

Parcel Lockers as a Logistic Concept: A Systematic Review of Implementation Strategies and Outcomes

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Abstract

Last-mile logistics, particularly parcel delivery to diverse customers, is increasingly significant due to the rise of online markets. Despite short distances, the last mile consumes the highest resources in delivery processes, prompting the exploration of various strategies and innovations. Focus has expanded beyond cost considerations to include ecological impacts, with technological advances offering substantial sector gains. The Covid-19 pandemic has accelerated e-commerce growth, intensifying parcel deliveries. Parcel lockers, introduced around two decades ago, have seen steady adoption, yet their full advantages remain underexplored. Recent literature has highlighted their relevance, with a surge in related articles in the past three years. This paper provides an overview of existing parcel locker technologies, their application, and implementation in delivery processes. Beginning with theoretical foundations, it employs a systematic literature review to analyze current research, covering methods, algorithms, and impacts on last-mile delivery and customer satisfaction. By synthesizing insights from diverse research, the paper offers a thorough examination of parcel lockers' state-of-the-art and their influence on last-mile logistics. It concludes with a summary of the reviewed literature and prospects for future developments in the field.

Keywords

Parcel lockers, last mile logistics, parcel delivery, Smart Logistics, Logistics 4.0

1. Introduction

Last-mile logistics, particularly parcel delivery to diverse customers, is a more relevant topic than ever, thanks to the booming online market. Even though the distances are usually rather short, the last mile consumes the highest number of resources in comparison to all preceding stages of delivery. After recognizing the critical importance of optimizing this aspect, various strategies and innovations have been explored. However, the focus is not only on cost considerations but increasingly also on the ecological impacts associated with short-distance transportation. The most significant gains for this sector can arise from technological advances and the resulting savings. Especially since the COVID-19 pandemic, e-commerce is growing rapidly and with it parcel deliveries. Some companies initiated the use of parcel lockers to tackle the problem with the last mile around two decades ago and looking at the numbers presented by some companies, the number of lockers is steadily rising (DHL Group 2023; Zunk et al. 2020).

However, the advantages and possibilities of these parcel lockers have not been fully examined yet and need a more extensive look. As indicated by the published literature, the subject gained relevance and was addressed in detail not too long ago. Most articles related to parcel lockers were published in the past three years. This paper provides an overview of both existing and developed technologies of parcel lockers, as well as their application and implementation in the delivery process. The paper commences with an explanation of the theory and background

concerning the covered topic. Subsequently, a systematic literature review method was employed to analyze the existing body of literature. The content of the selected literature was then processed and evaluated. Within this analysis, different viewpoints were covered, such as methods and algorithms for using and placing parcel lockers, the help and benefits in the last mile delivery and the impact on customer satisfaction. By gathering insights from various types of research, this paper offers a thorough examination of the state-of-the-art of parcel lockers and their influence on last-mile delivery. In the final section, a summary of the reviewed literature, coupled with a concise preview of essential future developments in this area is given.

2. Literature Review: Theory of Parcel Lockers and Last Mile Logistics

Last-mile logistics has always been crucial for the entire supply chain, particularly for CEP (Courier, Express, and Parcel) service providers, as it accounts for about two-thirds of the total transportation costs. The last mile is, like the name suggests, the final stage of the delivery, which is often a short distance, but it still takes a lot of resources (Grein 2021).

Consequently, numerous ideas are being explored to optimize this significant cost factor. However, not only are cost considerations important, but the ecological aspects of these often-short transport distances also need to be considered. Studies show that CO₂ emissions could be reduced by up to 57% with a different delivery approach (Statista 2024). The technological advances in this field are diverse. The adoption of electric vehicles is becoming more practical and self-driving vehicles are continuously making progress. Moreover, flying vehicles like drones are being increasingly considered as a viable option. The most significant change in the last couple of years undoubtedly resulted from the global pandemic of COVID-19, due to the shift in shopping habits caused by restrictions. Many shops were closed, and countless countries had complete lockdowns. Therefore, people around the globe resorted to ordering online. The increase in online orders averaged around 20% per year during the pandemic, necessitating rapid adaptation in logistics within a relatively short timeframe. This accelerated the trend to more e-commerce even further (Rusche 2021).

One possible solution is the concept of parcel lockers. These are compact storage compartments equipped with a control unit, which are strategically positioned, primarily in urban areas, but they are also expanding into more rural regions. The key benefit of parcel locker usage during the pandemic was the delivery without human interaction. The parcel can be ordered and delivered entirely without human contact and pickup is almost always possible 24/7, so they are much more flexible than home deliveries. However, the concept of parcel lockers is not entirely unfamiliar, at least not in some parts of Europe. The setup of the first lockers was over 20 years ago with just a few locker locations at that time. Now the network grew to about 12500 lockers from DHL in Germany alone, with over 23 million registered customers. In Austria, the network of lockers is also expanding, with DHL, holding a market share of 25%, operating more than 2200 locations (DHL Group 2023).

