

# The application of MCDA methods in the assessment of selected Polish e-banking services—a comparative analysis of MOORA, WPM, and TOPSIS

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**Abstract**—The main objective of this article is to compare the results of the quality assessment of electronic banking services using selected multi-criteria methods in a study conducted in Poland at the end of 2025. The study was conducted on a group of 570 students of the University of Warsaw in Poland, using the CAWI method. Three MCDA methods were used to analyze the results: MOORA, WPM, and TOPSIS, as well as two criterion weighting techniques (subjective and objective). The results were then compared based on their ranking positions. The convergence of the results was assessed using Pearson's correlation and Spearman's weighted correlation coefficient. To assess the divergence of ranking positions according to the selected methods, Euclidean distances between the ranking scores were calculated. The main conclusion from the research is that the methods considered can be used interchangeably in the assessment of the solutions of the type studied, but additional research is still needed. The next steps in the research should be to use other MCDA methods in the assessment of the quality of electronic banking services and to extend the research sample beyond the academic environment so that the results can be fully generalized.

**Index Terms**—evaluation of e-banking, survey, CAWI, MCDA, MOORA, WSP, TOPSIS.

## I. INTRODUCTION

ASSESSING the quality of electronic banking services from the perspective of a young individual customer is undoubtedly a complex decision-making problem. The two main areas are: the selection of criteria for assessing their quality. In this area, a number of authors refer to different sets of assessment criteria. They use both their own sets of criteria and cite various methods of constructing such a set. The problems encountered in this area include: determining the appropriate number of evaluation criteria, assignment them into groups, internal contradictions between criteria, and finally, the possible substitutability of criteria. The second area, which will undoubtedly pose a number of problems, is the selection of the appropriate method for evaluating the quality of IT solutions. The literature refers to the use of both simple and complex methods, e.g., methods from the multi-criteria MCDA group. The use of multi-criteria

methods is often associated with the problem of collecting results, as measures that are often incomprehensible to respondents, such as weight of significance or veto threshold, are required. An additional problem is the large number of multi-criteria methods proposed by researchers. Therefore, in the search for the best method for assessing the quality of electronic banking services, it is important to compare the results of assessments calculated using different methods, which will enable the identification of similarities in rankings or the discovery of the reasons for their discrepancies.

A review of the literature revealed that no comparative analysis of the results of electronic banking service quality studies using the following three multi-criteria methods, i.e., MOORA, WPM, and TOPSIS, has ever been conducted. This is a research gap that this article fills. The research problem presented, the research gap characterized, and the presentation of the state of previous research on the research problem made it possible to formulate the following research question: in research on the quality of electronic banking services, do the rankings obtained using different multi-criteria methods give results that can be described as acceptably similar?

The main objective of this article is to compare the results of the quality assessment of electronic banking services using selected multi-criteria methods in a study conducted in Poland at the end of 2025. The aim is to assess the similarities between the results obtained and to determine the specific positions of electronic banking services in the rankings and the reasons for this.

This article is a continuation of the author's [1] [2] research on the use of multi-criteria methods to assess the quality of electronic banking services and mobile banking applications.

## II. LITERATURE REVIEW

The literature on the subject provides a number of examples of the application of MCDM methods and considerations regarding the dimensions of the study (criteria) in order to examine the quality of electronic banking services

He also classifies banks using AHP/ANP methods and network analysis. Younos [4] focused on integrating AHP and Kano models to prioritize satisfaction factors in the use of electronic banking, with particular emphasis on security and accessibility. Rehaballah [5] used AHP and PROMETHEE methods to evaluate electronic banking. In their research, they focused on: internet banking, telephone banking, and ATMs. Zborowski [1] used, among other things, the ELECTRE method in variants I and III to evaluate selected electronic banking services. The evaluation was based on 18 criteria grouped according to economic, technical, and crisis resilience factors. Seth [6] used multi-criteria decision analysis techniques, TOPSIS and WASPAS, in their research study to evaluate and rank the five largest Indian banks based on various financial and operational criteria. The study took into account factors such as price, market capitalization, TTM PE ratio (price-to-earnings ratio for the last twelve months), return on equity, capital adequacy ratio (CAR), interest earned, and net interest margin (NIM). Chmielarz and Zborowski [7] used the multi-criteria COMET method in their study of the quality of electronic banking services. The article identifies the criteria most important to respondents and uses the results obtained in the study to determine the best alternative. The article demonstrates the usefulness of the COMET method for testing services of the type analyzed. Lin [8] presented an evaluation model that uses an integrated approach to decision-making regarding the selection of mobile banking service elements in the banking sector. The model was constructed from four elements. First, an analysis of the elements relevant to the evaluation of mobile banking services was performed. Then, the DEMATEL (Decision Making Trial and Evaluation Laboratory) method was used to identify complex relationships and build a network structure between the criteria required by organizations. Yıldız [9] in an article on determining the level of financial literacy among undergraduate students at the Faculty of Economics and Administrative Sciences at Kütahya Dumlupınar University in Turkey used the fuzzy DEMATEL method. It was shown that taking responsibility and creating a household budget by students is the most important factor and has a significant impact on the level of correlation with other factors. Sari [10] use weights obtained using the ROC (Receiver Operating Characteristic) method and aggregation using the WASPAS (Weighted Aggregated Sum Product Assessment) method for criteria such as security, popularity, ease of use, rating, and cost for five alternative applications. The study focused on the selection of a bank/application using supplier-oriented criteria. Özdağoğlu [11] used the fuzzy SWARA and fuzzy MOORA methods in their research. The research concerned the preferences of Turkish bank customers. As part of the research procedure, they used the SWARA method to assess the importance of criteria such as trust, mobile services, service quality, prices, etc.

