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Crowdsourcing and sharing economy models in urban logistics

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Abstract

Background and aim: Rapid urbanization and e-commerce growth subject urban logistics to immense pressure, causing negative environmental and economic externalities. This study aims to analyze and conceptualize the applicability of shared models and crowdsourcing in urban logistics, assessing their potential to enhance efficiency and sustainability, emphasizing transition markets like Bulgaria; ***Scope:*** The scope covers urban logistics, shared economy frameworks, and crowdsourcing in transition economies, limited primarily to Bulgaria's specific institutional and market barriers; ***Methods:*** The multi-component methodology proposes a conceptual framework integrating principles from the Physical Internet, system dynamics, and game theory. ***Results:*** Results indicate transitioning to shared urban logistics and crowd logistics paradigms is essential for a cleaner, more efficient environment; ***Conclusions:*** However, implementing these models faces serious institutional and market barriers in Bulgaria, requiring public authorities to shift from traditional restrictive approaches to proactive regulation and partnership. ***Originality****:* This study bridges a gap in the literature by systematically applying advanced logistics paradigms (HCL and PI) to the structural and cultural specifics of a transition market (Bulgaria). ***Practical implications:*** Findings provide a strategic foundation for municipalities to optimize Sustainable Urban Logistics Plans (SULPs) and regulatory frameworks.

Key words:
Urban logistics, sharing economy, crowdsourcing, sustainability

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1. Introduction

Contemporary metropolitan cities are at the epicenter of a profound structural transformation driven by rapid urbanization, digitalization, and the exponential growth of e-commerce. These macroeconomic, demographic, and social trends generate colossal and increasing pressure on urban logistics systems, which traditionally operate under the severely constrained capacity of transport infrastructure. On the other hand, there is also pressure from increasingly strict environmental regulations and escalating consumer demands for speed, transparency, and flexibility of deliveries (Giuliano, 2023; Taniguchi and Thompson, 2018). By 2050, over 68% of the global population is expected to live in urban areas, making the efficient and sustainable management of material flows a critical factor for economic competitiveness and quality of life (Holguín-Veras et al., 2023). This inevitably leads to challenges concerning the sustainability of (urban) logistics, which "seeks a balance between economic, environmental, and social aspects when making logistics decisions to meet customer requirements" (Rakovska, 2017, p. 73). In response to these systemic challenges, the paradigm of the sharing economy and crowdsourcing is emerging as an alternative and a fundamentally new approach to the decentralization of transport networks, the optimization of existing resources, and the reduction of negative externalities associated with the distribution of goods in densely populated urban environments (Buldeo Rai et al., 2025; Marcucci, Gatta and Le Pira, 2023). The transformation encompasses the shift from traditional models based on exclusive asset ownership to hyperconnected ecosystems based on access, collaboration, and dynamic capacity allocation (Crainic, Klibi and Montreuil, 2023).

The present academic work defines as its main object of study the logistics and freight transport systems in urban environments, examined through the lens of their architectural (urbanistic), technological, and operational evolution in the context of digital transformation. The subject of study encompasses the specific business models of sharing economy and the mechanisms of crowd logistics, which redefine traditional supply chains, interactions among stakeholders, and the integration between freight and passenger mobility.

The primary objective of the research is to analyze, systematize, and conceptualize the applicability of shared models and crowdsourcing in urban logistics by evaluating their potential to enhance economic efficiency, environmental sustainability, and social cohesion in modern cities. Special emphasis is placed on the challenges and prospects for transition markets like Bulgaria. To achieve this objective, a multi-component research methodology is applied, integrating:

To achieve this objective, a multi-component conceptual methodology is developed, integrating:

- Systematic Review and Analysis: Examination of established academic literature exploring optimal cost allocation, supplier relations, and the environmental impact of transport.
- Conceptual Modeling: Analysis of the theoretical frameworks of the Physical Internet and Hyperconnected City Logistics, which are highly likely to define the sector's future.
- System Dynamics (Theoretical Apparatus): Conceptual mapping of Causal Loop Diagrams to outline the interrelations among logistics productivity, vehicle fleets, access regulations, and environmental impacts, serving as a foundational architecture for future empirical simulations.
- Comparative and Behavioral Analysis: Utilization of sociological and economic theories, such as the Push-Pull-Mooring (PPM) theory, to assess the theoretical motivation of participants in crowd logistics platforms.
- Game Theory Principles: Proposing a theoretical framework for the future analysis of gainsharing mechanisms in collaborative networks by outlining the applicability of leader-follower models and the Shapley Value.

The study examines the problematics of urban logistics, conducts a detailed theoretical breakdown of shared models, analyzes their technological architecture, and concludes with an operational investigation of crowdshipping paradigms, providing, as far as possible, a comprehensive picture of the transforming sector.

