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Selecting the Flexible Last-Mile Delivery Models Using Multicriteria Decision-Making

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ABSTRACT

Postal service providers can reorganise the last-mile delivery process within the scope of universal service and apply some of the flexible models for the organisation of the delivery. In this paper, the question of the selection of Flexible Last-Mile Delivery Models (FLMDMs) is treated using multicriteria decision-making. We have identified four different sustainable last-mile delivery models with an emphasis on the number of delivery workers. One postal service provider from Europe was selected, where the proposed FLMDMs were tested. The proposed last-mile delivery models are ranked using Multiple Criteria Decision Analysis (MCDA) techniques. In this context, MCDA techniques are used to make a comparative assessment of alternatives. The obtained results suggest the AB delivery model as the optimal choice for the last-mile delivery and complete allocation of the number of delivery workers.

KEYWORDS

last-mile delivery; service provider; universal postal service; delivery workers; ranking; PROMETHEE; ARAS.

1. INTRODUCTION

In the past period, harmonisation of the postal market and a common regulatory framework for the postal sector have been put into effect. The goal is to achieve a single market for postal services throughout the European Union Postal Directives [1, 2, 3]. Directives ensure the provision of universal postal service (UPS) of a certain quality, available to all service users at affordable prices throughout the territory of that state on a permanent, transparent, impartial basis, under the supervision of the national regulatory authority. The national legislation of every member state provides a detailed description of the service itself, which results in great differences in legislation and practice. Differences are reflected in the definition of the scope of the universal area. Quality of universal postal service refers to the delivery time, and member states define in national legislation the time of transportation process via the postal network. Minimum five-day delivery with the possibility of an exemption (which is agreed upon with the national regulatory authority) is mandated [3]. Due to this possibility, the postal service provider can reorganise the last-mile delivery process within the scope of universal service and apply some of the flexible models for the organisation of the delivery process.

Last-mile delivery includes a set of operations that enable the delivery of items to recipients directly at their home or business addresses. It is the most important phase in the value chain of the postal service business because it completes the technological process, the recipient receives the item and satisfies their need. The postal, i.e. service providers in general, are the most represented last-mile delivery providers. Nowadays, when the needs of users are increasingly expressed in terms of sending and receiving items containing correspondence or goods, service providers through the provision of the last-mile delivery represent an integral part of the daily functioning of society. In addition to the advantages for the users, last-mile delivery also generates large costs for the operators as one of the main challenges facing the operators and service providers. It makes up a large portion of an operator's shipping costs even if processes go smoothly. It accounts for just over half of an order’s total shipping costs. Key factors driving up this cost include fuel consumption (frequent start-stop and spending more time on the road), diverse and complex routes, substantially more drivers, tight delivery times and failed delivery. However, the challenge is to find a sustainable environment in which the organisation of the delivery processes can occur. Human factor remains the key to the optimal performance of the last-mile delivery, as well as customer satisfaction.

In this paper, we have identified four different models of the last-mile delivery, within the scope of the UPS, intending to reduce the last-mile delivery costs by optimising the number of delivery workers. The selected model can be adjusted depending on the legal regulations and obligations of the country whose service provider is observed (possibility of introducing priority and non-priority mail, number of delivery days for universal postal service, i.e. the frequency of delivery, etc.). Furthermore, the proposed and selected flexible models can be applied to the delivery process of any service provider dealing with the UPS.

The main motivation of this research is to find a sustainable way in optimising the last-mile delivery in each variant of the delivery model (a variant is an alternative in the process of ranking by the Preference Ranking Organisation Method for Enrichment Evaluations – PROMETHEE and Additive Ratio Assessment – ARAS methods), i.e. an optimal number of workers for the last-mile delivery. This will allow for:

– optimisation of the number and size of delivery areas and last-mile delivery routes (the area that is covered by a delivery worker)
– optimisation of fleet and number of employees
– reduction of unproductive working hours and easier redistribution of resources within the postal network.

The specific goals of the research are to ensure the complete allocation of the required number of technological workers in the delivery (the number of delivery workers), by applying the originally proposed, flexible solution (models) for the organisation of the last-mile delivery.

For a better understanding, the research procedure performed in this paper is presented in *Figure 1*.

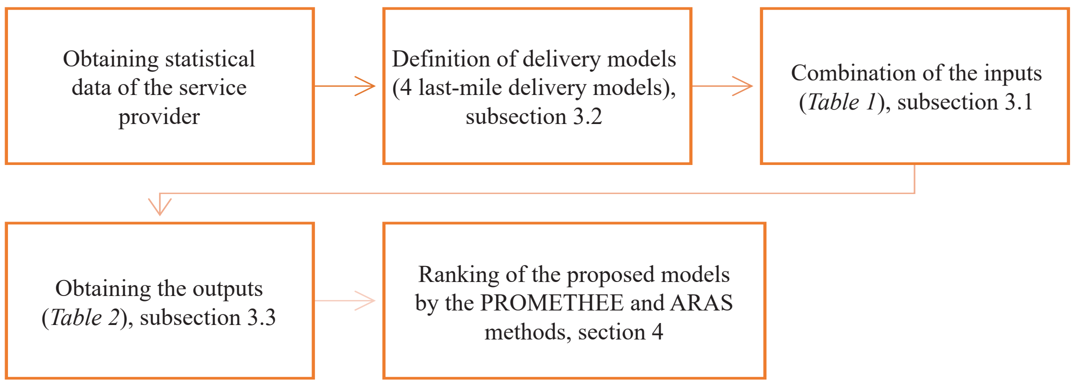


Figure 1 – Research procedure

The paper is organised in the following way. Section 2 presents a review of related literature. In Section 3 the development of flexible last-mile delivery models (FLMDM) is elaborated. In Section 4 the application of the methodology was carried out on a real-life example based on observed postal service provider and the results are presented. This section is divided into two subsections. The first subsection explains and applies the PROMETHEE method for obtaining the rank of the alternatives, while the second one elaborates on the ARAS method for obtaining the final rank of the alternatives (last-mile delivery models). The conclusions and directions for further research finally follow in Section 5.

2. LITERATURE REVIEW

According to the EU [1], a postal network is a system of organisation of all kinds of resources used by a designated universal postal service provider to collect postal items based on universal service obligation (USO) throughout the territory, directing and handling items from the access point to the distribution centre and distribution to the addresses indicated on the items. It consists of (1) "first-mile collection" (from pick-up of mail to the first mail processing step, including therefore post offices and collection boxes), (2) processing and handling of postal items, including transportation, and (3) "last-mile delivery" to either a PO Box or to the addressee [4].

The criteria for establishing a postal network are often combined depending on the geographical and demographical characteristics of a country. For example, Gracin and Stipetić [5] propose a modular procedure of designing postal network units. Mostarac et al. [6] analyse the concept of spatial accessibility in the postal system as well as the spatial characteristics of the research area. Boldron et al. [7] show that it may be desirable to scale down the national deadlines of mail delivery and restrict it to specific geographic areas. The liberalisation of the market resulted in the commercialisation of the service and far-reaching rationalisation of service provision processes [8].

The most important factors for the success of logistic providers are sustainability and delivery options [9]. Sustainability can be seen through the triple bottom line, which focuses on three dimensions: people, planet and profit [10]. The 2030 Agenda for Sustainable Development is, among other goals, dedicated to promoting productive employment and decent work for all [11].

Sustainability has been investigated by scholars in different research areas, as well as in the field of last-mile delivery. Klein and Popp [12] investigate how sustainability influences consumers' acceptance of delivery models in e-commerce. Thomas et al. [13] determine how sharing sustainability information about the last--mile delivery options affects consumer behaviours, while Ignat and Chankov [14] conclude that sustainability affects consumers' choice of delivery method. Mucowska [15] provided an extensive literature analysis in the field of sustainable last-mile delivery, where it is evident that the sustainable approach for delivery workers has not been dealt with. However, the workforce remains crucial to last-mail delivery, despite automation [16]. Bates et al. [17] emphasised the advantages of the human factor for the delivery processes.

