



A MODEL FOR PUBLIC POSTAL NETWORK REORGANIZATION BASED ON DEA AND FUZZY APPROACH

Jelena MILUTINOVIĆ¹, Dejan MARKOVIĆ², Bojan STANIVUKOVIĆ³,
Libor ŠVADLENKA⁴, Momčilo DOBRODOLAC^{5*}

¹*ICT College of Vocational Studies, Belgrade, Serbia*

^{2,3,5}*Faculty of Transport and Traffic Engineering, University of Belgrade, Belgrade, Serbia*

⁴*Faculty of Transport Engineering, University of Pardubice, Pardubice, Czech Republic*

Received 15 September 2018; revised 25 April 2019; accepted 29 April 2019

Abstract. One of the most important segments in management of Universal Service Providers (USPs) is reaching the decisions concerning changes in the postal network infrastructure. USPs decide on such matters based on an analysis of financial indicators and defined qualitative parameters in accordance with the international regulations and obligations imposed by a competent regulatory agency. In this paper, the previously known method to analyse the existing postal network and define the minimal number of Postal Network Units (PNU) is implemented and upgraded by a new approach based on Data Envelopment Analysis (DEA) and fuzzy logic. The final aim of the proposed new approach is to determine which of the considered PNU should be closed or reorganized having in mind the minimization of negative effects, both financial and social. The proposed model gives the indices for all considered postal branches, which allows the decision-maker to rank the importance of each unit. The proposed model is a business intelligence tool, which replaces a multidisciplinary team composed from managers of the company and policymakers from both the postal sector as well as a sustainable rural development sector in reaching an important decision on changing the postal network. This decision may be considered as extremely complex since it should sublimate the opposed criteria that relate to the business success of the company, state regulations and sustainability of the local community. The indices obtained in the proposed method exactly include the mentioned three categories. The authors demonstrate the applicability of the suggested methodology based on the real data acquired in a district of the Serbia, i.e. in a regional organizational entity of the USP and provide the analysis of the results reached for the rural delivery post offices.

Keywords: postal services, postal network units, social criteria, fuzzy logic, DEA, rural area.

Introduction

The Universal Postal Service (UPS) comprises of the postal services that are constantly offered to all customers by the same conditions, fulfilling the principles of predefined quality and affordable prices. The Universal Service Provider (USP) should provide a set of postal services at the whole state territory (EU 2008).

The globalization and liberalization of the postal market have caused the transition from the traditional monopolized manner of business to a profitable one. An integral part of the transformation process of USPs in the liberalized market is determining the efficiency of business processes, as well as points with the highest expenses. In this process, the USPs should include the indicators of quality determined by the regulatory agencies and fulfil the imposed targets. In the European Union, such princi-

ples are defined in the European Commission Directives (EU 1997, 2002, 2008). Besides, the USPs have a significant social and economic function, especially in the underdeveloped regions. This is the reason why postal services are considered as services of general economic interest in the most countries. Accordingly, having in mind that two opposed aims should be achieved, efficiency and availability, a redefining or reorganization of the post office network is a very complex and sensitive task.

The availability of the UPS is reflected in, among other things, the territorial availability of the postal network. The rationalization of expenses and financial profitability indicators and changes in the number and structure of population induced by demographical factors, have a significant influence on the process of restructuring of a

*Corresponding author. E-mail: m.dobrodolac@sfbg.ac.rs

postal network – shutting down a Postal Network Unit (PNU), changing the operating form, implementation of more economically organized plans that have a shorter working time or a narrower service portfolio. According to the Universal Postal Union (UPU) statistics, the number of total PNUs has been unsteady. There has been an obvious trend in developed countries in the last 30 years – national operators have been taking over the franchising model, so that the number of permanent PNUs went from 205000 to 160000 (UPU 2014). When it comes to the European Union member states, Okholm *et al.* (2018) define potential scenarios for the future provision of the UPS:

- status quo;
- reduce delivery frequency;
- reduce speed of delivery;
- allow different forms of delivery;
- remove uniform prices requirement;
- relax ubiquity (accessibility) requirement:
 - reduce the required number of post offices in rural areas by 25...50%;
 - reduce the required number of post offices in urban areas by 25...50%;
 - allow alternative models, e.g. mobile post offices, franchise model, etc.

In the same study, it is estimated how different scenarios impact the users, employees and other stakeholders.

The USP from Serbia continuously carries out the analysis of productivity for each PNU, and even though some of them achieve negative results, no post offices have been closed in the recent years due to the corresponding state policy in the postal sector. Nevertheless, the new offices were opened. However, to improve the financial results, it is necessary to reduce the number of permanent PNUs for the provision of UPS (Unterberger *et al.* 2018).

Since the policy of postal network expanding in the rural areas is unsustainable from the standpoint of profit, the model proposed in this paper offers a solution for downsizing or restructuring the post office network, having in mind both profitability and social factor in the decision-making process. It takes into consideration the most sensitive groups that would be affected by such decisions. From the operators' point of view, such activities lead to the optimization of expenses – reduction in the numbers of employees and delivery vehicles; however, this affects customers in various ways.

There are several papers dealing with the phenomenon of the postal network reorganization in rural areas by determining the number or set of unprofitable post offices that should be closed or restructured. These studies propose the minimum number of PNUs within the postal network, which is sufficient to provide the UPS according to the framework prescribed by the national quality standards. According to the authors knowledge, by analysing the *Clarivate Analytics Web of Science* database (<https://apps.webofknowledge.com>) in 2019, there is no evidence in the literature about the possible methodology to determine the exact PNUs, which should be shut down or

reorganized. The main aim of the previous studies was just to propose the minimum number of PNU to achieve the imposed regulations; however, a decision-maker responsible for the postal infrastructure needs more information. This was exactly a motive for the authors to propose a model, which would upgrade the existing knowledge in the field. In this paper, the authors calculate the minimum number of PNUs in a county using the existing knowledge in the field, and then, applying the original model based on the fuzzy logic uniquely determine which PNU should be closed or restructured to minimize the overall negative effects. The various aspects of importance have been considered, both on the part of the service provider and users – legal entities and population.

This paper introduces a fuzzy logic system, which the authors have developed as a business intelligence tool for deciding which PNUs in rural areas should be shut down or reorganized while taking into consideration not only the financial, but the social criterion. Aside from the social factor, other input variables are considered: the efficiency measured by Data Envelopment Analysis (DEA), postal service availability and economic activity of the micro location. As a result of the proposed model, there is a set of indices allocated to each considered PNU, which represents a preference for shutting down or restructuring. The applicability of the proposed model is demonstrated in the case of Zlatiborski District, one of the 29 districts in the Serbia. The results have proved the expectations of the authors that this model could be a useful tool for making decisions on reconfiguring the postal network in various territories and administrative units.

The paper is organized in the following way. The first section offers a literature review on different approaches in optimization of the postal network and its impact on the local community. In the second section, the current methods that are theoretically and practically used in defining the minimal number of permanent PNUs are introduced. In the third section, we propose a fuzzy logic based model. This part also provides an overview of the bibliography and characteristics of input and output variables. Further, the Wang–Mendel method for generating fuzzy rules based on empirical data is implemented. The fourth part depicts the application of the proposed model on the real data, offering a detailed analysis of the results. Final comments are given in the conclusions section.

1. The different approaches in optimization of the postal network and its impact on the local community

The existing methodologies are based on spatial indicators and provide criteria for minimal number of PNUs based on the number of residents in an area. However, deciding which PNU should be closed is the subject of further examination, which should be carefully done having in mind the importance of postal services for the society. This decision should be based not only on the financial indicators,

but also on social value, i.e. the importance that the post office and postal services have for their customers – both legal entities and individuals.

There are some significant papers, which consider this issue. In the paper of Higgs and Langford (2013) the authors examine the consequences that the reconfiguration of the postal network of Great Britain would have on different groups of customers, namely the elderly by means of spatial analysis. One of the rare studies that attempt to quantify the local financial influence and social importance of postal services was carried out by Taylor *et al.* (2006). A serious part of the study is based on the descriptions of a number of problems that a community faces after shutting down a PNU. Higgs and White (1997) examine the issue of deprivation in rural areas as the result of cancelling services important for everyday life. The important factors include demographical trends, demand for services, as well as the financial burden on the public sector as a result of reduction of expenses. The research of White *et al.* (1997) includes a case study in the Powys County in Mid Wales, with the goal of identifying the areas where post offices were closed between 1979 and 1994 by means of Geographic Information System (GIS). Through analysis, the authors identify areas where the reduction of services was made and where there is a significant percentage of population affected by spatial accessibility – the households without a private vehicle and retiree households. A sustainability study by Comber *et al.* (2009) name UK Post Office as a resource of multifold significance for the community, especially for older population – it is the only access point to pensions, paying bills, and a place to meet with other people. By means of genetic algorithm, a selection of 181 post offices was made, out of which 133 should be closed. A similar study by Ibrahim and Lawal (2015) was conducted in Leicestershire (UK). Out of existing 181 units, the plan was to keep 149 working, shut down 24, and consider the future of 8 post offices later. The authors suggest optimizing the GIS model in order to minimize the bad influence on affected groups, revising the decision to shut down a PNU, as well as revising the regulatory agency's accessibility standards. Neutens *et al.* (2012) explore the problem of temporal accessibility of public services in Ghent (Belgium) by analysing spatial data and daily activity patterns of residents, in particular for groups that are affected by a change in working hours the most – workpeople, parents of small children, etc. by means of the suggested model.

