Postboxes Quantitative Optimization Model

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Abstract: Technological developments are having a significant impact on purchasing habits and consumer behavior, and threaten the traditional model of the delivery of goods by post. The replacement of traditional letter-post items with electronic forms of communication has led to declines in the volume of postal items. Therefore, the collection of postal items has become very inefficient. This paper proposes that the postal network segment needs to be reorganized by reducing the current number of installed postboxes. To this end, a mathematical model has been defined. Considering that postboxes are one of the most basic access points to the postal network, territorial accessibility must be taken into account. The proposed model, with minor modifications, can easily be applied to optimize other access points in transportation networks. For testing purposes, this paper presents the results of computational experiments based on real data. The final result consists of scenarios that present a decision support system for the redesign of postal networks.

Keywords: reorganization; postal network; mathematical model; postbox

1. Introduction

The transfer of postal items is a typical example of supply chain logistics. One of the most important parameters of the quality of this service is its availability to users. In order to enable users to access the network and comply with the service quality requirements, the Post of Serbia network consists of 1964 postboxes (data from 2016) throughout the national territory. In recent years, a drastic decline in the volume of letter-post items has generally led to the underuse of these access points, whereby the current organization of letter collection services has become unsustainable. Each existing and active postbox requires maintenance and daily visits from postmen, which affects the total operational costs. Therefore, it is necessary to reorganize the postal network in order to reduce the number of existing postboxes and hence the number of postmen allocated to collection activities.

The conclusion reached by the Serbian Regulatory Agency for Electronic Communications and Postal Services (RATEL) is also in line with the above hypotheses [1]. According to this conclusion, and compared to 2012, the number of postboxes has declined by 123, nearly 6%. Although it can be concluded, based on this reduced number of postboxes, that this segment is also showing a decline in quality, the fact is that the number of items dropped into postboxes is decreasing year by year, and consequently, the reduction in the number of postboxes is justified. However, it must be pointed out that in accordance with the Article 13 of the Guidelines on the Conditions for the Commencement of Postal Activities published by the Ministry of Trade, Tourism and Telecommunications [2], a universal postal service provider must provide at least 2000 postboxes. As mentioned, according to the official data from 2016, the total number of postboxes was 1964, so it is undisputable that this requirement has not been fulfilled and that the public postal operator would need to remedy such noncompliance. As a solution, there are two options for providing the
required number of postboxes in accordance with the provisions of the aforementioned guidelines issued by the relevant ministry [2].

Due to a continuous decrease in the number of letters that are dropped into postboxes, along with the decreased volume of postal shipments from year to year, the first solution is to amend the current guidelines and to reduce the number of collection boxes that the universal postal service provider must supply. The second option would be that the operator adjusts the number of postboxes as prescribed by the current guidelines.

In this paper, the authors tried to achieve the first solution, i.e., to optimize the number of postboxes, and this was the main motivation for the development of the mathematical model presented herein. Bearing all of this in mind, it is necessary to make a decision about particular postboxes that will be removed at a strategic level while ensuring that this will not reduce the quality of service. Solving this problem requires consideration of special constraints. Firstly, strategy-wise, reducing the number of postboxes may lead to the deterioration of service accessibility conditions due to the longer distance some users will have to travel. Considering the nature of the universal postal service, decisions to remove certain postboxes should be made, ensuring equality in terms of access to services for citizens. It is also necessary to ensure that the smallest possible number of users of the service are affected by the changes, that is to say, the smallest number of users are forced to change their existing habits. Finally, from the operator’s point of view, it is better to remove postboxes located in remote and isolated locations. In other words, the objective is to keep the remaining, active postboxes as close as possible to each other in order to minimize the costs of postmen undertaking their duties.

The problem of optimizing the number and location of postboxes within the network has not been significantly considered in the literature to date. Labbé and Laporte developed a model for maximizing user comfort and postal service efficiency [3]. In their work, they considered the distance between senders and their assigned postbox, as well as the costs related to emptying postboxes.

Kujačić et al. indicated the need for criteria which determine the minimum required number of permanent postal units [4]. The authors defined four relevant criteria for the Republic of Serbia. Based on their conclusions, Blagojević et al. developed a mathematical formulation enabling the easier application of the existing criteria [5]. In addition, in the same paper, the well known Wang–Mendel method was used to determine the required number of the permanent postal units.

Grüner and Sebastian dealt with tactical problems in the final stage of the distribution of postal items [6]. Imich showed the mathematical formulation, as well as the corresponding solution, to the actual problem of the delivery of postal items [7].

