



Two-stage weighted PROMETHEE II with results' visualization

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Abstract

Multicriteria decision-making methods are widely spread and used to assist the decision-makers to resolve problems. Many of the methods are simple to deploy (WSA, TOPSIS), which is an advantage and because of the computer boom, there is no problem with calculations. However, more sophisticated methods are evolving. The modelling of preferences is improved (from linear in WSA to Gaussian in PROMETHEE), multilevel decision-making (such as AHP) is extended to modelling of dependencies between individual criteria (ANP). The presented method, two-stage weighted PROMETHEE, combines the advantages of generalized preferential functions in PROMETHEE methods, unambiguous arrangement (PROMETHEE II) and hierarchical approach (AHP). In addition, this paper demonstrates the application of the method to evaluate the order of 14 regions of the Czech Republic in regard to economic indices such as the unemployment rate, economic activity, average age, wages, free working places, income, consumption and investments. Data are taken from the Czech Statistical Office web and include the years 2012–2019. In the first stage, the position of each region is calculated; in the second stage, all years mentioned are considered, including the aspect of the weighted time series. Result visualization is made possible using the Visual PROMETHEE software.

Keywords Two-stage weighted PROMETHEE · Visual PROMETHEE · Czech regions evaluation · Economic indicators · Multi-criteria decision making

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1 Introduction

The issue of managerial decision-making has been connected for many years with the use of multicriteria decision-making methods (MCDM). These methods belong to the category of discrete multicriteria decision-making models wherein all the alternatives (a_1, a_2, \dots, a_m) and criteria (f_1, f_2, \dots, f_n) are known. The decision-maker sets the preferences by aspiration levels or requirements, criteria order, or criteria weights (Zopounidis and Pardalos 2010). Although there are many methods to discover the best alternative or the alternative order, new methods that connect the existing ones or use wider software options are emerging. As managers, companies, or the government no longer consider only one criterion for a decision, the application of the methods consequently expands. The decision problems may comprise various goals: to find the best alternative, to separate the alternatives into groups such as acceptable and unacceptable alternatives or good/bad; dominated and non-dominated, to find the clusters with similar or indifferent alternatives, or to create an order of alternatives (Ishizaka and Nemery 2013). The ranking may cover countries or regions (Ghasemi et al. 2021; Stankovic et al. 2021; Roszkowska and Filipowicz-Chomko 2020; Ulutaş and Karaköy 2019; Kuncova and Seknickova 2018; Kramulova and Jablonsky 2016; Latuszynska 2014; Kuncova and Doucek 2011; Dincer 2011), universities (Wu et al. 2012), institutions as banks, start-up or public benefit organizations (Beheshtinia and Omid 2017; Górecka and Chojnacka 2017; Nikoloudis et al. 2017), renewable energy resources, energy pathways or energy technologies (Seknickova and Jablonsky 2020; Lee and Chang 2018; Schröder et al. 2019; Regös 2013), materials or machines (Karande et al. 2016; Chatterjee and Chakraborty 2012), product (Turcksin et al. 2011), websites (Shayganmehr and Montazer 2021), people (Alguliyev et al. 2019) and others.

If the goal of the decision problem is to rank alternatives, it is necessary to select a method for the solution that provides this type of result. Methods that have been used to obtain a complete arrangement of alternatives include, for example, WSA—Weighted Sum Approach, WSM—Weighted Sum Method (Lee and Chang 2018; Dincer 2011), WASPAS—Weighted Aggregated Sum Product Assessment (Karande et al. 2016), SWARA—Stepwise Weight Assessment Ratio Analysis (Ghasemi et al. 2021), VIKOR—ViseKriterijumska Optimizacija i kompromisno Resenje (Lee and Chang 2018; Wu et al. 2012), AHP—Analytic Hierarchy Process (Shayganmehr and Montazer 2021; Beheshtinia and Omid 2017; Kramulova and Jablonsky 2016; Wu et al. 2012), TOPSIS—Technique for Order of Preference by Similarity to Ideal Solution (Lee and Chang 2018; Latuszynska 2014; Kuncova and Doucek 2011), some modifications of the ELECTRE methods—ELimination Et Choix Traduisant la REalité, such as modified ELECTRE II (Lee and Chang 2018) or modified ELECTRE III (Kuncova and Seknickova 2013, 2018, 2020), or the PROMETHEE II method—Preference Ranking Organization METHod for Enrichment Evaluations (Ghasemi et al. 2021; Shayganmehr and Montazer 2021; Stankovic et al. 2021; Seknickova and Jablonsky 2020; Schröder et al. 2019; Nikoloudis et al. 2017; Regös 2013; Turcksin et al. 2011; Koutroumanidis et al. 2002).

Countries and regions often belong to the areas of application of multicriteria evaluation. Regions are often compared with each other and evaluated mainly from an economic or environmental perspective, equally from a social or demographic and

from an epidemiological one connected with COVID-19 restrictions. TOPSIS and WSA methods are used by Dincer (2011) to evaluate the economic activity of European Union member states and candidate countries. Latuszynska (2014) and Kuncova and Doucek (2011) used TOPSIS method for the EU countries comparison from the ICT development viewpoint. Kramulova and Jablonsky (2016) used AHP for the selected country comparison. Kuncova and Seknickova (2013, 2018) compared Czech regions concerning economic indicators with WSA, TOPSIS and modified ELECTRE III methods. Roszkowska and Filipowicz-Chomko (2020) used TOPSIS to measure sustainable development in the area of education in the former 28 EU members. All methods provide a complete ranking of alternatives and belong among the easy-to-use methods. WSA and AHP maximize the utility function, whereas, the TOPSIS minimizes the relative distance from the ideal alternative. AHP and ELECTRE start with a pairwise comparison. AHP structures the problem into several sub-problems viewed as easier to resolve. This approach is unique compared to other methods and at the same time it is suitable for many problems. Therefore, AHP is one of the most frequently used methods in varied areas: countries and regions ranking (Kuncova and Seknickova 2018; Kramulova and Jablonsky 2016), websites (Shayganmehr and Montazer 2021), university (Wu et al. 2012), bank ranking (Beheshtinia and Omidi 2017), alternative energy sources comparison (Seknickova and Jablonsky 2020) etc. ELECTRE methods include preference relations similar to PROMETHEE. In all instances, the decision-maker may influence the strength of the preference through a fixed thresholds as indifference, preference and veto thresholds. In PROMETHEE methods more possibilities with higher sensitivity modelling of the preferences for each criterion are used. Stankovic et al. (2021) used PROMETHEE to compare seaport regions in seven countries on the European side of the Mediterranean; Koutroumanidis et al. (2002) compared regions of Greece using multicriteria methods; Lopes et al. (2018) studied the competitiveness of the Portugal tourist destinations; Ghasemi et al. (2021) used the combination of SWARA and PROMETHEE methods to evaluate countries as a medical tourism destination; Sungur and Zaranci (2018) ranked Turkey's provinces based on innovativeness, entrepreneurship, and human capital; Mlynarovic (2018) presented MCDM approach to identify investment opportunities among government bonds of selected countries; Skuflic et al. (2013) analyzed six Southeast European countries and 27 European Union countries to assess the attractiveness of destination for foreign direct investment.