3. Methods and Data Collection: Systematic Literature Review

To analyze the state-of-the-art of parcel lockers in urban areas, systematic literature research on the online platform “Scopus” was carried out. “Scopus” is a multidisciplinary abstract and citation database with the world’s biggest collection of abstracts, literature, and sources with over 87 million documents from over 17 million authors (Elsevier 2024; Scopus 2024).

At Scopus it is possible to search for specific literature by using keywords, in this case, the strings “parcel lockers”, “packets lockers“, and “packages lockers” were chosen with an “or” connection and connected with “and” to the Strings “city”, “cities”, “urban” or “last mile”. Furthermore, the restriction of six years, 2019 - 2024 was applied and the subject area was limited to “Engineering” and “Business, Management and Accounting”. As displayed in Figure 1, the search returned 71 results. After a brief review of the 71 documents, the literature was divided into three sections of relevance: 23 papers were low relevant, 27 papers were medium relevant, and 21 papers were chosen to be high relevant for this paper. The literature, selected as highly relevant, was thoroughly examined, and utilized for the topic addressed in this paper (Kaiblinger and Woschank 2022; Miklautsch and Woschank 2022; Pacher et al. 2024; Page et al. 2021; Woschank et al. 2020).

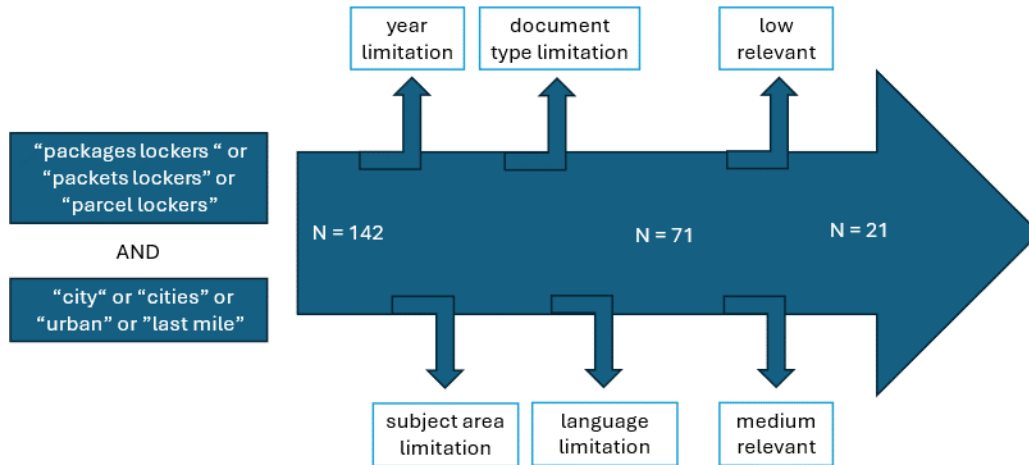


Figure 1. Process of Systematic Literature Review

4. Results and Discussion

The reviewed literature consisted of two document types: Articles and conference papers. Figure 2 illustrates that 89% of the identified literature comprises articles, while the remaining 11% are conference papers.

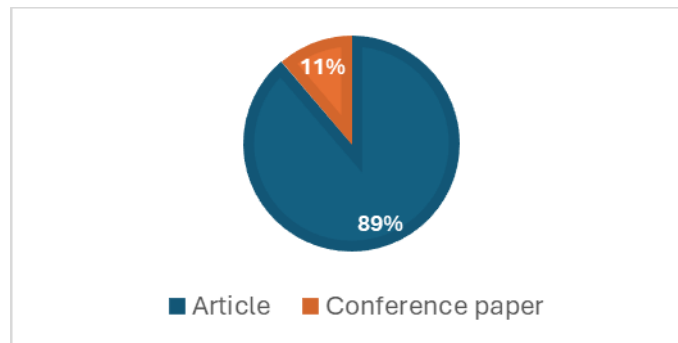


Figure 2. Document types

The fact that the topic has recently gained importance is evident from the distribution of literature over the last few years. As depicted in Figure 3, the number of documents significantly increased in 2021 and has continued to grow ever since.