Klingenberg *et al.* (2013) analyse the US Postal Service, which possess the largest retail network in the US with over 30000 retail locations. Attempts at optimization without considering interests of both the postal operator and the postal customers are likely to produce misleading results. The authors consider various factors, such as: (1) geographical diversity; (2) population density; (3) Internet broadband access; (4) diversity of transportation modes, transit routes or parking regulations; (5) quality of retail counter service/employee helpfulness; (6) constraints related to the existing retail network; (7) change in popula-

tion and employment over time; (8) changes in the use of postal services over time; (9) changes in demographic profile over time; (10) changes in transportation networks and transit routes over time; (11) accuracy of input data.

Okholm and Möller (2013) examines the need for adapting the UPS to the digital age by excluding basic bank services from the UPS in Norway and evaluated alternative solutions for providing the services to vulnerable users. The analysis reveals that at most 28500 individuals (mainly elderly or disabled individuals or people in sparsely populated areas) are dependent on the bank services provided in the postal network. By excluding bank services from the UPS, and loosening the requirements on the network structure, the Norwegian Government could save approximately €22 million in 2012. The research suggests that there are often alternative solutions available to solve the needs of the vulnerable users in more cost-efficient ways than the UPS. Based on the results of this research, the Norwegian Government has decided to exclude the provision of basic bank services at fixed service points from the UPS.

Schuster (2013) analyse the effect of privatization on UPS. His empirical estimation shows that privatization in fact had a negative effect on the quality of UPS in the way that the office density has been greatly reduced which implies that services are offered less frequently and that services are less available to all citizens. Traditionally, UPS redistribute from high to low income groups and from urban to rural areas. The fact that accessibility has decreased substantially implies that some rural areas might be negatively affected. He suggests extension of the discussion on the effects of privatization on different aspects of equity or total welfare and also an analysis of postal market reforms should basically focus on consumer perception and satisfaction.

In depopulating rural areas, one of the main issues is how to deal with the decline of local facilities such as schools, post offices and shops. It is often feared that closure of a local facility will negatively affect the accessibility of that service and the live ability of the village. Christiaanse and Haartsen (2017) examines how villagers experience the loss of a small local supermarket. A survey was conducted shortly before the closure of the supermarket in Ulrum, a depopulating village in the rural North of the Netherlands. 85% of respondents evaluated closure of the local supermarket as negative (regrettable or very regrettable). Elderly respondents and households without motorized transport were very negative about closure. In this study, respondents complained about a village feeling “empty” following the closure of facilities. From a policy-perspective it is worth considering the accessibility of facilities in rural areas for the elderly and less mobile residents and the major challenge might not necessarily lie in restructuring facilities, but in supporting a community's emotional process of “loss”.

The similar study was conducted by Cabras and Lau (2019). This paper investigates how the availability of services and amenities influences levels of community

cohesion in rural England. Authors measure levels of community cohesion in selected rural parishes between two points of time – 2000 and 2010 – using an index of indicators based on the presence or absence of retailers and amenities. Results of this analysis provide empirical evidence that the presence of facilities and services has a considerable impact on residents in rural areas, suggesting a significant relationship between the presence of small retailers and social engagement in the English countryside. The results indicate that some services such as libraries and post offices have a larger impact on community cohesion compared to others.

In the paper by Hamilton (2016) the effect of change in the postal network is analysed, particularly the impact on older people as a key customer group of the post office, overrepresented in rural areas. Over the timeframe of 2000–2013, 54.2% of the closures were in urban areas compared to 45.8% in rural areas. There were clearly immediate impacts that were the direct result of the outreach service, such as reduced reliability and lack of shelter. However, there were also indirect effects of the change that took a longer time to emerge; the loss of the post office branch affected the viability of the village shop, which had to adapt to. A mobile outreach served the case site, which came to the village for between one hour and fifteen minutes and two hours, four days per week, although it provided a good range of services, the participants were still angry over the closure of their branch and unhappy with the outreach as a replacement. Participants noted that the village shop (which used to contain the post office) had suffered as a result of the post office move and participants felt the village had lost a meeting place.

The availability principle is realized according to the standards depending on a determined criterion. The tendency for profitability and business policy, which reduces the costs negatively affects the population. On the other hand, the human impact of postal services has the social value is reflected in the improvement of the life of an individual or the society as a whole.

The authors believe that, in the further postal network reconfiguration process, aside from the minimal number of PNUs, the choice of parameters used for deciding which PNUs should be closed or restructured is crucial. On one hand, these have to include financial parameters, but on the other, the most sensitive groups of people with limited mobility that would be affected should be taken into account.

2. The current criteria for defining the minimal number of PNUs

According to the USP from Serbia (Pošta Srbije 2009) the location and territorial availability of PNUs ensure the provision of UPSs at the whole territory of the Serbia, in accordance with the imposed quality level. Planning the location of a PNU includes observing and quantifying gravitational parameters of potential customers. Spatial criteria are based on the number of residents in a certain

area and their distance from the closest PNU. Based on that number, it is possible to compare the existing and expected number of PNUs. Although each post office should maintain its social function through providing UPS, the financial criterion is based on the need for positive results. This criterion is relatively often not met. A PNU should be closed if the outcome of its work is not satisfactory, under the condition that the shutting down would not violate the quality criteria. As a possible solution, a USP may transform the current non-profitable PNU to some more economical form such as a self-service machine or mobile post office.

Various European countries have different criteria for determining the number of PNUs (Barham *et al.* 2007):

- the minimum PNUs in a certain area (county, country, city, etc.);
- the population served by a single PNU, with a difference between urban and rural areas;
- the maximum distance to the closest PNU;
- the maximum distance between two PNUs;
- the percentage of population living in a certain distance from a PNU.

These criteria are often combined depending on geographical and demographical characteristics of a country. According to ERGP (2014), 84% of 32 participating countries have regulatory agencies, which have developed clearly defined standards for determining the number of PNUs.

Since there is no exact and generally accepted method for testing the optimality of adopted criteria, a research by Kujacić *et al.* (2012) emphasizes the importance of defining the density of access points, distribution, and minimal number of permanent PNUs required for sustainable provision of UPS. The authors define the following criteria, which determine the minimum number of permanent units of postal network in the Serbia:

- every settlement with more than 1000 inhabitants (and municipality) should be provided with at least one permanent unit of postal network;
- in settlements with more than 500 inhabitants, but less than 1000 inhabitants, services are made through a mobile PNU or postman stand;
- in settlements with less than 500 inhabitants – provision of service is conducted by a postman in a delivery region;
- in settlements with more than 20000 inhabitants, there has to be at least one permanent unit of postal network on every 20000 inhabitants. Permanent PNU's cannot be farther than 3000 m from any building in the settlement and the distance between two PNU in a particular settlement cannot be more than 6000 m.

Authors analysed the territory of the Serbia and collected and processed data for 5525 settlements. As a result of applied methodology, the minimum number of post offices should be 1052, while the current number in the year 2012 was 1482.

A paper by Blagojević *et al.* (2013) includes two approaches based on the above-mentioned criteria. In the exact approach, the authors provide a mathematical formula for determining the required number of permanent post offices according to previously mentioned criteria defined by Kujačić *et al.* (2012). They develop following mathematical equation to determine number of required permanent postal units:

$$x_i = \begin{cases} 1, & \text{exist settlement with} \\ & \text{population between} \\ & \text{1000 and 20000;} \\ 0, & \text{otherwise;} \end{cases} \quad (1)$$

$$y_i = \begin{cases} 1, & \text{exist settlement 20000;} \\ 0, & \text{otherwise;} \end{cases} \quad (2)$$

$$N_i = x_i \cdot R_i + y_i \cdot \sum_{j=1}^M \frac{S_j}{20000}, \quad (3)$$

where: N is the number of permanent postal units per municipality; R is the total number of settlements per municipality with a population between 1000 and 20000 inhabitants; i is municipality; M is the total number of settlements per municipality i with more than 20000 inhabitants; S is the total number of inhabitants in settlements with a population of over 20000 inhabitants; j is the counter for settlements per municipality i with more than 20000 inhabitants.

The other approach is based on the use of Wang–Mendel method to generate the fuzzy rules from mathematical data (Wang, Mendel 1992). The input variables of proposed fuzzy model are the total number of settlements with a population between 1000 and 20000 (labelled as x_1) and the total number of inhabitants in settlements with a population of over 20000 (labelled as x_2). As output variable of fuzzy model, the authors adopt the number of permanent postal units in each settlement (denoted as y). To test the model, data were collected for the whole territory of the Serbia. The results showed that these two approaches are complementary and that the suggested model can be very useful in defining the number of branches in the postal network without consideration the concrete units to be shot down or reorganized.

The mentioned studies consider the minimal number of PNUs; however, even more complex and sensitive task is to determine the concrete PNUs that should be closed. A possible solution might be the implementation of the proposed model in this paper.

3. The proposed model for reconfiguration of the postal network

The proposed model is based on fuzzy logic. Fuzzy logic is a tool for processing imprecise linguistic information and it enables the operations with fuzzy data. The input values of each fuzzy logic system can be numerical data or linguistic variables. Linguistic variables used for this purpose are represented through appropriate fuzzy sets.

Fuzzy logic is especially convenient when modelling a system where experts, i.e. decision-makers play an active role (Teodorović, Šelmić 2012). In this paper, we implement a Wang–Mendel method (Wang, Mendel 1992) to define fuzzy rules in the Fuzzy Inference System (FIS). This method implies the use of both empirical data and expert opinion to complete the fuzzy rule database.