This paper proposes an extension of the PROMETHEE II method based on the hierarchical structure used for example in AHP. To date, other researchers identified similar principles: Arcidiacono et al. (2018) proposed an extension of the PROMETHEE by the incorporation Robust Ordinal Regression, Stochastic Multicriteria Acceptability Analysis (SMAA), bipolar Choquet integral and Multiple Criteria Hierarchy Process; Corrente et al. (2013) proposed an extension of ELECTRE and PROMETHEE to the case of the hierarchy of criteria. Turcksin et al. (2011) described the integrated AHP-PROMETHEE approach in an eight steps methodology.

This research is based on the weighted sum of the individual scenarios, in which each year is taken as an individual scenario with its weight that reflects the influence of the year on the overall assessment. This two-stage weighted PROMETHEE method is illustrated by the example of the Czech regional ranking during 2012–2019 based

on the eight economic criteria. The software VISUAL PROMETHEE visualizes the results of both stages and the sensitivity analysis applied on weights change.

Our motivation for the mentioned idea comes from the real usage of MCDM methods by companies or institutions. MCDM methods are used to evaluate alternatives described by qualitative and/or quantitative indicators. In some cases, however, the analysis is performed by analysts who are only marginally oriented in the issue. They are able to use methods with a priori information for analysis without any problems, especially if the weights of criteria and the method of transformation or normalization of criterion values to a utility or preferential function are precisely specified. However, if these weights or transformations are not unambiguous, e.g. in the case of qualitative values, or the proposed transformation is not suitable, e.g. the linear utility function of the WSA method is not appropriate for all cases, experts are invited to analyze their subjective evaluation.

The PROMETHEE methods, especially the PROMETHEE II method, can handle nonlinear preference functions well to have a complete arrangement of alternatives. In addition, the software implementation of the method is not complicated at all. For these reasons, it is often used to analyze economic subjects based on common economic indicators.

The quantitative evaluation of qualitative data problem solution was proposed by Saaty (1977) in AHP. In addition, the multi-level hierarchy offers the possibility to evaluate the alternatives according to the same criteria from several experts' points of view. At the next level, they evaluate the importance of individual criteria, and finally, the evaluation of individual experts and determination of their importance may be combined.

These facts suggest that a combination of the two methods may be a suitable tool for multi-criteria analysis. In the economic subjects' (alternatives) analysis, we increasingly encounter the problem of processing panel data, i.e. time series for several economic entities. An example is the development of economic indicators in individual regions over several consecutive years. One of the approaches used in this kind of comparison is an isolated evaluation of each year separately (Kuncova and Seknickova 2013, 2018). The disadvantage of this approach is the impossibility of evaluating the multi-year period as a whole and the failure to consider the influence of recent data. In such a case, a quality analysis of regions according to individual years using the PROMETHEE II method is easily performed. Using a similar procedure as in AHP, we can then aggregate information over a time period into one characteristic. In addition, different importance of individual years is added to the overall assessment.

2 Methodology and data

For the comparison of regions (Fig. 1), several techniques and methods are used such as statistical methods, econometric models, data envelopment analysis (DEA) models, or multicriteria decision-making (MCDM) models (Kuncova and Seknickova 2013). Method selection is connected with the comparative goal, the number of alternatives, or the number of criteria. If the goal is to compare the development of regions over several years, DEA models, time series, and econometric models or statistical analyses



Fig. 1 NUT3 regions in the Czech Republic (Source: EU2009.cz 2019)

are usually used. The authors proceed differently and use the principles of the AHP and PROMETHEE II methods. As Macharis et al. (2004) recommends, it is useful to connect these two methods or integrate a number of useful AHP features regarding the design of the decision-making hierarchy: ordering of goals, sub-goals, dimensions, criteria, projects, etc. and the determination of weights into PROMETHEE. The idea of the hierarchical structure in AHP is also applied. The proposed methodology uses three levels in the hierarchy: years, criteria and regions (Fig. 2). The two stages use the PROMETHEE II method for the analysis of the position of the Czech regions from the point of view of individual years from 2012 till 2019 in the first phase. From the point of view of the entire period in the second phase, the results are based on the weighted sum of the individual year evaluation with the weight reflective of the influence of the year in the overall assessment. The method may also assess regional risk when the criteria represents daily gains, current numbers of infected persons, numbers of hospitalized and of hospitalized in severe condition. In summary, using this method and procedure is wide. Instead of individual years, indicators in individual waves of the pandemic may be used.

2.1 AHP principles

The Analytic Hierarchy Process (AHP) is a methodology to solve MCDM problems and was invented by Saaty in 1977 as a method of measurement with ratio scales (Saaty 1977). It deploys a tree structure (Fig. 2) to simplify complex decision-making. The hierarchy may contain several levels with a minimum of three: the evaluation goal, criteria and alternatives. A four-level AHP (Fig. 2) may consist of the following levels:

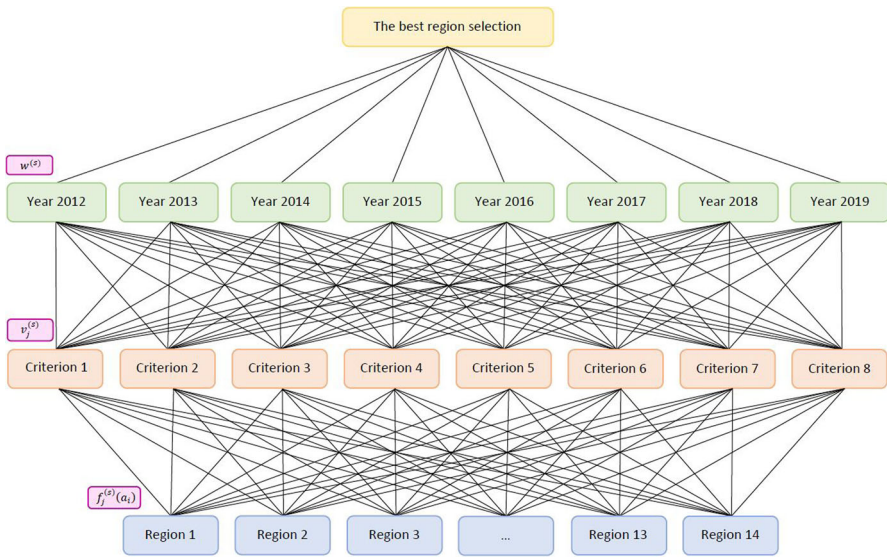


Fig. 2 Hierarchical structure of the model (Source: authors)

- *Evaluation goal*: analysis of alternative, e. g. region, and the selection of the best one or ranking,
- *Criteria groups* $G_s, s = 1, \dots, S$: in general, varied scenarios with generally different weights corresponding to this level, provided for example by varied decision-makers, conditions or groups of criteria; in this study these groups are presented by individual years,
- *Criteria* $f_j, j = 1, \dots, n$ and
- *Alternatives* $a_i, i = 1, \dots, m$.

Seknickova and Jablonsky (2020) state that the main principle of the AHP is based on pairwise comparisons of the elements at a particular hierarchy level with respect to an element of the previous level. In this way, the importance of the elements at the next level of the hierarchy with respect to weights is derived. This principle is applied to each level of the hierarchy tree. Pairwise comparison of all alternatives with respect to all sub-criteria allows deriving particular preference indices of the alternatives. Finally, their aggregation derives global preferences of all alternatives as well as their ranking.