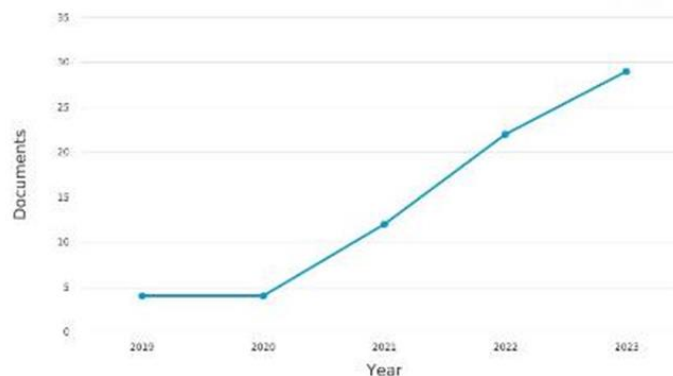


Figure 3. Distribution over the years

Figure 4 shows a heatmap with the number of documents published in the respective countries. It can be noted that the region around China has the most records, followed by North America. However, the topic has also been taken up and discussed both in Europe and Australia.

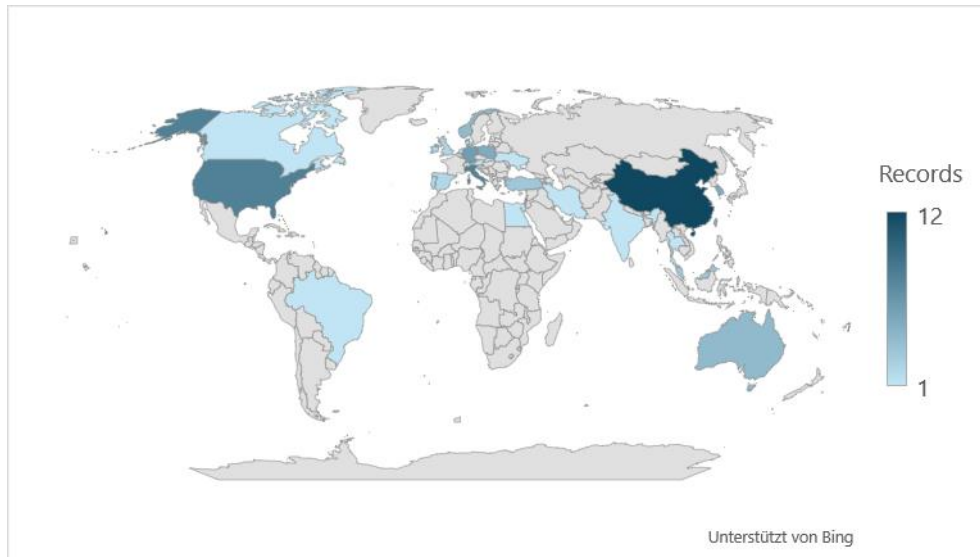


Figure 4. Heatmap of records by country

The reviewed papers, articles and journals had different approaches to the topic of parcel lockers. A few of them are focused on the optimization and the ideal placement of the lockers themselves, with a linear programming formulation (Kahr 2022) or utilizing the AHP in a Spherical Fuzzy environment with the EDBAM (Moslem and Pilla 2023). Raviv (2023) on the other hand presented an innovative model that uses a piecewise linear approximation to optimize the facility location for parcel lockers. Additionally, route planning was examined using various algorithms and computing methods, such as the Genetic Algorithm (GA) or Hybrid Q-Learning-Network-based Method (HQM) (Liu et al. 2023; Pan et al. 2021; Wang et al. 2020). The choice of algorithm alone can lead to completely different outcomes. The mentioned HQM can yield a result twice as effective as the GA, while requiring significantly less computation time, on the same hardware. Another vehicle routing problem, which focused on parcel lockers, was solved by using a data-driven framework. This research formulates an MT-VRPDO and proposes a heuristic solution using ALNS (Janinhoff et al. 2023a). Furthermore, an integrated simulation model was developed to assess the three-dimensional impact of green parcel delivery interventions like electric vehicles, parcel shops and parcel lockers (Bell et al. 2023).

The literature also addresses subjects like the comparison of effects in urban and rural environments (Seghezzi et al. 2022) and a comparison of cost savings and the alleged environmental benefits when using this fairly new technology (Bonomi et al. 2022; Kahr 2022) or empirically assessing the impact of parcel lockers in residential buildings on delivery times by experimenting (Ranjbari et al. 2023). Similar studies were made in Oslo where a network with different scenarios was designed and simulated with real-live empirical shipment data, made available by PostNord, a provider of postal services. To see the benefits and changes between scenarios, the vehicle routing solver SPIDER was implemented into the project (Pinchasik et al. 2023). Moreover, Ding et al. (2023) developed an analytical framework to determine the supply and demand for smart parcel lockers in a selected region and Corejova et al. (2022) took a more general approach by analyzing the infrastructure of automated parcel lockers and PUDO delivery facilities.

Various papers have aimed to identify the key attributes that a parcel locker should possess to be accepted by people and utilized as an alternative to home delivery. A study conducted by Tang et al. (2021) used the SERQUAL and the LSQ model, which were both also utilized in the study of Lai et al. (2022). In addition to that, Tang et al. (2021) also

employed the e-service quality model. With the Kano model, an alternative model was used within the research of Cieřła (2023).