Several studies can be cited as examples of the application of hybrid methods to assess the quality of electronic banking

services. Kaya & Kahraman [12] used the fuzzy AHP–ELECTRE method to determine the weights of the criteria and the fuzzy ELECTRE method to create fuzzy dominance for the full ranking of the websites of four Turkish banks. The criteria relate to the quality of websites/services such as security, competence, reliability, responsiveness, information, and ease of use. Paltayian [13] developed a four-step process consisting of: defining criteria, surveys and EFA (Exploratory Factor Analysis), the QFD (Quality Function Deployment) method with AHP weights, and sensitivity analysis. In their research, they considered electronic banking services in Greece. In the article, they focused on examining the significance of QFD/AHP service quality criteria and strategic implications. Ecer [14] used the Fuzzy AHP method in his study to evaluate the weights of the criteria, and then applied ARAS to evaluate 16 Turkish mobile banking services. The article on model development; decision criteria include facilitating conditions, self-efficacy, privacy/security risks, perceived usefulness/ease of use; the fuzzy approach corresponds to customers' linguistic perceptions. Asante [15] used the AHP method to assign weights to six customer-related criteria, then used the PL-TOPSIS method to evaluate and rank five alternative electronic payment methods. The criteria related to customers (reliability, ease of use, responsiveness, security, cost-effectiveness, usability); the alternative methods included: ATM, mobile payments, online banking, credit cards. The results obtained and the details of the fuzzy method make it directly relevant.

### III. RESEARCH METHODOLOGY

Many years of research into electronic banking websites and mobile banking applications led the author [16],[2] of this article to adopt the following, repeatedly tested research procedure:

- bibliographic analysis of the latest sources in the field of analysis and evaluation of the quality of websites and mobile applications using MCDA methods, with particular emphasis on electronic banking services and mobile banking applications,
- construction of a pilot version of the survey questionnaire to verify the correctness and clarity of the questions,
- development and refinement of a prototype survey questionnaire based on the above assessment, followed by the creation of the final version of the questionnaire,
- conducting the survey using the CAWI (Computer Associated Web Interview) method,
- selection of two methods from among MCDA for the evaluation of banking services in order to perform calculations and obtain results,
- comparative analysis and discussion of the results of the calculations and their statistics,
- drawing conclusions, formulating limitations and further directions for research.

The collected data on the evaluation of variants, i.e., electronic banking services, were averaged and normalized. Two calculations were made regarding the weighting of criteria. In

the first, they were averaged to achieve subjective preference weights, and in the second, the Entropy method was used to achieve objective preference weights. The results obtained were entered into the MCDMaker application (<https://mcdmaker-software.web.app/>) in order to recalculate them using the MOORA, TOPSIS and WPM methods. Two variants of significance weights (subjective and objective) were also used in the calculations.

### MOORA

MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) was developed by Brauers and Edmundas Kazimieras Zavadskas [17]. It belongs to the multi-criteria decision analysis (MCDA) methods, which allow for the ranking of a set of alternatives (decision variants) taking into account a number of often conflicting criteria. This method is distinguished by its computational simplicity and high efficiency, which makes it useful in complex decision-making problems in engineering, economics, and management [18].

The use of this method requires the construction of a matrix of assessments of the accepted criteria and alternatives (decision variants) [19]:

$$(x_{ij})$$

where  $x_{ij}$  is the response of alternative  $j$  to objective  $i$ ,  $i = 1, 2, \dots, n$  are the objectives,  $j = 1, 2, \dots, m$  are the alternatives.

MOORA refers to a ratio system in which each response of an alternative on an objective is compared to a denominator, which is representative for all alternatives concerning that objective. For this denominator the square root of the sum of squares of each alternative per objective is chose [20]:

$$N^{x_{ij}} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^m x_{ij}^2}}$$

with:

$x_{ij}$  = response of alternative  $j$  to objective  $i$ ,  $j = 1, 2, \dots, m$ ;  $m$  the number of alternatives,  $i = 1, 2, \dots, n$ ;  $n$  the number of objectives,  $N^{x_{ij}}$  = a dimensionless number representing the normalized response of alternative  $j$  to objective  $i$ ; these normalized responses of the alternatives to the objectives belong to the interval  $[0; 1]$ .

For optimization, these responses are added in case of maximization and subtracted in case of minimization:

$$NY_j = \sum_{i=1}^{i=g} N^{x_{ij}} - \sum_{i=g+1}^{i=n} N^{x_{ij}}$$

with:

$i = 1, 2, \dots, g$  for the objectives to be maximized,  $i = g + 1, g + 2, \dots, n$  for the objectives to be minimized,

$NY_j$  = the normalized assessment of alternative  $j$  with respect to all objectives.

In this formula linearity concerns dimensionless measures in the interval  $[0; 1]$ . An ordinal ranking of the  $NY_j$  shows the final preference.

The reference point theory starts from the already normalized ratios as defined in the MOORA method, namely formula (2). Next, the reference point theory chooses for maximization a reference point, which has as co-ordinates the highest co-ordinate per objective of all the candidate alternatives. For minimization, the lowest co-ordinate is chosen.

In order to measure the distance between the alternatives and the reference point, the Tchebycheff Min-Max metric is chose [21].

$$\min_{(j)} \left\{ \max_{(i)} |r_i - N^{x_{ij}}| \right\}$$

where:

$i = 1, 2, \dots, n$  are the objectives,  $j = 1, 2, \dots, m$  are the alternatives,

$r_i$  = the  $i^{th}$  co-ordinate of the maximal objective reference point; each co-ordinate of the reference point is selected as the highest corresponding co-ordinate of the alternatives,

$N^{x_{ij}}$  = the normalized objective  $i$  of alternative  $j$ .