2. Literature Review

Urban logistics is a complex, adaptive, and highly dynamic system that provides the "blood circulation" of urban economy by managing the flows of goods, raw materials, equipment, and waste between their production and consumption locations (Giuliano, 2023). This system faces a distinct dichotomy: on the one hand, the transportation of goods is crucial for economic activity, meeting human needs, and commerce. On the other hand, logistics processes generate a disproportionately high share of negative externalities that degrade the quality of life (Marcucci, Gatta and Le Pira, 2023).

2.1. Characteristics of Negative Externalities

Although urban freight vehicles account for a relatively small portion of total traffic typically between 6% and 18% of the total number of vehicles in cities they generate between 10% and 15% of the Vehicle Kilometers Traveled (VKT) (Giuliano, 2023). Even more alarming is the fact that this segment is responsible for over 20% of energy consumption and related greenhouse gas (GHG) and carbon dioxide (CO_2) emissions (McKinnon, 2023). In the European context, commercial vehicle movements are considered to cause over 20% of urban congestion, leading to massive economic losses measured by the value of travel time savings (Giuliano, 2023).

The environmental impact of urban logistics extends beyond global climate change. Local pollutants, such as nitrogen oxides (NOx) and fine particulate matter (PM10 and PM2.5), emitted mostly by the diesel engines of light and heavy-duty vehicles, pose serious health risks. Often, these environmental burdens are unevenly distributed, primarily affecting communities living near major transport corridors and industrial zones. Additional externalities include noise pollution, physical infrastructure damage (road surfaces), and an increased risk of traffic accidents involving pedestrians and cyclists (Giuliano, 2023).

2.2. Logistics Sprawl

A primary catalyst for the crisis in urban logistics over recent decades is the phenomenon known in academic literature as "logistics sprawl." The process, identified and studied in detail by authors like Dablanc, is characterized by the systematic relocation of warehouses, distribution centers, and logistics terminals from central urban areas to peripheral, ex urbanized zones (Dablanc, 2007). This exodus is provoked by the interplay of several factors. Foremost are the high real estate prices in city centers, gentrification processes, the transformation of industrial zones into residential or commercial complexes, and increasingly restrictive municipal access regulations for heavy-duty vehicles.

The paradoxical effect of this spatial decentralization is that, despite relieving the city center of large logistics bases, the distance from the warehouse to the end consumer increases drastically. This leads to an increase in VKT within the urbanized regions themselves, higher fuel consumption, and higher pollution levels (Dablanc, 2007). In their effort to compensate for the remoteness of the warehouses, operators are forced to use a greater number of smaller-capacity vehicles, further exacerbating traffic.

Parallel to logistics sprawl, the rapid growth of e-commerce, further amplified by the COVID-19 pandemic, has fundamentally transformed the structure of demand (Gatta, Marcucci and Le Pira, 2023). Traditional supply chains were built around consolidated business-to-business (B2B) transactions, where large volumes of goods were delivered to specific commercial sites. The modern omnichannel paradigm is heavily shifted toward business-to-consumer (B2C) transactions. Deliveries to end customers (B2C) are characterized by a high degree of geographic dispersion (scattered across residential areas based on population density), extremely small volume per individual shipment, and continuously growing expectations for express delivery (same-day or on-demand deliveries). This fragmentation of demand makes efficient freight consolidation nearly impossible. As a result, light commercial vehicles operate with critically low load factors ...averaging around 30-40%, with over 20% of urban distribution trips carried out with completely empty vehicles (Gatta, Marcucci and Le Pira, 2023). A comparison of these flow characteristics is outlined in Table 1.

Table 1

Flow Characteristics Comparison

Flow Characteristic	Traditional Model (B2B Dominance)	Contemporary Model (B2C Dominance / E-commerce)	Effect on Urban Logistics
Shipment size	Large (pallets, consolidated cartons).	Very small (single packages, envelopes).	Sharp drop in vehicle load factors.
Geographic dispersion	Concentrated (shopping streets, malls).	Highly dispersed (individual households across all zones).	Increase in routes, VKT, and parking search times.
Delivery frequency	Planned (weekly or daily).	High frequency, unpredictable (on-demand, same-day).	Increased number of trips, inability to optimally route.
Infrastructure needs	Availability of specialized loading zones.	Lack of loading zones in residential neighborhoods.	Illegal parking, blocking sidewalks/bike lanes, conflicts.

Source: *Authors' compilation, 2026*

In summary, the phenomenon of logistics sprawl, coupled with the dominance of B2C e-commerce, creates cascading negative effects on urban logistics. The systematic relocation of warehouses to peripheral zones drastically increases the distance to end consumers, directly resulting in higher Vehicle Kilometers Traveled (VKT). This extended travel distance contributes to elevated fuel consumption and increased pollution levels within urban areas. Additionally, to compensate for these greater distances and to handle fragmented shipment demands, operators rely on a higher volume of smaller-capacity vehicles operating at critically low load factors, which severely exacerbates urban traffic and congestion.

