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Enhancing the Efficiency of Parcel Locker Networks in Postal and Courier Services

Abstract

This article aims to enhance the efficiency of automated parcel pickup networks operated by postal and courier services by developing recommendations for optimizing parcel locker compartment sizes based on statistical analysis. *Methodology.* Statistical analysis methods were applied to determine optimal locker sizes. System analysis was used to structure and evaluate the postal service's shipment database. Additionally, graphical and tabular methods were employed to visualize the results and facilitate their interpretation. *Results.* Using Nova Poshta as a case study, the shipment structure was analyzed, identifying two categories of parcels suitable for delivery via parcel lockers. The consistency between the nationwide shipment structure and a control sample from Kyiv was assessed. Based on this analysis, an algorithm was developed to determine the share of parcels for which the existing locker sizes are optimal. *Practical implications.* The statistical analysis of the occurrence rate of parcels with varying dimensions facilitated the formulation of hypotheses regarding the most efficient locker compartment sizes. The implementation of the proposed algorithm allowed for the identification of the share of parcels for which the compartment sizes of both indoor and outdoor parcel lockers are optimal. *Value / originality.* The findings on optimal parcel locker compartment sizes provide a foundation for the efficient utilization of locker volume. This leads to improved throughput capacity of the parcel locker network, yielding a positive economic effect by reducing investment costs for network development.

Keywords

postal and courier services, efficiency, automation of parcel pickup, operational business processes, three-dimensional bin packing problem, statistical analysi

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1 Introduction

Postal and courier services play a vital role in the economic system, garnering significant attention from both domestic and international researchers. Numerous innovative solutions have been proposed to enhance the efficiency and automation of operational business processes in this sector, including the use of autonomous vehicles (Buko, Bulsa, & Makowski, 2022) and drones (Aurambout, Gkoumas, & Ciuffo, 2019) for parcel delivery.

In practice, however, leading postal and courier service providers like the Ukrainian company Nova Poshta have seen another key trend emerge: the development and expansion of automated parcel pickup networks (parcel lockers). This strategic direction is central to the digitalization of business processes, enabling customers to retrieve parcels via mobile applications without direct interaction with company personnel. Beyond streamlining operations, this system greatly enhances customer convenience. By the time of this study, Nova Poshta's parcel locker network had already outgrown its traditional branch network, bringing pickup points closer to customers. Moreover, parcel lockers offer the advantage of 24/7 accessibility, allowing recipients to collect shipments at their convenience, without the need to wait in line.

A key factor in ensuring the efficiency of parcel delivery through lockers is the optimal use of internal volume. The primary challenge lies in partitioning locker space into compartments of various sizes, ensuring that parcels of different dimensions can be accommodated simultaneously, while accounting for the varying frequencies of shipments of specific sizes.

2 Review of Scientific Research on the Bin Packing Problem

The task of improving the efficiency of a parcel locker network by optimizing compartment sizes can be viewed as a variation of the well-known bin packing problem (BPP). The core objective of BPP is to determine the optimal arrangement of items of various sizes within a bin, aiming either to maximize the utilization of available volume or to minimize the number of bins required. When applied to three-dimensional bins with rectangular faces, the problem can be understood as a three-dimensional bin packing problem (3D-BPP) (Martello, Pisinger, & Vigo, 2000). While the use of rectangular surfaces is not strictly necessary (Stoian et al., 2018), this specific case is particularly relevant for optimizing the sizes of parcel locker compartments. The three-dimensional bin packing problem is widely applied in addressing various practical issues. In logistics, for example, it is commonly used to optimize pallet arrangement (Elhedhli, Gzara, & Yildiz, 2019) and bin loading (Tian et al., 2016).

Despite significant research efforts, the three-dimensional bin packing problem (3D-BPP) remains unsolved due to its high computational complexity. Although there are some prospects for addressing 3D-BPP through the use of quantum computing (Romero et al., 2023; De Andoin et al., 2022), a general solution was not available at the time of this study.

It is worth mentioning that the task of optimizing parcel locker compartment sizes has certain characteristics that allow it to be simplified into a two-dimensional problem. Since the depth of parcel locker compartments is standardized across all units, it can be treated as a fixed parameter. Consequently, only height and width of the compartments remain variable and become subject to optimization, thus reducing the problem to two dimensions. However, even the two-dimensional bin packing problem remains NP-hard (Oliveira, Gamboa, & Silva, 2023) and, like its three-dimensional counterpart, lacks a general solution.

3 Research Methodology

This study applies statistical analysis methods to optimize compartment sizes within a network of automated parcel pickup points, offering a practical alternative to traditional bin packing approaches. System analysis methods were used to structure and evaluate Nova Poshta's shipment data. Furthermore, graphical and tabular tools were employed to visualize the research findings.