A simulation exercise on privatization illustrates the application of the MOORA and reference point methods.

### WPM

Weighted product model (WPM) [22], [23] is the extension of the weighted sum model (WSM) [24], [25]. Each alternative is compared with the other alternatives by multiplying a number of ratios, one for each decision criterion. Each ratio is raised to the power equivalent to the weights of the corresponding criterion [26].

Step 1: Forming an evaluation matrix ( $m_i \times n_j$ ) comparison scale [27]. Where,  $m$  is the number of alternatives and  $n$  is the number of criteria.

$$R(m_i \times n_j) = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}$$

Step 2: The evaluation or the decision matrix is normalized according to the requirements and thus creating the normalization matrix.

a) For positive criteria, (whose larger values is desired)

$$n_{ij} = \frac{r_{ij}}{r_j^{max}}$$

Where,  $i = 1, 2, 3, \dots, m$  and  $j = 1, 2, 3, \dots, n$

b) For negative or cost criteria, (whose smaller values is desired)

$$n_{ij} = \frac{r_j^{min}}{r_{ij}}$$

Where,  $i = 1, 2, 3, \dots, m$  and  $j = 1, 2, 3, \dots, n$

$r_j^{max}$  = Largest number in the column of  $j$

$r_j^{min}$  = Smallest number in the column of  $j$

Step 3: The ratio or the relative weightages is calculated comparing each alternative over another.

$$P\left(\frac{A_k}{A_l}\right) = \prod_{j=1}^n \left(\frac{n_{kj}}{n_{lj}}\right)^{w_j}$$

$k, l = 1, 2, 3, \dots, m$

Let us consider two alternatives  $A_k$  and  $A_l$ , in case of maximization problem, if  $P\left(\frac{A_k}{A_l}\right)$  is greater than 1 i.e.  $P\left(\frac{A_k}{A_l}\right) > 1$  then the alternative  $A_k$  is better than  $A_l$  and if  $P\left(\frac{A_k}{A_l}\right) < 1$  then  $A_l$  is better than  $A_k$ .

#### TOPSIS

The TOPSIS method is made up of six stages [28]. Initially, the decision-maker (DM) describes the decision problem with  $n$  criteria and  $m$  alternatives. A decision matrix  $D[x_{ij}]$  is then constructed, with rows representing the decision attributes of the alternatives, and columns representing the criteria:

$$D[x_{ij}] = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$$

Subsequently, the decision matrix undergoes normalization in the second step, with the following formulae:

$$r_{ij} = \frac{x_{ij} - \min_i(x_{ij})}{\max_i(x_{ij}) - \min_i(x_{ij})}$$

$$r_{ij} = \frac{\max_i(x_{ij}) - x_{ij}}{\max_i(x_{ij}) - \min_i(x_{ij})}$$

for the benefit and cost criteria respectively.

In the next step, the weights are imposed on the normalized decision matrix, thus resulting in a weighted normalized decision matrix, whose each element is computed with the formula:

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

In the fourth step, the positive (PIS) and negative (NIS) ideal solutions are obtained ( $V_j^+$  and  $V_j^-$ ):

$$V_j^+ = \{v_1^+, v_2^+, \dots, v_n^+\}$$

$$V_j^- = \{v_1^-, v_2^-, \dots, v_n^-\}$$

The best alternative should be as close as possible to PIS and as far as possible from NIS. Therefore, the Euclidean distances between each alternative and PIS and NIS are computed in the fifth step. Finally, in the last step of the algorithm, relative closeness to the ideal solution is obtained:

$$CC_i = \frac{D_i^-}{D_i^- + D_i^+}$$

The obtained closeness coefficient  $CC_i$  is the score value produced by the TOPSIS method and is used to construct the ranking of alternatives [29].

#### IV. CHARACTERISTICS OF THE RESEARCH SAMPLE

The study was conducted using the CAWI method at the end of 2025 among students of the University of Warsaw in Poland. In the study group, men accounted for a significant proportion of the total respondents (78.87%), while women accounted for 21.12%. The majority of respondents (76.73%) were young people aged 19 to 25. Respondents aged 26 to 27 accounted for 13.85%. The remaining group, i.e., people aged 28 and over, accounted for only 9.42%. The two largest groups were first-year students (23.25%) and second-year students (24.83%). 43.53% were third-, fourth-, and fifth-year students. The respondents came primarily from cities with more than 500,000 inhabitants (40.91%), followed by cities

with up to 100,000 inhabitants (24.83%) and cities with between 101,000 and 500,000 inhabitants (15.38%).

#### V. RESEARCH RESULTS AND FINDINGS

The survey form was divided into the following three parts: selection of an electronic banking service and assessment of the criteria included, assessment of the importance of the criteria, and survey details. The first part included 20 evaluation criteria divided into three groups of factors, i.e., economic, technical, and perceived quality. The economic factors included (C1, ..., C4): Fees and commissions, Product features, Product usability, and Product cost-effectiveness. The technical factors included (C5, ..., C13): Ease of use, Personalization, Performance/speed, Range of functionality, Content, Visualization, Account access channels, Security, and Additional services. The last group consisted of Perceived quality factors, which included (C14, ..., C18): Reliability, Credibility, Communication, Availability, and Dependability. The set of evaluation criteria was created using the theoretical model of customer satisfaction, trust, and loyalty in the use of electronic banking products and services proposed by Siudek T.[30] This model was modified based on the author's many years of experience.