Mitrović-Minić et al. [8] present a discussion regarding algorithms for the integrated management of mail collection and distribution activities. Abbatecola et al. provided a detailed description of a decision support system for postal delivery management in urban areas based on vehicle routing models [9]. Ulmer et al. used methods of approximate dynamic programming to offer solutions for dynamic vehicle routing with stochastic customer requests [10]. Ji and Chan developed a model by which to minimize both the total number of the postal vehicles used for the mail collection and delivery and the total distance travelled by postal vehicles in servicing post and delivery offices [11]. Various groups of authors have studied continuous approximation models in order to determine the optimal size of the territorial scope of services and the total transportation costs of postal traffic [12–15].

In order to address the aforementioned problem, the paper presents a mathematical model that has been tested using real data. The model is general and could be applied to actual data for the purposes of a case study or project, with a view to supporting the decision-making process related to the reorganization of the transportation network. The following section (Section 2) provides the general setting of the considered problem. Section 3 contains the mathematical formulation used to address the problem. A numerical example, as well as a discussion of the results, are given in Section 4. Conclusions and directions for future research are given in Section 5.

2. The General Setting of the Considered Problem
According to the European Parliament and the Council of the European Union Directive 97/67/EC, the postal service is defined as a universal service, which means that it is necessary that all the minimum standard quality requirements should be met and that the service must be accessible to all users, regardless of their geographical location [16]. In order to meet these standards, postboxes, as one of the basic types of access points to the postal network, must be distributed in a systematic manner across the whole territory. Accordingly, postboxes must be emptied daily in order to meet the required delivery deadlines. However, due to a dramatic reduction in the number of traditional letters, the average quantities of these shipments collected from the existing postboxes daily are very insignificant and therefore the overall organization of the collection activities is very inefficient. For this reason, and given the fact that sustainable transportation is one of the major concerns in cities, it is crucial to reduce the number of postboxes in order to reduce the cost and pollution that result from postmen visits. On the other hand, it is necessary to meet the specific requirements for the accessibility of these postal network units at the same time. This can be very problematic for the quality of the Universal Service [17].

Unlike the traditional letters whose average number collected through postboxes has seen a dramatic drop, the collection and distribution of some other postal items has significantly increased. The constant growth of e-commerce throughout the world in the last decade has caused the emergence of Automatic Delivery Stations (ADS), also called ‘collection and delivery points.’ Unlike postboxes, these objects are increasingly installed in the same or similar locations, often assuming the current function of postboxes. Given the fact that ADSs are a novelty for users, the approach to solving the problem of defining the need for their installation, number and location, is different from postboxes and requires the examination of potential users’ attitudes and habits [18–21]. An ADS offers the possibility of making a non-attended delivery (i.e., a delivery of goods without a recipient), thereby reducing the number of failed deliveries. They consolidate the demand of different customers at one point, increasing the ratio of deliveries per stop. Finally, they can be used as both delivery and collection points, where the customer, among other things, can return unsatisfactory items [22–24]. The main conclusion arising from those papers was that the cost reduction can even be achieved with a relatively low number of pick-up points. Generally, the first mile logistics (as the first stage of the supply chain) and the last mile logistics (as the last stage of that chain) have been a hot topic in the past few years [25–31]. An extended discussion on innovations in the area of postal distribution can be found in [32].

The reorganization of the postal network is of great importance to the public postal operator. In order to reduce the number of postboxes in accordance with the regulations, it is necessary to comply with the Rulebook on the General Conditions for Providing Postal Services [33]. According to this regulation, it is essential that the universal postal service provider respects the following criteria for postbox deployment:

- if located in a settlement in a rural area with more than 1000 inhabitants, a minimum of one postbox must be installed;
- if located in a settlement with a population below 1000, one postbox could be installed if more than five unregistered postal items are dropped on a daily basis;
- if located in an urban area having up to 200,000 inhabitants, a minimum of one postbox must be installed for every 5000 inhabitants;
- if located in an urban area with a population exceeding 200,000, a minimum of one postbox must be installed for every 10,000 inhabitants.

These regulations also provide that postboxes must be installed in all postal facilities; if this is impossible to do, however, a postbox should be installed in the immediate vicinity. Furthermore, postboxes must be installed in all important places of interest (bus and train stations, municipality halls, public institutions, etc.). The number of postboxes to be installed is set out in the total number of the postboxes installed according to the current criteria for settlements [33].