However, to define the domains of input variables and membership functions intervals, we used the collected empirical data. For the purpose of modelling the FIS, in this paper Mamdani’s max–min inference system (Mamdani, Assilian 1975) is applied.

Fuzzy logic has been implemented on numerous problems related to transportation; however, except the paper by Blagojević *et al.* (2013), to the authors knowledge, there is no other studies dealing with the reorganization of postal network by using this method.

By analysing the current knowledge in the field, which is described more detailed in the Section 2, the important parameters for considering the network reconfiguration include the following variables, which are also the inputs of FIS:

- postal efficiency measured using the DEA method;
- the proximity of an alternative post office (in the case of shutting down of one unit, the closest one should be identified, and its distance measured in [km]);
- the number of legal entities gravitating towards a PNU;
- the social criterion, i.e. the number of individuals from sensitive categories (limited mobility, low income) in the territory of a PNU.

The output of the FIS is the preference of the decision-maker to reach a decision to shut down or reorganize a certain PNU. The preference can be described as “the strength of the will” to reach a certain decision and it can be very low, low, medium, strong, or very strong (Figure 1).

Up until now, the judgment of the decision-maker was based on the financial profitability indicators. The advantage of the suggested model is based on the fact that it takes into consideration the social value, the human consequence of providing UPS under equal conditions at the whole national territory, with regards for those who would suffer the most from closing of a PNU. The model also includes a ranking system, so that the worst-ranked PNUs receive the highest preference for closing.

3.1. Input and output variables

The values for input variables are measured in Zlatiborski District. The minimal, maximal and average values from the sample for each variable are shown in Table 1. In addition, there are values for output variable – closing preference index, which are obtained as an average value of assessments made by 9 experts from the postal industry. The experts received information about the concrete values of input variables and their task was to evaluate each PNU by grade from 1 to 5 about the closing or restructuring preference. A mark 1 represents very small and 5 very

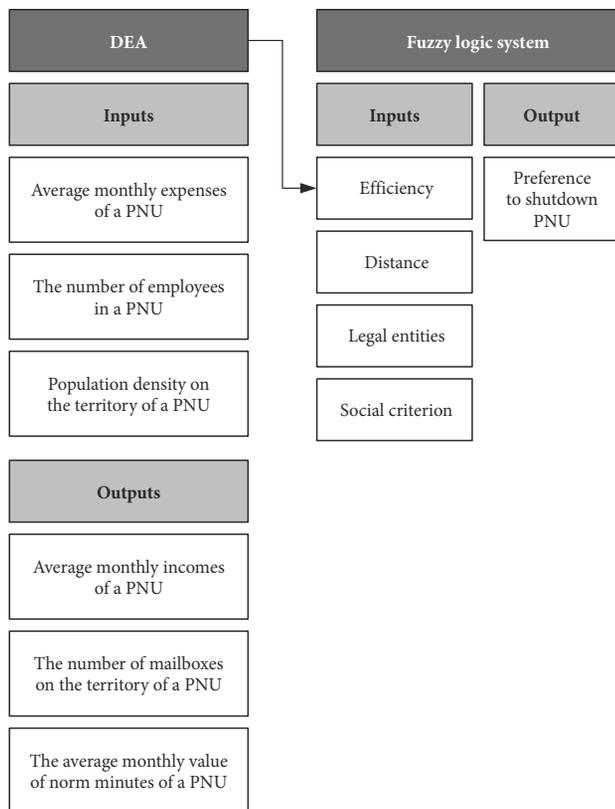


Figure 1. Schematic overview of the model

large closing preference of the PNU. For each considered PNU, the average assessment from all experts was calculated and then normalized in order to get the values from 0 to 1 (Table 1).

Based on the minimal, maximal and average values from the sample, we defined the intervals and corresponding membership functions, i.e. fuzzy sets for each input variable. For example, in the case of first input variable, the minimum value from the sample is 0.6207. This means that all values below this are considered as small with membership degree equal to 1, $\mu_A(x) = 1$. Further, the medium efficiency value in the sample is 0.9076. This value belongs to the fuzzy set *Medium* with membership degree equal to 1. Finally, the maximum efficiency value in the sample is equal to 1, which makes it a part of the fuzzy set *Large* with maximum degree. We use triangular and trapezoidal membership functions. However, other types of membership functions should not significantly change the results (Ali et al. 2015).

Table 1. The minimal, maximal and average values from the sample for input and output variables

	Efficiency	Distance	Legal entity	Social criterion	Preference index
Min	0.6207	2.9	6	189	0
Max	1	21.3	286	1466	1
Average	0.9076	9.9158	57.3421	574.6053	0.3637

The same principle is used for forming other input variables. The output variable is defined with five fuzzy sets describing the preference for closing or restructuring a PNU in a linear way, independently from values obtained from the experts. The experts' assessment is used for generating fuzzy rules from empirical data, according to the Wang–Mendel method.

3.1.1. Input variable x_1 – efficiency

The first input variable is the efficiency of a PNU calculated using the DEA method. The analysis shows how much an input should be decreased and/or an output increased in order for units to become efficient. The creators of DEA, Charnes et al. (1978) suggested an approach for determining efficiency through a non-parametrical technique, i.e. without a specific functional form, as opposed to statistical approaches. The relative efficiency of one Decision-Making Unit (DMU) is defined as a ratio of the weighted sums of their outputs (virtual output) and the weighted sums of their inputs (virtual input).

An important characteristic of DEA is that inputs and outputs for a certain DMU do not have to be homogeneous, but it is required that the units ranked during a single analytical process have the same kind of inputs and outputs. The DEA method is applicable to both profitable and unprofitable organizations, especially in the unprofitable service sector where outputs are not measured in monetary units, but their efficiency depends on the quality and scope of offered services. The original CCR DEA, based on abbreviations from the name of authors Charnes, Cooper and Rhodes (Charnes et al. 1978), input-oriented model is formulated as following Linear Programming (LP) problem:

$$\theta^* = \max \sum_{r=1}^s u_r \cdot y_{r0} \tag{4}$$

with constraints:

$$\sum_{i=1}^m v_i \cdot x_{i0} = 1; \tag{5}$$

$$\sum_{r=1}^s u_r \cdot y_{rj} \leq \sum_{i=1}^m v_i \cdot x_{ij}, \tag{6}$$

$$j = 1, 2, 3, \dots, n;$$

$$v_i \geq 0, u_r \geq 0,$$

where: θ^* is assessment of efficiency; x_{i0} , y_{r0} are i -th input and r -th output respectively for DMU_0 ; v_i is input weight; u_r is output weight.

As for the DMU for which a maximum in objective function (Equation (1)) is sought, the condition (Equation (2)) is true, meaning that it is obviously $0 < \theta \leq 1$, for each DMU. The weights v_i and u_r show the importance of each input and output and are determined in the model so that each DMU is efficient as much as possible.

Given that the condition (Equation (3)) is true for every DMU, it means that each of them lies on the efficiency frontier or beyond it. If $\max\theta = 1$, it means that efficiency is being achieved, so we can tell that DMU is efficient. Efficiency is not achieved for $\theta < 1$ and DMU is not efficient in that case.

The production units usually have no control over output and because that the analysis focuses on an input-oriented model. The analysis uses an approach that minimizes inputs to achieve certain outputs. This approach shows how much a production unit can reduce inputs to achieve a certain output–input-oriented model.

There is a number of papers whose authors used the DEA method in the domain of postal services. They used different approaches and different inputs and outputs. It is also interesting that this method may be applied at different levels – an individual postal operator and its network; city level; regional, national or, for example, European postal market.

There are numerous examples of measuring the postal network efficiency at national level (Tables 2 and 3). Filippini and Zola (2005) uses the econometrical approach

for determining the cost efficiency of the Swiss Post. The analysis was done in the Italian speaking area of Switzerland in 2001 and included 47 small local post offices. Doble (1995) measures technical efficiency of 1281 postal counters in the UK Post Office in 1989 for 13 weeks, from September to November. Cazals *et al.* (2008) analyse the cost efficiency of 1108 delivery Royal Mail post offices by means of Order-m Frontier method for determining efficiency expense limits. Deprins *et al.* (2006) defines three methods for measuring technical efficiency of 972 PNUs in Belgium. The first method, taken from Aigner and Chu (1968), was adjusted to the Cobb–Douglas production function. The second method applies Debreu–Farrell technical efficiency measures. The third method is an original one. The authors compare results based on all three methods and estimate work efficiency.