The survey included 34 electronic banking services offered by banks operating in Poland. Respondents were asked to evaluate two selected services. Due to the low number of responses or lack of responses, the further calculations took into account the 20 most recognizable electronic banking services on the Polish market offered by the following banks (A1, ..., A20): ALIOR Bank SA, Bank BPH SA, Bank Handlowy w Warszawie SA, Bank MILLENNIUM SA, Bank Ochrony Środowiska SA, Bank Pocztowy SA, Bank Polska Kasa Opieki SA, Bank Polskiej Spółdzielczości SA, BNP Paribas SA, Credit Agricole Bank Polska SA, ING Bank Śląski SA, mBank SA, PKO Bank Polski SA, PKO Bank Polski SA Inteligo, Revolut Bank UAB, Santander Bank Polska SA, Santander Consumer Bank SA, TOYOTA Bank Polska SA, UniCredit, and VeloBank SA.

After receiving the data and averaging and standardizing it, a reliability test was performed using Cronbach's alpha coefficient. For all criteria included in the study, Cronbach's alpha coefficient was 0.96, which indicates internal consistency and reliability of the sample.

After assessing the quality of electronic banking services, respondents were asked to indicate the importance of each criterion. The value of this indicator is used in both accepted methods, i.e., MOORA and WPM. In modeling decision-making problems, which is the case here, it is very important to determine the importance of decision-making criteria. Various methods of obtaining criterion weights are described in the literature. In this study, two methods of weighting criteria were used: subjective and entropy (Table 1).

TABLE I.  
AVERAGE WEIGHTING OF CRITERIA: SUBJECTIVE AND ENTROPY

| Criteria | Average weight of significance | Subjective | Entropy |
|----------|--------------------------------|------------|---------|
| C1       | 8.1229                         | 0.0567     | 0.0566  |
| C2       | 7.5009                         | 0.0524     | 0.0546  |
| C3       | 7.8261                         | 0.0547     | 0.0557  |
| C4       | 8.2344                         | 0.0575     | 0.0550  |
| C5       | 8.4197                         | 0.0588     | 0.0567  |
| C6       | 6.4461                         | 0.0450     | 0.0552  |
| C7       | 8.3667                         | 0.0584     | 0.0553  |
| C8       | 7.9263                         | 0.0554     | 0.0562  |
| C9       | 7.4802                         | 0.0523     | 0.0563  |

| Criteria | Average weight of significance | Subjective | Entropy |
|----------|--------------------------------|------------|---------|
| C10      | 6.8280                         | 0.0477     | 0.0540  |
| C11      | 7.8563                         | 0.0549     | 0.0537  |
| C12      | 8.8620                         | 0.0619     | 0.0569  |
| C13      | 6.2609                         | 0.0437     | 0.0560  |
| C14      | 8.6352                         | 0.0603     | 0.0564  |
| C15      | 8.8809                         | 0.0620     | 0.0554  |
| C16      | 8.1682                         | 0.0571     | 0.0551  |
| C17      | 8.5293                         | 0.0596     | 0.0560  |
| C18      | 8.8015                         | 0.0615     | 0.0550  |

Source: Own work

Table 1 presents the average weights of the criteria indicated by the respondents, which were then normalized using the mini-max method and presented in the next column. The last column contains the weights determined using the Entropy method.

The average and standardized results of the assessments of the alternatives under consideration, broken down into groups of criteria, are presented in Table 2.

Next, correlations were calculated for calculations with subjective and objective weights.

Correlations for calculations with subjective weights. Pearson's correlation coefficient

Formula for Pearson's correlation coefficient:

$$r_{xy} = \frac{\sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^N (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^N (y_i - \bar{y})^2}}$$

Weighted Spearman correlation coefficient ( $r_w$ ):