In each stage of the application of the AHP model, the decision-maker expresses their preferences on a scale from 1 to 9 proposed by Saaty (1980) as the best scale to represent weight ratios. Number 1 signifies that the i -th and the j -th element are equally important and 9 that the i -th element is absolutely more important than the j -th one. This creates one or several pairwise comparison matrices. Let us denote the pairwise comparison matrix $\mathbf{M} = \{m_{ij} | m_{ji} = \frac{1}{m_{ij}}, m_{ij} > 0, i, j = 1, \dots, k\}$, where k is the number of elements in the particular level of the hierarchy. Saaty (1990) suggests deriving the local priorities $w_i, i = 1, \dots, k$, as the eigenvector that belongs to the largest eigenvalue of matrix \mathbf{M} . Due to the computational difficulties, several approximation methods to derive priorities are recommended. Psychologist using

pairwise matrices before Saaty used the mean of the row, but later other researchers such as Saaty or Johnson tried to invent more sophisticated procedures (Ishizaka and Labib 2011). In 1985 Crawford and Williams (1985) adopted another approach using geometric mean. As it can be easily calculated by hand, it has been supported by a large segment of the AHP community (Ishizaka and Labib 2011). However, some researchers criticized the technique because of the rank reversal problem (Olson et al. 1993). Another approximation using the logarithmic scale replacing the 1–9 scale was suggested. It is used, for example, in the REMBRANDT system, Ratio Estimation in Magnitudes or deci-Bells to Rate Alternatives which are Non-Dominated, based on the AHP principles and suitable for the group multicriteria decision-making problems (Olson et al. 1993).

In a practical application, in the first step for each scenario G_s and each criterion j we perform a pairwise comparison of alternatives. As described above, for each alternative $a_i, i = 1, \dots, m$, we obtain local priority $p_i^{(s,j)} = p_{ij}^{(s)}$. At the second level, we perform a pairwise comparison of criteria for each scenario G_s and for each criterion $f_j, j = 1, \dots, n$ the weight $v_j^{(s)}$ is obtained. For each scenario G_s we can choose the winning alternative a_i according to the maximum value of

$$u_i^{(s)} = \sum_{j=1}^n v_j^{(s)} \cdot p_{ij}^{(s)}, \quad i = 1, \dots, m, s = 1, \dots, S. \quad (1)$$

At the third level of the hierarchy tree we can apply pairwise comparison to scenarios (groups of criteria). For each group of criteria $G_s, s = 1, \dots, S$ we obtain weight $w^{(s)}$. At the last level we can evaluate each alternative a_i with respect to all scenarios (groups of criteria) via the formula (2):

$$e_i = \sum_{s=1}^S u_i^{(s)} \cdot w^{(s)}, \quad i = 1, \dots, m. \quad (2)$$

The best alternative has the highest value of evaluation e_i and the alternatives are ranked according to a decreasing value of e_i .

2.2 PROMETHEE methods

The name PROMETHEE stands for “Preference Ranking Organization METHOD for Enrichment Evaluations”. It is an ensemble of methods that use preference relations or the outranking approach (Ishizaka and Nemery 2013). The PROMETHEE I, partial ranking, and PROMETHEE II, complete ranking, were developed by J. P. Brans in 1982. The main principles were described by Brans et al. (1984) and Brans and Vincke (1985) and used by these researchers to rank projects (Brans et al. 1986). Over the next two decades, J. P. Brans and B. Mareschal developed PROMETHEE III with ranking based on intervals, PROMETHEE IV, continuous case, PROMETHEE V with MCDA including segmentation constraints, and PROMETHEE VI, a representation of the human brain (Brans and Mareschal 2005).

With other MCDM methods, inputs as a set of alternatives (a_1, a_2, \dots, a_m) , a set of criteria (f_1, f_2, \dots, f_n) and the criteria weights (v_1, v_2, \dots, v_n) must be defined. The next steps depend of the method type—here PROMETHEE I and II are described.

PROMETHEE I and II methods comprise three main steps:

- (a) The computation of preference degrees for every ordered pair of alternatives on each criterion.
- (b) The computation of unicriterion flows.
- (c) The computation of global flows.

Based on the matrix \mathbf{F} containing the evaluation of each alternative according to each criterion, the difference between the pair of alternatives d_j is obtained:

$$d_j(a_i, a_k) = f_j(a_i) - f_j(a_k); i, k \in \{1, \dots, m\}, \quad j = 1, \dots, n. \quad (3)$$

A preference degree is a score between 0 and 1 that expresses how an alternative is preferred over another alternative. The value of the preference function P_j is calculated according to the function type specified by the decision-maker. Six types of preference functions exist (Alinezhad and Khalili 2019; Ishizaka and Nemery 2013):

- (a) Usual criterion: if the difference $d_j(a_i, a_k) > 0$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = 1$, otherwise 0.
- (b) Quasi-criterion: the threshold q must be defined. If the difference $d_j(a_i, a_k) > q$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = 1$, otherwise 0.
- (c) V-shape criterion—the threshold p must be defined. If the difference $d_j(a_i, a_k) > p$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = 1$, otherwise $P_j(a_i, a_k) = d_j/p$.
- (d) Level criterion: the thresholds q and p must be defined, $q < p$. If the difference $d_j(a_i, a_k) > p$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = 1$. If the difference $d_j(a_i, a_k) > q$ and $d_j(a_i, a_k) \leq p$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = 0.5$, otherwise $P_j(a_i, a_k) = 0$.
- (e) Linear criterion: the thresholds q and p must be defined, $q < p$. If the difference $d_j(a_i, a_k) > p$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = 1$. If the difference $d_j(a_i, a_k) > q$ and $d_j(a_i, a_k) \leq p$, alternative a_i is preferred over a_k with preference $P_j(a_i, a_k) = (d_j(a_i, a_k) - q)/(p - q)$, otherwise $P_j(a_i, a_k) = 0$.
- (f) Gaussian criterion: the preference is calculated via Gaussian curve (more details about this type of criterion and PROMETHEE methods are in (Alinezhad and Khalili 2019) or in (Ishizaka and Nemery 2013).

With respect to the criteria weights v_j the partial preference index matrix $\mathbf{\Pi}$ is calculated:

$$\pi(a_i, a_k) = \sum_{j=1}^n P_j(a_i, a_k) \cdot v_j, i, k \in \{1, \dots, m\}. \quad (4)$$

Finally, for each alternative $a_i, i = 1, \dots, m$, the leaving and entering flows are calculated. The leaving (positive) flow $\Phi_i^+ = \Phi^+(a_i)$ is calculated as the average of

rows of the preference index matrix:

$$\Phi^+(a_i) = \frac{1}{m-1} \sum_{k=1}^m \pi(a_i, a_k). \quad (5)$$

Similarly, the entering (negative) flow $\Phi_i^- = \Phi^-(a_i)$ is calculated as the average of columns of the preference index matrix:

$$\Phi^-(a_i) = \frac{1}{m-1} \sum_{k=1}^m \pi(a_k, a_i). \quad (6)$$

PROMETHEE II calculates for each alternative a_1, a_2, \dots, a_n the net flow

$$\Phi_i = \Phi(a_i) = \Phi^+(a_i) - \Phi^-(a_i) \quad (7)$$

as a difference of the leaving and entering flows for each alternative and then the full rankings are performed (the higher value of the net flow is better).

PROMETHEE I compares the positive and negative flows for each pair of alternatives—if the positive flow of alternative a_i is higher or equal than the positive flow of alternative a_k and if the negative flow of alternative a_i is lower or equal than the negative flow of alternative a_k , then a_i is preferred over a_k ; when both flows for both alternatives are equal, then the alternatives are indifferent. Otherwise, the alternatives are incomparable (Alinezhad and Khalili 2019; Ishizaka and Nemery 2013; Brans and Mareschal 2005).

