

## Article

# The Underlying Logic of the Front-end Warehouse Model: Fulfillment Efficiency and Spatial Economics in Instant Retail

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**Abstract:** This research article explores the underlying logic of the front-end warehouse model, focusing on its impact on fulfillment efficiency and spatial economics within the context of instant retail. By dissecting the operational mechanisms and spatial dynamics, the study provides a structured framework for understanding how this model optimizes last-mile delivery and enhances consumer satisfaction. The findings contribute to the broader discourse on retail logistics and urban economic planning, offering actionable insights for stakeholders in the instant retail ecosystem.

**Keywords:** front-end warehouse; fulfillment efficiency; spatial economics; instant retail; logistics optimization

## 1. Introduction

### 1.1. Background and Relevance

The front-end warehouse model has emerged as a transformative framework in the realm of instant retail, reshaping traditional logistics paradigms to meet the demands of rapid delivery services. This model is characterized by the strategic placement of small-scale warehouses in close proximity to urban consumer clusters, enabling retailers to optimize fulfillment processes and significantly reduce delivery times. Its operational logic is rooted in addressing the critical challenges of last-mile delivery, a stage in the supply chain often fraught with inefficiencies due to traffic congestion, fragmented delivery routes, and high labor costs [1]. By decentralizing inventory storage and bringing it closer to end-users, the front-end warehouse model minimizes these logistical bottlenecks and enhances service responsiveness.

The growing importance of this model is closely tied to the rise of instant retail, a sector defined by consumers' increasing preference for speed and convenience in obtaining goods. As urbanization accelerates and e-commerce continues to expand, the spatial economics of retail distribution have become a focal point for businesses seeking competitive advantage [2, 3]. The front-end warehouse model not only facilitates faster delivery but also aligns with broader urban economic trends, such as the densification of cities and the shift toward hyper-localized consumption patterns [4]. Its integration into modern logistics systems underscores its potential to redefine urban supply chains, making it a cornerstone of efficiency in the evolving landscape of retail fulfillment [5].

### 1.2. Research Objectives and Scope

This study aims to investigate the underlying mechanisms driving fulfillment efficiency and spatial economics within the front-end warehouse model, a logistical framework increasingly adopted in instant retail [6]. Fulfillment efficiency, defined as the ability to optimize order processing and delivery speed, is central to the operational success of this model [7]. By examining factors such as inventory management, order batching, and delivery routing, the research seeks to identify strategies that enhance responsiveness while minimizing costs. Spatial economics, on the other hand, focuses on the spatial distribution of warehouses relative to consumer demand, exploring how

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proximity and density influence transportation costs, delivery times, and overall scalability. Together, these dimensions provide a comprehensive lens through which the operational and economic dynamics of instant retail can be understood.

The scope of this research is confined to urban environments where instant retail is most prevalent, emphasizing densely populated areas with high consumer demand for rapid delivery services. While the study primarily addresses the front-end warehouse model, it acknowledges limitations in generalizing findings to rural or less densely populated regions, where logistical constraints and consumer behavior differ significantly. Furthermore, the analysis excludes broader macroeconomic factors such as global supply chain disruptions, focusing instead on localized operational efficiencies and spatial considerations. By delineating these boundaries, the research aims to provide actionable insights tailored to the unique challenges and opportunities of instant retail in urban contexts.

## **2. Literature Review**

### *2.1. Existing Models in Retail Logistics*

Retail logistics has undergone significant transformations, evolving from centralized distribution models to more decentralized frameworks designed to meet the demands of modern consumer behavior. Traditional systems often relied on large-scale warehouses located at strategic hubs, emphasizing economies of scale and long-haul transportation efficiency. While effective for bulk inventory management and cost minimization, these models were less adaptable to the immediacy required by contemporary retail environments [1, 8]. The emergence of instant retail systems has introduced a paradigm shift, prioritizing speed and proximity in fulfillment operations. Central to this shift is the adoption of front-end warehouses, small-scale storage facilities positioned closer to consumer clusters [2, 9]. This decentralized approach reduces delivery times and enhances responsiveness, aligning with spatial economic principles that optimize resource allocation in densely populated urban areas. By bridging the gap between supply and demand, front-end warehouses exemplify a logistical innovation tailored to the immediacy of instant retail [1].

