mile logistics, environmental sustainability, and stakeholder collaboration. Projects including CITYLAB, ENCLOSE, and SUCCESS illustrate how integrated freight intelligence can support spatial planning, reduce urban externalities, and foster innovative logistics solutions (Cruz & Montenon, 2016). In the United States, freight data observatories have informed freight trip generation models and urban zoning practices, with metropolitan planning organizations and academic institutions playing central roles (National Academies of Sciences, Engineering, and Medicine, 2011, 2016).

Urban freight observatories are increasingly seen as enablers of urban freight intelligence. They provide a foundation for evidence-based decision-making and facilitate dialogue among private operators, public authorities, and researchers. Recent international studies highlight their potential to address systemic barriers in data governance, particularly in fragmented or under-resourced contexts (Taniguchi & Thompson, 2018). By aligning freight data infrastructures with policy objectives, including emission reduction, traffic decongestion, and service equity, observatories contribute to the development of innovative, resilient, and sustainable cities (United Nations, 2015; Yoshizaki et al., 2021).

The Case of Lima: A Critical Data Gap

The observatory analyzed in this study was developed through an inter-institutional collaboration involving academic and logistics stakeholders.

OTUC represents an initiative designed to address these challenges by integrating data from GPS sensors, national census records, land-use data, and logistics operations to create interactive dashboards that reveal freight mobility patterns.

Its capabilities enable both descriptive and diagnostic analytics, empowering public and private stakeholders to visualize congestion hotspots, idle times, and delivery behaviors, and to inform policy and infrastructure decisions.

While international cases offer valuable frameworks, few Latin American cities have developed operational urban freight observatories with real-time data integration and open governance models. Lima, one of Latin America's largest metropolitan areas, exemplifies the abovementioned challenges. Its urban freight system suffers from limited data visibility, weak inter-institutional coordination, and insufficient infrastructure planning. OTUC represents a novel contribution in this regard. Leveraging a fleet dataset covering 14 months and 652 vehicles, the observatory provides localized, high-resolution insights into urban freight dynamics.

Methodology

The OTUC methodology integrates advanced data science techniques with urban logistics theory to address the complex challenges of freight monitoring in metropolitan environments. As shown in Figure 1, the OTUC methodology uses the Extract, Load, and Transform (ELT) framework, which enables data from any source to be used in analytical applications, including predictive models and logistics intelligence dashboards, through specific geographical transformations.

The development of OTUC-Lima follows the Design Science Research (DSR) framework proposed by Hevner et al. (2004), which structures the work reported in this paper. The problem addressed is the fragmentation of urban freight data and the resulting information asymmetries in Metropolitan Lima. The objective of the artifact is to integrate heterogeneous private and public data sources into reliable indicators of freight activity that can support decision-making. Design and development align with the ELT architecture and the spatial and temporal transformations described in this section, while the demonstration involves deploying the observatory on a 14-month operational dataset. The evaluation draws on the analytical capabilities and empirical findings presented in the Results and Discussion section. Finally, the artifact's communication occurs through this manuscript and through the platform's dissemination to academic, private, and municipal stakeholders.

The first stage includes extracting data from different sources, enabling us to leverage both private and public data. Private data includes high-frequency GPS raw sensor records from 652 delivery vehicles, complemented by Planning and Operations data related to delivery success, delivery points, sales, vehicle specifications, distribution center or warehouse locations, among others. Public datasets include census and open-source geographic information, spatially joined with administrative boundaries for context validation. Therefore, some of the public data extracted include socioeconomic levels, business types and quantities, total area, population, employment, and the city's road network. In the second stage, the raw extracted data is loaded into a Data Lake and then processed to produce a two-dimensional dataset, enabling efficient analytical queries to feed logistics intelligence dashboards or machine-learning predictive models.

The GPS and logistics dataset was provided by a single logistics operator serving Metropolitan Lima. It covers the period from June 2018 to July 2019 (14 months) and comprises approximately 54 million GPS records, equivalent to roughly 18 GB of raw data, collected at one-minute intervals from the 652 monitored delivery vehicles. Each record contains latitude, longitude, instantaneous speed, timestamp, and engine status. Because the dataset originates from a single operator, the findings reflect the operational footprint of the participating fleet rather than the entire urban freight market; this scope limitation and its implications for the generalizability of the results are acknowledged in the Conclusions.

