LUMEN ET VIRTUS
ISSN: 2177-2789

SMART LOCKERS AS A SOLUTION FOR ECOMMERCE LOGISTICS

https://doi.org/10.56238/levv13n31-004

Submitted on: 11/18/2023 **Publication date:** 12/18/2023

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ABSTRACT

This article aims to analyze smart lockers as a strategic alternative to the logistical challenges faced by e-commerce in the last mile stage. The research was conducted through a qualitative literature review, based on scientific publications, technical reports, and national and international case studies, with a time frame between 2015 and 2023. The dramatic growth of e-commerce, especially after the COVID-19 pandemic, has put pressure on traditional logistics systems, highlighting the need for solutions that combine operational efficiency, sustainability, and consumer convenience. Smart lockers emerge as a response to this demand, by allowing the decentralization of delivery, reduction of costs with redeliveries, reduction of pollutant emissions and improvement in the customer experience. Successful experiences in countries such as Poland, China and Singapore were analyzed, which demonstrate the feasibility and benefits of the wide deployment of these devices in urban space. In Brazil, although adoption still faces structural barriers, there is progressive growth driven by private companies and public initiatives. The integration of smart lockers with emerging technologies such as the Internet of Things and artificial intelligence extends their functionality and consolidates them as part of the smart city infrastructure. The analysis of the data allows us to conclude that lockers have the potential to transform the last-mile delivery system, promoting logistics innovation, urban sustainability, and greater digital consumer loyalty. The consolidation of this technology in Brazil depends on incentive policies, public-private partnerships, educational campaigns, and investments in urban and digital infrastructure.

Keywords: Smart cabinets. Urban logistics. Last mile. E-commerce. Sustainability.

INTRODUCTION

The accelerated transformation of e-commerce in recent years has driven the reconfiguration of the entire logistics system, requiring solutions that are increasingly dynamic and adaptable to the demands of a more demanding and connected consumer, especially in urban contexts where population density and mobility challenges impose limits on the efficiency of traditional distribution, with the last mile being the main bottleneck for fast delivery, safe and cost-effective.

With the exponential growth of e-commerce, intensified by the COVID-19 pandemic, companies began to face an unprecedented volume of online orders, putting pressure on their transportation and storage systems, which highlighted the fragility of conventional structures and drove the emergence of alternatives that met the growing demand without compromising operational sustainability (Marioti, 2021).

In Brazil, the percentage of online retail sales more than doubled in one year, revealing a transformation in consumer behavior and increasing the demand for logistics systems that reconcile scalability, agility, and predictability, a reality that found in smart lockers a practical, technological, and sustainable answer to last-mile delivery (Negreiros; Sousa, 2022).

The use of *smart lockers,* or smart lockers, has been gaining prominence in international and national markets as an efficient way to decentralize product delivery, reduce dependence on the presence of the recipient and mitigate the negative impacts caused by redeliveries and congestion, while allowing consumers greater autonomy to pick up orders at flexible times and easily accessible places (Soto Júnior et al., 2023).

In countries such as Sweden, Poland, China, and Singapore, the deployment of locker networks has been encouraged by public policies and investments in urban digital infrastructure, transforming smart lockers into key pieces of advanced logistics ecosystems that integrate technologies such as geolocation, artificial intelligence, and the Internet of Things for capacity optimization and real-time tracking (Vakulenko, 2023).

In the Brazilian context, although the use of lockers is still in the process of expansion, there is a promising movement led by large companies and logistics startups that seek scalable solutions with low environmental impact to serve the most congested metropolitan regions, with initiatives such as Correios Locker and Via Varejo's terminals gaining space in large urban centers (Mateus; Cardoso, 2021).

The biggest challenge still lies in the need to integrate smart lockers into an already saturated logistics network, requiring investments not only in technology and infrastructure, but also in consumer education, favorable legislation, and public-private partnerships that

enable their dissemination and adaptation to the different urban and socioeconomic profiles of the country (Nascimento et al., 2021).

Among the main benefits identified in the adoption of smart lockers are the reduction of operating costs related to the last mile, the optimization of delivery routes, the reduction of carbon emissions and the significant improvement in the customer experience, which now has greater predictability, security and convenience in the process of receiving products (Cruzeiro; Kloeckner, 2022).

This technology also has high potential for integration with emerging models of smart urban logistics, in which connected devices, big data, and artificial intelligence converge to generate more resilient, agile, and responsive systems to demand fluctuations and the daily obstacles of the urban fabric, especially in large Brazilian metropolises (Sethuraman et al., 2023).