Studies dealing with personnel and the workforce in the postal sector are scarce. Malhotra et al. [18] created the linear programming model for scheduling personnel in the United States postal distribution stations. Demazière and Mercier [19] refer to the singularities of the postal delivery officers' activities and their engagement with delivery areas. Flecker et al. [8] deal with the transformation of public services from the perspective of postal workers where only the social dimension of postal workers is considered, not their technological contribution to the postal value chain.

The last-mile delivery represents the most expensive and problematic part of the entire supply chain process and usually impacts the profits of companies as well as the customer experience [20]. Moreover, the entrance of new private competitors on the market, due to its gradual liberalisation [3], represents an additional factor pushing the postal operators towards more a cost-effective management of their technological processes [21]. Further studies focus on the cost and performance optimisation of parcel delivery [22]. Chromcová and Švadlenka [23] deal with optimisation in the light of the reconstruction of the postal transportation network, only in the parcel segment. Bruno et al. [24] propose and analyse two different strategies for rationalising post boxes, from demographic to spatial distribution criteria. Turska et al. [25] tried to optimise the route of the postal carrier of the selected delivery area through the solution of the traveling salesman problem. The authors Niroomand and Nsakanda [26] address the issue of improving collection flows in a public postal network while considering the contractor's obligations.

Furthermore, Laseinde and Mpofu [27] provide a solution to the last-mile challenges in postal operations. Sandoval et al. [28] address a last-mile logistic design problem faced by a courier and delivery company in Chile, although the same problem is likely to arise in the last-mile delivery operation of other postal companies. Yilmaz et al. [29] investigate the last-mile delivery models from the perspective of the growing e-commerce demands and focus on the delivery methods used by most delivery companies.

Alizadeh and Lahiji [30] discuss the provision of a multicriteria decision-making tool that allows customers to examine and choose, with certitude, the best possible delivery service. In the paper Wang et al. [31], the aim is to evaluate some key last-mile delivery companies in Vietnam regarding their sustainability performance by a fuzzy multi-criteria decision-making (F-MCDM) based framework. Krstić et al. [32] define innovative sustainable last-mile solutions and evaluate their potential application in the real-life logistics system of the city.

In the field of human resources, Polychroniou and Giannikos [33] present fuzzy multicriteria decision-making (MCDM) methodology for selecting employees. The purpose of the Widianta et al. [34] paper is to compare the four methods of multicriteria decision-making (MCDM) for the application of employee placement under predetermined criteria. Pourkhodabakhsh et al. [35] have identified factors affecting employee turnover using effective machine learning, meta-heuristic algorithms and multicriteria decision-making.

Selecting the best personnel among many alternatives is a multicriteria decision-making problem. Demirci and Kılıç [36] used three multicriteria decision-making techniques to solve recruitment problems via finding the optimal candidate for a job position. Dağdeviren [37] described a hybrid model which employs an analytic network process (ANP) and modified TOPSIS for supporting the personnel selection process in manufacturing systems. Korkmaz [38] used the TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method, which is one of the multicriteria decision-making techniques, as a personnel selection method in the logistics sector.

According to our knowledge, there is no evidence in the literature about the possible methodology to determine the optimal, sustainable and flexible model of the last-mile delivery process for a service provider from the aspect of optimising the number of delivery workers.

3. DEVELOPMENT OF THE FLEXIBLE LAST-MILE DELIVERY MODELS (FLMDM)

One postal service provider from Europe was selected, where the proposed FLMDMs were tested. The proposed last-mile delivery models are ranked using the Multiple Criteria Decision Analysis (MCDA) techniques. In this context, the MCDA techniques are used to make a comparative assessment of alternatives. These methods allow several criteria to be considered simultaneously in a complex situation and they are designed to help decision-makers to integrate different options, which reflect the opinions of the involved actors, in a prospective or retrospective framework [39]. In recent decades, the decision support system has been constantly growing in the field of transportation planning. A review of the PROMETHEE method in transportation was presented by Oubahman and Duleba [40]. In this paper, PROMETHEE is use as an outranking method to support decisions in selecting the FLMDM. To compare results obtained with PROMETHEE, we used the ARAS method to get a final rank of alternatives, i.e. last-mile delivery models.

The research proposed in this paper suggests delivery models that are independent of customer geography. Variables for optimal, flexible organisation of delivery are simplified and they do not depend on geographies. Our goal is to simplify inputs for the selection process, eliminating constraints such as traffic congestion, the ability to find parking in urban environments, etc. Such endeavours contribute to the creation of sustainable last-mile delivery models. Main inputs include a volume of items, the number of delivery norm minutes and the existing number of delivery workers. Specific processes of the last-mile delivery (on foot, bicycle, car, etc.) and the covered road distance are already included in the norm minutes. As a result, using the optimised number of workers would lead to lower wage costs and mail delivery deadlines. This approach can serve in the decision-making process for the postal sector (*Figure 2*).

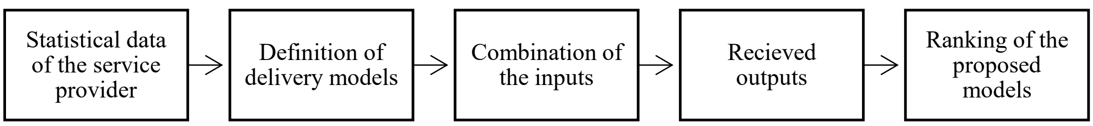


Figure 2 – Research approach

The existing way of organising the required number of technological working places and delivery workers for the last-mile delivery and calculation of the norm minutes does not allow accurate insight into costs by postal operators and their economy. Also, such a situation neglected legal possibilities (introduction of priority and non-priority mail and the possibility of introducing a new mandatory number of working days for delivery in the scope of the universal postal service). It also does not stimulate the optimisation of the organisational structure and the rationalisation of the number of workers in the post offices in a self-sustainable way. In this regard, some of the basic activities of the paper are:

– Identification of the norms applied in the delivery of items at the observed service provider. The norm represents the time required to perform individual service during a particular process. Norms are expressed in minutes by two decimal places;
– Identification of the volume of items of the observed service provider;
– Identification of the existing number of technological working places and delivery workers by post offices of the observed service provider.

To develop an FLMDM, it is necessary to define possible alternatives that may appear in the delivery of postal items to find out which solution is optimal for the observed service provider, by applying multicriteria decision-making. In addition to the alternatives, the criteria on which the alternatives are evaluated must also be defined. As alternative solutions, the following have been proposed:

1) Delivery of items 6 times a week in all delivery areas (existing solution);
2) Delivery of items 5 times a week (minimum provided by law) in all delivery areas;
3) Six-day delivery in delivery areas located in municipal places and five-day delivery in other delivery areas (6/5 delivery). Municipal places are places where the administrative centre of the municipality is located. They are the focal point of the municipality;
4) Delivery of items according to the AB delivery model, which implies the legal introduction of priority and non-priority mail.

Moreover, the ranking of alternatives was performed by applying multicriteria analysis according to the following proposed criteria:

1) Labour costs (direct and indirect)
2) Additional costs of using modern means of delivery (electric bicycles, motorcycles, vehicles, etc.)
3) The impact of the alternative on stimulating the introduction of new postal services
4) The impact of the alternative on the improvement of business relations with the economy (large users) and elements of the state structure (municipalities, local communities, etc.).

According to the census, the observed country has a total of 619,211 inhabitants [41]. Having in mind the requirements stated in EKIP [42], an observed service provider with 140 post offices (units) meets the following requirements:

– 13,812 km^2 [41]/157 units (post offices) = 87.97 km^2 by one post office.
– 619,211 inhabitants/157 units = 3944,01 inhabitants by one post office.

It should be noted that the observed service provider delivers postal items 6 times per week. The independent regulatory body may determine a different performance of the universal postal service. Due to the significant reduction of collection activities in the most expensive areas (rural areas), the reorganisation of geographical coverage is required. This was a challenge for the authors and one of the motives to deal with the topic processed in this paper. Reorganisation through the FLMDM will keep the financial, personal and territorial accessibility of the population in rural areas.