2.3 Two-stage weighted PROMETHEE

The extension of the previous methods is based on the weighted sum of the individual scenarios, as is described in formula (2). In this paper, we assume each year as a scenario G_s with weight $w^{(s)}$ that reflects the influence of the year s in the overall assessment (see Fig. 2).

For practical analysis, we can combine the sequence of the PROMETHEE method with the hierarchical approach of the AHP method and use the so-called two-stage weighted PROMETHEE method. The first stage is based on the classical application of the PROMETHEE method at the lowest level of the hierarchy, i.e. for each scenario G_s we evaluate the alternatives according to the criteria and calculate net flows $\Phi_i^{(s)} = \Phi^{(s)}(a_i)$ according to formula (7).

In the second stage, an overall evaluation of alternatives a_i is calculated by the formula:

$$e_i = \sum_{s=1}^S \Phi_i^{(s)} \cdot w^{(s)}, \quad i = 1, \dots, m, \quad (8)$$

where S denotes the number of scenarios (years in our case), $\Phi_i^{(s)}$ is the net flow of alternative a_i in scenario G_s and $w^{(s)}$ is the weight of scenario G_s (we assume weights are normalized, i.e. $\sum_{s=1}^S w^{(s)} = 1$). Similarly, as in PROMETHEE II, the higher value of the evaluation is better and alternatives (regions in our case) can be ranked.

This approach can be also applied to the PROMETHEE I method. In such a case, the weighted leaving and entering flows are calculated analogously to the formula (8) and the alternatives are ranked by the above-mentioned rules. But note that the two-stage weighted PROMETHEE method does not solve situation with incomparable alternatives and incomparable alternatives may occur similarly as in classical PROMETHEE I comparison. Therefore, the two-stage weighted PROMETHEE I method may not provide a complete arrangement of alternatives.

In the special case that all groups of criteria G_s have the same weight $w^{(s)} = \frac{1}{S}$, the formula (8) holds as average net flow over all groups of criteria:

$$e_i = \sum_{s=1}^S \Phi_i^{(s)} \cdot w^{(s)} = \frac{1}{S} \sum_{s=1}^S \Phi_i^{(s)}, \quad i = 1, \dots, m. \quad (9)$$

2.4 Visualisation result and VISUAL PROMETHEE

Manually solving multicriteria decision tasks is time-consuming. Various optimization software may be used advantageously.

In the first stage of the two-stage weighted PROMETHEE application, the PROMETHEE II, or PROMETHEE I, method implemented in any software may be used for each scenario. For example, we can use SANNA, a simple MS Excel-based application for multicriteria evaluation of alternatives using several important MCDM methods, including PROMETHEE (Jablonsky 2014). The results are displayed in an MS Excel sheet and the user views not only the leaving (5), entering (6) and net (7) flows, but also ongoing calculations, including partial preference indices (4). However, the final arrangement of alternatives is not visualized. The user must analyse the results, which is not easy task in the case of larger analysis.

The user must apply the second stage if they do not have the appropriate software. This software is Visual PROMETHEE (Mareschal and De Smet 2009). The authors have developed an application that solves problems using various methods of the PROMETHEE class. In addition, the results are properly visualized both numerically and graphically.

For the data analysis, the software Visual PROMETHEE, version 1.4 is used and is available at <http://www.promethee-gaia.net/visual-promethee.html>. It has implemented PROMETHEE I and PROMETHEE II, and was applied to data of Sect. 2.5 for years 2012–2019. For a detailed description of working with Visual PROMETHEE software, the authors recommend the Visual PROMETHEE User Manual that includes tutorials published by Mareschal (2013).

2.5 Data

The Czech Republic, according to the Nomenclature of Territorial Units for Statistics (NUTS) codes is divided into 14 regions (NUTS 3, Fig. 1): Prague, Central Bohemian Region, South Bohemian Region, Plzen Region, Karlovy Vary Region, Usti nad Labem Region, Liberec Region, Hradec Kralove Region, Pardubice Region, Vysocina Region, South Moravian Region, Olomouc Region, Zlin Region and Moravian-Silesian Region (czso.cz 2021). Each region is, according to the Local Administrative Units (LAU), divided into districts (LAU1) and municipalities (LAU 2) and follows its own economy.

Our analysis uses regional data from 2012 to 2019 available from the Czech Statistical Office (czso.cz 2021). Economic comparison of the regions is made from various notions: according to partial indicators such as GDP or unemployment or according to several indicators or criteria. Within the inclusion of a wider range of indicators, the assessed areas, criteria, are divided into indicators of macroeconomic performance or enforcement, growth potential, or quality of life (Martincik 2008). In addition to the demonstration of the method mentioned above, the goal is to assess the development of macroeconomic performance and growth potential of regions. Therefore, four indicators represent each of these two parts. According to Martincik (2008) eight criteria are used: income per capita, consumption per capita, investments per capita (all these three in thousands of Czech crowns per capita), unemployment rate, economic activity (percentage of economically active persons), average wage, average age, and the number of free working places per capita. For all fourteen Czech regions during the period of eight years, the data for these 8 criteria (denoted $f_j^{(s)}(a_i)$) are available; the AHP structure is displayed in Fig. 2. Basic data characteristics and statistics are found in Table 1.

The best region must have maximal income, consumption, capital expenditures, ratio of economic activity, and average wage. Vice versa, it must have a minimal unemployment rate, average age, and the number of free workplaces per capita. For the analysis, we assume, as well as in Kuncova and Seknickova (2018) and Kuncova

Table 1 2012–2019 Basic statistics of the data file (source: authors calculation based on data retrieved from czso.cz)

| Criterion | Unit | Extrem | Min | Max | Average | St.dev |
|--------------------------------|--------------|--------|--------|--------|---------|--------|
| Income per capita | ths. CZK/cap | max | 173.16 | 259.80 | 193.25 | 21.54 |
| Consumption per capita | ths. CZK/cap | max | 23.80 | 35.23 | 27.42 | 2.71 |
| Investments per capita | ths. CZK/cap | max | 5.79 | 13.91 | 8.41 | 2.17 |
| Unemployment rate | % | min | 3.13 | 10.75 | 7.34 | 2.18 |
| Economic activity | % | max | 56.77 | 61.95 | 58.41 | 1.47 |
| Average wage | CZK | max | 21 663 | 35 356 | 24 432 | 3 207 |
| Average age | year | min | 40.40 | 41.91 | 41.31 | 0.42 |
| Free working places per capita | pcs/cap | min | 0.0013 | 0.0080 | 0.0031 | 0.0016 |

and Seknickova (2020), that each criterion has the same weight $v_j^{(s)} = \frac{1}{8} = 0.125$, $j = 1, \dots, 8$ (i.e. 12.5%) for each year s , but the results' analysis indicates the impact of different weights of the regional ranking.

For the PROMETHEE, selecting the type of preference function and setting the parameters is required. In this data analysis, we assume that each criterion has a V-shape preference function with a preference threshold corresponding to the standard deviation (consult St.dev. in Table 1).