Sueyoshi and Aoki (2001) analyses 12 regional agencies of the Japanese post between 1983 and 1997 using the Malmquist index. In the paper by Maruyama and Nakajima (2002) the main idea was to define indicators of the productivity of post offices and the factors that affect those indicators. By determining technical efficiency through

Table 2. DEA – the national level (Europe)

Paper	Input	Output
Filippini, Zola (2005)	Total cost – price of capital and price of labour; Hourly price of labour	Collected mail; Delivered mail; Customer density (population/km ²)
Doble (1995)	Counter clerk serving hours	Quality of service – average waiting time [s]; Traffic – nine categories of transactions measured in Basic Transaction Hours; (BTHs) – [(number of transactions × counter transaction time)/3600]
Cazals <i>et al.</i> (2008)	Total number of hours worked	Total number of items
Deprins <i>et al.</i> (2006)	Total number of hours worked	Financial operations; Registered mail (received and delivered); Special delivery mail (received and distributed); Unaddressed printed matter (bulk mail) (distributed only); Outgoing mail (collection and presorting); Delivery points

Table 3. DEA – the national level (non-Europe)

Paper	Input	Output
Sueyoshi, Aoki (2001)	Number of post offices; Number of employees	Number of mails; Postal savings; Postal life insurance
Maruyama, Nakajima (2002)	Postal staff; Post office building area	Collection items; Delivery items
Borenstein <i>et al.</i> (2004)	Number of employees; Number of vehicles; Investments in training programs; IT investments; Physical area; Total cost; Infrastructure investments	Rate of external client satisfaction; Quality program – Performance Management and Accountability Toolkit (PMAT); Total revenue; Population serviced; Delivered load; Dispatched load; Number of objects delivered; Rate of absenteeism; Average time waiting in line; Workload system; Home delivery satisfaction rate

the analysis of 47 regions and 1145 post offices using the non-parametrical DEA method, inputs for the Tobit model were determined. Technical efficiency was further scrutinized based on two types of variables – the location of the PNU, population density, demand for postal services, geographical characteristics of the delivery area, and variables that have to do with strategic decisions and management efforts. Brazilian postal market was analysed by Borenstein *et al.* (2004). The paper analyses a relative efficiency of the Brazilian post where 85 out of 377 PNUs were chosen for analysis. They were organized into three groups – reception, delivery, and integrated units, so that input and output variables could be homogenized.

Ralević *et al.* (2016) proposes an original multi-input and multi-output model for measuring cost efficiency of delivery PNUs. A network of 1194 delivery PNUs in Serbia was analysed. The problem of numerousness and heterogeneity of these units was overcome by defining an original clustering algorithm. Knežević *et al.* (2011) suggests a model for optimizing the number of employees for twenty delivery post offices in the city of Belgrade (Serbia). The model is a hybrid between the DEA method and regression analysis, and its implementation has several phases. By means of regression analysis, the general characteristics of a DMU are determined first, and then using the input-oriented CCR DEA method, efficient DMUs are set apart – the reference set is comprised of inefficient units. Nedeljković and Drenovac (2012) uses two CCR models to determine efficiency of three delivery post offices in Belgrade in Serbia and examines the effect that the choice of input variables has on the efficiency rank. The third model uses the fuzzy DEA method to analyse the case

when not all precise data is available, because of which it has to be represented through fuzzy sets (Table 4).

It is interesting to compare different organizations in the same field, which are competitive (Table 5). The analysis whether and to what extent the competition affects a reduction of expenses and overall productivity is shown in the paper by Mizutani and Uranishi (2003). The sample refers to the organizations that deliver parcels in Japan – one of the DMUs was a public operator and other five DMUs were private operators.

The efficiency measurement of European postal operators was the main subject of interest for many authors (Table 6). Iturralde and Quirós (2008) analyses the efficiency of the European postal sector for 17 European postal operators through a change in efficiency by means of the Malmquist index. The paper by Ralević *et al.* (2015) measures profit efficiency in the postal sector by analysing data about Public Postal Operator (PPOs) in European Union and the Serbian postal operator. The proposed analytical process has two levels – in the first one, the DEA method is applied to all postal operators, and in the second one, non-standard DMUs are excluded using the Variable Returns to Scale (VRS) model, super-efficiency Constant Return to Scale (CRS) model, and slack-based model. One of the first studies (Çakır *et al.* 2015) to measure efficiency in the postal service sector using the context-dependent and measure-specific DEA method is based on a hybrid model that enables the ranking of efficient DMUs, and then sets short-term and long-term goals for inefficient DMUs. The hybrid DEA model measured the efficiency of national postal operators of 25 Organisation for Economic Co-operation and Development (OECD) countries.

Table 4. DEA – national and city level (Serbia)

Paper	Input	Output
Ralević <i>et al.</i> (2016)	Total number of staff; The costs for staff; Total number of permanent post offices; Expenditure required for the operation of permanent post offices	Number of letter-post items, domestic services; Operating revenue of letter-post items
Knežević <i>et al.</i> (2011)	Number of delivery post offices; Number of mailmen; Number of workers in preparation; Number of delivery workers; Work time of mailmen; Work time of workers in preparation; Work time of delivery workers; Covered area; Number of households Gross Domestic Product (GDP); Internet users	Letter mails; Registered letters; Insured letters; Parcels and post express
Nedeljković, Drenovac (2012)	Number of full time stuff; Average service time; Number of households	Total number of services
	Number of counters; Average waiting time in line; Covered area	Total number of services
	Number of full time stuff; Average service time (fuzzy); Number of households	Total number of services

Table 5. DEA – different operators

Paper	Input	Output
Mizutani, Uranishi (2003)	Total cost – sum of labour, material, payment for debts and depreciation costs	Number of transported goods

Table 6. DEA – European postal market

Paper	Input	Output
Iturralde, Quirós (2008)	Number of fulltime workers; Value of amortisation; Intermediate consumption – subtracting labour costs and depreciation from the total operating costs	Number of letters; Number of parcels; Number of km ² of the country belonging to each operator who provides a postal distribution service
Ralevic <i>et al.</i> (2015)	Total number of staff; Total number of post offices;	Total number of letter-post items, domestic services
Çakır <i>et al.</i> (2015)	Number of full time staff; Number of post offices	Number of letters [millions]; Number of parcels [millions]; Area [1000 km ²]

The DEA method is extremely sensitive to discussed variables, because exclusion of the important inputs or outputs can lead to biased results. The UPU was used as data base in order to ensure the comparability and consistency of the used data. The selection of variables in the proposed model is made according to previous research in this field on national territory, and also dependent of PPO data availability.

In the DEA model, which is proposed in this paper, the input variables are:

- average monthly expenses of a PNU;
- the number of employees in a PNU;
- population density on the territory of a PNU.

On the other hand the outputs are:

- average monthly incomes of a PNU,
- the number of mailboxes on the territory of a PNU,
- the average monthly value of norm minutes of a PNU (Figure 1).

The CRS DEA input-oriented method in the *DEA Excel Solver* software was applied to all delivery PNUs to determine how to gain a specific output with as little input as possible.

As previously defined, the first input variable E is the efficiency of a PNU calculated using the DEA method. This implies that a PNU can be efficient (value is 1) or inefficient (all other values less than 1). Therefore, the domain of the first input variable is [0, 1]. This domain is divided to the membership functions intervals according to the empirical data from our sample, as shown in Table 1.

The corresponding fuzzy sets of the first input variable are presented in Figure 2. As can be noticed, the efficiency can be LOW [0, 0, 0.62, 0.9], MEDIUM [0.62, 0.9, 1], and HIGH [0.9, 1, 1].

3.1.2. Input variable x_2 – distance

The second variable D relates to the consequences of closing. It includes the distance to the PNU that is the closest after the closing of the PNU being analysed. It is the additional distance [km] that clients would need to commute

in order to gain access to services. The domain of the second input variable is [1, 25], i.e. the distance can be LOW [1, 1, 2.9, 9.9], MEDIUM [2.9, 9.9, 21.3] and HIGH [9.9, 21.3, 25, 25]. The fuzzy numbers that correspond to these linguistic variables are presented in Figure 3.

In the research by Mostarac *et al.* (2019) the accessibility indicator was introduced to the postal system and calculated. This led to a detailed insight into the accessibility of the postal service, considering the distances between the point of demand and the point of supply (post office).

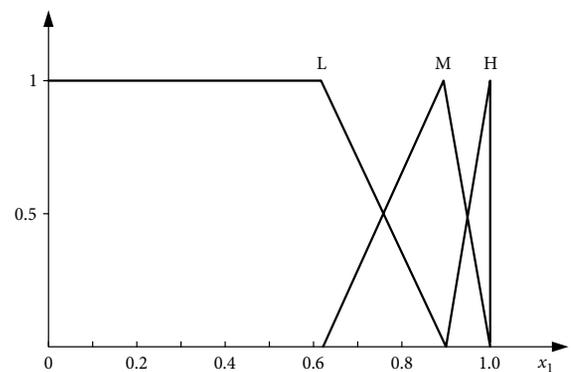


Figure 2. Input variable – efficiency (L – low; M – medium, H – high)

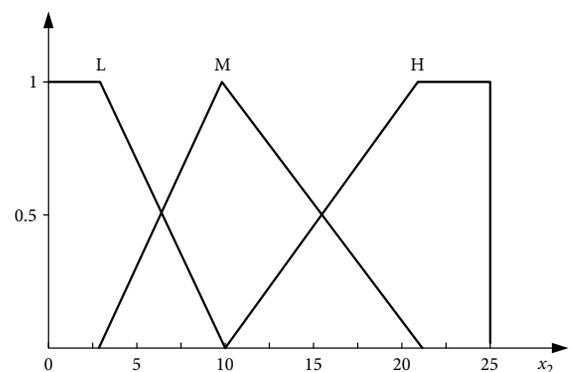


Figure 3. Input variable – distance (L – low; M – medium, H – high)

Several transportation modes could be adequate for implementation, with focus on rural areas: walking, cycling and usage of personal vehicles or public transportation. Since post offices are often located at the center of residential areas, the walking mode can be easily used to determine service access at smaller distances. Cycling is also preferable to use for small to medium distances, especially in communities lacking organized public transport. The personal vehicle transportation mode is appropriate to use for medium to longer distances, as it provides simplicity in the movement of the population. Public transport could also be considered, bearing in mind that it is usually not well (frequently) organized in smaller/rural communities. To model access to post offices using various transport modes, users' willingness to travel to post offices should be considered. This is generally expressed in distance or travel times needed in order to reach a service.