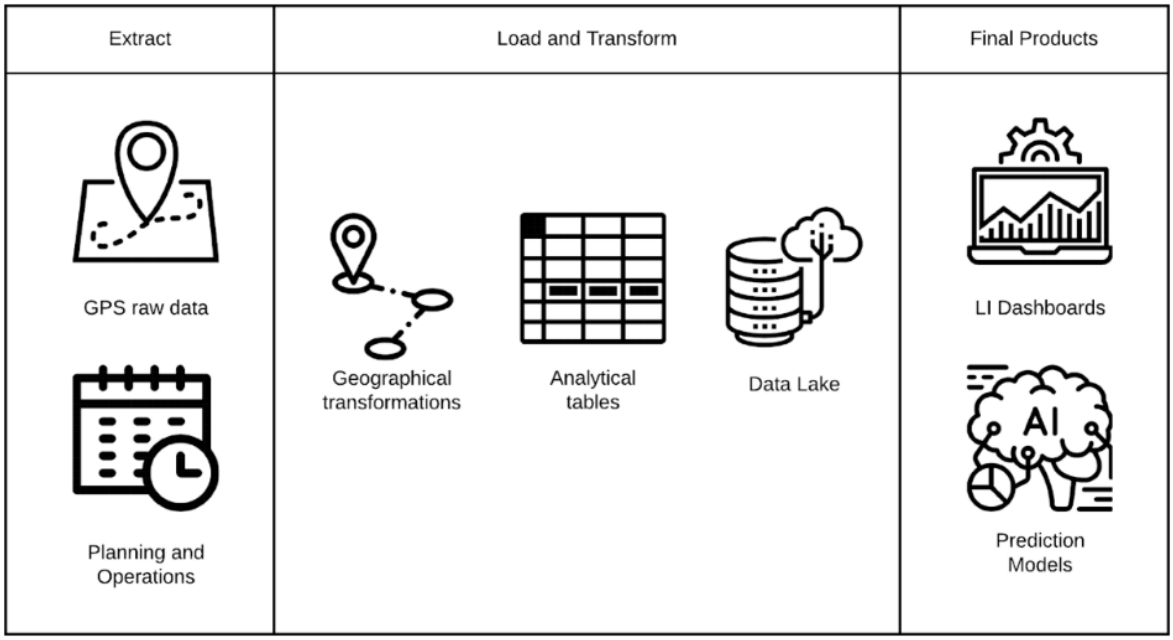


Figure 1. OTUC Methodology

Furthermore, this data processing includes several transformation steps, which are applied in the following order:

1. Map Matching Algorithm: This step enables GPS points to be aligned with the city's road network. The map-matching procedure aligns each GPS record with the nearest segment of the OpenStreetMap road network after quality-control filters remove invalid or inconsistent records. Because the pipeline was designed for operational monitoring rather than for algorithmic benchmarking, detailed performance metrics such as matching accuracy or discard rates were not systematically recorded; reporting these quality indicators is identified as an improvement for future iterations of the observatory.
2. Point in Polygon: This geographical operation associates each GPS record with a Polygon (In this case, the polygons are quadrants that divide the city into standard geographical areas).
3. Time-based grouping: In this step, data is aggregated in 15-minute and 1-hour time intervals, which enables applying temporal filters to calculate relevant indicators.

Steps 1 and 2 are geographical operations to allocate and group GPS data, while Step 3 is a temporal aggregation. These steps convert raw, decoupled data into several spatial datasets, providing a better understanding of the underlying logistics operations. Finally, the product is an interactive data analysis platform that enables geographical and temporal filters on aggregated data to calculate logistics indicators, such as average operating speed, detentions, travel times, and distances. The resulting data architecture also enables the future development of machine learning predictive models to extract knowledge from highly complex urban logistics environments. Some possible use cases include traffic flow prediction, freight type classification, and freight bottlenecks estimation.

Results and Discussion

The results comprise several dashboards organized into three categories: Spatial Analysis, Time Series Analysis, and Urban Context Analysis. These dashboards demonstrate how integrated freight intelligence systems can improve visibility over urban logistics operations across spatial and temporal dimensions. Beyond operational monitoring, the observatory enables the identification of congestion patterns, detention hotspots, and freight circulation dynamics that were previously difficult to detect using fragmented datasets. From an Information Systems perspective, the platform illustrates how integrated analytics infrastructures can support evidence-based urban freight governance in complex metropolitan environments. The spatial analysis dashboards allow visualization of indicators on a city map (using colors to represent indicator values) and the application of temporal and spatial filters (See Figure 2).