3.1 Phase I: Preparation of the input data

Currently, the delivery of postal items is being performed six days a week, with the exemption to deviate from the required obligation that cannot exceed 10% of the total number of households. These deviations may relate to:

– households located more than 500 m from the public road,
– households to which there is no suitable road for access to an operator,
– households located in hilly and mountainous areas with extremely difficult access conditions.

In accordance with these deviations, the service provider has been given the opportunity to reorganise the last-mile delivery process within the scope of universal service and apply some of the flexible, sustainable models proposed in the paper.

In the first phase of the research, three basic variables were considered as input data for further calculations.

1) The first variable is the norms that are applied in the delivery of items at the observed service provider. Based on the norms, the realised norm minutes were calculated based on the volume of items, by last-mile delivery routes. The realised norm minutes based on the travelled distance were also calculated, to obtain the total realised norm minutes needed to calculate the productivity of the last-mile delivery routes.
2) The second variable is the volume of delivered items by the observed service provider. The number of delivered registered and unregistered items monthly, for legal entities and individuals (given in *Table 1*), was identified by post centres, post offices in post centres and their respective last-mile delivery routes. *Table 1* contains a number of counter clerks and a number of delivery workers engaged in post centres (from PC1 to PC14). For every post office belonging to the competent post centre current last-mile delivery routes are listed. *Table 1* also contains the volume of items whose senders are legal entities (registered mail annually and monthly, unregistered mail annually and monthly) and the volume of items whose senders are individuals (registered mail annually and monthly; unregistered mail annually and monthly; registered

Table 1 – Part of the input data calculation

Post centres	Post offices belonging to the post centres	Number of workers – counter clerks	Number of workers – delivery workers	Current situation – last-mile delivery route	Volume of items whose senders are legal entities				Volume of items whose senders are individuals						Average monthly	
					Registered mail annually	Registered mail monthly	Unregistered mail annually	Unregistered mail monthly	Registered mail annually	Registered mail monthly	Registered money order annually	Registered money order monthly	Unregistered mail annually	Unregistered mail monthly	Registered	Unregistered
PC1	PO1	18	8	LMDR 1	15637	1303	47243	3937	1709	142	13581	1132	1006	84	2577	4021
				LMDR 2	15698	1308	46639	3887	1698	142	12986	1082	1024	85	2532	3972
				LMDR 3	15686	1307	43341	3612	1878	157	10214	851	909	76	2315	3688
				LMDR 4	15063	1255	42103	3509	1809	151	12876	1073	1065	89	2479	3597
				LMDR 5	15621	1302	56736	4728	1970	164	10563	880	919	77	2346	4805
				LMDR 6	15551	1296	46665	3889	1605	134	9999	833	917	76	2263	3965
				LMDR 7	15573	1298	52420	4368	1658	138	10850	904	1138	95	2340	4463
	PO2	1	1	LMDR 1	1950	163	21089	1757	217	18	7731	644	85	7	825	1765
	PO3	5	3	LMDR 1	5564	464	17091	1424	519	43	7268	606	442	37	1113	1461
				LMDR 2	5629	469	17935	1495	319	27	7527	627	236	20	1123	1514
				LMDR 3	5052	421	17512	1459	681	57	7357	613	303	25	1091	1485
	PO4	1	2	LMDR 1	1807	151	14533	1211	213	18	6586	549	126	11	717	1222
				LMDR 2	1531	128	14457	1205	233	19	6837	570	103	9	717	1213
	PO5	1	2	LMDR 1	3099	258	24133	2011	427	36	6982	582	182	15	876	2026
				LMDR 2	2950	246	25175	2098	639	53	6199	517	210	18	816	2115
	PO6	1	0	LMDR 1	47	4	17661	1472	129	11	5231	436	94	8	451	1480
	PO7	1	0	LMDR 1	28	2	11206	934	0	0	1549	129	0	0	131	934
	PO8	1	0	LMDR 1	0	0	9650	804	0	0	1156	96	0	0	96	804
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
PC14	PO1	11	8	LMDR 1	7739	645	44741	3728	1451	121	10772	898	407	34	1664	3762
				LMDR 2	7713	643	44133	3678	1449	121	10573	881	416	35	1645	3712
				LMDR 3	7921	660	75423	6285	1750	146	11852	988	375	31	1794	6317
				LMDR 4	7927	661	76656	6388	1457	121	9858	822	369	31	1604	6419
				LMDR 5	7892	658	64489	5374	1649	137	9423	785	345	29	1580	5403
				LMDR 6	7601	633	41025	3419	1635	136	10971	914	432	36	1684	3455
				LMDR 7	7820	652	49138	4095	1590	133	11959	997	520	43	1781	4138
	PO2	1	0	LMDR1	0	0	1309	109	2	0	1679	140	0	0	140	109
	PO3	1	0	LMDR1	159	13	13015	1085	0	0	3526	294	0	0	307	1085
	PO4	1	0	LMDR1	0	0	3211	268	0	0	728	61	0	0	61	268
	PO5	1	0	LMDR1	0	0	7436	620	0	0	2266	189	0	0	189	620
	PO6	1	0	LMDR1	0	0	6341	528	0	0	1545	129	0	0	129	528
	PO7	1	0	LMDR1	42	4	13917	1160	1	0	2339	195	0	0	199	1160
	PO8	1	0	LMDR1	0	0	14082	1174	0	0	2666	222	0	0	222	1174

money order annually and monthly). Data are obtained from the application implemented by the observed postal service provider within the adopted Methodology for standardisation of the collection and processing of statistical data [43]. Due to the extensiveness of the data, only a part is shown. In *Table 1,* the calculation of the average number of registered and unregistered monthly mail was performed (AMRM-Average Monthly Registered Mail and AMUM-Average Monthly Unregistered Mail), respectively. We need this information to forecast the number of priority mail.

3) The third used variable is the existing number of technological working places of delivery workers by post offices of the observed service provider. As with the second variable, the number of counter clerks and the number of workers in delivery were identified by post centres, post offices in post centres and their respective last-mile delivery routes (given in *Table 1*). The observed service provider, in the current organisation of the last-mile delivery (six days per week, without optimisation), has 280 delivery workers [44]. The goal is to reduce this number by alternative last-mile delivery models proposed further in this paper.

The norm minutes that quantify the delivery process, the volume of items and the number of delivery workers provide starting variables in the process of optimising the last-mile delivery. In this direction, the already mentioned four alternatives are recognised as possible models of the last-mile delivery organisation and they represent the second phase of development of a solution proposal, the phase of creating an FLMDM of an observed service provider.

3.2 Phase II: Alternatives as Flexible Last-Mile Delivery Models (FLMDM)

In this phase, alternatives that represent possible solutions for the organisation and optimisation of the last-mile delivery process are developed. Below is a description of each, noting that the calculations were made based on data when the observed service provider did implement a category of priority mail.

Alternative 1: Delivery of items 6 times a week in all delivery postal network units of the observed service provider (existing solution). The existing solution for the last-mile delivery implies a six-day delivery of items. Delivery covers all delivery areas, with the existing number of delivery workers.

Alternative 2: Delivery of items 5 times a week (minimum provided by law) in all delivery postal network units of the observed service provider. This alternative in terms of organising the last-mile delivery allows switching from six-day delivery of items to five-day delivery.

Alternative 3: Delivery of items 6 times a week in the delivery postal network units at the seat of the municipality and in all other postal network units 5 times a week. This alternative would significantly reduce the costs of the postal network (service provider) while maintaining the quality of services.

Alternative 4: Delivery of items by the AB delivery model (implies a legal definition of priority and non-priority mail). The AB delivery model implies the organisation of the delivery area in such a way that all items for which the delivery deadline is longer than D+1 (next day delivery), arrived at the destination post office in the days before the delivery deadline, are grouped by recipient address and delivered on one of the next working days.