3.1.3. Input variable x_3 – legal entities

The third variable LE is the number of legal entities at the territory of a PNU. According to the research by UPU (2014) more than 90% of world economy is driven by Micro-, Small-, and Medium-sized Enterprises (MSME). In developing countries, international commerce is still mostly unavailable to MSMEs, especially those in rural or remote areas. Postal infrastructure can offer three significant advantages to MSMEs with the goal of overcoming this challenge: geographical diffusion, affordable prices, and simple use. Closing a PNU has a significant effect on the local business community as well. The legal entities located close to a PNU, experience decreased turnover because a part of the routine of the local population is visiting PNUs and purchasing. Owners of local enterprises use PNU services as a part of their everyday business routine. In the case of a PNU being shut down, they need to plan a certain time and a remote location for gaining access to postal services. This slows down the information flow, causes delays, additional expenses for gas, and leads to negative ecological effects (Ipsos MORI 2009). Therefore, by shutting down a PNU, the local business community would suffer additional expenses and difficulties in conducting business.

The domain of the third input variable is $[0, 300]$, i.e. the number of legal entities can be LOW $[0, 0, 6, 57.3]$, MEDIUM $[6, 57.3, 286]$, and HIGH $[57.3, 286, 300, 300]$. The fuzzy numbers that correspond to these linguistic variables are presented in Figure 4.

3.1.4. Input variable x_4 – social criterion

The fourth variable is based on the idea that shutting down a PNU has the most detrimental effect on sensitive population groups. Ipsos MORI (2009) carried out the research on the consequences of shutting down a post office in a village with 1000 residents after 6.5 months from this event. The ability to use a wide offer of services throughout the week in a favourable location and interaction with employees caused the locals to see the change as negative. For working residents, the everyday commute to work in nearby towns is also an opportunity to gain

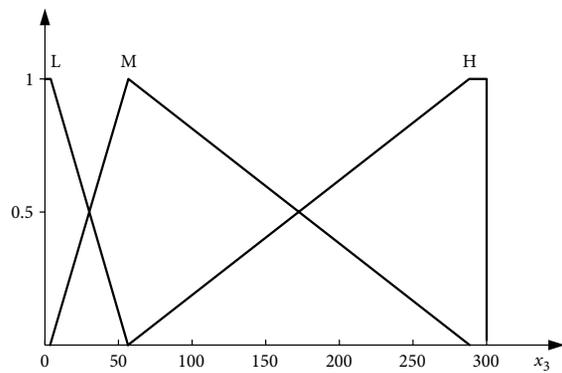


Figure 4. Input variable – legal entities (L – low; M – medium, H – high)

access to postal services. The situation is different for sensitive populations, to whom the access to postal services becomes difficult or impossible. Allocating the PNU and changing business hours made older and immobile residents dependable on the good will of others (family members, friends or neighbours). Their mobility is minimized.

The categories included in the analysis were:

- retirees;
- persons who receive social benefits based on different criteria, and who need a post office in order to obtain those benefits;
- persons with disabilities;
- persons who receive benefits for taking care of others;
- persons who receive unemployment benefits;
- single parents.

These categories are characterized by limited mobility due to illness or commuting difficulties. Every relocation has an impact on their (in)ability to access postal services or their overall experience with the postal network. That change also create additional expenses for people with low income. In addition to this, parents of small children can hardly adjust their daily schedules in order to organize the additional commute required for gaining access to postal services, which affect their dissatisfaction and possibility of gaining access to services.

Based on study by US PSOIG (2014) around 59% of the US Postal Service branches are located in the places where there is one or no representatives of the banking sector, which often makes them the only economic entity in rural areas. In the Serbia as well, the banks have been closing their offices in those parts of the country where business is not profitable: 16 counties in Serbia do not have a single bank, while PNUs can be found in each Serbian county.

Having all the mentioned in mind, the domain of the fourth input variable (SC) – social criterion, i.e. the number of persons from sensitive populations in a territory of a PNU is $[100, 1.500]$, i.e. the number of clients can be LOW $[100, 100, 189, 574.6]$, MEDIUM $[189, 574.6, 1.466]$, and HIGH $[574.6, 1.466, 1.500, 1.500]$. The fuzzy numbers that correspond to these linguistic variables are presented in Figure 5.

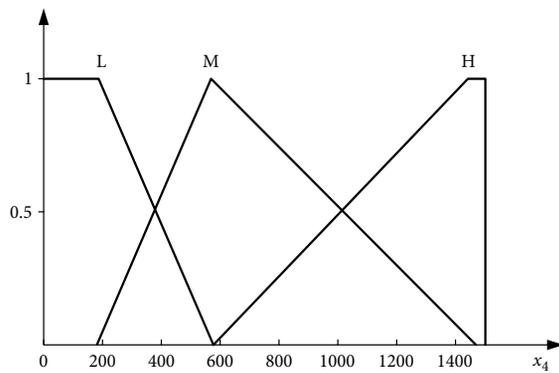


Figure 5. Input variable – social criterion (L – low; M – medium, H – high)

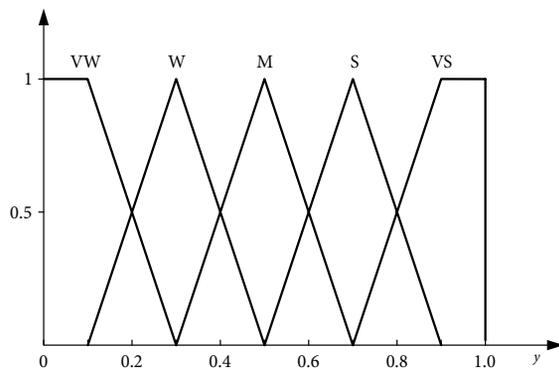


Figure 6. Output variable – closing preference (preference index) (VW – very weak; W – weak; M – medium; S – strong; VS – very strong)

3.1.5. Output variable y – preference

The output variable is the preference, represented by the value of preference index, which is the preference of the decision-maker (regional manager) to reach a decision to shut down a certain PNU. The domain of the output variable P is $[0, 1]$, and it can be VERY WEAK $[0, 0, 0.1, 0.3]$, WEAK $[0.1, 0.3, 0.5]$, MEDIUM $[0.3, 0.5, 0.7]$, STRONG $[0.5, 0.7, 0.9]$ and VERY STRONG $[0.7, 0.9, 1, 1]$. The fuzzy numbers that correspond to these linguistic variables are presented in Figure 6.

3.2. Generating fuzzy rules based on empirical data

To generate fuzzy rules, we use the empirical data and expert opinion as well. The implemented method is based on the procedure proposed by Wang and Mendel (1992) and it consists of the following five steps:

- *the first step* – divide the inputs and outputs spaces into fuzzy regions. Assume that the domain intervals of x_1 , x_2 and y are $[x_1^-, x_1^+]$, $[x_2^-, x_2^+]$ and $[y^-, y^+]$, respectively, where “domain interval” of a variable means that most probably this variable will lie in this interval (the values of a variable are allowed to lie outside its domain interval). In our case, the intervals are defined based on data in Table 1. Divide each domain interval into $2 \cdot N + 1$ regions (N can be different for different variables, and the lengths of these

regions can be equal or unequal). The shape of each membership function can be triangular, but other divisions of the domain regions and other shapes of membership functions are possible. The result of the first step implementation can be seen in Figures 2–6.

- *the second step* – generate fuzzy rules from given data pairs. The first part is to determinate degrees of given input–output pairs in different region. Then it needs to assign to given $x_1^{(i)}$, $x_2^{(i)}$ or $y^{(i)}$ to the region with the maximum degree and finally, obtain one rule from one pair of desired input–output data. After this procedure we made rules, the one for each input–output data, in our case there are 38 rules.
- *the third step* – assign a degree for each rule. Since there are usually lots of data pairs, and each data pair generates one rule, it is highly probable that there will be some conflicting rules, i.e., rules that have the same IF part but a different THEN part. One way to resolve this conflict is to assign a degree to each rule generated from data pairs, and accept only the rule from a conflict group that has maximum degree. In this way not only is the conflict problem resolved, but also the number of rules is greatly reduced. In this part of procedure, we eliminate conflict rules and also remove the same rules. In this way, we obtained 19 rules (Table 7).
- *the fourth step* – create a combined fuzzy rule base. The base with fuzzy rules is completed according to the following strategy: one part of the database is a set of rules obtained from empirical data and another from human experts, in this case by the authors of this paper. The used principle lies on the assumption that a preference index is higher if the inputs are lower. The complete fuzzy rule database consists of 81 rules, where 19 is obtained from empirical data and remaining 62 rules are defined by the authors.
- *the fifth step* – determine a mapping based on the combined fuzzy rule base.

4. Model application – results and discussion

4.1. General information

The criteria for defining rural areas are various and can be based not only on the socio-economic and spatial characteristics, but also on certain characteristics of rural areas that are important for the purpose of research. Some of them are the number of residents, population density, spatial criteria – the position in relation to a city or the most important object, financial activity – the number of residents that work in agriculture or their income. Depending on the purpose of the classification, the corresponding criteria should be chosen (Ranković Plazinić, Jović 2014). The most commonly used definitions are the ones from the OECD and the European Union, although there has been an increased tendency for countries to come up with their own definitions taking into considerations local specificities.