2.3. Regulatory and Managerial Response

To address these challenges, local authorities traditionally rely on fragmented regulatory mechanisms. The academic literature distinguishes two main types of measures: "push" (coercive) and "pull" (incentivizing) (Holguín-Veras et al., 2023). Push measures include technical and regulatory restrictions, such as Low Emission Zones (LEZ), bans on trucks over a certain tonnage in historical centers, congestion charging, and strict time windows for making deliveries. Although these measures have an immediate effect on reducing local traffic, they often inflict financial damage on businesses, increase the cost of logistics services, and force carriers to use multiple smaller vans instead of one large truck, which paradoxically can increase total emissions (Giuliano, 2023). On the other hand, pull measures are aimed at promoting efficiency. They include economic incentives for transitioning to electric vehicles, providing access to bus lanes for eco-friendly logistics operators, encouraging off-peak deliveries through financial compensation for receivers, and building municipal consolidation centers (Holguín-Veras et al., 2023).

Despite these efforts, the traditional one-sided approach proves insufficient to solve systemic problems. The complexity of urban logistics, the multitude of stakeholders (municipalities, carriers, merchants, citizens), and their conflicting interests necessitate a transition to an entirely new paradigm. In this context, sharing economy and crowdsourcing models emerge, offering transformation through collaboration, optimization of spare capacity, and a radical change in business processes (Taniguchi and Thompson, 2018). In Bulgaria, the prevailing concept of the leading role of businesses (mostly large and international companies) in undertaking changes in the urban environment and restrictions leads to asymmetric and often unsustainable results. The reasons for this are short deadlines and problematic communication with stakeholders. Measures are often imposed quickly, and their success depends on the economic importance of the respective measure. This leads to a negative reaction from citizens and small businesses. In this way, many sensible changes in the urban environment remain unrealized due to poor communication and relatively low economic impact. Even the successful implementation of a given measure leads to a series of predictable problems that take months, years, and in some cases decades to resolve, standing as a monument to the process through which they emerged. One of the most visible results of this approach is the so-called "urban overbuilding," which creates

not only fundamental problems for urban logistics but is now a major factor in the future development of cities as a whole.

3. Material and Methods

3.1. Conceptual Framework and Business Models of Shared Logistics

The sharing economy, applied to the logistics sector, represents an innovative conceptual and business framework where physical assets, resources, space, time, and skills are dynamically allocated and jointly utilized by multiple independent participants. This process is typically managed by advanced digital platforms (Crainic, Klibi and Montreuil, 2023). Unlike the neoclassical economic model, based on exclusive ownership and the encapsulation of resources within the boundaries of a single corporation, shared logistics is based on an access economy. The goal is the utilization of excess or underutilized capacity, such as unused warehouse space, cargo vehicle capacity, as well as the free time of city residents.

The theoretical foundation of shared urban logistics is structured around collaboration mechanisms, which can be classified into two main directions: horizontal and vertical collaboration (integration). Horizontal collaboration occurs between participants operating at the same level in the supply chain for example, competing logistics operators, courier companies, or manufacturers (Janjevic et al., 2018). The goal of this integration is to consolidate freight flows to eliminate overlapping routes. In the classic delivery scenario, three different courier companies send three separate half-empty vans to the same street. With horizontal collaboration, goods are consolidated in a joint hub and delivered with a single fully loaded vehicle (often zero-emission). A practical manifestation of this model is Urban Consolidation Centres (UCC) and co-loading (Janjevic et al., 2018). Vertical collaboration encompasses the integration between different stages of the supply chain from the manufacturer, through the distributor and logistics service provider, to the end customer and public authorities (Taniguchi and Thompson, 2018). This type of collaboration relies heavily on data and information sharing. Examples include the management of access permits, the real-time synchronization of delivery routes with municipal intelligent traffic management systems, and the dynamic reservation of loading/unloading zones. To map the complexity of the ecosystem, academic research and European projects (e.g., CIVITAS, NOVELOG, ReVeAL) define a specific classification of shared business models in urban logistics (Buldeo Rai et al., 2025; Dablanc, 2007). As shown in Table 2, it can be divided into three main categories:

Table 2

Classification of Shared Logistics Models

Sharing Category	Description and Mechanisms	Examples and Applications in Urban Logistics
Sharing of physical assets	Joint use of physical infrastructure (space) and vehicles to reduce capital investments. Includes the concept of "proximity logistics," which brings logistics nodes back to city centers as compact facilities.	Urban Consolidation Centres (UCC), microhubs, dark stores, shared fleets, networks of agnostic parcel lockers accessible to different couriers.
Sharing of services and time	Engaging the general public or non-professional participants in executing logistics tasks. Transformation from centralized execution to decentralized crowdsourcing.	Crowdshipping, use of independent couriers, integrating parcels into ridesharing systems, taxi networks, and others.
Sharing of data	Creating interoperable digital platforms that connect the supply and demand of logistics capacity. Relies on open data and API integrations.	Digital freight brokers (e.g., Uber Freight, Amazon Flex), cloud-based routing platforms, municipal databases for parking availability.