The growing appreciation of sustainability in logistics chains also drives the use of lockers as a strategy to mitigate environmental impacts, given that their implementation reduces light and heavy vehicle traffic in central areas, rationalizes the use of fossil fuels, and contributes to the construction of greener urban logistics in line with ESG guidelines (Severo et al., 2023).

Due to their ability to function as advanced logistics points, smart lockers support reverse logistics and can be used for B2B and B2C operations, expanding their versatility and becoming a support infrastructure not only for retail, but also for sectors such as education, health, and administrative services, when integrated with digital management systems (Schmitz, 2023).

In view of this scenario, the main objective of this article is to analyze the feasibility and impacts of the use of smart lockers as a strategic solution to the logistical challenges of e-commerce, based on case studies, international experiences and recent academic literature, seeking to understand the potential of this technology to transform last-mile delivery in Brazil and position the country among the references in urban logistics innovation.

METHODOLOGY

The present study adopts a qualitative approach of exploratory nature, with a design based on a literature review, whose objective is to understand in a critical and interpretative way the role of smart lockers as a logistics alternative in the last mile of e-commerce, allowing the analysis of theories, models, practical applications and trends observed in

different national and international urban contexts from relevant and updated secondary sources, as advised by Gil (2017) and Lakatos and Marconi (2021).

To carry out the review, scientific articles, academic dissertations, technical reports and specialized publications extracted from recognized databases such as Scielo, Google Scholar, INFORMS, Emerald Insight, University Repositories and institutional journals were consulted.

The established time frame covers the period from 2015 to 2023, with an emphasis on academic productions from the last five years, given the speed of transformation of digital logistics chains and the emergence of new technologies applied to the last mile, especially after the intensification of e-commerce during and after the COVID-19 pandemic, a factor that significantly changed the dynamics of urban distribution on a global scale.

The descriptors used in the bibliographic searches were: "smart lockers", "smart lockers", "last mile logistics", "urban e-commerce", "automation in delivery", "logistics sustainability" and "technology in distribution", combined with each other through Boolean operators (AND, OR) and applied in different bases to expand the scope of the research without losing the analytical and thematic focus necessary for the construction of a reasoned discussion.

The inclusion criteria involved materials published in journals or repositories of recognized academic quality, with a clear methodology, a focus on logistics applied to digital retail, and a direct approach to smart lockers or last-mile logistics systems, while the exclusion criteria included opinion texts, without scientific validation, outdated studies, or documents that had redundant or excessively generalist content.

As a methodological framework, the proposal of Lakatos and Marconi (2021) is adopted, who define bibliographic research as an effective means of investigating a phenomenon based on the knowledge accumulated and consolidated in scientific productions, especially in areas where the practices under development are still in the consolidation phase in the market, as is the case of the application of smart lockers in Brazil.

This strategy allows us to understand not only the operational benefits of smart lockers, but also the cultural, legal, economic, and structural obstacles that impact their implementation, opening space for reasoned propositions and suggestions for improvements applicable to the national scenario, based on international experiences and evidence extracted from the literature analyzed.

CHALLENGES OF LOGISTICS IN CONTEMPORARY E-COMMERCE

The dizzying growth of e-commerce has caused profound transformations in distribution logistics, putting pressure on traditional operating models and exposing critical bottlenecks in the supply chain. With the intensification of the demand for fast and safe deliveries, especially in densely populated urban contexts, technological solutions such as smart lockers emerge as promising alternatives to address the structural deficiencies of the so-called "last mile", reducing costs, optimizing time and improving the consumer experience.

GROWTH OF E-COMMERCE AND LOGISTICS IMPACTS

The expansion of e-commerce, accelerated by the context of the COVID-19 pandemic, has made this sales channel reach new heights in terms of volume and representativeness. In Brazil, e-commerce went from 5% to 13% of total retail sales between 2019 and 2020, representing an abrupt and unprecedented growth in the sector, which triggered serious impacts on the available logistics infrastructure (Mateus; Cardoso, 2021). This change in behavior was driven by the entry of new consumers into the digital environment, of which about 24% made their first online purchase during the pandemic, demanding speed, reliability, and convenience in the delivery process (Marioti; 2021).

The international scenario followed the same trend. In Latin American countries such as Honduras, Costa Rica, and Mexico, delivery services have faced an overload due to the multiplication of orders and the scarcity of solutions that enable agility in urban deliveries, especially in metropolitan centers (Salinas Lizardo; 2021). This reality reinforces the importance of mechanisms that can decompress logistics flows, decentralize delivery points, and offer functional alternatives to conventional distribution methods, with *smart lockers* being one of these promising tools (Vakulenko; 2023).