By introducing the AB delivery model, the process of delivering non-priority mail has changed with increasing productivity and delivery efficiency. By reducing the number of delivery points to delivery workers on their daily routes, the time required to complete the delivery is reduced, as is the length of the delivery route itself. Applying such a model would reduce labour costs and transportation costs. This centralised delivery model leads to a reduction in the number of delivery workers in certain areas, the use of more cost-effective ways of moving through the last-mile delivery route and a greater number of deliveries per day per delivery worker.

The AB model proposes priority mail that is delivered daily and non-priority mail delivered to half of the last-mile delivery route every other day (days A and B). During the A days, priority mail is delivered (in this case the observed service provider in a base year did not have a category of priority mail and we applied an expert estimate of 10% of registered items per last-mile delivery route) as well as half quantities of non-priority mail (registered and unregistered items). Priority mail and the other half of the non-priority mail would be delivered on day B. From the aspect of the quality of service, introducing the AB model maintains the required quality standards. Non-priority mail would be delivered within D+2 and priority mail within D+1.

3.3 Phase III: Finding the optimal FLMDM using the PROMETHEE and ARAS methods

A ranking of possible alternatives (delivery models) was performed to confirm the selection of the optimal framework for the organisation of the last-mile delivery in the observed service provider. This can be achieved by using multicriteria analysis for various delivery models based on the existing situation and the conditions in which delivery is performed in advanced postal administrations in the European Union. For this purpose, the PROMETHEE and ARAS methods were applied as methods of multicriteria analysis. Before ranking, the output variables should be obtained, as a part of inputs for the multicriteria analysis performed in Section 4.

The structure of the output data is described in *Table 2*, where only a part of the obtained outputs is shown due to the extensiveness of the data. The output data are calculated on the basis of service provider's input data presented in *Table 1*. The postal network consists of post centres (from 1 to 14), post offices and last-mile delivery routes. Transportation means are not considered. The list of the output acronyms is shown in *Appendix*.

Output variables for each last-mile delivery route are described as follows.

Estimated Priority Mail Monthly: $EPMM=0.1\cdot AMRM$. Based on the experiences of European countries and the analysis of independent regulatory agencies in the region, it was determined by an expert's estimate that this number is around 10% of registered mail. The experts considered the Universal Postal Union statistics database, annual reports of European postal operators and regulatory bodies, as well as European postal statistics. This output variable is estimated in the described way for the postal service providers that have not yet introduced the category of priority mail. In case there is a category of priority mail at the observed provider, the actual volume of priority mail will be taken for further analysis. In the case of the provider observed in this paper, the analysis was performed on data from one base year and the provider introduced priority mail in the next year.

Estimated Non-Priority Mail Monthly: $ENPMM=0.1\cdot AMRM+AMUM$.

Furthermore, in *Table 2*, the data obtained from the observed postal service provider, which refers to the current system of six-day delivery, are presented by post offices. The data on realised services by volume of items Achieved Norm Minutes Based on the Volume of Items – for delivery (*ANMVID*) and distance travelled Achieved Norm Minutes Based on the Road Distance – six-day delivery (*ANMRD*6) are specially stated. Achieved Norm Minutes Based on the Volume of Items – for delivery (*ANMVID*) are shown in norm minutes based on statistical records and obtained as follows:

Norm Minutes for Postal Items Sent by Individuals: $NMSI=AMRM\cdot 2.2$ (the statistical norm for this type of postal item) + $AMUM\cdot 0.2$ (the statistical norm for this type of postal item).

Norm Minutes for Postal Items Sent by Legal Entities: $NMSLE=AMRM\cdot 2.5$ (the statistical norm for this type of postal item) + $AMRMO\cdot 2$ (the statistical norm for this type of item)) + $AMUM\cdot 0.2$ (the statistical norm for this type of postal item).

According to the above, we get that: $ANMVID=NMSI+NMSLE$

The variable Achieved Norm Minutes Based on the Road Distance – six-day delivery (*ANMRD*6) also provides statistical data on the norm minutes based on the road distance, i.e. distance travelled. These data contain differentiation in standardisation depending on whether the road in the last-mile delivery route is crossed on foot, by moped or by bicycle.

The next output variable is the Estimated Norm Minutes Based on the Road Distance (*ENMRD*) for different delivery systems monthly. That variable presents predicted new norm minutes for the travelled road distance for different systems (flexible models, i.e. alternatives) of delivery, per month. The travelled road distance will be different for different alternatives, i.e. last-mile delivery models (the volume of services does not change because the demand for the service remains the same). Thus, for five-day delivery, a 20% reduction in travelled road distance per last-mile delivery route is estimated compared to the current six-day model, and, accordingly, the ENMRD for five-day delivery is calculated as:

$$ENMRD5=ANMRD6\cdot 0.8$$

For 6/5 delivery, *ENMRD*6/5 was calculated separately for postal units at the seat of the municipality (as a six-day delivery (variable *ANMRD*6) and especially in all other postal network units (as a five-day delivery (variable *ENMRD*5)):

$$ENMRD6/5=\begin{cases} ANMRD6, & \text{if it is a municipality} \\ ENMRD5, & \text{if it is not a municipality} \end{cases}$$

Table 2 – Output data calculation

			Estimated number of postal items, by priority, monthly		Productivity monthly		Estimation of norm minutes based on the road distance for different delivery systems monthly			Estimation of the total achieved norm minutes for different delivery systems, monthly				Estimation of productivity for different delivery systems, monthly				Estimation of the number of delivery workers for different delivery systems monthly – no replacement				Estimation of the number of delivery workers for different delivery systems monthly – with replacement			
Post centres	Post offices belonging to the post centres	Last-mile delivery route	Priority (EPMM)	Non-priority (ENPMM)	Achieved norm minutes based on the volume of items – for delivery (ANMVID)	Achieved norm minutes based on the road distance – Six-day delivery (ANMRD6)	Five-day delivery (ENMRD5)	6/5 delivery (ENMRD6/5)	AB delivery (ENMRDAB)	Six-day delivery (TANM6)	Five-day delivery (TANM5)	6/5 delivery (TANM6/5)	AB delivery (TANMAB)	Six-day delivery (EP6)	Five-day delivery (EP5)	6/5 delivery (EP6/5)	AB delivery (EPAB)	Six-day delivery (EDWWithoutR6pc)	Five-day delivery (EDWWithoutR5pc)	6/5 delivery (EDWWithoutR6/5pc)	AB delivery (EDWWithoutRABpc)	Six-day delivery (EDWWithR6pc)	Five-day delivery (EDWWithR5pc)	6/5 delivery (EDWWithR6/5pc)	AB delivery (EDWWithRABpc)
PC1	PO1	LMDR 1	258	6340	6290	1425	1140	1425	855	7715	7430	7715	7145	88%	84%	88%	81%								
		LMDR 2	253	6251	6190	1591	1273	1591	955	7781	7463	7781	7145	88%	85%	88%	81%								
		LMDR 3	231	5771	5707	1141	912	1141	684	6847	6619	6847	6391	78%	75%	78%	73%								
		LMDR 4	248	5828	6004	901	721	901	541	6905	6725	6905	6544	78%	76%	78%	74%								
		LMDR 5	235	6916	5996	4858	3886	4858	2915	10853	9882	10853	8910	123%	112%	123%	101%								
		LMDR 6	226	6002	5645	1970	1576	1970	1182	7615	7221	7615	6827	87%	82%	87%	78%								
		LMDR 7	234	6569	5901	2642	2114	2642	1585	8544	8015	8544	7487	97%	91%	97%	85%								
	PO2	LMDR 1	82	2507	2044	3318	2655	3318	1991	5362	4699	5362	4035	61%	53%	61%	46%								
	PO3	LMDR 1	111	2462	2632	2313	1851	2313	1388	4945	4482	4945	4020	56%	51%	56%	46%								
		LMDR 2	112	2525	2656	3397	2718	3397	2038	6053	5373	6053	4694	69%	61%	69%	53%								
		LMDR 3	109	2466	2591	3557	2845	3557	2134	6148	5436	6148	4725	70%	62%	70%	54%								
	PO4	LMDR 1	72	1867	1718	4819	3855	4819	2891	6536	5573	6536	4609	74%	63%	74%	52%								
		LMDR 2	72	1858	1711	2357	1885	2357	1414	4068	3597	4068	3125	46%	41%	46%	36%								
	PO5	LMDR 1	88	2814	2226	1223	978	1223	734	3449	3204	3449	2960	39%	36%	39%	34%								
		LMDR 2	82	2850	2130	2430	1944	2430	1458	4560	4074	4560	3588	52%	46%	52%	41%								
	PO6	LMDR 1	45	1885	1203	2707	2166	2166	1624	3910	3369	3369	2827	44%	38%	38%	32%								
	PO7	LMDR 1	13	1052	450	1807	1446	1446	1084	2257	1896	1896	1534	26%	22%	22%	17%								
	PO8	LMDR 1	10	891	354	1464	1171	1171	878	1818	1525	1525	1232	21%	17%	17%	14%	12	11	12	10	13	12	13	11
…	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….
PC14	PO8	LMDR 1	22	1373	679	3,348	2,678	2,678	2,009	4,027	3,357	3,357	2,688	46%	38%	38%	31%	6	6	6	5	7	6	6	6
														62%	57%	61%	53%	184	171	181	158	198	185	196	171
														Labour costs				91886	85441	90652	78996	99237	92276	97904	85316
														Ranking of alternatives								-0.53	0.00	0.13	0.40