Table 7. The rules from data pairs after eliminating the conflict and the same rules

Rule number	Input 1	Input 2	Input 3	Input 4	Output
	Efficiency (DEA)	Distance [km]	Legal entities	Social criteria	Closing preference
			Overall number in the PNU territory	Number of clients from sensitive populations in the PNU territory	Preference index (interval 0...1)
1	L	H	L	L	M
2	L	H	L	M	S
3	L	H	M	M	S
4	M	L	L	L	W
5	M	L	M	M	M
6	M	M	L	L	M
7	M	H	L	L	VS
8	M	H	L	M	VS
9	M	H	M	L	M
10	M	H	M	M	VW
11	H	L	M	L	VW
12	H	L	M	M	VW
13	H	L	H	H	VW
14	H	M	L	L	VW
15	H	M	L	M	VW
16	H	M	H	H	VW
17	H	H	L	L	M
18	H	H	L	M	VW
19	H	H	M	M	VW

Notes: L – low; M – medium, H – high; VW – very weak; W – weak; M – medium; S – strong; VS – very strong.

Table 8. Statistic indicators for the counties of Zlatiborski District

County	Area [km ²]	Population	Population density [per 1 km ²]	Number of residential area	
				Urban	Rural
Arilje	349	19106	55	1	21
Bajina Bašta	673	26956	40	1	35
Kosjerić	358	12354	35	1	26
Nova Varoš	581	17066	29	1	32
Požega	424	30294	71	1	41
Priboj	553	30057	54	1	31
Prijepolje	825	41368	50	1	79
Sjenica	1059	28847	27	1	100
Užice	668	80152	120	2	39
Čajetina	647	15090	23	1	23

The definition of rural areas in Serbia is not officially coordinated to those of the OECD and European Union. The official statistics in Serbia recognizes only two types of residential areas: “urban” and “other”, the latter being in the place of rural areas although it is not precise enough.

The territory of the Serbia is divided into 29 districts. Each one includes a number of counties and cities. Zlatiborski District takes up an area of 6140 m² and includes ten counties (Bajina Bašta, Kosjerić, Užice, Požega, Čajetina, Arilje, Priboj, Nova Varoš, Sjenica and Prijepolje)

and 438 residential areas, among which 11 are urban and 427 belong to the “other” category (Table 8) (SORS 2011).

The territory of the Serbia has three regional, one international, and 14 local Postal Logistics Centers (PLC). In this paper, the proposed model is applied to the regional business unit of Serbian USP called Užice. It is important to note that Zlatiborski District has ten counties; however, Sjenica County belongs to the regional business unit of Kraljevo, and thus it is not taken into consideration in this paper.

Depending on the presence of certain technological phases (collection, sorting, transport, and delivery), the PNUs can be divided into collecting post offices, delivery post offices (they deliver the shipment to home or business address of addressee), indoor delivery post offices (delivery is organized just in the postal unit) and reload-ing–sorting post offices. This paper analyses only the de-livery post offices; however, these units also collect and deliver mail in the unit itself. The territory of Užice has 59 post offices, out of which 38 are rural delivery post offices (Table 9).

Table 9. The number of permanent and rural delivery PNUs in the counties in business unit Užice

County	Number of permanent post offices	Rural delivery PNUs
Arilje	3	2
Bajina Bašta	7	6
Kosjerić	4	3
Nova Varoš	6	5
Požega	6	4
Priboj	4	2
Prijepolje	5	3
Užice	16	7
Čajetina	8	6

4.2. Obtained results

To maximize the utilization of the proposed model, we combined the obtained results with the methodology proposed by Blagojević *et al.* (2013). By implementing the methodology proposed by Blagojević *et al.* (2013) on the data related to the regional business unit Užice, we obtained the results about the minimal number of PNUs in each county (Table 10). By this we determine the counties where there should be a reduction in the number of PNUs. These are the following: Bajina Bašta, Nova Varoš, Požega, and Užice (grey background in Table 10).

The input data for the DEA method, as well as for the values of the third input variable, were obtained upon request from the regional business unit of Užice. Distance values for the second input variable were obtained from the Internet using the application *PlanPlus* (<https://www.planplusonline.com>). For the fourth variable, official data from the SORS (2011) was used. Upon applying the model in the MATLAB software (*Fuzzy Logic Toolbox* – <https://www.mathworks.com/products/fuzzy-logic.html>), the preference indices for closing each of the 38 rural delivery post offices were obtained. The results can be seen in the last column of the Table 11.

The current practice of the USP from Serbia is to determine the ranks of PNUs annually. PNUs are divided into ranks according to their importance to the overall functioning of the postal network. All PNUs that are a part of Serbian USP are divided into unranked (the highest rank) and posts with ranks one to eight (higher rank represents

lower importance). The elements taken into consideration are the average monthly gross product (expressed in norm minutes¹) from the previous year and the realized average monthly income of a PNU in the previous year. The ranking of PNUs is conducted based on the number of points that are calculated using the following equation:

$$\text{number of points} = \frac{(\text{number of norm minutes} + (\text{PNU income} / \text{correctional factor}))}{1000} \quad (7)$$

The correctional factor is the ratio between the overall realized income and the number of norm minutes of all PNUs in the previous year.

Table 12 shows in grey colour those counties that, according to the applied criteria from Blagojević *et al.* (2013) have a higher number of current permanent PNU than the model proposes. Within each of these counties, for each rural delivery PNU a closing preference index is provided according to the proposed model, which gives the regional manager a valuable tool and support in decision-making. Therefore, there is not only a proposition for reducing the number of permanent PNUs, but also a suggestion, which concrete PNU should be closed based on the model output. The fourth and fifth column (Table 12) show the rank of rural units and points calculated by the Equation (7) according to which the ranking was conducted. When making a decision about shutting down a PNU, two types of information are available to the regional manager: the global business importance or rank and closing preference index, which is based on the specificities of an area and socio-demographic characteristics. In the empirical example, in counties marked with grey colour (Table 12), the candidates for closing are those PNUs with the highest preference index also marked with grey colour.

The result of the proposed methodology may be considered as very useful in making an extremely delicate decision about shutting down a PNU. Its value lies in offering an exact closing preference index for each PNU using the totally transparent procedure.

It is interesting to note that PNU with the highest closing preference index usually has the lowest PNU rank. Nevertheless, the proposed model still brings an additional quality of a decision taking into account a social factor. For example, in the Nova Varoš County, the highest closing preference index has PNU Bistrica, which is not with the lowest PNU rank in the observed county assigned by the USP.

Finally, we should stress that a decision to shut down a PNU does not necessary mean that postal services should be totally abolished at the place of this PNU. The solution for the USP could be to reorganize its network of postal branches and to introduce some other forms of service offering.

¹ All services offered in a PNU are normalized, which makes it possible to use the number of services by type to determine the overall realized norm minutes for a certain period of time, which represents a productivity measure of a PNU (Pošta Srbije 2009).

Table 10. Values obtained by applying the criteria for determining the number of permanent PNUs by counties in business unit Užice

County	Current number of permanent PNUs	Mathematical formulation (Blagojević et al. 2013)	Fuzzy model (Blagojević et al. 2013)
Arilje	3	3	5
BajinaBašta	7	3	5
Kosjerić	4	1	4
Nova Varoš	6	1	4
Požega	6	4	5
Priboj	4	6	7
Prijepolje	5	9	9
Užice	16	16	9
Čajetina	8	8	10

Table 11. Input and output values for the rural delivery PNUs in regional business unit Užice obtained by the proposed model

No	Post office	Name	Input 1	Input 2	Input 3	Input 4	Output
			Efficiency	Distance [km]	Number of legal entities	Social criteria	Closing preference index
1	31305	Brodarevo	1	21.3	180	1466	0.1239
2	31310	Čajetina	1	5.3	286	1086	0.2109
3	31335	Sastavci	1	16.3	22	1013	0.2048
4	31213	Ježevica	0.97875	11.7	82	947	0.2393
5	31311	Bela Zemlja	1	5.2	142	870	0.1999
6	31204	Karan	1	4.5	65	858	0.1752
7	31318	KokinBrod	1	7.6	44	803	0.2540
8	31236	Divljaka	0.93668	8.8	129	887	0.2911
9	31244	Šljivovica	0.80714	10.2	168	466	0.4577
10	31255	Rogačica	0.88258	6.2	72	937	0.3580
11	31312	Mačkat	0.94207	6.1	168	748	0.3367
12	31265	Ražana	1	9.4	59	681	0.2859
13	31263	Varda	1	9.7	30	661	0.2188
14	31306	Jabuka	1	14.4	48	606	0.2433
15	31242	Kremna	1	9.1	39	584	0.2494
16	31337	Banja kod Priboja	0.82927	2.9	79	834	0.4780
17	31253	Zlodol	1	7.8	25	483	0.2641
18	31237	Roge	1	10	22	440	0.2734
19	31251	Mitrovac	1	13.3	15	418	0.2763
20	31234	Brekovo	0.93569	13.3	13	398	0.4103
21	31317	Draglica	0.99869	7.6	20	383	0.2977
22	31322	Božetići	0.98845	17.9	12	372	0.3685
23	31319	Jasenovo kod Nove Varoši	0.82842	15.6	21	347	0.4642
24	31206	Ravni	0.85222	8.6	42	624	0.3995
25	31254	Kostojevići	1	6.2	36	356	0.3163
26	31243	Mokra Gora	0.97688	13.3	21	340	0.3491
27	31241	Bioska	0.79006	9.1	18	545	0.4353
28	31307	Aljinovići	0.81123	17.7	6	226	0.5998
29	31325	Bistrica	0.73991	11.1	21	441	0.4734
30	31209	Ljubiš	0.85249	8.2	33	483	0.4686
31	31256	Perućac	0.90803	12.4	58	300	0.3965
32	31214	Gornja Dobrinja	0.82161	11.7	29	289	0.4744
33	31262	SečaReka	0.6207	6.9	45	510	0.6148
34	31215	Jelen Do	0.88864	5.5	28	342	0.4121
35	31258	Bačevci	0.75353	11.2	16	189	0.6037
36	31207	Sirogojno	0.71872	8.1	32	392	0.5584
37	31208	Rožanstvo	0.77986	8.1	29	216	0.5695
38	31203	LunovoSelo	0.84817	4.5	24	294	0.4689
Average			0.90763	9.916	57.34	574.61	0.3637