THE LAST MILE AS A LOGISTICAL BOTTLENECK

Despite all the technological advances in inventory management and transportation, the final last mile of delivery to the consumer remains one of the biggest challenges for the logistics sector. It is estimated that this phase represents up to 53% of the total cost of delivery in e-commerce operations, making it a critical point for the competitiveness and sustainability of operations (Negreiros; Sousa, 2022). Among the main obstacles faced at this stage are the absence of the recipient at the time of delivery, routing failures, urban

congestion, and difficulties in accessing high-flow locations, such as commercial and residential buildings (Nascimento et al.; 2021).

In addition, the high rates of returns and redeliveries further aggravate the logistics overload, compromising the customer experience and significantly increasing the operating costs of carriers and *marketplaces* (Cruzeiro; Kloeckner, 2022). The adoption of *lockers* as alternative pick-up points appears as a functional solution to many of these obstacles, allowing the decentralization of deliveries and the consumer's autonomy to access the product at more convenient times (Soto Júnior et al.; 2023). This directly contributes to the reduction of the delivery cycle time and the optimization of distribution vehicle routes, with a positive impact also on the reduction of emissions (Vakulenko; 2023).

TRENDS AND NEEDS FOR INNOVATION IN URBAN DELIVERIES

With the intensification of environmental pressures and the transformation of consumption habits, it is imperative to adopt more sustainable, flexible and customer-centric logistics models. In this scenario, smart lockers are a consolidated trend in the global market, not only for their operational efficiency, but also for their contribution to urban redesign, by reducing the circulation of delivery vehicles and emissions of polluting gases (Severo et al.; 2023). Growing urbanization and the search for digital convenience have led consumers to value alternative delivery options that allow speed, autonomy and predictability (Cruzeiro; Kloeckner, 2022).

In countries such as Sweden, Poland, and Singapore, public policies and private investments have favored the implementation of large networks of *lockers*, associated with intelligent management systems based on data, artificial intelligence, and geolocation (Vakulenko; 2023). Amazon's case is emblematic in this context: with the application of advanced package allocation algorithms and dynamic capacity management, the company was able to significantly increase the efficiency of its *lockers*, showing the potential for scale and innovation of this technology (Sethuraman et al.; 2023). These movements point to a future in which the *locker* will be a structuring part of the smart urban infrastructure, becoming not only a pick-up point, but a strategic link in the urban logistics value chain.

SMART CABINETS: CONCEPT, OPERATION AND APPLICATIONS

Smart *lockers* represent a logistics innovation that has gained prominence in the last decade, especially in the context of urban last-mile delivery. Created to offer greater autonomy to the consumer and efficiency to the logistics process, these devices have been consolidating themselves as strategic alternatives to fill gaps in traditional distribution, both

in Brazil and in several countries in Europe, Asia and Latin America. This chapter presents its main characteristics, the application models already consolidated and the national panorama of opportunities and challenges for the expansion of this technology.

DEFINITION AND CHARACTERISTICS OF *SMART LOCKERS*

Smart lockers are automated modular compartments, usually installed in easily accessible areas, such as subway stations, supermarkets, universities, and condominiums, and that allow consumers to pick up packages autonomously with the use of passwords, *QR codes*, or app recognition (Soto Júnior et al.; 2023). They operate with electronic locking systems and real-time connectivity, ensuring security in storage and full traceability of the object from entry to withdrawal (Vakulenko; 2023). The most modern versions are already integrated with technologies such as the Internet of Things (IoT), *machine learning*, and space optimization systems, increasing the efficiency of package allocation based on dwell time and type of delivery (Sethuraman et al.; 2023).

As for their application, *lockers* can serve both the end public (B2C model), as in the case of e-commerce deliveries, and companies (B2B model), as a tool for managing documents or objects in corporate environments (Severo et al.; 2023). In addition, there are mixed-use or collective models, aimed at public areas, and private models, used by retail chains or specific institutions, such as universities and hospitals (Schmitz; 2023). The structural and operational versatility of *smart lockers* makes them adaptable to different logistics flows and urban realities, allowing them to expand in places with high population density or high turnover of people.

USE CASES AND INTERNATIONAL EXPERIENCES

International examples of successful locker implementation are varied and offer concrete evidence on the operational benefits of this solution. One of the most consolidated models is Amazon Locker, which uses artificial intelligence algorithms to optimize package distribution and reduce rejections in deliveries based on *dwell time* and type of shipment analysis (Sethuraman et al.; 2023). In Europe, Poland's InPost system stands out for its wide network of *lockers* interconnected by a single platform, which provides fast deliveries, real-time tracking, and integration with local and international *marketplaces* (Vakulenko; 2023).