4 Formation and Analysis of the Research Information Database

To address the optimization of compartment sizes in the automated parcel pickup network, a comprehensive database was created. This included all types of shipments handled by Nova Poshta during the study period.

Nova Poshta classifies shipments into five categories, only two of which – documents and parcels – are eligible for delivery via parcel lockers. During the study period, the dataset included approximately 488,000 document shipments and 5,496,000 parcel shipments, forming the basis for further analysis.

The remaining shipment categories – Cargo (457,000 shipments), Tires and Rims (22,000 shipments), and Pallets (14,000 shipments) – are not eligible for parcel locker delivery and are handled through specialized freight offices. The handling of such large or heavy consignments is constrained by infrastructure limitations, including the absence of necessary access routes or unloading facilities for heavy-duty vehicles at certain offices.

The analysis next focused on the internal structure of the Parcels category, which was subdivided into three types: Standard Parcels (42% of total shipments); Small Parcels, (56%); and Special Parcels (2%). These are distinguished by at least one large dimension despite relatively low weight. Due to their dimensions, Special Parcels are not compatible with parcel lockers and were therefore excluded from further consideration. The analysis was solely confined to Small and Standard Parcels, which are eligible for delivery through the parcel locker network.

To verify the proportional breakdown of parcel types, 1,250 control measurements were conducted at eight Nova Poshta offices in Kyiv. The results, summarized in Figure 1, indicated the following ratio between Standard Parcels and Small Parcels (Figure 1).

As shown in Figure 1, the structure of shipments in the control sample aligns with the structure derived from nationwide data.

Subsequently, a database of parcels with accurately measured dimensions was compiled, using data from three innovative sorting terminals: Khmelnytskyi (KHIT), Kyiv (KIT), and Lviv (LEE). Parcel dimensions were automatically recorded at these terminals using the Cubiscan system developed by the Dutch company Vanderlande.

Additionally, at the Kyiv terminal, 10,544 manual measurements were performed on small parcels. In total, this process yielded a dataset of 1,697,924 shipments with objectively measured dimensions.

For statistical processing of this data, the SPSS software package was chosen, as it is a reliable tool

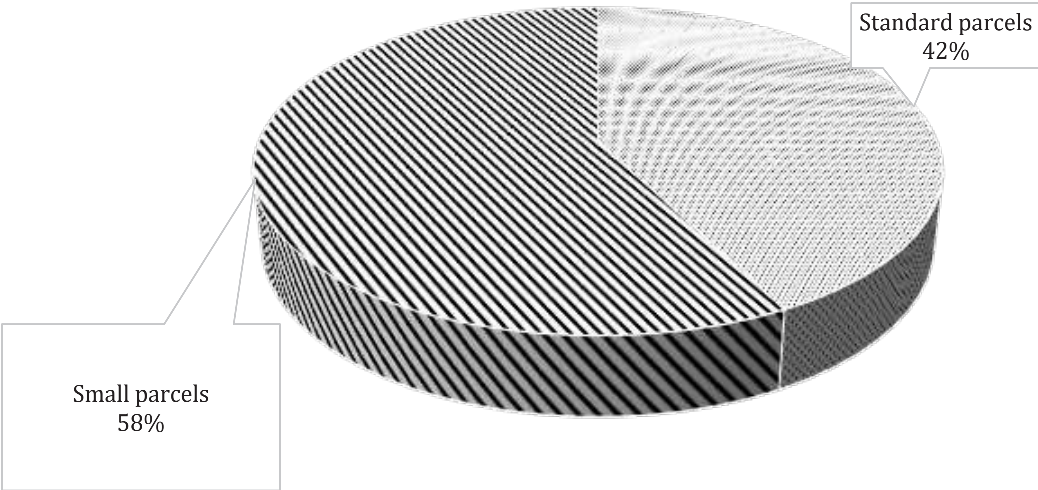

FIGURE 1 Structure of Shipments Based on Control Measurements at Nova Poshta Offices in Kyiv

Source: Compiled by the author based on Nova Poshta data

for both academic research and business data analysis (Chernyak, & Chornous, 2020).

The first stage of the analysis involved generating descriptive statistics, summarized in Table 1.

Table 1 presents statistical summaries for the three primary measured dimensions of each parcel: maximum, average, and minimum. Although some parcels had both the maximum and average dimensions reaching 70 cm, the 95th percentile values indicate that 95% of parcels had a maximum dimension no greater than 58 cm and an average dimension no greater than 48 cm. Notably, some parcels had a minimum dimension of up to 49 cm. This is particularly significant because parcel lockers have standardized depths: 31 cm for indoor lockers and 47 cm for outdoor lockers. Due to these depth constraints, parcels exceeding the respective minimum dimension thresholds were excluded from further analysis. As a result, 537,105 parcels (31.6%) were removed. The remaining parcels were divided into two separate datasets: one for those to be delivered through indoor lockers and another one for outdoor lockers.