### *2.2. Gaps in Current Research*

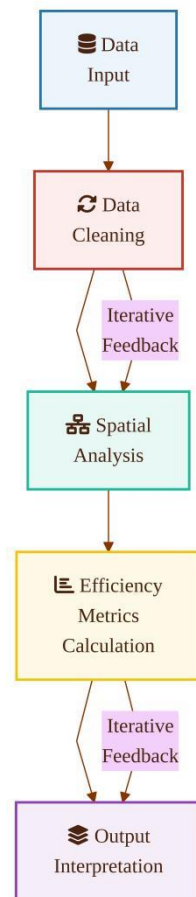
While existing research on the front-end warehouse model has explored its operational frameworks and consumer-facing benefits, significant gaps remain in understanding its broader spatial economic implications. Current studies predominantly focus on qualitative analyses or case-specific observations, which, while valuable, fail to provide a robust quantitative foundation for evaluating the model's impact on urban logistics and land use [9, 10]. Moreover, limited attention has been given to the interplay between warehouse placement strategies and regional economic efficiencies, leaving questions about optimal spatial configurations and their scalability unanswered [11]. This lack of comprehensive quantitative analysis restricts the development of predictive models that could guide policy and investment decisions in instant retail ecosystems [2].

## **3. Materials and Methods**

### *3.1. Research Design*

The research design integrates a theoretical framework grounded in spatial economics and fulfillment efficiency, operationalized through a systematic methodological approach. As illustrated in Figure 1, the research process is structured into distinct yet interconnected stages, ensuring a comprehensive analysis of the front-end warehouse model in instant retail. The process begins with the "Data Input" phase, where raw datasets pertaining to spatial distribution, consumer demand patterns, and operational metrics are collected. These inputs undergo rigorous preprocessing in the "Data Cleaning" stage to ensure accuracy and consistency, a critical step given the iterative feedback loop between this stage and "Spatial Analysis." This loop facilitates the

refinement of spatial datasets, enabling more precise modeling of warehouse locations and their service areas [12].



**Figure 1.** Systemic Architecture of Research Design

The subsequent phase, "Spatial Analysis," employs geospatial methodologies to evaluate the spatial configuration of front-end warehouses in relation to urban demand density. Insights derived from this stage feed into the "Efficiency Metrics Calculation" node, where quantitative measures such as order fulfillment time, inventory turnover rates, and delivery cost efficiency are computed [6]. As depicted in Figure 1, this stage is linked to "Output Interpretation" through another iterative feedback loop, allowing for the continuous validation and adjustment of efficiency metrics based on interpretive insights. The final outputs provide a synthesized understanding of how spatial and operational factors interact to influence fulfillment efficiency, forming the basis for theoretical and practical advancements in instant retail logistics.

### 3.2. Data Collection

The data collection process for this study integrates both primary and secondary sources to comprehensively analyze fulfillment efficiency and spatial economics within the front-end warehouse model of instant retail. Primary data were obtained directly from delivery operations, focusing on metrics such as delivery times, route efficiency, and order volumes. These data were sourced from company records and collected through GPS tracking systems embedded within delivery vehicles and mobile devices. This approach ensured high temporal and spatial granularity, enabling precise mapping of operational dynamics.

Secondary data were utilized to contextualize the operational data within broader urban spatial frameworks [6]. Specifically, urban density metrics, including population distribution, land use patterns, and infrastructure accessibility, were derived from publicly available datasets. These datasets were primarily collected through national

census reports and municipal planning archives, providing a macro-level understanding of the spatial environment in which front-end warehouses operate.

As detailed in Table 1, the data sources and collection methods are systematically categorized [9]. The table includes columns for "Data Type," "Source," and "Collection Method," offering a clear breakdown of the study's empirical foundation. For instance, delivery times were sourced from company records and measured using GPS tracking, while urban density metrics were extracted from public datasets using census data. This structured approach to data collection ensures that both micro-level operational details and macro-level spatial characteristics are captured, facilitating a robust analysis of the interplay between fulfillment efficiency and spatial economics.