The first approach for scenario weight settings respects the idea that the impact of recent and newer data on the overall evaluation is stronger and that the influence of older data decreases with each year. We assume a model of a simple arithmetic delay, in which it is expressed using a point-weighted weights. 2012 is evaluated by 1 point, 2013, 2 points, 2014, 3 points, ..., and 2019 is evaluated as 8 points. After normalization, each point reflects the weight $1/36 = 0.0278$, i.e. 2.78%, and so years 2012–2019 are weighted by vector $\mathbf{w} = (0.0278, 0.0555, 0.0833, 0.1111, 0.1389, 0.1667, 0.1944, 0.2222)$. In the second approach, we assume that each yearly result has the same weight $w^{(s)} = 1/8$ (vector $\mathbf{w} = (0.125, 0.125, 0.125, 0.125, 0.125, 0.125, 0.125, 0.125)$).

Note that we may use a more progressive weight vector with polynomial or exponential weights, but the application procedure remains the same. In this case study, the results do not change fundamentally.

3 Results

Similarly, as with previous research (Kuncova and Seknickova 2013, 2018, 2020) the analysis is aimed to rank the fourteen Czech regions concerning selected economic criteria of Sect. 2.5. This paper uses the same criteria as previous. The period is 2012–2019, but the rankings are created using a two-stage weighted PROMETHEE and Visual PROMETHEE software to visualize the results.

In the first stage, we obtain a ranking of regions for each year that was presented by scenario or group of criteria G_s , $s = 1, \dots, 8$. For the evaluation of the period 2012–2019 the weighted sum using formula (8) was applied. We place 14 alternatives, in Visual PROMETHEE called Actions, with the values of 8 criteria (Criteria) with equal weights into the application. If the criteria were of varied importance, it is possible to adjust the weight vector. Criteria may also be divided into Criteria Groups and/or Clusters for a better orientation based on common characteristics. The evaluation is then performed for each year that has been loaded as a new scenario (Scenario). In Group Decision Support System (GDSS) part of this software, we used Scenarios Comparison, and analysed data by both approaches mentioned above. According to the results in the second stage, we decided to use colours in Visual PROMETHEE to better view the differences since in Fig. 3 the less rated regions are too close to each other, and their names are not shown. However, the same colour coding is used in Table 3 and in Figs. 3 and 5. We suggested 6 action categories of regions (Table 3) and differentiated them in colours for better visibility of changes.

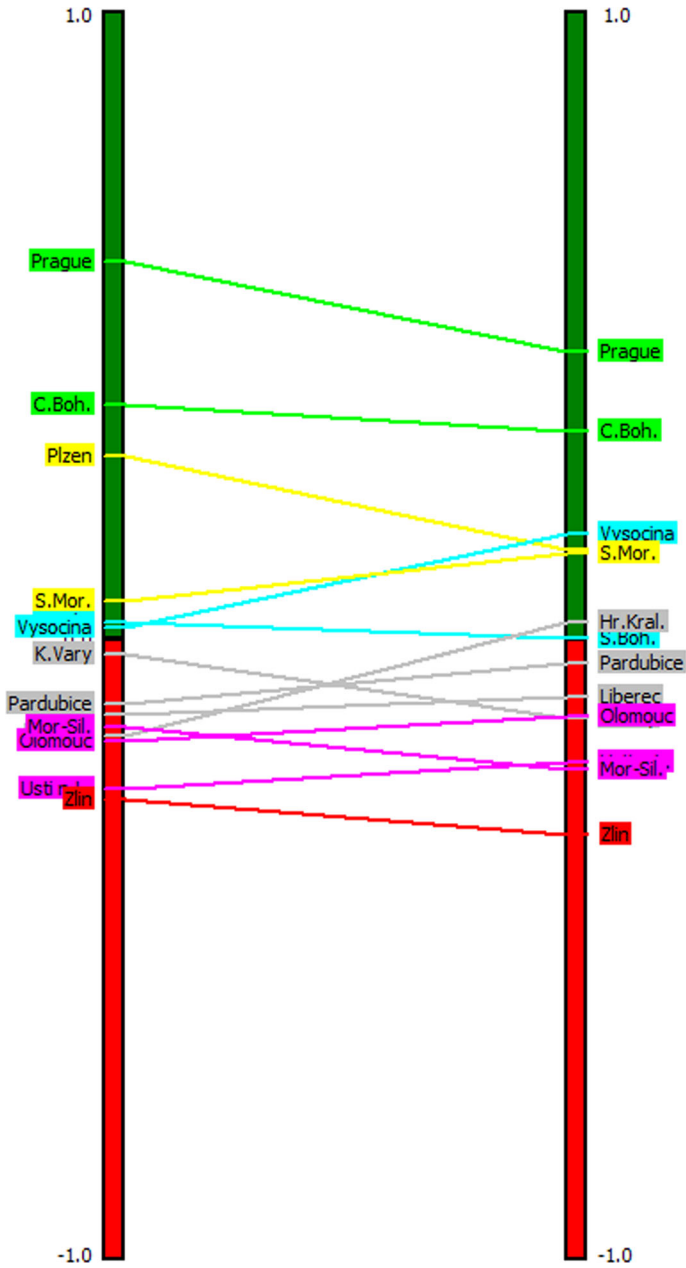


Fig. 3 Pairwise comparison of the PROMETHEE II results in 2012 and 2019 (Source: the authors, Visual PROMETHEE)

3.1 The first stage—results for 2012–2019 separately

In the first stage, PROMETHEE II method was used for each year separately, and the results are presented in Table 2 and visualized by the software Visual PROMETHEE (Figs. 3, 4). Table 2 summarizes the results for all years, net flows and rankings (blue numbers) in each year (avg. flows and weighted flow are described in chapter 3.2). Visual PROMETHEE allows the user to choose the colour separation of individual alternatives, which is useful for result display. The separation of the regions into the final six groups is done by a visual judgment based on the PROMETHEE II Network (Fig. 6), where clusters of individual regions are visible. These colours remain the same in all other analyses to make the changes in the graphs more noticeable.

Figure 3 displays the results of the first and the last year of the period. The left column graphically indicates the value of the net flow of regions in 2012 obtained by the PROMETHEE II method. The right column has the same values for 2019. Specific numerical values can be read in the appropriate columns of Table 2. We performed a similar analysis for any two or more years. All results are shown in Fig. 4.

The position of Prague is the highest in both years 2012 and 2019, but the decreasing trend is clear as the net flow decreased from 0.597 to 0.452. A similar but weaker decline from 0.366 to 0.324 was observed in the second region, Central Bohemian, which was in the same action category, green category, as the Prague region. They were in the same positions in 2019. The situation in the second category, yellow, is interesting, where the difference in 2012 (0.233) was significantly larger than in 2019 (0.006). The Plzen region was deteriorating rapidly from 0.282 to 0.132, while the South Moravian region slightly improved from 0.049 to 0.126. Thus, its assessment in 2019 is almost identical. The exact opposite situation occurred in the third, blue, action category where Vysocina and South Bohemian regions are similar in 2012 (0.004 and 0.015) but completely different in 2019 (0.158 and -0.011). The last, red, category shows the worst-rated Zlin region, which was rated as the worst in 2012. Since then, however, the rating is still declining (from -0.270 to -0.328) and remains in last place in 2019.

The aim of this article is not to find the causes and justification of the regional positions or changes, we do not focus on a more detailed analysis of the results. This analysis demonstrates the method and the possibility of the result visualization.