Source: *Authors' compilation, 2026*

The introduction of horizontal sharing raises serious questions regarding the governance of these ecosystems. The literature distinguishes three main governance models:

- **Convened Collaboration:** The network is managed by an independent logistics provider (often a 4PL Fourth Party Logistics) or a public body (e.g., a municipality) acting as a neutral orchestrator. This model is typical for most Urban Consolidation Centres (UCC). The orchestrator minimizes transaction costs and information asymmetry by collecting a fixed or variable consolidation fee.
- **Collaboration "Inter pares" (Among equals):** A decentralized model where partners (e.g., several competing providers) directly share resources without an external coordinator. This approach offers the highest operational transparency and eliminates intermediary fees, but it hides critical risks of trade secret leakage (e.g., client lists) and opportunistic behavior (the so-called "free rider" problem).
- **Collaboration "Primus inter pares" (First among equals):** A hybrid model where one of the participants (usually the one with the largest market share or key infrastructure) takes the leading role. They manage the network on behalf of the coalition, dictating routing and consolidation rules. The risk here lies in the potential abuse of a dominant position when allocating the most profitable routes.

A key issue in models without an external orchestrator is the allocation of generated savings or profits (gainsharing) (Janjevic et al., 2018). If three companies merge their shipments, how should the saved fuel and time costs be divided? Proportional methods (based on the number of shipments) often prove unfair, as they fail to account for the geographic distance of a specific route belonging to one of the partners. Therefore, modern models apply concepts from game theory. Therefore, we propose that modern shared logistics frameworks should integrate theoretical concepts from game theory, such as the Shapley value, to guide future gainsharing mechanisms. In theory, the Shapley value guarantees an efficient, symmetrical, and individually rational distribution by calculating the average marginal contribution of each participant across all possible sub-coalitions, thereby stimulating the sustainability of the collaboration. It must be noted that calculating specific Shapley values requires comprehensive multi-agent empirical data; while this falls outside the scope of the current conceptual overview, it stands as a recommended mechanism for subsequent applied research. Table 3 provides a comparative summary of these three governance models.

Table 3

Governance Models Comparison

Characteristic	Convened (Orchestrator)	Inter pares (Among equals)	Primus inter pares (First among equals)
Level of centralization	High (External hub)	Low (Decentralized)	Medium to High (Internal leader)
Trust between partners	Low requirement	Extremely high requirement	Moderate requirement
Intellectual property risk	Low (Orchestrator keeps secrets)	High	Medium (Leader has data access)
Complexity of gainsharing	Low (Agreed fee)	Very high (Needs a mathematical model)	High (Leader may demand a premium)

Source: *Author's elaboration based on Janjevic et al., 2018*

Examining shared logistics in Bulgaria reveals a complex picture typical of transition economies, where modern digital concepts clash with structural market deficits (Stefanova, 2022). In the Bulgarian legal and economic space, there is no official definition of the term "sharing economy" (although terms like [In Bulgarian: *ikonomika na spodelyaneto*] or "collaborative economy" are used in the media) (Stefanova, 2022). The logistics market in Bulgaria is highly fragmented. Road transport serves over 98% of all domestic freight, placing an immense burden on the depreciated road network (Zampou, 2015; Cebeci, 2018). The market structure is dominated by micro-enterprises two-thirds of operators follow the "one truck, one owner" model, while companies with fleets exceeding 20 vehicles are the exception (Zampou, 2015). This fragmentation creates a fiercely competitive environment bordering on unhealthy competition, where the culture of collaboration is underdeveloped and immature. The main barriers to horizontal logistics integration in Bulgaria

include high levels of distrust and suspicion among participants, fear of losing competitive advantage, concerns about the quality of service for the end customer, and resistance from trade unions

Despite these barriers, Sofia and major cities have seen the rise of startups in certain segments of the sharing economy from ridesharing (Spark, Bolt, BinBin) and short-term rentals (AirBnB) to crowdsourced delivery platforms (Glovo, Wolt, Takeaway). Furthermore, at the European level, it is highly recommended that Bulgarian municipalities urgently update and implement their Sustainable Urban Logistics Plans (SULPs), integrating policies that promote collaborative logistics, the use of shared microhubs, and the introduction of a regulatory framework protecting gig-economy workers (European Commission, 2024). The development of these models is critical for the country to overcome its infrastructure deficits and fully capitalize on its geostrategic position as a logistics bridge between Europe and Asia.

3.2. Technological Architecture of Shared Logistics

The integration of sharing economy models into a complex urban environment is practically impossible without a sustainable, interoperable, secure, and scalable technological architecture. Contemporary academic research and industrial innovations conceptualize this architecture through the interplay of two visionary paradigms: the Physical Internet (PI) and Hyperconnected City Logistics (HCL) (Crainic and Montreuil, 2016; Crainic, Klibi and Montreuil, 2023). The Physical Internet concept, introduced by researchers like Benoit Montreuil, represents a fundamental shift in how we understand the transport of goods. Much like the digital internet, which routes data packets through an open network of servers and routers regardless of their content, the PI seeks to transform the movement of physical objects (Montreuil, 2011). At the core of the PI is the encapsulation of goods into standardized, eco-friendly, smart, and modular containers (pi-containers). Instead of each logistics operator building and maintaining its own closed and isolated network of warehouses and trucks (leading to inefficiencies and empty miles), PI envisions an open global logistics network. In this network, goods move freely through shared terminals and are transported by different carriers, based on standardized protocols (Montreuil, 2011; Crainic, Klibi and Montreuil, 2023). Hyperconnected City Logistics (HCL), defined by Crainic, Klibi, and Montreuil, adapts the principles of the Physical Internet to the specifics of urban morphology. According to their theoretical framework, HCL is built upon 14 core concepts categorized into two main clusters: "Open Logistic Web" and "Means and Ways."' which are detailed in Table 4.