In Asia, the Alibaba group created the Cainiao Smart Logistics Network, responsible for operating thousands of lockers in China, with a focus on operational intelligence and automation of last-mile logistics in urban centers (Marioti; 2021). In Singapore, the Locker

Alliance initiative centralized the use of public lockers, allowing multiple delivery companies to share the same terminal, optimizing urban space and reducing the carbon footprint of the distribution system (Vakulenko; 2023). These experiences show that, when well planned and integrated into the urban logistics network, the adoption of *smart lockers* can bring significant gains in efficiency, scalability, and sustainability (Salinas Lizardo; 2021).

SITUATION IN BRAZIL: OPPORTUNITIES AND LIMITATIONS

In Brazil, the application of smart lockers has advanced, although it still faces structural, regulatory, and cultural obstacles. Initiatives such as Correios Locker, the terminals of Panvel Farmácias, Via Varejo and the independent *lockers* of the startup Clique Retire already operate in large centers, especially São Paulo, Curitiba and Porto Alegre (Mateus; Cardoso, 2021). These solutions have been adopted mainly by companies that want to expand their delivery capacity without expanding their physical distribution centers, offering more autonomy to the consumer and relieving the traditional logistics system (Negreiros; Sousa, 2022).

However, there are barriers that hinder the expansion of the technology in the national territory. Among them, the high initial cost of implementation, the low logistics culture aimed at decentralization, and the lack of integration with public policies for urban mobility and digital infrastructure stand out (Nascimento et al.; 2021). Another factor is the public's lack of knowledge about how *lockers* work, as shown by a survey in São Paulo subway stations, where most users said they had never had contact with this type of technology, despite expressing interest in using it (Cruzeiro; Kloeckner, 2022).

Even in the face of these limitations, *smart lockers* are pointed out as a viable and scalable alternative to improve the logistics performance of Brazilian e-commerce, as long as they are accompanied by consumer education, incentive to innovation by the State, and partnerships between retailers and logistics operators (Vakulenko; 2023).

SMART CABINETS AS A STRATEGIC SOLUTION

The incorporation of smart lockers into the e-commerce logistics system goes beyond operational modernization: it represents a structural transformation strategy. These devices have become part of cutting-edge supply chain solutions, with a direct impact on reducing operating costs, increasing delivery efficiency, enhancing the consumer experience, and integrating with emerging digital technologies. With this multifunctionality, *smart lockers* are increasingly perceived as advanced and sustainable logistics points,

capable of meeting the complexity of urban logistics in an intelligent, scalable, and adaptable way.

COST REDUCTION AND EFFICIENCY INCREASE IN THE LAST MILE

The last mile is one of the most costly and unpredictable phases of delivery, accounting for up to 53% of the total logistics value, especially due to redeliveries caused by the absence of the recipient, congestion and routing failures (Negreiros; Sousa, 2022). Smart lockers help overcome these obstacles by providing fixed pick-up points in strategic locations, such as subway stations, supermarkets, and pharmacies, reducing travel time and the need for multiple delivery attempts (Nascimento et al.; 2021). This translates into reduced fuel, carbon emissions, and pressure on distribution centers, making the system more efficient and environmentally sustainable (Vakulenko; 2023).

The Natura study, for example, points out that automated logistics hubs and locker flow mechanisms can alleviate distribution bottlenecks at peak times, such as commemorative dates and promotional campaigns, by decentralizing the flow of orders and speeding up service to metropolitan regions (Severo et al.; 2023). In Amazon's experience, the use of locker capacity management algorithms resulted in a 9% increase in *throughput* and savings of $24.3 million over three years, confirming the positive impact on operational efficiency (Sethuraman et al.; 2023).

IMPROVING CUSTOMER EXPERIENCE

In addition to the operational gains, *smart lockers* offer more autonomy and convenience for the consumer, who can pick up his order at the most convenient time, without depending on the presence at home or the availability of an attendant (Cruzeiro; Kloeckner, 2022). This directly contributes to the reduction of frustrations, delays, and returns, raising the levels of satisfaction and loyalty of the consumer public (Schmitz; 2023). Research data indicate that more than 77% of users would choose to use *lockers* even if they had other options, and about 80% of those who have already used the technology have come to prefer it over traditional methods (Mateus; Cardoso, 2021).

These indices reflect the value perceived by the customer not only in the functional aspect, but also in the sense of control, security, and practicality, which align with the expectations of today's digital consumer (Vakulenko; 2023). The adoption of *lockers* also facilitates the process of exchanges and returns, especially when integrated with the reverse logistics of e-commerce, reducing friction in the post-sale stages and strengthening

the brand's reputation (Negreiros; Sousa, 2022). Thus, *smart lockers* act as relationship tools, not just delivery, expanding the company's perception of value to the customer.