In order to simplify the model, the paper deals with the problem of optimizing the number of postboxes in the case of settlements having up to 200,000 inhabitants. The complete optimization of the entire postal network requires that modelling and optimization is performed separately for each
type of settlement. The largest number of cities in the Republic of Serbia belongs to this category. If we look at the population of all the cities, including the wider area of the cities, only Belgrade, Niš and Novi Sad have more than 200,000 inhabitants according to the latest census, whereas the other 25 cities belong to the category considered herein.

3. The Mathematical Formulation of the Problem

In order to solve the described problem, it is necessary to identify the postboxes that should be removed at a strategic level. In order to discretize the inhabited areas analyzed, zones with postal service users were formed. The division of settlements into zones can be accomplished using the Geographic Information System (GIS), as Jung et al. suggested [34], or some other suitable mathematical tools, such as the K-means clustering technique.

The proposed model takes into account the fact that the removal of certain postboxes may negatively impact the availability that must be provided to all postal users, which may lead to a decline in the service quality. Therefore, the first objective is to minimize the number of postal service users who are forced to change their existing postbox. If, however, the existing postbox has to be removed, then such users are redirected to the nearest active postbox. The second objective relates to the minimization of the distance that users must cross to send a letter via the new postbox. An additional objective has been included in the mathematical model, which is important from the postal operator’s point of view. Specifically, it is necessary that the distance between the remaining, active postboxes should be minimized so as to optimize the costs of postmen’s visits, as well as their workload.

In order to comply with the conditions set by the relevant regulations, the postboxes installed in places of interest must not be removed.

Taking into account the defined objectives, as well as the proposed constraints, the following notations can be defined:

- \( I \) — a set of zones within a single settlement, the counter \( i \)
- \( J \) — a set of postboxes in the settlement, counters \( j, k \)
- \( a_i \) — the number of inhabitants in the zone \( i \)
- \( A = \sum_{i \in I} a_i \) — the total population in all zones (the number of inhabitants in the settlement)
- \( S = \left[ \frac{A}{5,000} \right] \) — the number of necessary postboxes in the settlement
- \( J_0 \subset J \) — a subset of the postboxes that must not be removed (at post offices, railway and bus stations, health centers)
- \( r_{jk} \) — the distance between the two active postboxes \( j, k \)
- \( d_i \) — the distance between users (the zone center) and the postbox
- \( d_i = \min_{j \in J} \{d_{ij}\} \) — the shortest distance from the users in zone \( i \) \((i \in I)\) to the nearest postbox
- \( J_j \) — a subset of the zones closest to the postbox \( j \) \((j \in J)\): \( J_j = \{i \mid d_i^{\min} = \min_{k \in J} \{d_{ik}\} = d_{ij} \}\)

The following binary variables have been introduced:

- \( x_{ij} = \begin{cases} 1, & \text{if users in the zone } i \text{ use the postbox } j \\ 0, & \text{otherwise} \end{cases} \) (1)
- \( y_j = \begin{cases} 1, & \text{if postbox } j \text{ remains active} \\ 0, & \text{otherwise} \end{cases} \) (2)
- \( z_{jk} = \begin{cases} 1, & \text{if postbox } j \text{ and } k \text{ are used} \\ 0, & \text{otherwise} \end{cases} \) (3)

The mathematical formulation for the optimization of the 'number of postboxes' problem is:
The objective function (4) that should be minimized represents the total number of postal service users who have to change their postbox due to the removal of the existing one. The minimization of the total distance that all affected users have to cross to reach the closest postbox is represented by the objective function (5). The objective function (6) minimizes the overall distance between the remaining active postboxes. The constraints arising from the mathematical formulation can be defined as follows:

- Only active postboxes can be used (Constraint 7).
- One postbox must be assigned to each zone (Constraint 8).
- The number of postboxes that must remain active in accordance with the regulations (Constraint 9).
- The postboxes from set \( J_0 \) must remain in use (Constraint 10).
- The variable \( z_{jk} \) takes the value of 1 when the variables \( y_j \) and \( y_k \) are equal to 1 (Constraint 11).
- The binary nature of the variables is defined by Constraints (12), (13) and (14).

4. A Numerical Example

The proposed model was tested on a real-life example, where the input data were the actual data obtained from Kragujevac in the Republic of Serbia (see Figure 1). The data provide that Kragujevac is a city with nearly 180,000 inhabitants and occupies an area of close to 900 km². The city from the example currently has 68 deployed postboxes, out of which 16 are fixed, i.e., installed in places of importance.
Figure 1. The location and the pickup area (the red zone) of the city of Kragujevac (Source: [35]).