Table 4

HCL Architectural Cluster

HCL Architectural Cluster	Core Concepts (Layers and Mechanisms)	Technological Expression and Function in Urban Environment
Open Logistic Web	Cluster networks, mobility networks, service networks, resource networks, stakeholder networks, cyber-physical networks, governance networks.	Multi-layered system of physical and digital interactions. Integration of passenger and freight mobility. Creation of cyber-physical systems for total transparency between the physical object and its digital record.
Means and Ways	Open sharing, flow consolidation, live monitoring, protocol-based execution, network resource deployment, capacity planning.	Dynamic routing of shipments through joint urban nodes; algorithmic protocols for fair distribution of logistics tasks and revenues; real-time tracking of every pi-container.

Source: *Author's elaboration based on Crainic, Klibi and Montreuil, 2023*

The construction of this hyperconnected cyber-physical architecture is made possible by the technological leaps associated with Industry 4.0 and Industry 5.0. The heart of this architecture is the Internet of Things (IoT). Developments in microelectronics have made sensors and modems extremely compact, energy-efficient, and cheap (often under a dollar per component) (Taniguchi and Thompson, 2018). These IoT devices, integrated directly into pi-containers, vehicles, and urban infrastructure (e.g., smart parking zones), generate massive datasets (Big Data) on location, temperature, humidity, and real-time status. To prevent

latency in processing this data, the deployment of 5th-generation networks is critical. The 5G infrastructure provides the bandwidth and ultra-reliable communication necessary to synchronize entire cities and manage autonomous vehicles, drones, or sidewalk delivery robots (Taniguchi and Thompson, 2018). The data collected via IoT and transmitted over 5G are processed by artificial intelligence (AI) and machine learning algorithms. Crowd intelligence and AI algorithms can instantly analyze millions of factors (traffic, weather conditions, accidents) to dynamically optimize vehicle routes (dynamic routing), forecast demand, and dynamically manage access control in urban zones (Crainic, Klibi and Montreuil, 2023). Specific mobile applications (smartphone-based information systems) are also being developed to integrate GPS, road network data, and AI clustering to dynamically assign available loading/unloading zones to drivers based on their location and delivery schedule. Lastly, technologies like Blockchain are finding increasingly broader applications in ensuring security, traceability, and building trust (Crainic, Klibi and Montreuil, 2023). In multi-agent ecosystems where hundreds of independent providers (crowd workers) interact without a central regulator, blockchain guarantees the immutability of transactions through smart contracts and secures the distribution of rewards.

While the academic literature frequently highlights the operational benefits and the decreasing per-unit costs of individual IoT components, it is critical to acknowledge the immense aggregate capital expenditures (CapEx) required to establish this hyperconnected ecosystem. Deploying a dense, city-wide 5G network, maintaining the requisite cloud computing infrastructure for AI processing, and ensuring robust cybersecurity present staggering financial and infrastructural barriers. Assuming widespread availability and low implementation costs for these technologies is overly optimistic, particularly in transition economies like Bulgaria. Municipal budgets are heavily constrained and often entirely insufficient to independently finance the continuous infrastructure upgrades required to realistically build and support a fully functioning digital logistics web.

The architecture of shared logistics goes beyond operational management and delves deep into the realm of strategic urban planning. Modern Sustainable Urban Logistics Plans (SULP) increasingly rely on approaches based on System Dynamics (Marcucci, Gatta and Le Pira, 2023). System Dynamics provides the mathematical and conceptual apparatus for modeling nonlinear systems with multiple feedback loops, such as crowdsourcing logistics ecosystems. By building Causal Loop Diagrams, analysts can model the complex interactions between access control policies, the behavior of independent couriers (crowdsourcing agents), demand fluctuations, and emission levels. Within our proposed conceptual framework, the state of the logistics system at a given time can be formally represented as a theoretical construct through a system of differential equations:

$$\frac{dS(t)}{dt} = f(S(t), C(t), D(t), E(t), \theta)$$

"Where:

- $S(t)$ is the state vector of the system (e.g., transport network capacity, availability of crowdsourcing couriers).
- $C(t)$ represents the control variables (access fees, incentives for shared deliveries).
- $D(t)$ is the stochastic demand for logistics services.
- $E(t)$ denotes the externalities (emissions, congestion).
- θ is the set of static urban parameters (infrastructure).