All dashboards described in this section are publicly accessible through the OTUC-Lima profile on Tableau Public (https://public.tableau.com/app/profile/otuc.lima; archived version: https://web.archive.org/web/20260709223133/https://public.tableau.com/app/profile/otuc.lima/vizzes), supporting the open dissemination of the observatory's outputs.
Each dashboard category is designed to support specific planning and policy decisions. The Spatial Analysis dashboards enable municipal authorities to identify road segments with chronically low operating speeds, informing decisions about restricted delivery time windows and designated loading zones. The Time Series Analysis dashboards support operational planning decisions by revealing weekly and hourly freight patterns, allowing operators and regulators to design differentiated delivery fees or shift incentives. The Urban Context Analysis dashboards integrate socioeconomic and land-use data, enabling planners to assess freight equity across districts with different income levels and commercial densities, supporting evidence-based decisions about last-mile infrastructure investment.

Analysis of the 14-month dataset reveals several key patterns in Lima's urban freight activity. The average operating speed across the metropolitan road network was 28.5 km/h, with significant variation by road type: motorways averaged 47.2 km/h compared to 28.8 km/h on local streets. Operating speeds also varied over the course of the day, peaking at 36.3 km/h around 9:00 and declining to 25.7 km/h toward 23:00. Monthly averages remained stable at around 30 km/h for most of the period but fell to approximately 23.5 km/h in the October–December 2018 quarter, a slowdown consistent with the year-end peak in commercial demand. Freight circulation was concentrated between 10:00 and 15:00, in the window between the morning (7:30–9:00) and evening (18:00–19:00) private transport peaks, and dropped sharply on Sundays. Idle detention analysis recorded over 4.4 million idle events, during which vehicles remained stationary with the engine on for an average of 42.6 minutes per stop. These patterns, previously invisible due to data fragmentation, provide a quantitative basis for targeted policy interventions such as delivery time windows and designated loading zones in high-congestion areas.

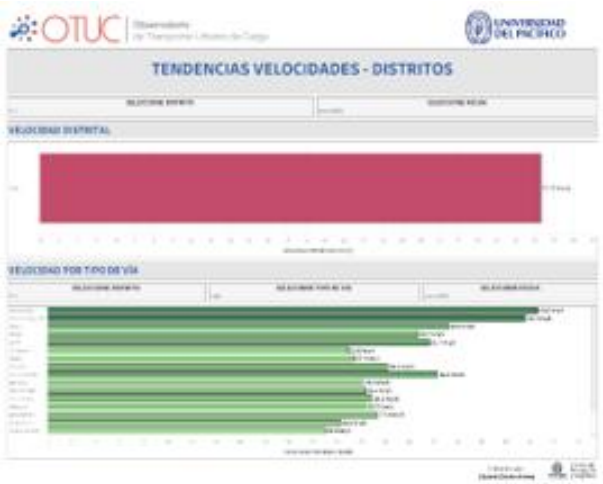


(a) Street average operation (b) Quadrant average operation speed (c) Idle detention location and duration

Figure 2. Spatial Analysis Dashboards

The data reveal substantial variation in average operating speed across the metropolitan road network, as observed in Figures 2a and 2b, which aggregate this indicator at the street and grid quadrant levels, respectively.
These dashboards include filters by month, year, and time of day, allowing the average circulation speed to be shown for specific hours within the same month or year. Furthermore, the average operating speed and the number of vehicles on each road or quadrant are presented. Additionally, Figure 2a contains the name of each road, and the grid quadrant size in the dashboard of Figure 2b can be customized (e.g., 200 by 200 meters). Furthermore, Figure 2c presents the idle detentions map for an individual freight truck or a fleet, which contains the location and time a vehicle remains idle (stopped with the engine on). Furthermore, this dashboard contains four filters: three temporal filters: year, month, and time of day; and one filter to select the vehicles. Additionally, the indicators presented are the average detention time, total detention, and fleet size. Therefore, this interactive map shows the coordinates of idle detentions, a color gradient from yellow to red, and the size of the point marker represents the total idle hours.

In contrast, the Time Series Analysis dashboards present indicators aggregated by month, allowing the user to visualize medium- and long-term trends. Therefore, these dashboards intend to deliver valuable insights regarding logistics operations planning (See Figure 3).