For the AB delivery model for each last-mile delivery route the ENMRD is reduced by 50% (delivery of non-priority mail every other day) and increased by the norm minutes based on the road distance for priority mail (10% of the travelled road distance in six-day delivery).

$$ENMRDAB = \left(\frac{ANMRD6}{2}\right) + (ANMRD6 \cdot 0.1)$$

The next output variable is the estimation of the total achieved norm minutes for different delivery systems on a monthly basis (*TANM*). It implies the total number of norm minutes based on the road distance and based on the volume of items (for delivery), per month, for the appropriate delivery model (alternative). This means the following: for the six-day delivery model *TANM*6=*ANMVID*+*ANMRD*6, for the five-day delivery model *TANM*5=*ANMVID*+*ENMRD*5, for the 6/5 delivery model *TANM*5/6=*ANMVID*+*ENMRD*5/6, for the AB delivery model *TANMAB*=*ANMVID*+*ENMRDAB*.

Based on the previously described and obtained variables, the productivity of the last-mile delivery routes for different last-mile delivery systems (*EP*) is estimated, per month. It is expressed as a percentage and is obtained by dividing the total number of achieved norm minutes for each delivery model by 8800 norm minutes. The number of 8800 norm minutes was taken based on a 40-hour working week (regardless of the delivery system). The norm for 8-hour working hours is 400 minutes, so we get that: 22 working days per month ? 400 minutes = 8800 norm minutes monthly, for the six-day delivery model $EP6 = \frac{TANM6}{8800}$, for the five-day delivery model $EP = \frac{TANM}{8800}$, for the 6/5 delivery model $EP5/6 = \frac{\frac{TANM5}{6}}{8800}$, for the AB delivery model $EPAB = \frac{TANMAB}{8800}$.

The following set of output variables represents the optimised number of delivery workers for different last-mile delivery models. *Table 2* shows the optimal number of delivery workers per post centre, with belonging post offices (for example, for post centre 1, there are 8 belonging post offices. In *Table 2* the numbers of workers 12, 11, 12, 10, 13, 12 and 13 are optimised numbers of workers sufficient for delivery at post centre 1, due to the four delivery models, respectively).

Estimates of the number of delivery workers were made in two variants, with and without working replacement (for example vacation or sick leave periods).

In the variant of Estimated Number of Delivery Workers Without Replacement (*ENDWWithoutR*) we have for every delivery model by post centre per month as follows:

- for the six-day delivery model $EDWWithoutR6_{pc} = \sum_{i=1}^{n} \frac{TANM6_i}{8800}$ where *i* is the number of the last-mile delivery routes within the observed post centre
- for the five-day delivery model $EDWWithoutR5_{pc} = \sum_{i=1}^{n} \frac{TANM5_i}{8800}$
- for the 6/5 delivery model $EDWWithoutR6/5_{pc} = \sum_{i=1}^{n} \frac{TANM6/5_i}{8800}$
- for the AB delivery model $EDWWithoutRAB_{pc} = \sum_{i=1}^{n} \frac{TANMAB_i}{8800}$.

In this way, the number of employees who are 100% productive is obtained. The procedure was done for each delivery model, as presented. As shown in *Table 2*, we obtained the number of 184, 171, 181 and 158 delivery workers, respectively. Having in mind the fact that for the current last-mile delivery organisation within the scope of the USO, the observed service provider engages 280 delivery workers, we can conclude that our approach, proposed in this paper, gives better and more rational results.

Furthermore, as it has already been shown, the number of delivery workers with replacement is estimated, for different models of delivery on a monthly basis by post centres (*EDWWithR*). It was previously established that it is necessary to provide 8% of the reserve of delivery workers for replacement during the holidays. This means:

- for the six-day delivery model $EDWWithR6_{pc} = EDWWithoutR6_{pc} + EDWWithoutR6_{pc} \cdot 0.08$
- for the five-day delivery model $EDWWithR5_{pc} = EDWWithoutR5_{pc} + EDWWithoutR5_{pc} \cdot 0.08$
- for the 6/5 delivery model $EDWWithR6/5_{pc} = EDWWithoutR6/5_{pc} + EDWWithoutR6/5_{pc} \cdot 0.08$

– for the AB delivery model $EDWWithRAB_{pc} = EDWWithoutRAB_{pc} + EDWWithoutRAB_{pc} \cdot 0.08$

By summing up the data, the total number of required delivery workers was obtained, with replacements, by post centres. As shown in *Table 2*, the optimal number of workers is significantly less than the current (198, 185, 196, and 171, respectively).

In the end, the labour costs are calculated for each delivery model for the estimated number of delivery workers without replacement (*LCWithoutR*) and with replacement (*LCWithR*), as presented below:

– for the six-day delivery $LCWithoutR6_{pc} = \sum_{pc=1}^{m} EDWWithoutR6_{pc} \cdot 500$ where *pc* is the number of post centres at the observed provider and 500 is the cost of salary per delivery worker (average salary is €500)

– for the five-day delivery $LCWithoutR5_{pc} = \sum_{pc=1}^{m} EDWWithoutR5_{pc} \cdot 500$

– for the 6/5 delivery $LCWithoutR6/5_{pc} = \sum_{pc=1}^{m} EDWWithoutR6/5_{pc} \cdot 500$

– for the AB delivery $LCWithoutRAB_{pc} = \sum_{pc=1}^{m} EDWWithoutRAB_{pc} \cdot 500$

– for the six-day delivery $LCWithR6_{pc} = \sum_{pc=1}^{m} EDWWithR6_{pc} \cdot 500$

– for the five-day delivery $LCWithR5_{pc} = \sum_{pc=1}^{m} EDWWithR5_{pc} \cdot 500$

– for the 6/5 delivery $LCWithR6/5_{pc} = \sum_{pc=1}^{m} EDWWithR6/5_{pc} \cdot 500$

– for the AB delivery $LCWithRAB_{pc} = \sum_{pc=1}^{m} EDWWithRAB_{pc} \cdot 500.$

These data, which refer to labour costs with replacements for various last-mile delivery models were used as input data for the multicriteria analysis, using the PROMETHEE and ARAS methods. The ranking of alternatives is discussed in detail in Section 4.

4. RESULTS AND DISCUSSION

This paper provides insight into the implementation of multicriteria decision-making in the field of the last-mile delivery models evaluation and selection, with the aim to obtain an optimised number of delivery workers. This section couples two possible methods to solve the defined problem: the PROMETHEE method to select the best last-mile delivery model and then the ARAS to compare the results and come to a more confident conclusion to the presented problem.