In the first stage of PROMETHEE ranking, it is preferable to use the PROMETHEE II method. For the two-stage weighted PROMETHEE, it is necessary to use the same type of PROMETHEE method for each year. The obtained net flows and the ranks for 2012–2019 are in Table 2 and are clearly displayed in Fig. 4. From the results it suggests that the favourable region in this analysis is Prague, the winner over all years. The second place, Central Bohemian, is also unequivocal. The other ranking is dependent by year. Hradec Kralove and Vysocina regions improved their positions from 2012 until 2019, but, for example, the Zlin region was the last in both years and Karlovy Vary worsened its position in 2019 compared to 2012 by 4 places. Note that the graphical display of these results by GDSS in the Visual PROMETHEE tool significantly simplifies the evaluation of regions and Visual PROMETHEE is a very useful tool for results analysis. Although, the names of regions are not always visible

Table 2 2012–2019-Flows and rankings according to PROMETHEE II (source: the authors)

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Avg | Weig |
|------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------------|----------------------|
| Prague | 0.597 (1) | 0.621 (1) | 0.696 (1) | 0.479 (1) | 0.681 (1) | 0.608 (1) | 0.603 (1) | 0.452 (1) | flow 0.592 (1) | flow 0.576 (1) |
| Central Bohemian | 0.366 (2) | 0.334 (2) | 0.301 (2) | 0.374 (2) | 0.284 (2) | 0.321 (2) | 0.261 (2) | 0.324 (2) | 0.321 (2) | 0.311 (2) |
| South Bohemian | 0.015 (5) | -0.037 (6) | 0.018 (6) | 0.014 (6) | 0.017 (6) | 0.064 (6) | 0.050 (6) | -0.011 (7) | 0.016 (6) | 0.021 (6) |
| Plzen | 0.282 (3) | 0.254 (3) | 0.222 (3) | 0.156 (4) | 0.152 (4) | 0.150 (3) | 0.073 (5) | 0.132 (4) | 0.178 (3) | 0.147 (3) |
| Karlovy Vary | -0.038 (7) | -0.107 (8) | -0.109 (8) | 0.007 (7) | -0.082 (9) | -0.075 (8) | -0.106 (9) | -0.140 (11) | -0.081 (7) | -0.091 (8) |
| Usti nad Labem | -0.253 (13) | -0.215 (13) | -0.275 (13) | -0.304 (14) | -0.203 (11) | -0.202 (12) | -0.244 (13) | -0.212 (12) | -0.239 (13) | -0.232 (13) |
| Liberec | -0.135 (9) | -0.106 (7) | -0.116 (9) | -0.099 (9) | -0.058 (7) | -0.142 (9) | -0.123 (10) | -0.106 (9) | -0.111 (9) | -0.109 (10) |

Table 2 (continued)

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Avg | Weig |
|-------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Hradec Kralove | -0.168 (11) | -0.195 (12) | -0.173 (10) | -0.157 (10) | -0.152 (10) | -0.037 (7) | -0.054 (7) | 0.016 (6) | -0.115 (10) | -0.082 (7) |
| Pardubice | -0.117 (8) | -0.130 (10) | -0.062 (7) | -0.012 (8) | -0.062 (8) | -0.163 (11) | -0.160 (11) | -0.050 (8) | -0.095 (8) | -0.095 (9) |
| Vysocina | 0.004 (6) | 0.040 (5) | 0.073 (5) | 0.034 (5) | 0.031 (5) | 0.066 (5) | 0.129 (3) | 0.158 (3) | 0.067 (5) | 0.087 (5) |
| South Moravian | 0.049 (4) | 0.128 (4) | 0.183 (4) | 0.199 (3) | 0.201 (3) | 0.119 (4) | 0.109 (4) | 0.126 (5) | 0.139 (4) | 0.143 (4) |
| Olomouc | -0.178 (12) | -0.285 (14) | -0.310 (14) | -0.232 (12) | -0.213 (12) | -0.161 (10) | -0.069 (8) | -0.136 (10) | -0.198 (11) | -0.173 (11) |
| Zlin | -0.270 (14) | -0.188 (11) | -0.229 (12) | -0.198 (11) | -0.321 (14) | -0.315 (14) | -0.287 (14) | -0.328 (14) | -0.267 (14) | -0.285 (14) |
| Moravian-Silesian | -0.155 (10) | -0.115 (9) | -0.218 (11) | -0.260 (13) | -0.271 (13) | -0.231 (13) | -0.183 (12) | -0.224 (13) | -0.207 (12) | -0.219 (12) |

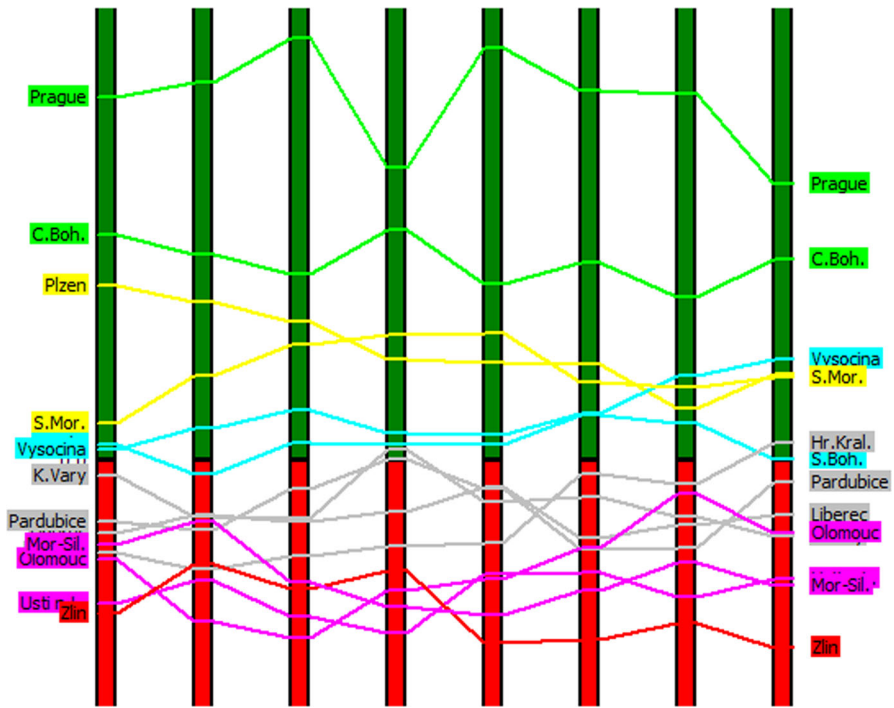


Fig. 4 PROMETHEE II results for all years (Source: the authors, Visual PROMETHEE)

on both sides of the graph (Fig. 4), the coloured lines corresponding with the regional group colour clearly indicate the location in the selected years. It is, therefore, relatively easy to determine the position with a name not indicated.

3.2 The second-stage—results for 2012–2019

In the second stage of the two-stage weighted PROMETHEE method, for an overall evaluation, we synthesize the results from the first stage according to formula (8). As we described above, in the first approach, the vector of weights used in formula (8) was $w = (0.0278, 0.0555, 0.0833, 0.1111, 0.1389, 0.1667, 0.1944, 0.2222)$ and by the Visual PROMETHEE, these weights of scenarios are displayed in Fig. 5. Numerical values of the weighted sum of flows and ranks are found in the last columns of Table 2. According to the resulting order, the regions are arranged in Table 3, from which the designation colour of regions is evident. In the second approach, the weight vector $w = (0.125, 0.125, 0.125, 0.125, 0.125, 0.125, 0.125, 0.125)$ is used in formula (8). The results are displayed in Table 2 in the column 'Avg. Flow'. Note that the regional ranking according to the non-weighted and weighted flows differs only at places 7–10, therefore, the weight change has little influence on results.