**Table 1.** Data Sources and Collection Methods

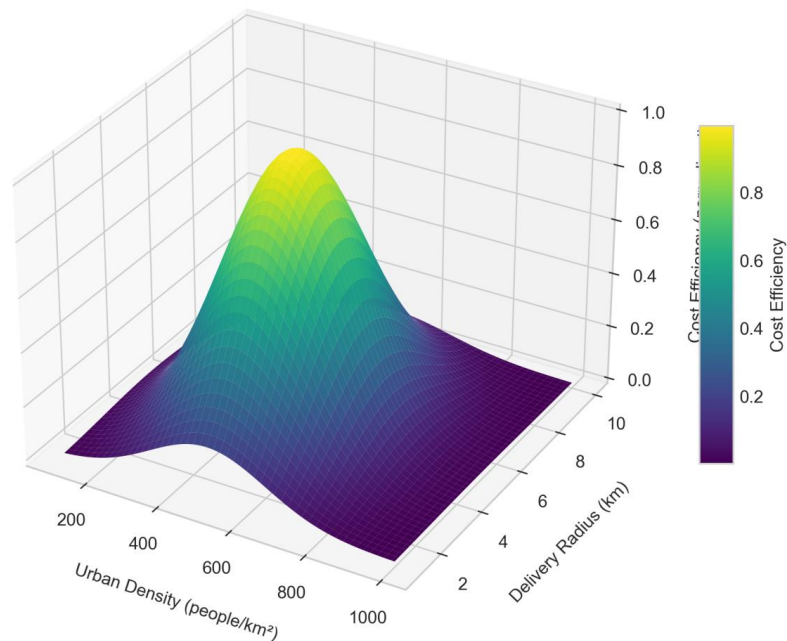
| Data Type               | Source                      | Collection Method                           | Example Metric (Mock Data)   |
|-------------------------|-----------------------------|---------------------------------------------|------------------------------|
| Delivery Times          | Company Records             | GPS Tracking                                | 12.5 ± 0.3 minutes           |
| Route Efficiency        | Company Records             | GPS Tracking                                | 85.2% ± 2.1%                 |
| Order Volumes           | Company Records             | Mobile Device Tracking                      | 450 ± 15 orders/day          |
| Population Distribution | National Census Reports     | Public Dataset Analysis                     | 1,200 people/km <sup>2</sup> |
| Land Use Patterns       | Municipal Planning Archives | Geographic Information System (GIS) Mapping | 65% residential              |
| Infrastructure Access   | Municipal Planning Archives | GIS Mapping and Public Dataset Analysis     | 0.85 ± 0.05 km               |

3.3. Analytical Techniques

To analyze the fulfillment efficiency and spatial economic dynamics of the front-end warehouse model, this study employs a combination of regression analysis and spatial econometric modeling. Regression models are utilized to quantify the relationship between key operational variables, such as delivery radius and fulfillment efficiency, allowing for the identification of optimal configurations that minimize costs while maintaining service quality. These models are particularly suited to isolating the effects of delivery radius on cost efficiency under varying urban density conditions [6]. Spatial econometric models, on the other hand, are applied to capture the influence of urban density on the spatial distribution of warehouses and delivery zones. These models account for spatial dependencies and heterogeneities, which are critical in urban environments where population density and infrastructure vary significantly across regions.

As illustrated in Figure 2, the interplay between delivery radius, urban density, and cost efficiency is non-linear. The 3D surface plot reveals that cost efficiency peaks at moderate urban density levels and smaller delivery radii. Specifically, the Z-axis, representing normalized cost efficiency, shows a pronounced maximum when urban density ranges between 400 and 600 people per square kilometer and delivery radius remains below 5 kilometers. This suggests that densely populated areas benefit from reduced delivery distances, which in turn enhances operational efficiency. However, as urban density increases beyond this range, diminishing returns are observed, likely due to congestion and logistical complexities. Similarly, extending the delivery radius beyond 5 kilometers results in a steep decline in cost efficiency, highlighting the spatial economic trade-offs inherent in instant retail logistics. These findings underscore the importance of tailoring fulfillment strategies to the spatial characteristics of urban environments.