The dataset for indoor lockers contained 529,931 shipments, representing 31.2% of the original dimensional database. These parcels had a minimum dimension of no more than 30 cm, meeting the depth limitation of indoor lockers.

The dataset for outdoor lockers comprised 630,888 shipments, accounting for 37.2% of the total. These parcels had a minimum dimension no greater than 46 cm, ensuring compatibility with the depth of outdoor lockers.

5 Formulating a Hypothesis on the Optimal Dimensions of Parcel Locker Compartments

The statistical analysis of shipment data allowed for the formulation of a hypothesis regarding the optimal dimensions of parcel locker compartments. Based on the developed assumptions, seven effective

TABLE 1 Descriptive Statistics for Parcel Dimensions in the Nova Poshta Database

Indicators		Maximum Dimension	Average Dimension	Minimum Dimension
Number of Valid Data Entries		1 697 924	1 697 924	1 697 924
Median		35.00	29.00	21.00
Mode		39.00	20.00	20.00
Minimum		18.50	1.00	0.00
Maximum		70.00	70.00	49.00
Percentiles	25	27.00	23.50	17.00
	50	35.00	29.00	21.00
	75	40.00	38.00	27.00
	95	58.00	48.00	38.00

Source: Compiled by the author based on Nova Poshta data height options were identified: 8 cm, 12 cm, 16 cm, 24 cm, 32 cm, 48 cm, and 64 cm. Additionally, four suitable width options were defined: 12 cm, 22 cm, 42 cm, and 64 cm.

Using SPSS software, the next stage of the analysis involved determining the number of shipments for which a particular parcel locker compartment (i.e., with a defined height and width – depth being standardized) would be optimal. The procedure for identifying the optimal compartment size for each shipment included the following steps:

Step 1. Among all the dimensions of a shipment, the one closest to the standardized compartment depth is identified.

Step 2. For the two remaining dimensions (width and height), all compatible compartment options are determined.

Step 3. For each feasible locker option, the unused area[1] S is calculated using the formula:

$$S = X \cdot Y - a \cdot b, \quad (1)$$

Where:

X, Y are the width and height of the compartment, respectively;

a, b are the width and height of the shipment, respectively.

Step 4. The optimal locker compartment for each shipment is selected based on the criterion of minimum unused area S.

Using the number of shipments for which each compartment size is optimal, the percentage distribution was calculated to identify the most efficient compartment types.

The results of these calculations for compartments with a depth of 31 cm (i.e., intended for indoor use) are shown in Table 2.

As seen in Table 2, only one compartment type (64 × 12) was not optimal for any shipment. Several compartment options proved to be optimal for fewer than 1% of shipments. These may be considered redundant and excluded from the design of parcel lockers for indoor use.

Conversely, certain compartment types (e.g., 22 × 8 and 42 × 8) were found to be optimal for more than 10% of shipments. These compartments should therefore represent a larger share of the compartment structure.

Similar calculations were performed for parcel lockers intended for outdoor use (with a depth of 47 cm). A comparison of the indoor and outdoor locker options revealed that while the overall distribution patterns remained consistent, some quantitative differences emerged. The most notable decreases in share were found for the 42 × 48 cm compartment (a drop of 6.8%) and the 42 × 12 cm compartment (down by 6.1%). Conversely, the greatest increases were recorded for the 12 × 24 cm (up by 5.4%) and 22 × 24 cm (up by 5.3%) compartments. Notably, the compartment type with the lowest share remained unchanged.

6 Assessing the Effect of Using Optimized Parcel Locker Options

The data on shipment shares corresponding to various locker compartment options provide a foundation for evaluating potential volume savings in parcel lockers. This, in turn, enables an assessment of the possible economic impact – either through reduced material intensity and thus lower investment costs (if the total locker volume is decreased), or through increased throughput capacity of the parcel locker network (if the actual locker volume remains

TABLE 2 Share of Shipments for Which Parcel Locker Compartments (Indoor Use) Are Optimal

№	Compartment Type[2]	Share (v_i)	№	Compartment Type	Share (v_i)
1	12 * 12	3.8%	15	42 * 12	6.8%
2	12 * 16	4.8%	16	42 * 16	5.7%
3	12 * 24	2.6%	17	42 * 24	8.2%
4	12 * 32	2.7%	18	42 * 32	4.3%
5	12 * 48	0.3%	19	42 * 48	8.4%
6	12 * 64	0.3%	20	42 * 64	4.1%
7	12 * 8	2.4%	21	42 * 8	11.3%
8	22 * 12	8.2%	22	64 * 12	0.0%
9	22 * 16	3.4%	23	64 * 16	0.6%
10	22 * 24	3.5%	24	64 * 24	0.2%
11	22 * 32	1.3%	25	64 * 32	0.6%
12	22 * 48	0.3%	26	64 * 48	2.2%
13	22 * 64	0.3%	27	64 * 64	0.5%
14	22 * 8	12.8%	28	64 * 8	0.4%
Total distributed					100%

Source: Compiled by the author

[1] The area of the vertical projection of the compartment is considered, as the depth is excluded from the analysis by selection in Step 1

[2] Width, cm * height, cm

unchanged and the saved space is used to install more compartments). An increase in the throughput capacity leads to cost savings in both the establishment and maintenance of the locker network, as fewer lockers would be needed to handle the same volume of shipments.