Visual PROMETHEE also displays the alternatives' position in a 2D graph (Fig. 6).

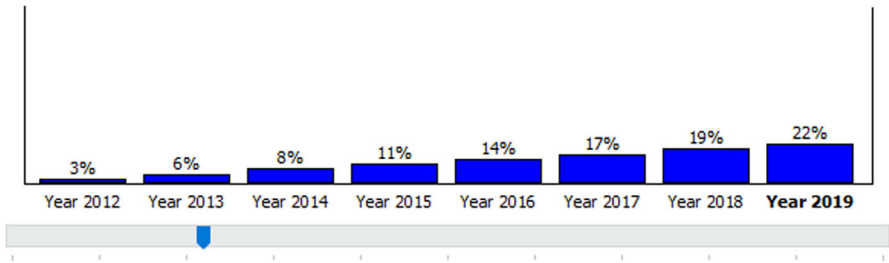


Fig. 5 Weights of scenarios (years) (Source: the authors; Visual PROMETHEE)

Table 3 Action categories and colours of regions based on the net flows (Source: the authors)

| Region | Prague | Central Bohemian | Plzen | South Moravian | Vysocina | South Bohemian | Hradec Kralove | Karlovy Vary | Pardubice | Liberec | Olomouc | Moravian-Silesian | Usti nad Labem | Zlin |
|----------|--------|------------------|-------|----------------|----------|----------------|----------------|--------------|-----------|---------|---------|-------------------|----------------|-------|
| Net flow | 0.57 | 0.31 | 0.15 | 0.14 | 0.09 | 0.02 | -0.08 | -0.09 | -0.09 | -0.11 | -0.17 | -0.22 | -0.23 | -0.28 |
| Category | 1 | | 2 | | 3 | | 4 | | | 5 | | | 6 | |
| Rank | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |

It is clear that the colour differentiation corresponds to the individual categories according to the proximity of the regions in the graph.

We can see that Prague is the clear leader and the second place is the Central Bohemian region for the entire period. Prague is the heart of Central Bohemia, and therefore the economy of Central Bohemian is closely linked to the Prague economy. The third, fourth, and fifth places are South Moravian, Plzen and Vysocina Region respectively. The centre of South Moravian Region is Brno, the second-largest city of the Czech Republic, and the centre of the Plzen Region is the fourth largest city. As the region furthest from Prague, Zlin ranks last due to poor values in almost all criteria. The differences between the best and the worst alternative, between the Prague and Zlin regions, are also evident from the visualization of the deviations of the individual normalized criteria from the average. While Prague has most of the above-average values (Fig. 7) and loses only in the number of free workplaces per capita, Zlin is unfortunate (Fig. 8).

3.3 Analysis of criteria weights

The evaluation of alternatives, in our case regions, clearly depends, among other things, on the setting of the criteria weights. The question remains as how to correctly determine the weight vector. The determination of weights is subjective and lacks a clear objective way. If we have no preferences, we set equal weights of all criteria. As stated in Sect. 2.5, also for our analysis, we first assume each criterion has the

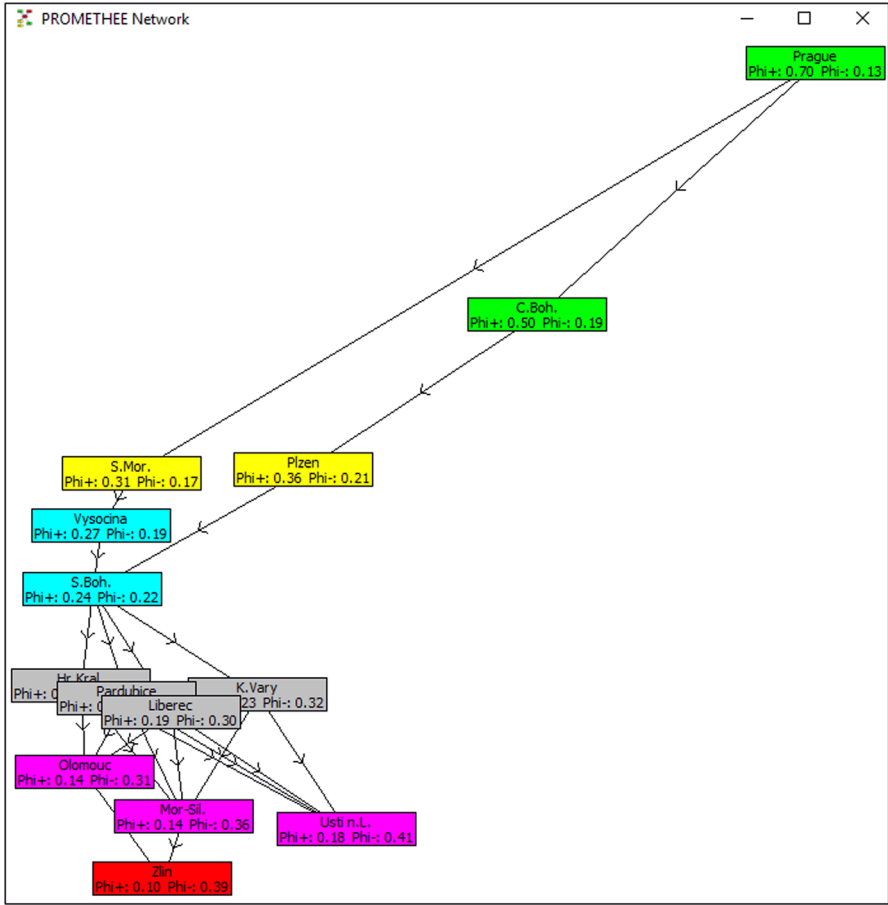


Fig. 6 PROMETHEE II network in Visual PROMETHEE (Source: the authors, Visual PROMETHEE)

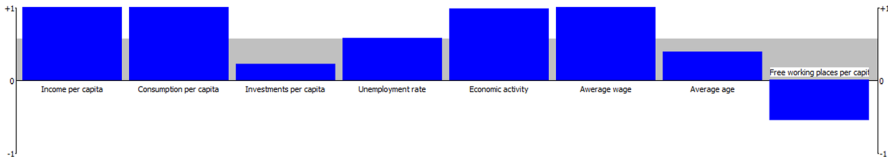


Fig. 7 Action profile of Prague, the Capital City (Source: the authors, Visual PROMETHEE)



Fig. 8 Action profile of Zlin (Source: the authors, Visual PROMETHEE)

Table 4 Stability intervals (Source: the authors)

| Criterion | Current value (%) | From (%) | To (%) | Decrease (%) | Increase (%) | Interval width (%) |
|--------------------------------|-------------------|----------|--------|--------------|--------------|--------------------|
| Income per capita | 12.5 | 10.54 | 14.39 | 1.96 | 1.89 | 3.85 |
| Consumption per capita | 12.5 | 11.85 | 14.64 | 0.65 | 2.14 | 2.79 |
| Investments per capita | 12.5 | 10.01 | 19.96 | 2.49 | 7.46 | 9.95 |
| Unemployment rate | 12.5 | 11.48 | 13.03 | 1.02 | 0.53 | 1.55 |
| Economic activity | 12.5 | 11.70 | 13.43 | 0.80 | 0.93 | 1.73 |
| Average wage | 12.5 | 10.37 | 14.15 | 2.13 | 1.65 | 3.78 |
| Average age | 12.5 | 9.00 | 13.24 | 3.50 | 0.80 | 4.24 |
| Free working places per capita | 12.5 | 11.88 | 12.95 | 0.62 | 0.45 | 1.07 |

same weight $v_j = 1/8 = 0.125$ (i.e. 12.5%) and the results are presented in previous sections.