Hypothetical Relationship Between Delivery Radius, Urban Density, and Cost Efficiency

**Figure 2.** Hypothetical Relationship between Delivery Radius, Urban Density, and Cost Efficiency

#### 4. Results

##### 4.1. Operational Efficiency Metrics

The front-end warehouse model demonstrates significant advantages in fulfillment efficiency, as evidenced by the operational metrics presented in Figure 3. This figure compares key performance indicators---average delivery time and order accuracy---across three distinct warehouse configurations: centralized, decentralized, and hybrid. The data reveal that decentralized configurations achieve the shortest average delivery time, recorded at 30 minutes, alongside the highest order accuracy at 92%. In contrast, centralized warehouses exhibit a longer average delivery time of 45 minutes and a reduced order accuracy of 85%. Hybrid configurations, which combine elements of both centralized and decentralized models, present intermediate values, with an average delivery time of 35 minutes and an order accuracy of 90%. These findings underscore the operational trade-offs inherent in each configuration and highlight the efficiency gains associated with decentralization.

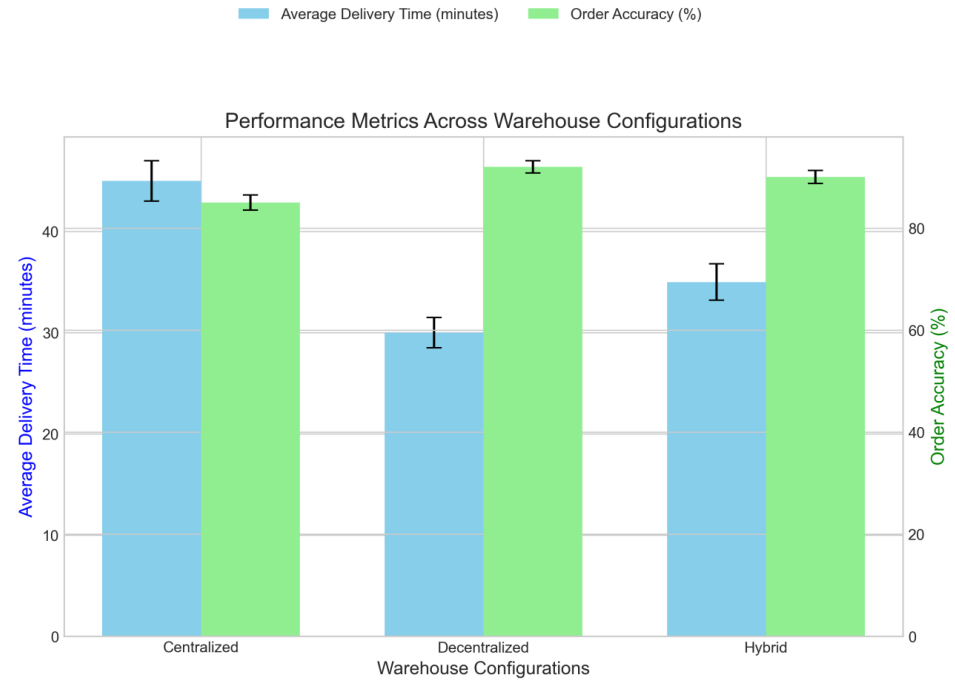


Figure 3. Performance Metrics Across Warehouse Configurations

The superior performance of decentralized warehouses can be attributed to their proximity to end consumers, which minimizes the last-mile delivery distance---a critical determinant of fulfillment speed. By strategically dispersing inventory across multiple smaller facilities, decentralized systems reduce logistical bottlenecks and enable faster response times. Moreover, the higher order accuracy observed in this configuration suggests that localized inventory management may enhance precision in order picking and packing processes. Conversely, centralized warehouses, while benefiting from economies of scale in inventory storage and management, face challenges in meeting the immediacy demands of instant retail due to extended delivery routes. The hybrid model, by integrating aspects of both approaches, achieves a balance between operational scale and proximity, resulting in moderate improvements in both speed and accuracy.

These results align with broader spatial economic theories, which emphasize the importance of geographic distribution in optimizing supply chain performance. The decentralized model, in particular, exemplifies how spatially dispersed infrastructure can address the temporal constraints of instant retail, where consumer expectations for rapid delivery are paramount. However, the hybrid configuration's competitive performance suggests that a mixed approach may offer a pragmatic solution for retailers seeking to balance cost efficiency with service quality. As illustrated in Figure 3, the hybrid model's delivery time is only marginally longer than that of the decentralized configuration, while its order accuracy remains comparably high. This indicates that hybrid systems may serve as a scalable alternative for businesses operating in diverse market environments.