4.1 Application of the PROMETHEE method to obtain the rank of the last-mile delivery models

Results are obtained according to the following phases.

Phase 1: Construction of an evaluation matrix. A double-entry table for the selected criteria and alternatives has been compiled by using quantitative data. This matrix accounts for deviations of evaluations on pairwise comparisons of two alternatives (*a* and *b*) on each criterion.

Phase 2: Identification of the preference function $P_j(a, b)$ for each criterion *j*. The preference function is used to determine to what extent alternative *a* is preferred to alternative *b* and it translates the difference in evaluations of the two alternatives into a preference degree. These preferences are represented in a numerical scale ranging between 0 and 1. The value “1” represents a strong preference of alternative *a* over *b*, whereas “0” represents the indifferent preference value between the two alternatives [39]. The PROMETHEE requires defining the preference function of each criterion, the choice between six preference functions depends on the decision-maker, who must define the preference or the indifference thresholds. *Figure 3* shows preference function characteristics.

Phase 3: Calculation of the overall preference index $\Pi(a, b)$. The overall preference index $\Pi(a, b)$ represents the intensity of preference of *a* over *b* and it is calculated as follows:

$$\Pi\ (a,\ b) = \sum_{j=1}^{k} P_j\left(a,b\right) \cdot w_j \tag{1}$$

where $\Pi(a, b)$ is the overall preference intensity of a over b with respect to all the K criteria, w_j is the weight of criterion j, and $P_j(a, b)$ is the preference function of a over b with respect to criterion j. $\Pi(a, b) \sim 0$ implies a weak global preference of a over b, whereas $\Pi(a, b) \sim 1$ implies a strong global preference of a over b.

Phase 4: Calculation of the outranking flows, i.e. positive flow $\Phi^+(a)$ and negative flow $\Phi^-(a)$. In the PROMETHEE method, two flow measures can be determined for each alternative. There is a positive flow (it shows how much the alternative a outperforms other alternatives)

$$\Phi^+(\mathrm{a}) = \frac{1}{n-1} \sum_{b \in A} \Pi\left(a,b\right) \tag{2}$$

and negative flow (it shows how much other alternatives outperform alternative a)

$$\Phi^-(\mathrm{a}) = \frac{1}{n-1} \sum_{b \in A} \Pi\left(b,a\right) \tag{3}$$

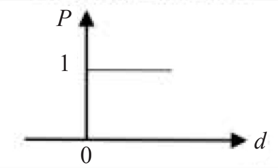
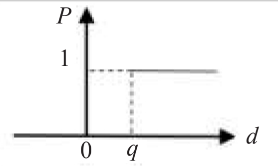
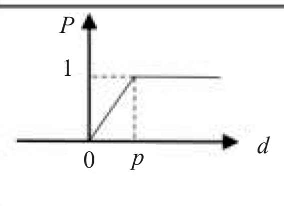
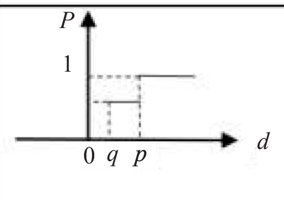
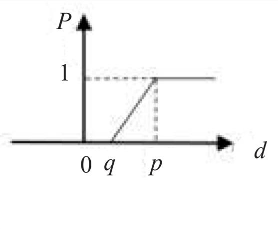
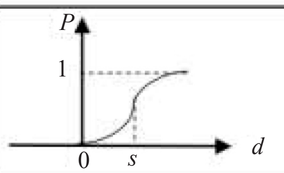
Preference function	Definition	Parameters
	Type I: Usual criterion $P(d) = \begin{cases} 0 \text{ if } d \le 0 \\ 1 \text{ if } d > 0 \end{cases}$	--
	Type II: U-shape criterion $P(d) = \begin{cases} 0 \text{ if } d \le q \\ 1 \text{ if } d > q \end{cases}$	q
	Type III: V-shape criterion $P(d) = \begin{cases} 0 \text{ if } d \le 0 \\ \frac{d}{p} \text{ if } 0 < d \le p \\ 1 \text{ if } d > p \end{cases}$	p
	Type IV: Level criterion $P(d) = \begin{cases} 0 \text{ if } d \le q \\ \frac{1}{2} \text{ if } q < d \le p \\ 1 \text{ if } d > p \end{cases}$	p, q
	Type V: V-shape with indifference preference $P(d) = \begin{cases} 0 \text{ if } d \le q \\ \frac{d-q}{p-q} \text{ if } q < d \le p \\ 1 \text{ if } d > p \end{cases}$	p, q
	Type VI: Gaussian criterion $P(d) = \begin{cases} 0 \text{ if } d \quad 0 \\ 1 - e^{\frac{d^2}{2s^2}} \text{ if } d > 0 \end{cases}$	s

Figure 3 – PROMETHEE preference functions [39]

Phase 5: Comparison of the outranking flows to define the alternatives' complete ranking by calculating the net flow. The comprehensive ranking is important in the case of detecting incomparability between criteria, it equals the difference between leaving and entering flow. The higher the net flow, the better the alternative is performing. Only two relations between alternatives are concluded for the comprehensive flow, which are preference and indifference relations.

$$\Phi(a) = \Phi^{+}(a) - \Phi^{-}(a) \quad (4)$$

The value of the net flow belongs to [-1,1] interval and the sum of the net flows computed in a problem equals 0, because the amount of entering flows is the same as the leaving flows.

$$-1 \le \Phi(a) \le 1 \quad (5)$$

The first step is to identify the alternatives and then to determine the criteria based on which the ranking of the set of alternatives was performed. The four delivery models described in the previous sections are taken as alternatives. Alternatives are ranked based on four criteria. Expert opinion was used to define the criteria, assign weight coefficients to each criterion and determine the type of preferential function of the PROMETHEE method. The result of the analysis is determining alternatives of the highest rank (priority).

The following last-mile delivery models were used as alternatives in the application of the PROMETHEE method: A1 – the six-day delivery, A2 – the five-day delivery, A3 – the combination of six-day and five-day delivery (6/5 delivery), A4 – the AB delivery.

To define the criteria, a proposal of four criteria was given, using the opinion of experts. The following criteria were set by the analysis of expert opinion:

K1. Labour costs (direct and indirect) – labour costs are a very important criterion because these costs represent the largest part of the operating costs of the service provider. For each of the proposed alternatives, the number of delivery workers was calculated and labour costs were obtained according to this indicator (in the example verified here, we note that the costs were taken approximately based on the estimate that the average salary of a delivery worker is approximately 500 euros).

K2. Additional costs of using modern means of delivery (electric bicycles, motorcycles, vehicles, etc.) – this criterion became important especially with the fourth alternative because in that case electric scooters or mopeds are introduced in all the last-mile delivery routes.

K3. The impact of the alternative on stimulating the introduction of new postal services – the introduction of new services can be considered in all four alternatives, although the importance of this criterion is the weakest in the existing delivery organisation (Alternative 1). With each subsequent alternative, the importance of this criterion is stronger because it opens new opportunities for offering services by reorganising the delivery area and adapting to the needs and requirements of users.

K4. The impact of the alternative on the improvement of business relations with the economy ("Large users") and elements of the state structure (municipalities, local communities, etc.) – the impact of this criterion is strongest with the fourth alternative because the introduction of the AB delivery model (which implies the existence of priority mail services) gives a great opportunity to key (big) users and elements of state structure to use priority mail that would be delivered every day. In fact, these entities (key users and elements of state structure) are expected to be the "big users" of priority mail.

The PROMETHEE method provides the ability to select preferred functions from a set of offered function types. Thus, the choice of the generalised criterion according to the intensity of preference was made. Then, the weight coefficients of the criteria were determined, so that the experts estimated that the first two criteria weight 0.3 and the other two weight 0.2 (*Table 3*). The sum of these criteria must be equal to 1.