The resulting value on the left side of the equation, $\frac{dS(t)}{dt}$, represents the continuous rate of change of the logistics system's state over time. We explicitly present this differential equation to serve as the formal theoretical representation of the system's dynamic behavior.

While the current study does not seek to solve this equation empirically, establishing this mathematical logic is critical for future system dynamics simulations. In practical terms, this equation acts as the algorithmic engine for scenario testing. For example, if municipal authorities modify a control variable $C(t)$ such as

implementing a new Low Emission Zone or altering crowdsourcing incentives computationally solving for $\frac{dS(t)}{dt}$ allows them to forecast the resulting cascade of effects on system capacity $S(t)$ and emission levels $E(t)$ over time. This continuous forecasting is practically applied in the development of Digital Twins, enabling policymakers to simulate the efficacy of urban interventions in a risk-free virtual environment before real-world implementation.

We explicitly present this equation to serve as a formal theoretical representation of the system's state. It is designed as the foundational architecture for future predictive modeling; the current study does not seek to solve this equation empirically, but rather to establish the necessary mathematical logic for subsequent system dynamics simulations.

This mathematical and logical approach (Sterman, 2000) finds its highest practical expression in the creation of Digital Twins virtual, real-time data-driven replicas of the physical city. They allow local authorities and logistics operators to test simulation scenarios (e.g., introducing a new micro-consolidation center or adopting a massive shift to a crowdsourced "last-mile" delivery model) in a completely safe virtual environment. This minimizes investment risks and optimizes the efficacy of interventions before their real-world implementation (Marcucci, Gatta and Le Pira, 2023). For a digital twin to be effective in the context of the sharing economy, it must integrate heterogeneous data streams. In crowd logistics, couriers act as mobile sensors, feeding telemetry data that powers the model across the various architecture levels outlined in Table 5

Table 5

Architecture Level in Crowd shipping

Architecture Level	Function Description	Specifics in Crowd shipping
Physical level	Infrastructure, road network, vehicles, urban environment.	Personal vehicles of citizens (cars, bicycles, scooters), pedestrian couriers.
Sensor/Transport level	Data collection (IoT, GPS, traffic cameras) and transmission.	GPS tracking from crowdsourcing platform mobile apps; crowdsensing data.
Modeling level	Machine learning algorithms, System Dynamics, simulations.	Predicting independent courier availability relative to time windows and dynamic pricing.
User level	Dashboards and interfaces for decision-making by stakeholders.	Tools for SULP policy optimization and local traffic impact assessment.

Source: *Authors' compilation, 2026*

In Bulgaria, the concept of a digital twin is taking its first steps, providing a unique opportunity for empirical research in urban logistics. A key example is the GATE Institute pilot project (GATE, 2024) to develop a digital twin of the city of Sofia, currently focusing on the Lozenets district. The choice of Lozenets as a test zone is highly relevant for shared logistics research due to its specifics: high building density, narrow streets, severe parking deficit, and a high share of e-commerce consumption. This creates an ideal environment to simulate alternative crowdsourcing models based on micro-mobility (cargo bikes) or pedestrian deliveries, which conventional light commercial vehicle logistics struggles to serve efficiently. The GATE project not only gathers spatial and IoT data but also develops the foundational human and research capacity required to scale the technology. The digital twin provides a deep understanding of the micro-district's real-time operations, which is fundamental for calibrating logistics models. Parallel to this technological development, an institutional framework is also present. There is published documentation by the municipal enterprise "Sofiaplan" for the creation of a Sustainable Urban Logistics Plan (SULP) for the Sofia Municipality (Sofiaplan, 2024). Although the actual drafting of the plan had not yet started as of early 2026, this delay can be viewed as a strategic opportunity. It allows the future SULP of Sofia to be built not upon traditional, static planning methods but to directly integrate data and simulation capacities from GATE's digital twin. Such synergy would enable local authorities to test ex-ante the impact of policies promoting the sharing economy (e.g., establishing shared micro-delivery "hubs" in Lozenets or introducing low-emission zones) and forecast the complex urban system's reaction before ratifying the strategic document. Crucially, future empirical research should utilize the real-time telemetry and spatial data generated by this digital twin to directly

operationalize the system dynamics differential equations and game-theoretic gainsharing models proposed in our theoretical framework.

However, transitioning from a localized, micro-district pilot to a comprehensive, city-wide Digital Twin ecosystem introduces enormous infrastructure costs that local authorities would have to bear. Maintaining a functional Digital Twin requires continuous financial outlays for real-time spatial data acquisition, system maintenance, and complex API integrations with private logistics operators. Therefore, a realistic implementation strategy cannot rely solely on municipal funding. It must instead be structured around phased geographic rollouts and robust Public-Private Partnerships (PPPs), where the financial burden of the technological architecture is systematically shared among local authorities, telecommunication operators, and private logistics stakeholders.