POTENTIAL FOR INTEGRATION WITH EMERGING TECHNOLOGIES

The effectiveness of smart lockers is not limited to their physical structure; it expands exponentially when associated with technologies such as the Internet of Things (IoT), geolocation, mobile applications, *blockchain* , and artificial intelligence, composing an intelligent logistics ecosystem (Soto Júnior et al.; 2023). Companies such as Amazon and InPost have already implemented predictive algorithms for real-time package allocation and capacity adjustments, increasing the success rate of deliveries and decreasing the wait time for pickup (Sethuraman et al.; 2023).

In addition, integration with apps allows consumers to track each step of the delivery, receive automatic notifications, and access the locker with secure and personalized authentication, which reinforces the usability and reliability of the system (Vakulenko; 2023). In more advanced projects, such as Singapore's Locker Alliance, *smart lockers* are seen as shared infrastructures, connected to public and private networks, capable of simultaneously serving different logistics operators and, in the future, integrating additional services, such as receiving official documents or picking up perishable products (Salinas Lizardo; 2021).

In this sense, *smart lockers* emerge as multifunctional urban logistics nodes, able to operate as distribution hubs, collection points, reverse logistics centers, and smart data platforms, consolidating themselves as a vital link between e-commerce, the consumer, and the smart city of the future (Vakulenko; 2023).

CONCLUSION

The analysis of the implementation of smart lockers as a logistics solution for e-commerce shows a significant change in the way companies deal with last-mile challenges, revealing that the integration of automated technologies into the urban distribution chain is not just about operational modernization, but about the strategic redefinition of the entire delivery experience. with direct impacts on efficiency, sustainability and consumer satisfaction.

The data presented throughout the research demonstrate that smart lockers have the potential to reduce logistics costs, minimize delivery failures, decentralize the distribution process and, at the same time, offer consumers greater autonomy in picking up their orders, representing a positive break in traditional delivery models, especially in large

urban centers where traffic and population density compromise the predictability and agility of operations.

International experience indicates that the massive adoption of this technology depends not only on technical or financial factors, but also on public policies, incentives for innovation and the involvement of multiple actors in the logistics chain, which reinforces the need for an integrated approach between the private sector and urban managers so that smart lockers are no longer a one-off solution and become part of the permanent logistics infrastructure of cities.

When considering the Brazilian case, there is a progressive advance in the adoption of lockers, although with limitations related to infrastructure, lack of public knowledge, cost of implementation and absence of specific regulations that encourage their expansion, factors that impose barriers to the growth of the model, but which also show a latent opportunity for transformation and technological leadership in the Latin American logistics scenario.

The use of smart lockers transcends e-commerce logistics and becomes part of the logic of smart cities, where public spaces, services, and technologies converge to promote greater fluidity, connectivity, and sustainability, which is a promising path to reorganize urban mobility, reduce emissions, and ensure more efficiency in the provision of services to an increasingly connected and demanding population.

The operational benefits of this technology, such as the reduction of redeliveries, the improvement of the logistics success rate, and the lower dependence on time windows, make smart lockers a viable and scalable alternative, capable of serving both small digital retailers and large marketplace chains, promoting competitiveness and digital inclusion in a horizontal way.

The positive perception of consumers in relation to the autonomy and security provided by lockers also contributes to their strengthening, showing that the value perceived in the delivery experience goes beyond punctuality, involving elements such as convenience, control and less friction in the relationship with brands, which reinforces the strategic role of logistics as a vector of loyalty.

By broadening the discussion to the field of sustainability, it is observed that smart lockers have significant potential to contribute to environmental goals and to the construction of a more responsible supply chain, especially when integrated with reverse logistics systems, shared use and urban planning strategies aimed at reducing the environmental impact of last-mile distribution.

The integration of lockers with emerging technologies such as IoT, artificial intelligence, blockchain, and geolocation offers even more possibilities for the advancement of digital logistics, creating predictive, adaptive, and connected systems that align with global trends in automation, hyper-personalization, and energy efficiency, consolidating the role of smart lockers as multifunctional urban logistics hubs.

Thus, it is concluded that smart lockers represent a viable, efficient and sustainable logistics solution for e-commerce, with great potential for expansion in Brazil and in the world, and it is necessary to foster public policies, expand access to technology and promote collaboration between logistics agents, in order to enable their full integration into the urban fabric and transform the last mile into a competitive and socially responsible differential.

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