Another approach and another possible solution can be non-stationary lockers in different variants (Schwerdfeger and Boysen 2022; Wang et al. 2020). Different variants span from “conventional” trucks with mounted compartments to models with interchangeable drivers or vehicles and even autonomous vehicles, equipped either with mounted or loaded lockers (Schwerdfeger and Boysen 2022). A more technical perspective on the topic of parcel locker systems was provided by Ooi and Tan (2021), who introduced a system utilizing IoT technology and other technical refinements like dimension scanning. Finally, a systematic literature review aimed to identify trends in sustainable last-mile delivery in cities from various stakeholders’ perspectives. Results indicated that the most frequently discussed stakeholders were receivers and shippers and that there has been a significant increase in the number of papers published since 2018-2019 related to sustainable last-mile delivery. Moreover, the highest number of papers were published by German, Chinese and Italian authors, and the most cited articles, which implicate popularity, were related to the measures introduced for last-mile delivery (e.g.: parcel lockers) (Kiba-Janiak et al. 2021). The results from all the given sources are not quite uniform. All except one have based their research around business-to-customer (B2C) delivery, although it can be an option for business-to-business (B2B) deliveries and even more synergies in that field (Pan et al. 2021).

Regarding the infrastructure of parcel lockers between different European countries, there is a vast difference in the number of automated parcel lockers and PUDO delivery points (Corejova et al. 2022). Furthermore, parcel lockers inside residential buildings are highly welcomed by residents and implementing them can decrease the time couriers spend in buildings while delivering by up to 60%. In addition to that, a reduction in delivery vehicle dwell times at loading zones of 33% was also observed (Ranjbari et al. 2023). From the example of the case study of Tianjin, it is possible to deduce that there is a mismatch between demand and supply for smart parcel lockers. Hence, demand is greater than supply for such facilities (Ding et al. 2023).

By using the integrated simulation model to assess the impact of electric vehicles, parcel shops and parcel lockers on the last mile, it was possible to reduce delivery cost by up to 23%, delivery time by up to 40% and emission levels by up to 53% (Bell et al., 2023). These are similar results to the studies of Pham and Lee (2019) and Pinchasik et al. (2023). This indicates that utilizing the proposed simulation model for optimizing last-mile delivery can lead to economic, social, and ecological benefits. After all, the most crucial factor for parcel lockers is customer acceptance, given that the implementation of such a complex system would incur significant costs, making it feasible only if their usage is high enough. According to the papers utilized in the content analysis, a few key elements for customer satisfaction were timeliness, 24/7 customer support and reliability, but many others should not be overlooked (Tang et al. 2021; Cieřła 2023; Lai et al. 2022).

5. Conclusion

From the viewpoint of Industrial Engineering and Management respectively from the interdisciplinary perspective of modern Engineering Education, it can be stated that the steadily growing e-commerce market and the increasing number of parcel deliveries call for novel professional and educational concepts to improve the last-mile problem or, more generally spoken, the entire delivery process (Pacher et al. 2022; Pacher et al. 2023; Pacher et al. 2024; Zunk and Marchner 2009; Zunk 2018; Zunk et al. 2020). The infrastructure of parcel lockers varies significantly between European countries. Their implementation within residential buildings is well-received, contributing to reduced delivery and vehicle dwell times. However, numerous algorithms and methods for placing parcel lockers are mentioned. The integration of electric vehicles, parcel shops and parcel lockers in the last mile demonstrates substantial benefits, including reduced delivery costs, time, and emission levels. The literature included examples of studies conducted to acquire the necessary data for validating and confirming assumptions. Furthermore, a few papers focused on identifying crucial factors related to customers, recognizing the significance of customer acceptance for the successful and practical application of parcel lockers in the delivery process.

The concept of parcel lockers, in its various forms, has the potential to make a difference in future last-mile delivery concepts. It is not only an option for consumers but can also be utilized by other businesses for mutual benefit. However, achieving optimal utilization requires time for development. The key lies in conducting more real-world studies and tests to gather reliable data. Some parcel lockers are already operating in urban areas, used, and maintained by big companies like DHL or Amazon (Pan et al. 2021).

The real solution will not be solely one approach or the other. It will be the combination of different methods. Although the studies presented somewhat different results and solutions, the consensus is consistently similar: there can be ecological and economic advantages if used correctly. The outcomes regarding cost and emissions savings vary significantly depending on the article and method used, with some proposing solutions to routing or placement problems. Despite the results not being perfectly accurate or entirely correct, they offer a solid foundation for further research and can contribute to solving this. Nevertheless, for it to be implemented as a last-mile concept everywhere, especially on a large scale, extensive research, tests, and studies are still required.

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