After defining all alternatives and criteria, the next step is to minimise or maximise the values of each criterion in terms of economy, as well as to form a generalised criterion for each criterion based on preference functions. *Table 3* shows the most important values for each criterion: minimised or maximised value, relative weighting coefficients and preference function for each criterion. Then, certain parameters P and Q (based on the type of preference function), minimum and maximum values for each criterion, mean and standard deviation.

Table 3 contains numerical input data for calculation that are entered from *Table 2* (labour costs of the estimated number of delivery workers for different delivery systems with replacement) and the labour cost function is

Table 3 – Input for the multicriteria analysis

	Labour costs (K1)	Additional costs of using modern means of delivery (K2)	The impact of the alternative on stimulating the introduction of new postal services (K3)	The impact of the alternative on the improvement of business relations with the economy (K4)
Six-day delivery	-99,236,17	0,00	2	3
Five-day delivery	-92,275,39	0,00	3	3
Combination of six-day and five-day delivery	-97,903,35	0,00	4	4
AB delivery	-85,314,60	-100,999,00	5	5
MIN or MAX	MIN	MIN	MAX	MAX
Importance of criteria	0.3	0.3	0.2	0.2
Type of preference function	5	5	1	1
P-Preference limit	-	-	-	-
Q-Indifference limit	1,000,00	5,000,00	-	-
Minimum	-99,236,17	-100,999,00	2	3
Maximum	-85,314,60	0	5	5
Mean	-93,682,38	-25,249,75	3.5	3.75
Standard deviation	6,341,94	50,499,50	1.291	0.957

maximised (1-value by alternatives). The function of the costs of using modern means of delivery was maximised (1-value by alternatives). Input data for criterion 3 are also entered, as well as for criterion 4. Furthermore, the data on the importance of the criterion is entered (the sum must be 1).

Using the PROMETHEE method, alternatives are ranked based on the value of net flow $\Phi(a)$, which is shown by *Equation 4*. The term "net flow" implies the validity of the alternative in the sense that the higher the value, the better the alternative, i.e. the alternative will have higher priority. In our case of determining the optimal FLMDM, the pure flow value indicates the priority of the delivery model as an alternative.

The results of the application of the PROMETHEE method are shown in *Table 4*. Based on the obtained results and the ranking of alternatives, it can be concluded that the highest ranking (priority) of the alternative is the A4-AB delivery model. The results suggest the implementation of the AB delivery model. Regarding the robustness of the obtained results, it is necessary to point out that we can expect that this alternative would be sufficient for seasonal increases in volumes and would have sufficient personnel capacity. During such periods it is recommended to use the AB model with the replacements because then full personnel capacity is engaged.

Table 4 – Ranking of alternatives based on net flow values

Rank	Alternative	Net flow $\Phi(a)$	Output flow $\Phi^+(a)$	Input flow $\Phi^-(a)$
1	AB delivery	0.40	0.70	0.30
2	Combination of six-day and five-day delivery	0.13	0.47	0.33
3	Five-day delivery	0.00	0.37	0.37
4	Six-day delivery	-0.53	0.10	0.63

4.2 Application of the ARAS method to obtain the rank of the last-mile delivery models

For the selection of alternatives, the Additive Ratio Assessment (ARAS) method is applied. It is evident in the literature that the ARAS method was combined with many other MCDM methods. There are several real-life studies where the ARAS method was used, for example [45–48]. The ARAS method is one of the recently developed multicriteria decision-making methods developed by [49]. A procedure to solve the problems of multicriteria decision-making by applying the ARAS method can be described through the following steps [48].

Step 1. Forming the decision-making matrix and determining the weights of the criteria. A decision-making matrix consists of feasible alternatives rated on criteria. In this step, the expert determines the optimal performance rating for each criterion. If the expert has no preferences, then the optimal performance ratings can be determined as:

$$x_{j} = \max_{i} x_{ij} \tag{6}$$

where x_{0j} is the optimal performance rating in relation to the j^{th} criterion.

Step 2. Normalise decision-making matrix $R=[r_{ij}]$. In this step, the normalisation is done by the following equation:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{7}$$

where r_{ij} is the normalised performance rating of the i^{th} alternative in relation to the j^{th} criterion.

Step 3: Definition of weighted normalised decision matrix $V=[v_{ij}]$. The weighted normalised performance ratings are calculated by using the following formula:

$$v_{ij} = w_j \cdot r_{ij} \tag{8}$$

where v_{ij} is the weighted normalised performance rating of the i^{th} alternative in relation to the j^{th} criterion.

Step 4. Determine the value of the optimality function

$$S_i = \sum_{j=1}^{n} v_{ij} \tag{9}$$

where S_i is the value of the optimality function of i^{th} alternative.

Step 5. Calculate the degree of utility for each alternative. The calculation of the utility degree Q_i of an alternative a_i is by applying the following formula:

$$Q_i = \frac{S_i}{S_o} \tag{10}$$

where Q_i is the degree of the utility of the i^{th} alternative, and S_i and S_o are the optimality criterion values, obtained from *Equation 9*. The calculated values Q_i are between 0 and 1.

Step 6. Rank the alternatives and/or select the most efficient one. The considered alternatives are ranked by ascending Q_i, i.e. the alternatives with the higher values of Q_i have a higher rank and the alternative with the largest value of Q_i is the best-placed one.

The obtained results of the ARAS method application are presented in the following tables. The initial decision-making matrix is presented in *Table 5*.

Table 5 – The initial decision-making matrix

	Labour costs	Additional costs of using modern means of delivery	The impact of the alternative on stimulating the introduction of new postal services	The impact of the alternative on the improvement of business relations with the economy
Optimal value – OV	85,316.00	0.00	5	5
Six-day delivery	99,237.00	0.00	2	3
Five-day delivery	92,276.00	0.00	3	3
Combination of six-day and five-day delivery	97,904.00	0.00	4	4
AB delivery	85,316.00	101,000.00	5	5
Weights	0.3	0.3	0.2	0.2

The next step is normalisation of the input data and it is presented in *Table 6*.

Table 6 – Normalisation of the initial decision-making matrix

	Labour costs	Additional costs of using modern means of delivery	The impact of the alternative on stimulating the introduction of new postal services	The impact of the alternative on the improvement of business relations with the economy
OV	0.21	0.00	0.26315789	0.25
Six-day delivery	0.18	0.00	0.105263158	0.15
Five-day delivery	0.20	0.00	0.157894737	0.15
Combination of six-day and five-day delivery	0.19	0.00	0.210526316	0.2
AB delivery	0.21	1.00	0.263157895	0.25
Weights	0.3	0.3	0.2	0.2

The normalised weighted values, the values of the optimality function, as well as the degrees of the utility of the alternative are presented in *Table 7*.

Table 7 – Normalised weighted values, values of optimality function and the degrees of the alternative utility

	Labour costs	Additional costs of using modern means of delivery	The impact of the alternative on stimulating the introduction of new postal services	The impact of the alternative on the improvement of business relations with the economy	S_i	Q_i	Rank
OV	0.06	0.00	0.05	0.05	0.17		
Six-day delivery	0.06	0.00	0.02	0.03	0.11	0.23	4
Five-day delivery	0.06	0.00	0.03	0.03	0.12	0.26	3
Combination of six-day and five-day delivery	0.06	0.00	0.04	0.04	0.14	0.30	2
AB delivery	0.06	0.30	0.05	0.05	0.47	1.00	1

The results obtained from the ARAS method confirm the results obtained by the PROMETHEE method. The alternatives, i.e. the last-mile delivery models obtain the same rank through both methods. The AB model is the best ranked model for delivery organisation in the observed case.

5. CONCLUSIONS

Results obtained in this paper represent an assessment of the optimal flexible model for the organisation of the last-mile delivery of a service provider within the scope of universal postal service. Using the multicriteria decision analysis, the paper compares four delivery models: 6-day delivery service (existing solution), 5-day delivery service, 6-day delivery service for municipal places/5-day for other areas, and an AB delivery model with priority and non-priority mail.