(a) Street type speed report



(b) Monthly and hourly average speed reports



(c) Hourly average speed report by district per day of week



(d) Average speed histogram and average speeds on 15-minute intervals

Figure 3. Time Series Analysis Dashboards

The data further reveal systematic differences in average operating speed across political divisions and road types (road classifications are based on OpenStreetMap), as evidenced in the two histograms of Figure 3a. Furthermore, these dashboard histograms include only freight trucks circulating within the selected districts during the period. Therefore, these filters allow for both geographical and temporal comparisons. Similarly, Figure 3b presents the average monthly general report on operating speed (in the selected months) as a bar chart. The other section presents the average hourly operating speed as a line chart, with the maximum and minimum values highlighted. Furthermore, there is a district filter for comparing multiple districts.

Figure 3c shows the average number of vehicles in circulation per hour for each day of the week. Furthermore, the date filter allows you to select the period (in months) for calculating the average number of vehicles in circulation. Finally, the district filter enables users to analyze a specific geographical area. This enables us to easily visualize how peak congestion hours vary on different days of the week. In contrast, Figure 3d shows two graphs. The first is a histogram showing the number of vehicles grouped by average speed. District, date, and time filters can be applied to this histogram. The second graph shows the

average operating speed every 15 minutes for each day of the week. This analysis may help users understand the regional relationships and inform the offering of differentiated delivery fees based on these values.

Finally, the Urban Context Analysis dashboards aim to integrate complementary information that could help explain patterns identified in the two previous dashboard sections. Figure 4a presents district-level information about the general population, population by gender and socioeconomic levels, total area, and population density. Furthermore, the population variation by age group from 2007 to 2017 is shown to analyze population evolution. Finally, the district's economic activity is presented as percentages by company type, workers' percentages by company type by size (net income and employees), and the number of companies by economic activity. In addition, Figure 4b shows a holistic view that combines operation information with complementary urban context information. This dashboard includes four elements. The graph in the upper-left shows the average operating speed in 100x100-meter colored quadrants as an information layer over Lima's map. The boxes in the upper-right section show aggregated population, housing, and operating speed indicators. The bar graph in the lower-left presents the number of stops grouped by duration ranges (e.g., 303,727 stops have occurred with a duration of 5 minutes or less). The lower-right table shows the count of Points of Interest (PoIs) by business type within the selected area.

Conclusions and Future Work

Lima, being a megacity, presents significant challenges for last-mile distribution, including traffic regulations, driver behavior, curbside loading and unloading constraints, and fragmented commercial practices. At the same time, opportunities exist to better align supply and demand through strategies and practical solutions aimed at improving freight transportation systems in metropolitan areas (Taniguchi & Thompson, 2018), through policies aimed at improving infrastructure management, parking management, vehicle strategies, traffic management, prices, incentives and taxes, logistics management, cargo and public space management (National Academies of Sciences, Engineering, and Medicine, 2015) maximizing their benefits and reducing their negative impacts. An improvement in logistics management with adequate urban planning (Taniguchi & Thompson, 2018) would directly impact the sustainability of the city and its communities (United Nations, 2015) in more habitable cities, increasing the competitiveness of businesses at different socioeconomic levels and strengthening logistics with sustainable logistics projects, measurement of indicators, and investment in technology.