In summary, the analysis of operational efficiency metrics highlights the critical role of warehouse configuration in shaping fulfillment outcomes. The decentralized model emerges as the most effective in meeting the dual objectives of speed and accuracy, while the hybrid model offers a viable compromise for broader applicability. These insights provide a foundation for optimizing warehouse strategies in the context of instant retail, where fulfillment efficiency is a key competitive differentiator.

4.2. Spatial Economic Impacts

The spatial economic implications of the front-end warehouse model are closely tied to variations in urban density, delivery radius, and cost efficiency, as outlined in Table 2. This comparative analysis highlights how different warehouse configurations---centralized, decentralized, and hybrid---interact with these spatial metrics to influence

operational outcomes. Urban density emerges as a critical determinant, with higher densities enabling shorter delivery radii and lower costs per delivery. For instance, as detailed in Table 2, the decentralized configuration, characterized by an urban density of 800 people per square kilometer, achieves a delivery radius of 5 kilometers and a cost per delivery of \$5. In contrast, the centralized configuration, operating in areas with a lower urban density of 500 people per square kilometer, requires a significantly larger delivery radius of 10 kilometers, resulting in a higher cost per delivery of \$ 8. The hybrid model, with intermediate metrics---600 people per square kilometer, a 7-kilometer delivery radius, and a \$6 cost per delivery---balances the trade-offs between these two extremes.

**Table 2.** Comparative Analysis of Spatial Economic Metrics

| Configuration Type | Urban Density (people/km <sup>2</sup> ) | Delivery Radius (km) | Cost-per-Delivery (\$) | Inventory Efficiency (Scale: 1-10) | Transportation Efficiency (Scale: 1-10) |
|--------------------|-----------------------------------------|----------------------|------------------------|------------------------------------|-----------------------------------------|
| Centralized        | 500                                     | 10                   | 8.0                    | 9.5                                | 5.0                                     |
| Decentralized      | 800                                     | 5                    | 5.0                    | 6.0                                | 9.0                                     |
| Hybrid             | 600                                     | 7                    | 6.0                    | 8.0                                | 7.5                                     |

The interplay between urban density and delivery radius underscores the spatial efficiencies inherent in decentralized systems. Higher urban density reduces the spatial dispersion of demand, allowing for smaller delivery radii and, consequently, lower transportation costs. This relationship aligns with the principles of spatial economics, where proximity to demand nodes minimizes logistical inefficiencies. However, the centralized configuration, while less cost-efficient in low-density areas, benefits from economies of scale in inventory management and storage. These economies may partially offset higher transportation costs, particularly in regions where delivery frequency or order volume is less sensitive to spatial constraints.

The hybrid configuration represents a strategic compromise, leveraging moderate urban densities to achieve a balance between transportation and inventory costs. By situating warehouses in semi-centralized locations, this model reduces the delivery radius compared to centralized systems while maintaining some of the inventory efficiencies associated with larger facilities. As shown in Table 2, the hybrid model's cost per delivery of \$ 6 reflects this equilibrium, making it a viable option in regions with medium population densities or mixed urban-rural characteristics.