Table 12. Rural delivery PNUs by counties (ranks and closing preference indexes)

County	PNU	Name	Points	PNU rank	Closing preference index
Užice	31203	Lunovo Selo	14097	7	0.4689
	31204	Karan	276874	6	0.1752
	31206	Ravni	22341	6	0.3995
	31241	Bioska	19805	6	0.4353
	31242	Kremna	263757	6	0.2494
	31243	Mokra Gora	213247	6	0.3491
	31311	Bela Zemlja	367868	5	0.1999
Čajetina	31207	Sirogojno	203776	6	0.5584
	31208	Rožanstvo	9786	7	0.5695
	31209	Ljubiš	189637	6	0.4686
	31244	Šljivovica	199135	6	0.4577
	31310	Čajetina	953906	4	0.2109
	31312	Mačkat	311704	5	0.3367
Požega	31213	Ježevica	335376	5	0.2393
	31214	Gornja Dobrinja	138148	7	0.4744
	31215	Jelen Do	129313	7	0.4121
	31237	Roge	152397	7	0.2734
Arilje	31234	Brekovo	135724	7	0.4103
	31236	Divljaka	353758	5	0.2911
Bajina Bašta	31251	Mitrovac	117277	7	0.2763
	31253	Zlodol	168094	6	0.2641
	31254	Kostojevići	194101	6	0.3163
	31255	Rogačica	330178	5	0.3580
	31256	Peručac	185107	6	0.3965
	31258	Bačevci	119332	7	0.6037
Kosjerić	31262	SečaReka	159747	7	0.6148
	31263	Varda	204149	6	0.2188
	31265	Ražana	22528	6	0.2859
Prijepolje	31305	Brodarevo	721316	4	0.1239
	31306	Jabuka	254512	6	0.2433
	31307	Aljinovići	76709	8	0.5998
Nova Varoš	31317	Draglica	156564	7	0.2977
	31318	KokinBrod	27928	6	0.2540
	31319	Jasenovo kod Nove Varoši	134079	7	0.4642
	31322	Božetići	118907	7	0.3685
	31325	Bistrica	167198	6	0.4734
Priboj	31335	Sastavci	273587	6	0.2048
	31337	Banja kod Priboja	216484	6	0.4780

A modern mode of serving the customers is installing the self-service machines. These machines are able to collect the postal items, they may be used by the customers to pick up the shipment in delivery phase and also to perform various types of financial services without any presence of postal employee. Another possible mode is introducing a mobile post office. In this case the postal services are offered in specially equipped vehicles, such as trucks or trains. They are stationed in several location during the day and the customers are informed about their

work schedule. The proposed new forms of PNU should bring to the reduction in costs for USP while the needs of customers for postal services would be satisfied.

Conclusions

The universal service mechanism based on the human concept of interconnecting all levels of society has been changing along with the institutional and technological changes. However, the necessity of everyday communica-

tion and exchange of goods and information on a local, regional, national and international level calls for a certain infrastructure that should be available to all citizens, organizations and public institutions. A sustainable USP business model requires a precise definition of necessary criteria for setting apart unprofitable PNUs in different areas, while the human concept of UPS calls for recognizing the importance of the differences in functioning and sustaining local communities and the needs of the most vulnerable group of populations.

A number of papers have worked on determining the minimal number of permanent PNUs. However, to reduce or restructure the postal network in practice, the information about the minimal number of units is not sufficient. The essential question is how to determine the importance of considered PNUs and to rank them accordingly which would be a starting point for decision-making process about the postal infrastructure optimization. The model proposed in this paper gives an answer on this question.

In the first part of this paper, an existing methodology from the literature is used to determine the minimal number of PNUs at some region. Further, we propose a new model based on fuzzy logic to unambiguously, without discrimination and transparently suggest, which PNU should be closed or restructured in order to affect as little as possible the local business community and the most vulnerable group of people. Further, this paper suggests the new forms of serving the customers in order to reduce a negative impact of closing the traditional PNU. Although this paper analyses rural areas, by further analysis of parameters, which characterize suburban and urban areas, the model could also be applied to the complete administrative units or whole national territory.

Acknowledgements

This research was supported by the Serbian Ministry of Education, Science and Technological Development (Project No TR36022) and the University of Pardubice (Czech Republic).

Author contributions

Jelena Milutinović chosen the sample to be analysed in coordination with the designated public postal operator and was responsible for data collection and methodology of research implementation.

Dejan Marković coordinated all the activities and prepared the organization and writing of the paper.

Bojan Stanivuković made a research on the current knowledge in the considered topic.

Libor Švadlenka performed a measurement of postal branches efficiency by using DEA.

Momčilo Dobrodolac calculated the preference indices for considered postal branches by using fuzzy logic.

Disclosure statement

The authors state that they do not have any competing financial, professional, or personal interests from other parties.

References

- Aigner, D. J.; Chu, S. F. 1968. On estimating the industry production function, *The American Economic Review* 58(4): 826–839.
- Ali, O. A. M.; Ali, A. Y.; Sumait, B. S. 2015. Comparison between the effects of different types of membership functions on fuzzy logic controller performance, *International Journal of Emerging Engineering Research and Technology* 3(3): 76–83.
- Barham, L.; Maunder, S.; Dodgson, J. 2007. *Access to Postal Services: a Final Report for Postcomm*. NERA Economic Consulting (National Economic Research Associates).
- Blagojević, M.; Šelmić, M.; Macura, D.; Šarac, D. 2013. Determining the number of postal units in the network – fuzzy approach, Serbia case study, *Expert Systems with Applications* 40(10): 4090–4095. <https://doi.org/10.1016/j.eswa.2013.01.038>
- Borenstein, D.; Becker, J. L.; Do Prado, V. J. 2004. Measuring the efficiency of Brazilian post office stores using data envelopment analysis, *International Journal of Operations & Production Management* 24(10): 1055–1078. <https://doi.org/10.1108/01443570410558076>
- Cabras, I.; Lau, C. K. M. 2019. The availability of local services and its impact on community cohesion in rural areas: evidence from the English countryside, *Local Economy: the Journal of the Local Economy Policy Unit* 34(3): 248–270. <https://doi.org/10.1177/0269094219831951>
- Cazals, C.; Dudley, P.; Florens, J.-P.; Patel, S.; Rodriguez, F. 2008. Delivery offices cost frontier: a robust non parametric approach with exogenous variables, *Review of Network Economics* 7(2): 294–308. <https://doi.org/10.2202/1446-9022.1150>
- Charnes, A.; Cooper, W. W.; Rhodes, E. 1978. Measuring the efficiency of decision making units, *European Journal of Operational Research* 2(6): 429–444. [https://doi.org/10.1016/0377-2217\(78\)90138-8](https://doi.org/10.1016/0377-2217(78)90138-8)
- Christiaanse, S.; Haartsen, T. 2017. The influence of symbolic and emotional meanings of rural facilities on reactions to closure: the case of the village supermarket, *Journal of Rural Studies* 54: 326–336. <https://doi.org/10.1016/j.jrurstud.2017.07.005>
- Comber, A.; Brunson, C.; Hardy, J.; Radburn, R. 2009. Using a GIS-based network analysis and optimisation routines to evaluate service provision: a case study of the UK Post Office, *Applied Spatial Analysis and Policy* 2(1): 47–64. <https://doi.org/10.1007/s12061-008-9018-0>
- Çakır, S.; Perçin, S.; Min, H. 2015. Evaluating the comparative efficiency of the postal services in OECD countries using context-dependent and measure-specific data envelopment analysis, *Benchmarking: an International Journal* 22(5): 839–856. <https://doi.org/10.1108/BIJ-10-2013-0098>
- Deprins, D.; Simar, L.; Tulkens, H. 2006. Measuring labor-efficiency in post offices, in P. Chander, J. Drèze, C. K. Lovell, J. Mintz (Eds.). *Public Goods, Environmental Externalities and Fiscal Competition*, 285–309. https://doi.org/10.1007/978-0-387-25534-7_16
- Doble, M. 1995. Measuring and improving technical efficiency in UK post office counters using data envelopment analysis, *Annals of Public and Cooperative Economics* 66(1): 31–64. <https://doi.org/10.1111/j.1467-8292.1995.tb00877.x>
- ERGP. 2014. *ERGP Report 2014 on the Quality of Service and End-User Satisfaction*. European Regulators Group for Postal Services (ERGP). 86 p. Available from Internet: <https://ec.europa.eu/docsroom/documents/14379/attachments/1/translations>
- EU. 1997. *Directive 97/67/EC of the European Parliament and of the Council of 15 December 1997 on Common Rules for the Development of the Internal Market of Community Postal*