3.3. Operational Paradigms of Crowd Logistics

The rise of the sharing economy, supported by the described technological architecture, has catalyzed the emergence of one of the most landscape-altering innovations in urban distribution crowd logistics. In particular, its most widespread manifestation is crowd shipping. This concept represents a radical departure from traditional supply chains. Crowd shipping is defined as outsourcing logistics tasks (collection, transport, and delivery of parcels, most often in the "last mile" segment) to a network of ordinary citizens rather than professional couriers or logistics companies (Chen et al., 2017). This process is coordinated entirely through digital platforms (mobile apps) that act as brokers among the sender, receiver, and courier. The fundamental value of this model is the integration of freight and passenger mobility. Instead of deploying new freight transport capacity, the model utilizes existing transport networks and the spare resources of citizens who are already moving around the city for other reasons (commuting to work, shopping).

Operational Models of Crowd shipping - Depending on the mode of transport and integration with urban infrastructure, operational models of crowdshipping are classified into several major paradigms:

- **Crowd shipping with personal vehicles:** In this model, individuals use their own cars to make deliveries for extra income. While providing flexibility and speed, the model is subject to severe criticism in the academic literature. The reason is that it often generates entirely new, dedicated trips rather than densifying existing ones. This leads to increased traffic, congestion, and carbon emissions, directly contradicting the principles of sustainable urban logistics (Gatta, Marcucci and Le Pira, 2023).

- **Transit-based crowd shipping:** Considered the true ecological alternative, this model engages commuters who use the mass transit network daily (metro, buses, trams). Operationalizing this model requires the establishment of a dense network of automated parcel lockers within transit stations or in their immediate vicinity. The user-passenger picks up the parcel from one station along their route and drops it off at another (close to the end receiver). This approach completely eliminates the need for additional motorized trips and drastically reduces emissions and noise (Gatta, Marcucci and Le Pira, 2023).

- **Co-modality via taxi networks and ridesharing:** Integrating parcels into taxi services or ridesharing systems. Algorithms dispatch taxis to pick up returned goods (reverse logistics) from local stores before picking up a passenger, or to deliver parcels after dropping one off. This utilizes empty trunk capacity and reduces empty taxi runs, lowering the carbon footprint compared to using conventional cargo vehicles for the same purpose (Chen et al., 2017).

- **Integration with local communities and retail outlets:** To overcome the limitations of logistics terminals, companies integrate local shop networks as microhubs (e.g., traditional small neighborhood shops in India called Kirana). An innovative example is the integration of e-commerce (like Flipkart/Ekart) with the "Dabbawala" network in Mumbai a cooperative system of workers delivering lunchboxes via bicycles and public transport, who simultaneously deliver B2C parcels (Odongo et al., 2019).

Behavioral Models and Sustainability Assessment - a key challenge for the survival of crowd logistics platforms is achieving and maintaining a "critical mass" of participants (Marcucci, Gatta and Le Pira, 2023). Understanding the motivation of crowd workers is of fundamental importance. Research applies the Push-Pull-Mooring (PPM) theory (Odongo et al., 2019). Results indicate that financial rewards act as the primary pull factor for joining the platforms. However, for the long-term engagement of participants, building trust toward the platform plays a critical mediating role. In parallel, entry barriers (complex procedures) and a lack of job satisfaction act as push factors (Odongo et al., 2019). From a strategic perspective, the distribution of benefits in these multi-agent systems is modeled using game theory. "Leader-follower" games are employed, where the platform (the leader) and individual crowd couriers (the followers) seek an optimal balance between costs and profits (Janjevic et al., 2018). Despite its immense potential, crowd shipping platforms face significant barriers. The literature notes that while many such initiatives are launched, few manage to remain economically viable. To be successful and generate real social, environmental, and economic benefits, they require a rethinking of public policies adapting labor legislation to the gig economy, investing in shared parcel lockers, and active promotion of co-modality by municipalities (European Commission, 2024).

The transfer of the described global operational and behavioral paradigms to the Bulgarian economic, infrastructural, and cultural environment reveals unique opportunities and specific local barriers. The concentration of the population in several large urban centers (Sofia, Plovdiv, Varna) and the dynamic growth of e-commerce in the country put traditional courier networks under severe pressure, stimulating innovative solutions. Analyzing the four main paradigms, the following trends are observed in Bulgaria:

- **Dominance of Dedicated trips:** Currently, this is the most widespread crowd shipping model in the country, driven primarily by food and essential goods delivery platforms (Glovo, Takeaway, etc.). As noted in academic literature, in cities with extremely high motorization rates like Sofia and Plovdiv, this model often generates entirely new personal car traffic. This exacerbates congestion and emission problems, directly contradicting municipal sustainability goals.

- **Unrealized transit-based potential:** The biggest ecological alternative for Bulgaria lies in integration with the capital's metro system and abandoned underground spaces (mostly defunct bomb shelters). The Bulgarian market is rapidly developing networks of automated parcel lockers (BoxNow, Easybox, as well as the lockers of established national couriers). Strategically positioning these lockers in or adjacent to metro stations creates the perfect physical ecosystem for Mass Transit-based Crowd shipping, where daily commuters transport parcels along their usual routes without generating a new carbon footprint. In the future, this could also happen at night, utilizing automated train operations.