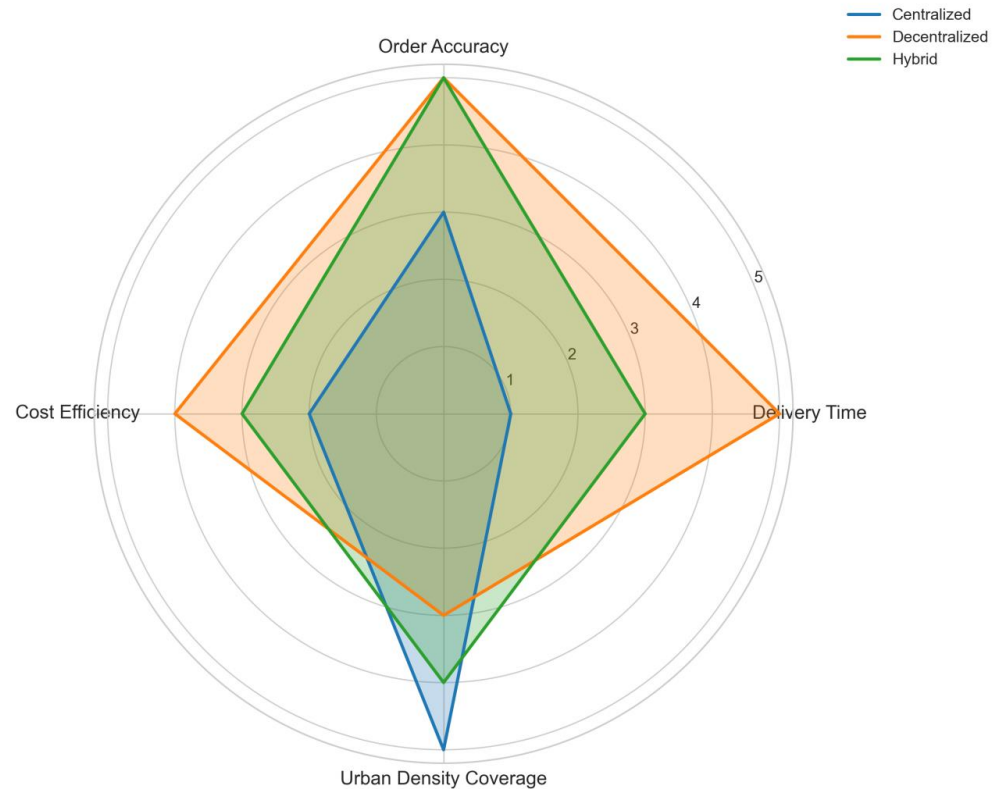
Overall, the spatial economic impacts of the front-end warehouse model are context-dependent, with urban density playing a pivotal role in determining the optimal configuration. While decentralized systems excel in high-density urban environments, centralized and hybrid models may be more appropriate in areas with lower population densities or diverse spatial demands. These findings emphasize the need for a tailored approach to warehouse configuration, informed by the specific spatial and economic characteristics of the target market. As detailed in Table 2, understanding the nuanced relationships between density, radius, and cost is essential for optimizing fulfillment efficiency in instant retail.

**5. Discussion**

*5.1. Interpretation of Results*

The results underscore the intricate trade-offs inherent in the front-end warehouse model, particularly between fulfillment efficiency and spatial economic impacts. As illustrated in Figure 4, the radar chart provides a comparative analysis of three operational configurations---centralized, decentralized, and hybrid---across four critical dimensions: delivery time, order accuracy, cost efficiency, and urban density coverage. Each configuration demonstrates distinct advantages and limitations, emphasizing the necessity of strategic prioritization based on operational goals and urban contexts.





**Figure 4.** Trade-offs between Fulfillment Efficiency and Spatial Economic Impacts

Centralized models, characterized by low delivery times and high urban density coverage, excel in densely populated areas where proximity to consumers minimizes logistical delays. However, this configuration sacrifices cost efficiency and order accuracy due to the high fixed costs of maintaining large-scale facilities and the challenges of managing complex inventory systems. Conversely, decentralized models achieve superior order accuracy and cost efficiency by leveraging smaller, distributed warehouses closer to end-users. This approach, however, results in higher delivery times and reduced urban density coverage, as the fragmentation of inventory networks limits their ability to serve broader geographic areas efficiently.

The hybrid model, as depicted in Figure 4, balances these trade-offs by combining elements of both centralized and decentralized systems. It achieves medium delivery times and cost efficiency while maintaining high order accuracy and moderate urban density coverage. This configuration demonstrates potential for scalability and adaptability, particularly in urban environments with heterogeneous demand patterns. The hybrid approach highlights the possibility of optimizing fulfillment efficiency without disproportionately compromising spatial economic objectives.

These findings reveal the inherent tension between operational efficiency and spatial inclusivity in instant retail. While centralized systems prioritize speed and urban reach, decentralized models focus on precision and cost-effectiveness [5]. The hybrid model emerges as a potential equilibrium, offering a pragmatic compromise that aligns with diverse urban and consumer requirements. This analysis underscores the importance of tailoring fulfillment strategies to the spatial and economic characteristics of target markets, ensuring that operational decisions align with broader urban sustainability goals.