TABLE II.  
AVERAGE AND STANDARDIZED QUALITY SCORES FOR THE ALTERNATIVES

| Alternative | Technical  |        |        |        |                   |        |        |        |        |
|-------------|------------|--------|--------|--------|-------------------|--------|--------|--------|--------|
|             | C5         | C6     | C7     | C8     | C9                | C10    | C11    | C12    | C13    |
| A1          | 0.0474     | 0.0474 | 0.0483 | 0.0488 | 0.0483            | 0.0478 | 0.0485 | 0.0508 | 0.0501 |
| A2          | 0.055      | 0.0554 | 0.0557 | 0.0481 | 0.0518            | 0.0555 | 0.0435 | 0.0472 | 0.0558 |
| A3          | 0.0363     | 0.0432 | 0.042  | 0.0395 | 0.0399            | 0.0423 | 0.0445 | 0.0502 | 0.0447 |
| A4          | 0.0505     | 0.0514 | 0.0521 | 0.0518 | 0.0501            | 0.0523 | 0.0515 | 0.0515 | 0.0511 |
| A5          | 0.0563     | 0.0511 | 0.0464 | 0.0535 | 0.0558            | 0.0461 | 0.0487 | 0.0445 | 0.0516 |
| A6          | 0.048      | 0.0501 | 0.0415 | 0.0409 | 0.0531            | 0.0508 | 0.0461 | 0.0475 | 0.0385 |
| A7          | 0.0559     | 0.057  | 0.0526 | 0.0539 | 0.0535            | 0.0567 | 0.0573 | 0.0548 | 0.0568 |
| A8          | 0.0539     | 0.0531 | 0.0531 | 0.0516 | 0.055             | 0.0561 | 0.0546 | 0.0515 | 0.0542 |
| A9          | 0.0482     | 0.0516 | 0.0513 | 0.0519 | 0.0519            | 0.0508 | 0.0519 | 0.0519 | 0.0515 |
| A10         | 0.0469     | 0.0443 | 0.046  | 0.047  | 0.045             | 0.0426 | 0.0444 | 0.0468 | 0.0438 |
| A11         | 0.0526     | 0.0512 | 0.0535 | 0.0518 | 0.0516            | 0.053  | 0.0541 | 0.0546 | 0.053  |
| A12         | 0.0543     | 0.0537 | 0.0552 | 0.0545 | 0.0531            | 0.0545 | 0.0553 | 0.0544 | 0.0524 |
| A13         | 0.0527     | 0.0509 | 0.0527 | 0.0519 | 0.0509            | 0.0499 | 0.052  | 0.0546 | 0.0511 |
| A14         | 0.0461     | 0.0518 | 0.0471 | 0.0468 | 0.0472            | 0.0433 | 0.0435 | 0.0504 | 0.048  |
| A15         | 0.0549     | 0.0575 | 0.0578 | 0.0572 | 0.0556            | 0.057  | 0.0521 | 0.0492 | 0.0572 |
| A16         | 0.0482     | 0.0497 | 0.0482 | 0.0487 | 0.0489            | 0.0487 | 0.0501 | 0.0498 | 0.0477 |
| A17         | 0.0493     | 0.0452 | 0.0464 | 0.0481 | 0.0432            | 0.0481 | 0.0507 | 0.0504 | 0.0415 |
| A18         | 0.0539     | 0.049  | 0.0531 | 0.0544 | 0.0513            | 0.0532 | 0.0527 | 0.0496 | 0.0563 |
| A19         | 0.0448     | 0.0416 | 0.0491 | 0.0501 | 0.0478            | 0.0454 | 0.0501 | 0.0386 | 0.0458 |
| A20         | 0.0448     | 0.0448 | 0.048  | 0.0492 | 0.0462            | 0.0459 | 0.0485 | 0.0515 | 0.0488 |
|             | Economical |        |        |        | Perceived quality |        |        |        |        |
|             | C1         | C2     | C3     | C4     | C14               | C15    | C16    | C17    | C18    |
| A1          | 0.0497     | 0.0492 | 0.0491 | 0.0508 | 0.0483            | 0.0483 | 0.0503 | 0.0481 | 0.05   |
| A2          | 0.0522     | 0.0506 | 0.0509 | 0.0517 | 0.0429            | 0.0419 | 0.05   | 0.0463 | 0.0441 |
| A3          | 0.0489     | 0.0439 | 0.0463 | 0.0413 | 0.052             | 0.054  | 0.0445 | 0.0456 | 0.0482 |
| A4          | 0.0508     | 0.0507 | 0.0496 | 0.0495 | 0.0505            | 0.0519 | 0.0517 | 0.0507 | 0.0511 |
| A5          | 0.0464     | 0.0424 | 0.0455 | 0.0488 | 0.0507            | 0.0458 | 0.0446 | 0.054  | 0.0468 |
| A6          | 0.0489     | 0.0427 | 0.0469 | 0.0431 | 0.048             | 0.0507 | 0.0431 | 0.0426 | 0.0474 |
| A7          | 0.0546     | 0.0566 | 0.054  | 0.0571 | 0.0547            | 0.0572 | 0.0544 | 0.0552 | 0.0546 |
| A8          | 0.0559     | 0.0547 | 0.0545 | 0.0584 | 0.0511            | 0.0523 | 0.0531 | 0.0505 | 0.0472 |
| A9          | 0.0457     | 0.0471 | 0.0487 | 0.0494 | 0.05              | 0.0508 | 0.0523 | 0.0524 | 0.0527 |
| A10         | 0.0435     | 0.0448 | 0.0434 | 0.0431 | 0.0455            | 0.0453 | 0.0458 | 0.0469 | 0.0472 |
| A11         | 0.0525     | 0.0514 | 0.0504 | 0.0514 | 0.0529            | 0.053  | 0.0557 | 0.0538 | 0.0538 |
| A12         | 0.0513     | 0.0521 | 0.0513 | 0.051  | 0.0533            | 0.0544 | 0.055  | 0.0543 | 0.0536 |
| A13         | 0.0512     | 0.0504 | 0.0505 | 0.051  | 0.0532            | 0.0552 | 0.0527 | 0.0528 | 0.053  |
| A14         | 0.0392     | 0.0519 | 0.0509 | 0.0438 | 0.0514            | 0.0484 | 0.046  | 0.0495 | 0.053  |
| A15         | 0.0557     | 0.0575 | 0.0572 | 0.0585 | 0.0493            | 0.0492 | 0.0487 | 0.053  | 0.054  |
| A16         | 0.0502     | 0.0486 | 0.047  | 0.0484 | 0.0499            | 0.0495 | 0.0495 | 0.0485 | 0.0476 |
| A17         | 0.0537     | 0.0533 | 0.0522 | 0.0481 | 0.0475            | 0.0432 | 0.0487 | 0.0476 | 0.0448 |
| A18         | 0.0497     | 0.0527 | 0.0526 | 0.0513 | 0.052             | 0.0533 | 0.0522 | 0.0514 | 0.0522 |
| A19         | 0.0493     | 0.0478 | 0.0489 | 0.0488 | 0.0494            | 0.0497 | 0.0514 | 0.0476 | 0.0496 |
| A20         | 0.0504     | 0.0516 | 0.0502 | 0.0545 | 0.0473            | 0.0458 | 0.0504 | 0.0491 | 0.0488 |

Source: Own work

$$r_w = 1 - \frac{6 \sum_{i=1}^N (x_i - y_i)^2 ((N - x_i + 1) + (N - y_i + 1))}{N^4 + N^3 - N^2 - N}$$

#### Calculation results and rankings for subjective weights

Table 3 presents preference values calculated using the MOORA, WPM, and TOPSIS methods, along with corresponding rankings for calculations with subjective weights.