According to the regulation, the total number of deployed postboxes must be at least:

\[ S = \frac{A}{5,000} = \frac{180,000}{5,000} = 36 \]

i.e., it is necessary that 32 postboxes be removed. Figure 2 shows the spatial layout of the deployed postboxes. The red squares show the postboxes that must remain in use.

Figure 2. The spatial layout of the postboxes (red squares represent postboxes that must not be removed).

In this example, the size of each of the 900 zones in total was assumed to be 1 km² (1 km x 1 km). Figure 3 graphically shows an illustrative example of the network divided into zones.
Figure 3. An illustrative example of dividing a settlement into zones with users and postboxes.

In order to solve the presented problem, the lexicographic method of multi-objective optimization was used. As a priority of the objective functions, the order in which they are shown in the previous section has been maintained. Since there are three objective functions, it is necessary to solve three integer programming problems. All problems were resolved using the academic version of the CPLEX 12.6 software (IBM ILOG CPLEX Optimization Studio from IMB company - USA, version 12.6).

The lexicographic method implies that the proposed problem is partially solved by each objective function, after which, in each subsequent step, the obtained objective function solution becomes a new constraint. The first integer programming problem which was resolved has the following form:

\[-\text{min } F_1\]
\[-\text{s.t.}\]
\[-(7–14)\]

The result obtained after this step of the lexicographic method shows that 74,250 users will use postboxes in new locations, i.e., they will have to change their existing habits related to sending letters via postboxes.

The second integer programming problem is as follows:

\[-\text{min } F_2\]
\[-\text{s.t.}\]
\[-(7–14)\]

This construction of the problem leads us to the conclusion that the total distance that all users will have to travel equals 395,009.14 km.

The third integer programming problem has the following form:

\[-\text{min } F_3\]
\[-\text{s.t.}\]
\[-(7–14)\]

Finally, the objective function F3, which represents the total distance between all of the remaining active postboxes, is 9668.3 km. Based on the obtained solutions, the layout of the postboxes that should remain in use is shown in Figure 4.
5. Discussion

The total distance between the postboxes when all 68 are in use is 35,967.96 km. After the applied optimization, the total distance between the remaining active postboxes is 73.12% shorter than the initial solution. It can be concluded that a decrease in the number of postboxes leads to a reduction in the kilometers travelled by postmen, a reduction in the emission of pollutants and savings in time needed for touring and emptying the active postboxes. Every minute postmen save on letter collecting is valuable for their engagement in the last mile delivery, a growing segment of supply chain logistics. All of those facts make the proposed mode suitable not only for postal operators, but also for all of the logistic companies dealing with the first mile pick-up problem.

At this point, however, it must be recognized that the environmental benefits of a reduction in the number of postboxes could be mostly reversed because private car trips from citizens to the remaining postboxes are expected to increase. From the service provider’s point of view, a reduction in postboxes may be necessary, but it will only lead to a reduction in the service quality. All affected citizens will have to travel more and spend more time and money. The proposed model minimizes the number of such affected citizens and the total distance that they have to cross to reach the closest postbox, but it cannot provide benefits for all. Thus, environmental benefits should be discussed in future research by comparing two metrics—the decrease in CO₂ emissions by the postal operator and the increase in CO₂ emissions by additional citizens’ trips.

The environmental protection dimension is not the primary goal (benefit) that should be achieved by the reorganization of service providers. The primary issue is to reduce the negative financial effects of the letter-item downward trend, which causes a loss to the postal operator. At the same time, the focus is on the protection of the interests of the citizens who are inevitably affected.

6. Conclusions

The decreasing trend in the volume of letter items leads to the insufficient use of postboxes. As a consequence, the current organization of letter collection has become ineffective and hence unsustainable. Each existing and active postbox requires maintenance and daily postmen visits, which has an impact on overall operating costs. Therefore, a reorganization of the postal network is necessary in order to reduce the number of existing postboxes and hence the number of postmen allocated to the collection activities.

In this paper, the mathematical model developed for the purpose of the optimization of the number of postboxes in the network is presented in the example of the settlements of up to 200,000 inhabitants. With minor modifications, the same model can be used to optimize the set of access points in all distribution logistics systems. The model takes into account all the applicable constraints and requirements prescribed by the relevant regulations. The proposed model has been
tested using real data. The actual implementation of the presented model would require the integration of all the categories of settlements in the model, the provision of actual data on the number of inhabitants per zone, as well as data on the actual number of users served by each postbox. In their future research, the authors will apply a metaheuristic as a tool in order to solve this difficult combinatorial problem in the network.

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