Choosing an optimal FLMDM and optimisation of the number of delivery workers using multicriteria decision-making is introduced in this paper for the first time. Relevant variables that evaluate the business of the service provider are included. In that sense, the paper treats data related to the number of postal items and the number of norm minutes individually and in total by services and last-mile delivery routes, and the number of delivery workers as the basic input variables. Using these input data, an optimised number of delivery workers were obtained, as well as the productivity of the last-mile delivery routes for each delivery model. All inputs were processed through four flexible models of delivery organisation, which represent four alternatives in the model of multicriteria analysis. The goal was to get a model, i.e. the highest-ranking alternative to show which delivery model is the most suitable for the observed service provider with an emphasis on the optimised number of delivery workers.

To qualitatively apply the proposed models, it is necessary to:

- ensure comprehensive collection and processing of statistical data regarding the volume of services performed at the last-mile delivery routes,
- provide monitoring of the monthly travelled road distance in the last-mile delivery routes, primarily with the aim of recording and accurately standardising the share of the travelled road distance in the total productivity of delivery workers,
- ensure regular updating of the number of technological jobs and delivery workers.

In accordance with the results, the following is proposed: when any service provider with the universal postal service obligation meets the legal requirements regarding the application of all proposed alternatives (category of priority mail has been introduced), it is recommended that the provider (operator) organises the last-mile delivery according to the flexible models proposed in this paper. Depending on the specifics of each service provider and available data, the results will vary for the last-mile delivery organisation. Specifically, for the postal service provider observed in this paper, the recommended optimal organisation of the last-mile delivery is in accordance with a flexible model of alternative 4 – the AB model. This is confirmed by the PROMETHEE and ARAS methods by ranking the proposed alternatives according to the defined criteria. The AB model is a type of dynamic model of delivery organisation that includes, among other things, monitoring contracts with large customers and, depending on that, merging and creating last-mile delivery routes. In that sense, it would be possible to create daily last-mile delivery routes following the daily number of postal items for delivery. That is the main advantage of a dynamic delivery model. Another main advantage of the dynamic AB delivery model would be the optimised redistribution of the number of workers and the reduction of human resources costs. All delivery workers would be distributed to the last-mile delivery routes according to actual daily needs.

Having in mind the fact that for the current last-mile delivery organisation the observed service provider engages 280 delivery workers (six-day delivery, without optimisation), we can conclude that our approach gives better and more rational results. All proposed FLMDMs offer the optimal number of workers for the last-mile delivery, which significantly reduces the labour costs of service providers and reflects financial sustainability. Even in the case of a currently implemented delivery model (six-day delivery, without optimisation), better results and improvements are obtained with our approach.

The authors believe that the obtained results may represent a general guideline for any service provider. Improvements in the number of delivery workers and labour costs are evident regardless of the proposed flexible model applied in the last-mile delivery organisation. In this paper, according to the PROMETHEE and ARAS, the AB delivery model gives the best results, but the other models also reach significant savings in the number of workers at the level of the entire postal network. In our research, we decided to use the PROMETHEE and ARAS methods because they are an efficient decision-making support deployed in case of a finite number of criteria.

Future research would include the elaboration of a detailed model of the AB delivery and its application in real conditions to see whether the solutions of the delivery model presented in this paper have found practical application. Furthermore, new forms of postal locations (franchises, agencies, mobile post offices) were not dealt with in this research. Moreover, the expansion of the network for collecting items (by increasing the number of postal mailboxes), the expansion of the retail network, the optimisation of transport and the installation of a collective postal mailbox in less populated rural areas were also neglected. Future models should encompass these inputs as well. It would also be beneficial to expand the optimal flexible model, by including other input variables, such as demographic and geographic characteristics, financial indicators of the post offices and centres, etc.

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Izbor fleksibilnih modela dostave duž poslednje milje korišćenjem višekriterijumskog odlučivanja

Abstrakt

Provajderi poštanskih usluga mogu reorganizovati proces dostave u domenu univerzalne usluge primenom nekih od fleksibilnih modela. U ovom radu pitanje izbora fleksibilnih modela dostave duž poslednje milje (Flexible Last-Mile Delivery Models - FLMDM) rešavano je korišćenjem višekriterijumskog odlučivanja. Identifikovana su četiri različita održiva modela dostave, sa akcentom na broju dostavljača. Odabran je jedan provajder poštanskih usluga iz Evrope za testiranje predloženih modela. Modeli su rangirani korišćenjem određenih tehnika višekriterijumskog odlučivanja. U ovom kontekstu tehnike višekriterijumskog odlučivanja su korišćene za uporednu procenu alternativa. Dobijeni rezultati preporučuju AB model dostave kao optimalan izbor za dostavu duž poslednje milje i potpunu alokaciju broja dostavljača.

Ključne reči

dostava duž poslednje milje; provajder usluga; univerzalna poštanska usluga; dostavljači; rangiranje; PROMETHEE; ARAS.

Appendix: The summary of output acronyms

AMRM	Average Monthly Registered Mail
AMUM	Average Monthly Unregistered Mail
AMRMO	Average Monthly Registered Money Orders
EPMM	Estimated Priority Mail Monthly
ENPMM	Estimated Non-Priority Mail Monthly
ANMVID	Achieved Norm Minutes Based on the Volume of Items - for delivery
ANMRD6	Achieved Norm Minutes Based on the Road Distance – six-day Delivery
NMSI	Norm Minutes for Postal Items Sent by Individuals
NMSLE	Norm Minutes for Postal Items Sent by Legal Entities
ENMRD5	Estimated Number of Norm Minutes Based on the Road Distance for five-day delivery
ENMRD6/5	Estimated Norm Minutes Based on the Road Distance for 6/5 delivery
ENMRDAB	Estimated Norm Minutes Based on the Road Distance for AB delivery
TANM6	Total Number of Achieved Norm Minutes for six-day delivery
TANM5	Total Number of Achieved Norm Minutes for five-day delivery
TANM6/5	Total Number of Achieved Norm Minutes for 6/5 delivery
TANMAB	Total Number of Achieved Norm Minutes for AB delivery
EP6	Estimated Productivity for six-day delivery
EP5	Estimated Productivity for five-day delivery
EP6/5	Estimated Productivity for 6/5 delivery
EPAB	Estimated Productivity for AB delivery
$EDWWithoutR6_{pc}$	Estimated Number of Delivery Workers for six-day delivery, monthly, without replacement, by post centre
$EDWWithoutR5_{pc}$	Estimated Number of Delivery Workers for five-day delivery, monthly, without replacement, by post centre
$EDWWithoutR6/5_{pc}$	Estimated Number of Delivery Workers for 6/5 delivery, monthly, without replacement, by post centre
$EDWWithoutRAB_{pc}$	Estimated Number of Delivery Workers for AB delivery, monthly, without replacement, by post centre
$EDWWithR6_{pc}$	Estimated Number of Delivery Workers for six-day delivery, by post centre, monthly, with replacement
$EDWWithR5_{pc}$	Estimated Number of Delivery Workers for five-day delivery, by post centre, monthly, with replacement
$EDWWithR6/5_{pc}$	Estimated Number of Delivery Workers for 6/5 delivery, by post centre, monthly, with replacement
$EDWWithRAB_{pc}$	Estimated Number of Delivery Workers for AB delivery, by post centre, monthly, with replacement
$LCWithoutR6_{pc}$	Labour Costs for six-day delivery, without replacement
$LCWithoutR5_{pc}$	Labour Costs for five-day delivery, without replacement
$LCWithoutR6/5_{pc}$	Labour Costs for 6/5 delivery, without replacement
$LCWithoutRAB_{pc}$	Labour Costs for AB delivery, without replacement
$LCWithR6_{pc}$	Labour Costs for six-day delivery, with replacement
$LCWithR5_{pc}$	Labour Costs for five-day delivery, with replacement
$LCWithR6/5_{pc}$	Labour Costs for 6/5 delivery, with replacement
$LCWithRAB_{pc}$	Labour Costs for AB delivery, with replacement