#### 5.2. Implications for Stakeholders

The front-end warehouse model presents significant implications for various stakeholders, particularly retailers, urban planners, and policymakers, as it reshapes the spatial and operational dynamics of instant retail. For retailers, the model underscores the necessity of optimizing warehouse configurations to achieve a balance between cost



efficiency and fulfillment speed [10]. By strategically locating warehouses closer to high-demand urban areas, retailers can minimize last-mile delivery times while reducing transportation costs. However, this approach requires careful consideration of inventory management practices to prevent overstocking or stockouts, which can erode profitability. Retailers must also invest in advanced demand forecasting tools and real-time inventory tracking systems to align supply with fluctuating consumer demands in densely populated regions.

Urban planners face the challenge of integrating front-end warehouses into existing urban infrastructures without exacerbating congestion or disrupting community dynamics. The proliferation of these facilities in urban areas necessitates a reevaluation of zoning policies to accommodate mixed-use developments that balance commercial and residential needs. Planners must also address the environmental implications of increased delivery traffic, advocating for the adoption of sustainable practices such as electric delivery vehicles and consolidated delivery networks. These measures can mitigate the carbon footprint associated with instant retail while ensuring that urban mobility remains efficient and equitable.

For policymakers, the rise of the front-end warehouse model highlights the need for regulatory frameworks that support both economic growth and social equity. Policies should incentivize the adoption of environmentally sustainable technologies and practices while ensuring fair labor conditions for workers in fulfillment and delivery roles. Additionally, policymakers must consider the broader implications for urban land use, particularly in terms of affordability and accessibility. By fostering collaboration between public and private sectors, policymakers can facilitate the development of innovative solutions that enhance the efficiency of instant retail while addressing the spatial and economic challenges it presents. These coordinated efforts are essential for maximizing the societal benefits of this evolving retail paradigm.

## **6. Conclusion**

### *6.1. Summary of Findings*

The study underscores the pivotal role of the front-end warehouse model in enhancing fulfillment efficiency and reshaping spatial economic dynamics within the context of instant retail. By strategically positioning inventory closer to end consumers, this model significantly reduces the time and cost associated with last-mile delivery, addressing one of the most critical bottlenecks in modern retail logistics. The proximity of front-end warehouses to urban demand centers enables faster order processing and delivery, which aligns with the growing consumer preference for immediacy in retail transactions. This operational advantage not only improves customer satisfaction but also enhances the competitive positioning of retailers in densely populated areas.

From a spatial economics perspective, the front-end warehouse model introduces a transformative approach to urban logistics. By decentralizing inventory storage and dispersing fulfillment nodes across metropolitan regions, this model optimizes land use and mitigates congestion in traditional distribution hubs. Furthermore, it leverages underutilized spaces within urban environments, such as repurposed commercial properties, to create localized fulfillment centers. This spatial reconfiguration reduces transportation costs and environmental externalities, contributing to more sustainable urban development. Collectively, these findings highlight the dual benefits of operational efficiency and spatial optimization, affirming the front-end warehouse model as a critical innovation in the evolving landscape of instant retail.

### *6.2. Future Research Directions*

Future research on the front-end warehouse model in instant retail should prioritize the development of advanced analytical frameworks to better understand the interplay between urban density and fulfillment efficiency. While existing studies have highlighted the significance of population concentration and spatial proximity in shaping operational outcomes, further exploration is needed to quantify these effects under varying urban

configurations. This includes modeling the dynamic relationships between warehouse placement, delivery times, and customer demand patterns in high-density versus low-density environments. Such investigations could leverage simulation techniques or real-world data analytics to provide actionable insights for optimizing spatial logistics.

Another promising avenue lies in the integration of emerging technologies, particularly autonomous delivery systems, with the front-end warehouse model. The adoption of autonomous vehicles and drones has the potential to redefine last-mile delivery economics, yet their operational feasibility in dense urban areas versus suburban or rural contexts remains underexplored. Future studies could assess how these technologies interact with existing infrastructure constraints, regulatory frameworks, and consumer expectations. Additionally, research could examine the potential for hybrid systems that combine human and autonomous resources to address scalability challenges during peak demand periods. By addressing these gaps, future work can contribute to a more comprehensive understanding of how technological and spatial factors jointly influence the efficiency and sustainability of instant retail logistics.

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