- Services and the Improvement of Quality of Service*. European Union (EU). Available from Internet: <http://data.europa.eu/eli/dir/1997/67/oj>
- EU. 2002. *Directive 2002/39/EC of the European Parliament and of the Council of 10 June 2002 Amending Directive 97/67/EC with Regard to the Further Opening to Competition of Community Postal Services*. European Union (EU). Available from Internet: <http://data.europa.eu/eli/dir/2002/39/oj>
- EU. 2008. *Directive 2008/6/EC of the European Parliament and of the Council of 20 February 2008 Amending Directive 97/67/EC with Regard to the Full Accomplishment of the Internal Market of Community Postal Services*. European Union (EU). Available from Internet: <http://data.europa.eu/eli/dir/2008/6/oj>
- Filippini, M.; Zola, M. 2005. Economies of scale and cost efficiency in the postal services: empirical evidence from Switzerland, *Applied Economics Letters* 12(7): 437–441. <https://doi.org/10.1080/13504850500109709>
- Hamilton, C. 2016. Changing service provision in rural areas and the possible impact on older people: a case example of compulsory post office closures and outreach services in England, *Social Policy and Society* 15(3): 387–401. <https://doi.org/10.1017/S1474746415000391>
- Higgs, G.; Langford, M. 2013. Investigating the validity of rural–urban distinctions in the impacts of changing service provision: the example of postal service reconfiguration in Wales, *Geoforum* 47: 53–64. <https://doi.org/10.1016/j.geoforum.2013.02.011>
- Higgs, G.; White, S. D. 1997. Changes in service provision in rural areas. Part 1: the use of GIS in analysing accessibility to services in rural deprivation research, *Journal of Rural Studies* 13(4): 441–450. [https://doi.org/10.1016/S0743-0167\(97\)00030-2](https://doi.org/10.1016/S0743-0167(97)00030-2)
- Ibrahim, S.; Lawal, D. M. 2015. Assessment of the proposed impact of post-office closure in Leicestershire (UK) using GIS-based network analysis, *International Journal of Geomatics and Geosciences* 6(1): 1–10.
- Ipsos MORI. 2009. *Impact of Post Office Closures: Area 1*. Ipsos MORI, London, UK. 7 p. Available from Internet: https://www.nao.org.uk/wp-content/uploads/2009/06/0809558_Ipsos_Case_Studies_Area1_Report.pdf
- Iturralde, M. J.; Quirós, C. 2008. Analysis of efficiency of the European postal sector, *International Journal of Production Economics* 114(1): 84–90. <https://doi.org/10.1016/j.ijpe.2008.03.001>
- Klingenberg, J. P.; Bzhilyanskaya, L. Y.; Ravnitzky, M. J. 2013. Optimization of the United States postal retail network by applying GIS and econometric tools, in M. A. Crew, P. R. Kleindorfer (Eds.). *Reforming the Postal Sector in the Face of Electronic Competition*, 118–131. <https://doi.org/10.4337/9780857935809.00014>
- Knežević, N.; Trubint, N.; Macura, D.; Bojović, N. 2011. A two-level approach for human resource planning towards organizational efficiency of a postal distribution system, *Economic Computation and Economic Cybernetics Studies and Research* (4): 155–168.
- Kujačić, M.; Šarac, D.; Jovanović, B. 2012. Access to the postal network of the public operator, in *Proceedings of International Conference “The Role of Strategic Partnership and Re Engineering or the Public Postal Network in the Sustainable Provision of Universal Service”*, 26 October 2012, Budva, Montenegro, 15–25.
- Mamdani, E. H.; Assilian, S. 1975. An experiment in linguistic synthesis with a fuzzy logic controller, *International Journal of Man–Machine Studies* 7(1): 1–13. [https://doi.org/10.1016/S0020-7373\(75\)80002-2](https://doi.org/10.1016/S0020-7373(75)80002-2)
- Maruyama, S.; Nakajima, T. 2002. *Efficiency Measurement and Productivity Analysis for Japanese Postal Service*. Tokyo, Japan. 26 p. Available from internet: <https://www.yu-cho-f.jp/research/old/pri/reserch/discus/postal/2002/dp02-03.pdf>
- Mizutani, F.; Uranishi, S. 2003. The post office vs. parcel delivery companies: competition effects on costs and productivity, *Journal of Regulatory Economics* 23(3): 299–319. <https://doi.org/10.1023/A:1023368327735>
- Mostarac, K.; Kavran, Z.; Rakić, E. 2019. Accessibility of universal postal service according to access points density criteria: case study of Bjelovar–Bilogora County, Croatia, *Promet – Traffic & Transportation* 31(2): 173–183. <https://doi.org/10.7307/ptt.v31i2.3019>
- Nedeljković, R. R.; Drenovac, D. 2012. Efficiency measurement of delivery post offices using fuzzy data envelopment analysis (possibility approach), *International Journal for Traffic and Transport Engineering* 2(1): 22–29.
- Neutens, T.; Delafontaine, M.; Schwanen, T.; Van de Weghe, N. 2012. The relationship between opening hours and accessibility of public service delivery, *Journal of Transport Geography* 25: 128–140. <https://doi.org/10.1016/j.jtrangeo.2011.03.004>
- Okholm, H. B.; Cerpickis, M.; Möller Boivie, A.; Facino, M.; Gårdebrink, J.; Almqvist, M.; Basalisco, B.; Geus, M.; Apon, J. 2018. *Main Developments in the Postal Sector (2013–2016)*. European Commission, 102 p.
- Okholm, H. B.; Möller, A. 2013. Vulnerable users in times of declining demand: the case of basic bank services in Norway and Sweden, in M. A. Crew, P. R. Kleindorfer (Eds.). *Reforming the Postal Sector in the Face of Electronic Competition*, 148–162. <https://doi.org/10.4337/9780857935809.00016>
- Pošta Srbije. 2009. *Opšti plan poštanske mreže*. Beograd, Republika Srbija. (in Serbian).
- Ralević, P.; Dobrodolac, M.; Marković, D. 2016. Using a non-parametric technique to measure the cost efficiency of postal delivery branches, *Central European Journal of Operations Research* 24(3): 637–657. <https://doi.org/10.1007/s10100-014-0369-0>
- Ralevic, P.; Dobrodolac, M.; Markovic, D.; Mladenovic, S. 2015. The measurement of public postal operators’ profit efficiency by using data envelopment analysis (DEA): a case study of European Union member states and Serbia, *Inžinerinè Ekonomika – Engineering Economics* 26(2): 159–168. <https://doi.org/10.5755/j01.ee.26.2.3360>
- Ranković Plazinić, B.; Jović, J. 2014. Women and transportation demands in rural Serbia, *Journal of Rural Studies* 36: 207–218. <https://doi.org/10.1016/j.jrurstud.2014.08.002>
- Schuster, P. B. 2013. One for all and all for one: privatization and universal service provision in the postal sector, *Applied Economics* 45(26): 3667–3682. <https://doi.org/10.1080/00036846.2012.727982>
- SORS. 2011. *Census 2011: The Census of Population, Households and Dwellings in the Republic of Serbia*. Statistical Office of the Republic of Serbia (SORS). Available from Internet: <https://www.stat.gov.rs/en-us/oblasti/popis/popis-2011>
- Sueyoshi, T.; Aoki, S. 2001. A use of a nonparametric statistic for DEA frontier shift: the Kruskal and Wallis rank test, *Omega* 29(1): 1–18. [https://doi.org/10.1016/S0305-0483\(00\)00024-4](https://doi.org/10.1016/S0305-0483(00)00024-4)
- Taylor, J.; Rubin, G.; Raymond, P. 2006. *The Last Post: the Social and Economic Impact of Changes to Postal Services in Manchester*. New Economics Foundation. 60 p.
- Teodorović, D.; Šelmić, M. 2012. *Računarska inteligencija u saobraćaju*. Saobraćajni fakultet, Univerzitet u Beogradu, Republika Srbija, 210 s. (in Serbian).

- Unterberger, M.; Vešović, P.; Mostarac, K.; Šarac, D.; Ožegović, S. 2018. Three-dimensional corporate social responsibility model of a postal service provider, *Promet – Traffic & Transportation* 30(3): 349–359. <https://doi.org/10.7307/ptt.v30i3.2761>
- UPU. 2014. *Development Strategies for the Postal Sector: an Economic Perspective*. Universal Postal Union (UPU), Bern, Switzerland. 237 p. Available from Internet: <https://unstats.un.org/unsd/trade/events/2014/beijing/documents/postal/UPU%20-%20Trends%20Development%20Strategies%20For%20The%20Postal%20Sector.pdf>
- US PSOIG. 2014. *Providing Non-Bank Financial Services for the Underserved*. Report No RARC-WP-14-007. US Postal Service Office of Inspector General (US PSOIG), Arlington, VA, US. 33 p. Available from Internet: https://www.uspsaig.gov/sites/default/files/document-library-files/2015/rarc-wp-14-007_0.pdf
- Wang, L.-X.; Mendel, J. M. 1992. Generating fuzzy rules by learning from examples, *IEEE Transactions on Systems, Man, and Cybernetics* 22(6): 1414–1427. <https://doi.org/10.1109/21.199466>
- White, S. D.; Guy, C. M.; Higgs, G. 1997. Changes in service provision in rural areas. Part 2: changes in post office provision in Mid Wales: a GIS-based evaluation, *Journal of Rural Studies* 13(4): 451–465. [https://doi.org/10.1016/S0743-0167\(97\)00031-4](https://doi.org/10.1016/S0743-0167(97)00031-4)