TABLE III.  
PREFERENCE FUNCTION VALUES AND RANKINGS FOR CALCULATIONS  
WITH SUBJECTIVE WEIGHTS

| Alternative | Preference values |          |          | Rankings |     |        | Average |
|-------------|-------------------|----------|----------|----------|-----|--------|---------|
|             | MOORA             | WPM      | TOPSIS   | MOORA    | WPM | TOPSIS |         |
| A1          | 0.177256          | 0.490997 | 0.490813 | 11       | 10  | 10     | 10.33   |
| A2          | 0.181279          | 0.000000 | 0.487233 | 10       | 14  | 11     | 11.67   |
| A3          | 0.090201          | 0.000000 | 0.324381 | 19       | 14  | 19     | 17.33   |
| A4          | 0.227472          | 0.634931 | 0.626105 | 8        | 8   | 8      | 8.00    |
| A5          | 0.165246          | 0.000000 | 0.458343 | 14       | 14  | 14     | 14.00   |
| A6          | 0.108447          | 0.000000 | 0.340093 | 18       | 14  | 18     | 16.67   |
| A7          | 0.331781          | 0.923336 | 0.883272 | 1        | 1   | 1      | 1.00    |
| A8          | 0.277198          | 0.750869 | 0.733813 | 4        | 5   | 5      | 4.67    |
| A9          | 0.218655          | 0.596797 | 0.597163 | 9        | 9   | 9      | 9.00    |
| A10         | 0.086053          | 0.000000 | 0.260368 | 20       | 14  | 20     | 18.00   |
| A11         | 0.272666          | 0.756259 | 0.735090 | 5        | 4   | 4      | 4.33    |
| A12         | 0.289303          | 0.803598 | 0.778894 | 3        | 3   | 2      | 2.67    |
| A13         | 0.254250          | 0.704391 | 0.692585 | 7        | 7   | 7      | 7.00    |
| A14         | 0.153516          | 0.000000 | 0.441578 | 15       | 14  | 15     | 14.67   |
| A15         | 0.303614          | 0.817177 | 0.766537 | 2        | 2   | 3      | 2.33    |
| A16         | 0.174150          | 0.481059 | 0.480710 | 12       | 11  | 13     | 12.00   |
| A17         | 0.153018          | 0.351583 | 0.437745 | 16       | 13  | 17     | 15.33   |
| A18         | 0.255943          | 0.710387 | 0.702953 | 6        | 6   | 6      | 6.00    |
| A19         | 0.152318          | 0.000000 | 0.438951 | 17       | 14  | 16     | 15.67   |
| A20         | 0.172102          | 0.454668 | 0.482013 | 13       | 12  | 12     | 12.33   |

Source: Own work

TABLE IIIV.  
PEARSON CORRELATION COEFFICIENTS AND WEIGHTED SPEARMAN  
CORRELATION COEFFICIENT FOR SUBJECTIVE WEIGHTS

| Pearson correlation                |          |          |            |
|------------------------------------|----------|----------|------------|
|                                    | MOORA    | WPM      | TOPSIS     |
| MOORA                              | -        | 0.902593 | 0.99612768 |
| WPM                                | 0.902593 | -        | 0.90712551 |
| TOPSIS                             | 0.996128 | 0.907126 | -          |
| Spearman's correlation coefficient |          |          |            |
|                                    | MOORA    | WPM      | TOPSIS     |
| MOORA                              | -        | 0.939427 | 0.9924812  |
| WPM                                | 0.939427 | -        | 0.9432811  |
| TOPSIS                             | 0.992481 | 0.943281 | -          |

Source: Own work

Referring to the rankings presented in Table 3, it can be concluded that for the three MCDA methods considered, in five cases the alternatives occupied the same place, i.e.: (A18) TOYOTA Bank Polska SA 6th place, (A13) PKO Bank Polski SA 7th place, (A4) Bank MILLENNIUM SA 8th place, (A9) BNP Paribas SA 9th place, (A5) Bank Ochrony Środowiska SA 14th place. Considering the average of the rankings, the top three places were taken by the following alternatives: (A7) Bank Polska Kasa Opieki SA, (A15) Revolut Bank UAB, (A12) mBank SA.

Table 4 presents the results of calculations for Pearson's correlation coefficients and Spearman's weighted correlation coefficient.

Referring to Table 4, which presents the values of the correlation coefficients of ranking similarity: WS and  $r_w$ . The highest value of the asymmetric WS coefficient (0.996128) was recorded for the MOORA-TOPSIS method pair, and the lowest correlation was observed for MOORA-WPM (0.902593). The highest value of the asymmetric coefficient  $r_w$  (0.992481) was recorded for the MOORA-TOPSIS method pair, and the lowest correlation was observed for MOORA-WPM (0.939427). It can be said that the results of the ranking similarity study did not show any outliers.

Table 5 presents the Euclidean distances between pairs of places in the ranking of the analyzed methods in the case of weights calculated using the entropy method.