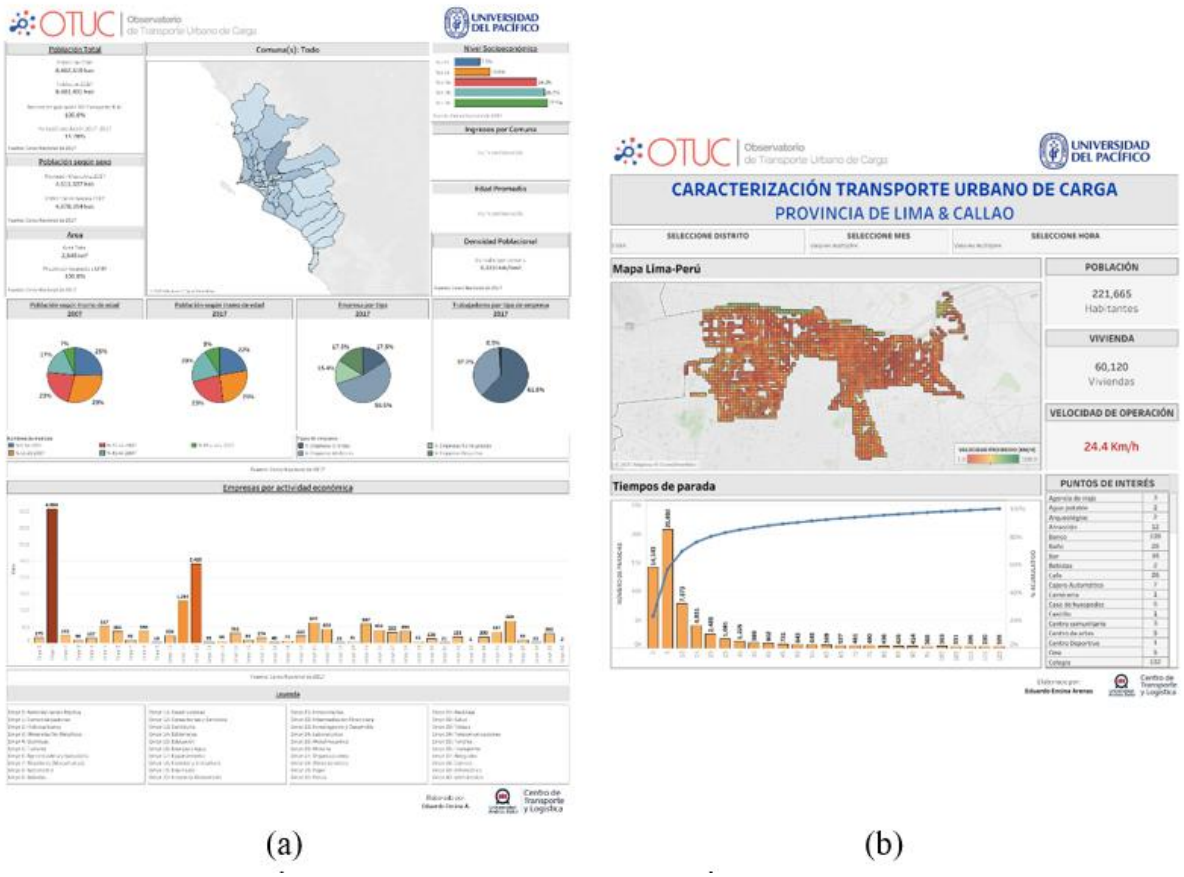


Figure 4. Urban Context Analysis Dashboards

The challenge is to model cargo logistics in cities to process the collected data and generate information for estimating trips from freight transport. This includes freight trip generation associated with e-commerce flows, such as shipments delivered directly from companies to customers or to designated pickup points. This is why the design, implementation, and use of Cargo Observatories in cities can allow joint work between companies, government, and academia to improve the design of last-mile logistics systems in megacities.

From an Information Systems perspective, OTUC-Lima illustrates how urban freight observatories can function as socio-technical information infrastructures that support data-driven governance in emerging megacities. The study also highlights the importance of inter-organizational data integration, analytics capabilities, and collaborative governance mechanisms for addressing complex urban logistics challenges in highly fragmented metropolitan environments.

Sustaining OTUC-Lima as a long-term observatory requires the institutionalization of concrete data governance mechanisms. These include: (1) non-disclosure agreements between academic and private-sector partners establishing data ownership, access rights, and permitted uses; (2) operational data anonymization protocols that aggregate GPS records to the quadrant level before sharing with public authorities, thereby protecting competitive information; (3) a multi-stakeholder data committee comprising representatives from participating companies, municipal agencies, and the academic institution, responsible for approving data uses and resolving disputes; and (4) alignment with Peru's Personal Data Protection Law

(Ley 29733) and relevant privacy regulations. Building stakeholder trust through these mechanisms is not merely a legal requirement but a precondition for the observatory's long-term operational viability.

The OTUC-Lima architecture is designed to be replicable in other Latin American cities, subject to the following baseline conditions: (1) access to GPS data from at least one major freight operator willing to engage under a data-sharing agreement; (2) availability of open-source census, land-use, and road-network datasets; and (3) an academic or public institution capable of serving as a neutral data integration hub. Cities that meet these conditions could adapt the ELT pipeline and dashboard framework with relatively low incremental investment. However, certain contextual factors specific to Lima, including the high informality of the last-mile delivery market, limited regulatory enforcement capacity, and the absence of standardized freight vehicle registration data, may not transfer directly to other contexts and should be accounted for in replication efforts.

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Use of Generative AI and Language Tools

The authors used generative AI tools, including ChatGPT (OpenAI), during the research process to support idea exploration, manuscript structuring, and language refinement. In addition, Grammarly was used for grammar and language editing. All substantive analysis, interpretation of results, and final writing were performed and verified by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the manuscript.

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