- **Informal co-modality and ridesharing:** Hundreds of social media groups (e.g., Facebook ridesharing groups) have functioned as a form of "informal crowd shipping" in Bulgaria for years, where citizens send parcels via traveling drivers on intercity routes. This widespread practice proves the society's high cultural readiness for integrating passenger and freight mobility. The challenge for the logistics sector is digitalizing and dispatching this through legitimate platforms in an urban setting.

- **Neighborhood stores as microhubs:** The equivalent of the Indian Kirana in Bulgaria is the traditional small neighborhood store or kiosk. Leading courier operators in the country are already successfully using these sites as partner drop-off points. Upgrading this model through crowd logistics would transform them into genuine microhubs from which local residents could make pedestrian or bicycle "to-the-door" deliveries within their micro-districts.

Examining motivation through the lens of PPM theory, the financial incentive for extra income remains the leading pull factor for joining the Bulgarian gig economy. However, there is a critical local barrier to building trust (mooring factor), Cash on delivery (COD). Unlike Western European markets, the share of cash payments upon delivery remains traditionally high in Bulgaria. Entrusting goods and collecting cash through non-professional crowd couriers generates fraud risks and complicates the financial clearing of platforms. The

full deployment of peer-to-peer (P2P) logistics in the country is directly proportional to the pace of transition toward digital card payments. From a strategic and legal standpoint, the search for balance in multi-agent systems ("leader-follower" games) already leads to periodic social tension and strikes by couriers in the country. The main reason is a regulatory vacuum, the Bulgarian labor legislation struggles to define the status of crowd workers. To operate, platforms widely use chains of intermediary companies (so-called "fleet partners"). The forthcoming adaptation of national legislation to the European Platform Work Directive will be crucial for the model's sustainability. Finally, to generate real environmental benefits, crowd shipping initiatives require the active participation of Bulgarian municipalities. The introduction of Low Emission Zones (LEZ) in Sofia is an initial step that should act as a push factor for conventional diesel vans and must be accompanied by active promotion of zero-emission co-modality and the provision of municipal spaces for open, shared parcel locker networks.

4. Conclusion

The main objective of this academic work, to analyze, systematize, and conceptualize the applicability of sharing economy models and crowdsourcing in urban logistics systems can be confidently stated as achieved. The conducted analysis proves that traditional, fragmented delivery models, based on exclusive asset ownership, have reached their limits regarding environmental, spatial, and economic efficiency. In the face of the avalanche-like growth of e-commerce (B2C) and the phenomenon of logistics sprawl, cities are facing critical levels of congestion and pollution. The research reveals that the transition to shared urban logistics is fundamental for achieving a cleaner and more efficient urban environment. The conceptual frameworks based on horizontal and vertical integration clearly demonstrate the advantages of freight consolidation and shared infrastructure use (microhubs, parcel lockers). This transition relies entirely on building a sustainable technological architecture, defined by the paradigms of the Physical Internet (PI) and Hyperconnected City Logistics (HCL). Through the synergy of IoT sensors, 5G networks, artificial intelligence algorithms, and Digital Twins, logistics flows can be dynamically routed in real-time, optimizing every cubic centimeter of spare capacity. The analysis of crowd logistics operational paradigms proves the immense potential for integrating passenger and freight mobility. Transit-based crowd shipping proves particularly promising, transforming ordinary public transport commuters into key logistics agents, minimizing the carbon footprint of urban logistics. Despite the undeniable technological and conceptual advantages, the implementation of these models faces serious institutional and market barriers. The analysis of the Bulgarian context illustrates the difficulties faced by transition economies like extreme market fragmentation, a lack of collaboration culture, regulatory deficits, and delays in applying Sustainable Urban Logistics Plans (SULPs**).** Crucially, these are compounded by severe financial and infrastructural barriers; the enormous capital required to deploy the prerequisite smart infrastructure (5G networks, city-wide IoT coverage, and functioning Digital Twins) cannot realistically be absorbed by local municipalities alone.

Furthermore, it is important to acknowledge the significant geographical and institutional limitations of this study. The analysis of market and cultural barriers focuses almost exclusively on the specific circumstances of Bulgaria. We explicitly clarify that our findings regarding cultural and market barriers such as the strong resistance to digital payments and reliance on cash-on-delivery are specific to transition economies and serve as a baseline. Consequently, these conclusions have limited generalizability and may not apply to more technologically advanced and mature markets.

To realize the full potential of shared urban logistics, public authorities must abandon the traditional "push" approach of restrictions and adopt the role of a proactive regulator and partner. This requires creating flexible regulatory frameworks for workers in the sharing economy, public-private partnerships to build shared infrastructure and jointly finance advanced technological architectures, and standardization in data exchange. The leading role of municipalities as stakeholder coordinators is also vital for ensuring the sustainability of measures and their successful communication among stakeholders. Only by building this hyperconnected

ecosystem can cities guarantee their viability, transforming logistics from a source of problems into an engine of economic value and sustainability.

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