Referring to Table 5, which presents the Euclidean distances between places in the ranking, the largest difference in

TABLE V.  
EUCLIDEAN DISTANCE VALUES BETWEEN PAIRS OF PLACES IN THE  
MOORA, WPM, AND TOPSIS METHOD RANKINGS FOR ENTROPY  
WEIGHTS

| Alternative | MOORA - WPM | MOORA - TOPSIS | WPM - TOPSIS | Sum |
|-------------|-------------|----------------|--------------|-----|
| A1          | 1           | 1              | 0            | 2   |
| A2          | 4           | 1              | 3            | 8   |
| A3          | 5           | 0              | 5            | 10  |
| A4          | 0           | 0              | 0            | 0   |
| A5          | 0           | 0              | 0            | 0   |
| A6          | 4           | 0              | 4            | 8   |
| A7          | 0           | 0              | 0            | 0   |
| A8          | 1           | 1              | 0            | 2   |
| A9          | 0           | 0              | 0            | 0   |
| A10         | 6           | 0              | 6            | 12  |
| A11         | 1           | 1              | 0            | 2   |
| A12         | 0           | 1              | 1            | 2   |
| A13         | 0           | 0              | 0            | 0   |
| A14         | 1           | 0              | 1            | 2   |
| A15         | 0           | 1              | 1            | 2   |
| A16         | 1           | 1              | 2            | 4   |
| A17         | 3           | 1              | 4            | 8   |
| A18         | 0           | 0              | 0            | 0   |
| A19         | 3           | 1              | 2            | 6   |
| A20         | 1           | 1              | 0            | 2   |

Source: Own work

results occurs in the comparison of the MOORA-WPM and WPM-TOPSIS methods, amounting to 6 points. The highest differences, calculated as the sum of the Euclidean distances between the results of the analyzed methods, occur in the evaluation of alternatives: (A10) Credit Agricole Bank Polska SA 12 points and (A3) Bank Handlowy w Warszawie SA 10 points.

*Calculation results and rankings for the case of objective weights*

Table 6 presents the preference values calculated using the MOORA and WPM methods and the corresponding rankings for calculations with objective weights.

Referring to the rankings presented in Table 6, it can be concluded that for the three MCDA methods considered, in ten cases the alternatives occupied the same place, i.e.: (A5) Bank Ochrony Środowiska SA 14th place, (A7) Bank Polska Kasa Opieki SA 1st place, (A15) Revolut Bank UAB 2nd place, (A12) mBank SA 3rd place, (A8) Bank Polskiej Spółdzielczości SA 4th place, (A11) ING Bank Śląski SA 5th place, (A18) TOYOTA Bank Polska SA 6th place, (A13) PKO Bank Polski SA 7th place, (A4) Bank MILLENNIUM

TABLE VV.

PREFERENCE FUNCTION VALUES AND RANKINGS FOR CALCULATIONS WITH OBJECTIVE WEIGHTS

| Alternative | Preference values |          |          | Rankings |     |        | Average |
|-------------|-------------------|----------|----------|----------|-----|--------|---------|
|             | MOORA             | WPM      | TOPSIS   | MOORA    | WPM | TOPSIS |         |
| A1          | 0.176787          | 0.489455 | 0.488157 | 11       | 10  | 11     | 10.67   |
| A2          | 0.188439          | 0.000000 | 0.513418 | 10       | 14  | 10     | 11.33   |
| A3          | 0.086647          | 0.000000 | 0.307223 | 19       | 14  | 19     | 17.33   |
| A4          | 0.227276          | 0.634240 | 0.624754 | 8        | 8   | 8      | 8.00    |
| A5          | 0.166983          | 0.000000 | 0.464777 | 14       | 14  | 14     | 14.00   |
| A6          | 0.108907          | 0.000000 | 0.343441 | 18       | 14  | 18     | 16.67   |
| A7          | 0.331756          | 0.923092 | 0.884185 | 1        | 1   | 1      | 1.00    |
| A8          | 0.279332          | 0.758332 | 0.745943 | 4        | 4   | 4      | 4.00    |
| A9          | 0.218034          | 0.594990 | 0.593476 | 9        | 9   | 9      | 9.00    |
| A10         | 0.084871          | 0.000000 | 0.254914 | 20       | 14  | 20     | 18.00   |
| A11         | 0.270883          | 0.751168 | 0.727081 | 5        | 5   | 5      | 5.00    |
| A12         | 0.288041          | 0.799916 | 0.773641 | 3        | 3   | 3      | 3.00    |
| A13         | 0.251614          | 0.696925 | 0.680129 | 7        | 7   | 7      | 7.00    |
| A14         | 0.152839          | 0.000000 | 0.438282 | 15       | 14  | 15     | 14.67   |
| A15         | 0.3071            | 0.827639 | 0.780703 | 2        | 2   | 2      | 2.00    |
| A16         | 0.174127          | 0.481076 | 0.480414 | 12       | 11  | 12     | 11.67   |
| A17         | 0.152512          | 0.351983 | 0.437208 | 16       | 13  | 16     | 15.00   |
| A18         | 0.255911          | 0.709539 | 0.699957 | 6        | 6   | 6      | 6.00    |
| A19         | 0.149981          | 0.000000 | 0.427993 | 17       | 14  | 17     | 16.00   |
| A20         | 0.170922          | 0.450468 | 0.476743 | 13       | 12  | 13     | 12.67   |

Source: Own work

SA 8th place, (A9) BNP Paribas SA 9th place. This is twice as many as when subjective rankings were used. Considering the average of the rankings, the top three places were taken by the following alternatives: (A7) Bank Polska Kasa Opieki SA, (A15) Revolut Bank UAB, (A12) mBank SA. The same was true when subjective ranks were used.

Table 7 presents the results of calculations for Pearson's correlation coefficients and Spearman's weighted correlation coefficient.

TABLE VIIV.