To illustrate the evaluation process, we consider the example of an indoor parcel locker. Based on the data presented in Table 4, we calculate the following key indicators:

1. Percentage of shipments accommodated by a compartment of type i assuming a uniform distribution of compartment structure (***w$_i$***). This metric also reflects the share of each compartment type in the baseline parcel locker and is directly determined by the number of compartment types (***n***) using the formula:

$$w_i = \frac{1}{n} \tag{2}$$

2. Frontal area of each compartment type i (***S$_i$***), alculated as the product of its width (***X$_i$***) and height (***Y$_i$***):

$$S_i = X_i \cdot Y_i \tag{3}$$

3. Weighted frontal area of the optimized (***So***) and baseline (***Sb***) parcel locker options, calculated as the sum of each compartment type's frontal area (as per formula 3) multiplied by its share in the optimized (***v$_i$***)[3] and baseline (***w$_i$***) options:

$$S_o = \sum_{i=1}^{n} S_i \cdot v_i$$

$$S_b = \sum_{i=1}^{n} S_i \cdot w_i \tag{4}$$

4. Locker volume savings effect (***E***)[4] when using an optimized compartment structure compared to the baseline:

$$E = \frac{S_b - S_o}{S_b} \cdot 100 \tag{5}$$

Given that the number of compartment types (***n***) equals 28, and using the data from Table 4, we calculate the frontal areas for both the optimized (***So***) and baseline (***Sb***) locker options using formula (4). Substituting these values into formula (5) gives the quantitative assessment of volume savings (***E***):

$$E = \frac{1020 - 772}{1020} \cdot 100 = 24{,}3\% \tag{6}$$

Thus, implementing the proposed optimization approach enables nearly 25% savings in parcel locker volume, which can significantly lower investment costs during network scaling.

It is important to note that this estimated benefit does not account for additional operational advantages, such as improved handling of shipment flows. The baseline version of parcel lockers with a uniform distribution of compartments is not only more voluminous and costly but also results in two negative operational effects. First, certain compartments (typically the narrowest ones) may remain unused due to a lack of corresponding shipment sizes. Second, some shipments may not be accommodated due to the absence of sufficiently large compartments.

In practice, achieving the full benefits of the optimized structure can be challenging, as real-world parcel lockers rarely employ all 28 compartment types. Additionally, it is essential to ensure that the total width and height of compartments align with the overall locker dimensions.

Nenertheless, both theoretical analysis and practical results have shown that utilizing shipment distribution data to determine optimal locker compartment options significantly enhances the efficiency of developing and scaling the parcel locker network of Nova Poshta.

7 Conclusions

To conclude, statistical analysis of shipment structures and the effective sizing of locker compartments has yielded valuable insights for enhancing the efficiency of last-mile delivery processes through parcel locker networks.

Preliminary statistical analysis of the frequency of shipments with varying dimensions enabled the development of hypotheses regarding optimal locker compartment sizes. Based on these findings, seven effective height options and four width options are proposed. While compartment depth remains standardized, it is adjusted depending on the installation environment – distinguishing between lockers intended for indoor and outdoor installation.

The implementation of the proposed algorithm within a statistical analysis package enabled the determination of the share of shipments for which the locker compartment sizes of each type (both for indoor and outdoor installation) are optimal. This data provides a foundation for defining the most efficient allocation of total locker volume among individual compartments. Optimizing locker volume usage not only increases the capacity of the parcel locker network but also contributes to significant economic benefits by reducing investment costs for its establishment.

Future research should focus on modeling the parcel locker network's resilience to deviations from standard business process flows. Such deviations may be triggered by various risk factors, including fluctuations in the typical frequency distribution of parcel sizes. Addressing these potential disruptions will be key to ensuring robust and scalable parcel locker operations.

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[3] The values of this indicator for the parcel locker intended for indoor installation are presented in Table 4.

[4] The percentage of parcel locker volume savings is used as the measure of beneficial effect, as it represents the actual parameter being optimized. However, given the standardized depth of parcel locker compartments, this indicator is effectively determined by the savings in frontal area.

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