PEARSON'S CORRELATION COEFFICIENTS AND SPEARMAN'S CORRELATION COEFFICIENTS FOR OBJECTIVE WEIGHTS

| Pearson correlation                |          |          |          |
|------------------------------------|----------|----------|----------|
|                                    | MOORA    | WPM      | TOPSIS   |
| MOORA                              | -        | 0.896362 | 0.997327 |
| WPM                                | 0.896362 | -        | 0.898532 |
| TOPSIS                             | 0.997327 | 0.898532 | -        |
| Spearman's correlation coefficient |          |          |          |
|                                    | MOORA    | WPM      | TOPSIS   |
| MOORA                              | -        | 0.941354 | 1.000000 |
| WPM                                | 0.941354 | -        | 0.941354 |
| TOPSIS                             | 1.000000 | 0.941354 | -        |

Source: Own work

Referring to Table 7, which presents the correlation values of the similarity coefficients of the rankings:  $WS$  and  $r_w$ . The highest value of the asymmetric  $WS$  coefficient (0.99732686) was recorded for the MOORA-TOPSIS method pair, and the lowest correlation was observed for MOORA-WPM (0.89636208). The highest value of the asymmetric coefficient  $r_w$  (1.00) was recorded for the MOORA-TOPSIS pair, while the results of the other two combinations are the same. It can be said that the results of the ranking similarity study did not show any outliers.

Table 8 presents the Euclidean distances between pairs of places in the ranking of the analyzed methods in the case of entropy weights.

Referring to Table 8, which presents the Euclidean distances between places in the ranking, the largest difference in results occurs in the comparison of the MOORA-WPM and WPM-TOPSIS methods, and amounts to 6 points. The highest differences calculated as the sum of the Euclidean distances between the results of the analyzed methods occur in the evaluation of alternatives: (A10) Credit Agricole Bank Polska SA 12 points and (A3) Bank Handlowy w Warszawie SA 10 points. The indicated values are the same for subjective ranks.

The results of the analyses carried out in this and the previous article confirm that multi-criteria decision-making problems are highly complex. Therefore, it is difficult to clearly identify a universal method for determining the optimal solution. Initial efforts focused on determining whether it is possible to replace the results obtained using complex multi-criteria methods with solutions based on simpler methods. It can

TABLE VIII.  
EUCLIDEAN DISTANCE VALUES BETWEEN PAIRS OF PLACES IN  
THE MOORA, WPM, AND TOPSIS METHOD RANKINGS FOR  
ENTROPY WEIGHTS

| Alter-native | MOORA - WPM | MOORA - TOPSIS | WPM - TOPSIS | Sum |
|--------------|-------------|----------------|--------------|-----|
| A1           | 1           | 0              | 1            | 2   |
| A2           | 4           | 0              | 4            | 8   |
| A3           | 5           | 0              | 5            | 10  |
| A4           | 0           | 0              | 0            | 0   |
| A5           | 0           | 0              | 0            | 0   |
| A6           | 4           | 0              | 4            | 8   |
| A7           | 0           | 0              | 0            | 0   |
| A8           | 0           | 0              | 0            | 0   |
| A9           | 0           | 0              | 0            | 0   |
| A10          | 6           | 0              | 6            | 12  |
| A11          | 0           | 0              | 0            | 0   |
| A12          | 0           | 0              | 0            | 0   |
| A13          | 0           | 0              | 0            | 0   |
| A14          | 1           | 0              | 1            | 2   |
| A15          | 0           | 0              | 0            | 0   |
| A16          | 1           | 0              | 1            | 2   |
| A17          | 3           | 0              | 3            | 6   |
| A18          | 0           | 0              | 0            | 0   |
| A19          | 3           | 0              | 3            | 6   |
| A20          | 1           | 0              | 1            | 2   |

Source: Own work

be assumed that the rankings obtained using the three methods considered are similar to each other, especially when using objective weights.

## VI. SUMMARY

The aim of this study was to compare the impact of the results of the quality assessment of electronic banking services using selected multi-criteria methods and weighting techniques on the objectivity of the rankings obtained. The case study in this work was the problem of choosing the best banking service for a potential young individual customer.

Based on the analyses conducted, it was concluded that in the case of multi-criteria selection problems, certain conditions should be met. The first is to make the right choice of evaluation criteria (attributes) that will be relevant from the point of view of both the user and the essence of the problem being analyzed. The next is the appropriate selection of a method that will ensure that the collected data is properly processed. The method of comparing the results obtained is also important. It is also important to properly apply the weights of the criteria reflecting the preferences of the respondent.

The research shows that when subjective weights of criteria are used, the most comparable rankings are obtained using the MOORA and TOPSIS methods. The results obtained using

the WPN method differed from the other rankings, but the difference cannot be considered significant. When objective weights of importance were used to calculate the results, the rankings obtained using the MOORA and TOPSIS methods were the same. In the case of the ranking obtained using the WPN method, as in the case of subjective ranks, the results differed from the others, but the difference cannot be considered significant.

In reference to this conclusion, it is difficult to judge the optimality of the methods used or their objectivity. However, referring to previous and current analysis results, it seems appropriate to conclude that by selecting and combining several MCDA methods and conducting a comparative analysis, it is possible to determine a set of methods that give convergent and optimal results for a given group of alternatives.

The theoretical implications include confirmation of the possibility of using MOORA, WPN, and TOPSIS methods to evaluate alternatives in the study of electronic banking services. With their use, a number of considerations can be made in the following areas: determining the ranking of alternatives, comparing these rankings, analyzing the ranking, and evaluating the criteria for the analyzed type of software. The implications include guidelines for designers of electronic banking services on what features are important to young users of the type of internet software under analysis.

The considerations made are not without limitations, which were due to the research sample covering the academic environment of a single research center in Poland. Further research should involve the use of other multi-criteria methods (e.g., EXPROM, MAUT, VIKOR, etc.) in studies on the quality assessment of electronic banking services.

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