It is clear from formula (4) et seq. that even a relatively small change in one component of the criteria weight vector \mathbf{v} may affect the resulting order of the regions. The stability interval determines how large this change may be to maintain the resulting order. Let us change the weight v_j of only one criterion, *ceteris paribus*. Table 4 indicates the size the changes are to maintain the resulting order listed in Table 3. The grey columns indicate the stability intervals.

We can see that modification of the weight of the criterion by half a percent does not cause a change in order, except for the increase in the number of free working places per capita. However, the larger the change, the more impact on the order. Visual PROMETHEE visualizes stability interval for each criterion, Fig. 9 illustrates the stability intervals for investments and free working places. We are able to analyse that to change the order, a much smaller change in the weight of the free working places is sufficient than, for example, the weight of the investments. Based on the graphs, we also deduce which changes will occur in the order in the case of changes out of stability intervals.

Let us illustrate the change in weight for the criterion Free working places per capita (v_8) with stability interval $v_8 \in (0.1188, 0.1295)$, as indicated in Table 4. If all criteria have the same weight (i.e. $v_8 = 12.5\%$), the final ranking is displayed in Table 3 and Fig. 10. Ranked as 1, the Prague region, second is Central Bohemian, third place Plzen, South Moravian as fourth with the last place occupied by the Zlin region.

In the case of change in stability interval $v_8 = 12.9\%$ the final ranking is identical. For $v_8 = 13.0\%$ Plzen is the 4th and the third is South Moravian, the rank changes, however, Prague remains as the best with Zlin as the last.

A larger change out of the stability interval causes larger changes in the order and for $v_8 = 29.0\%$ Zlin is no longer the last, replaced by the Pardubice region. In addition,

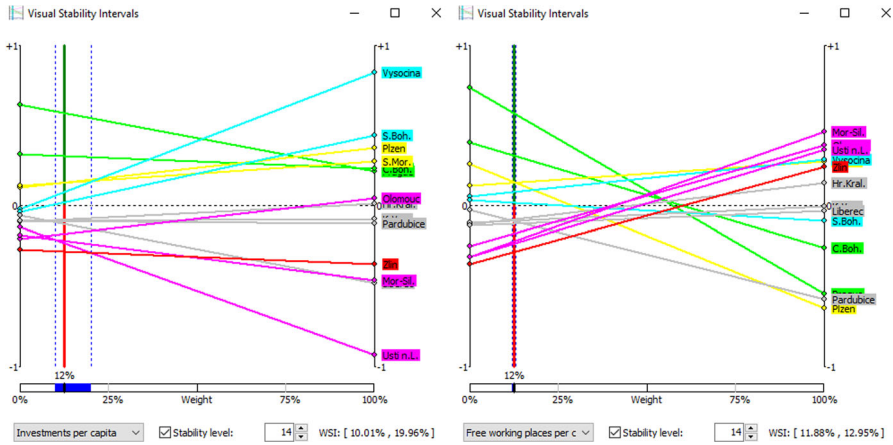


Fig. 9 Stability intervals for Investments per capita and Free working places per capita (Source: the authors, Visual PROMETHEE)

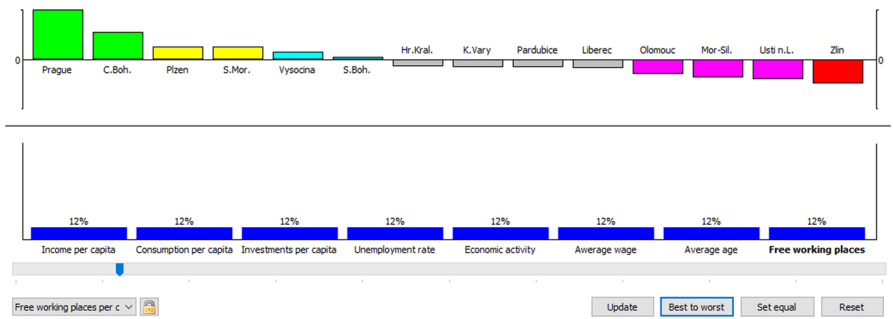


Fig. 10 Two-stage weighted PROMETHEE II final ranking for identical criterion weights (Source: the authors, Visual PROMETHEE)

Prague loses its first place for the $v_8 = 43.0\%$ with the South Moravian Region as replacement. Plzen experiences a deep drop, a greater sensitivity to weight change is evident. The changes in the final ranking are displayed by Visual PROMETHEE, in Fig. 11.

4 Conclusions

This research aimed to present the two-stage weighted PROMETHEE method which combines the advantages of the generalized preference functions in PROMETHEE methods, unambiguous arrangement, PROMETHEE II, and hierarchical approach from AHP. The principles and steps are demonstrated by the example of the evaluation of the Czech regions in diverse areas as economic indices: the unemployment

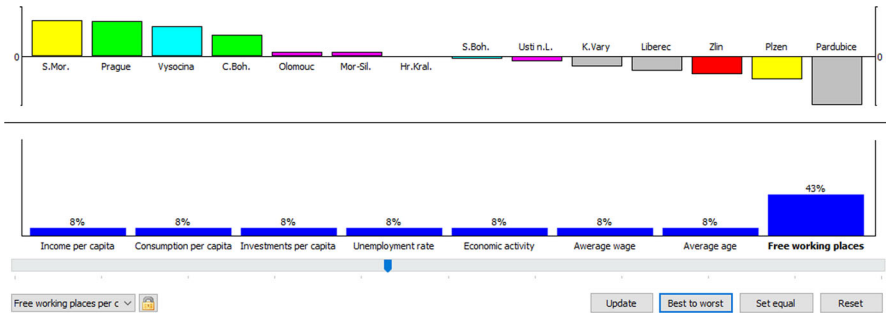


Fig. 11 Two-stage weighted PROMETHEE II final ranking after change of weight v_8 (Source: the authors, Visual PROMETHEE)

rate, economic activity, average age, wages, free workplaces, income, consumption and investments.

Using the two-stage weighted PROMETHEE method, we analysed 14 Czech regions from 2012 to 2019 in 8 criteria perspectives. For the calculations and result visualisations, the software Visual PROMETHEE is deployed. The best region with respect to the analysed criteria is Prague, and the second place being the Central Bohemian region. The last place is designated for the Zlin region. Based on this analysis (Table 2) we may also conclude the same results as in Kuncova and Seknickova (2018, 2020), that South Moravian Region with negative net flows in 2012 and 2013 and positive later, indicates an amelioration. The same conclusions are drawn for the South Bohemian and Vysocina regions with positive net flows from 2017. For all years, the regional rank remains consistent. The results between non-weighted and weighted PROMETHEE methods are negligible.

The Visual PROMETHEE software is a valuable tool for two-stage weighted PROMETHEE analysis. It is intuitive and provides not only a calculation based on PROMETHEE methods but also the result visualisation and sensitivity analysis visualisation. Its great advantage is the possibility to use scenarios and modify the evaluation of alternatives according to the yearly individual criteria and the possibility to change these weights. Equally, another advantage is the possibility to divide the alternatives into colour-separated groups, categories, which permit the graphical display. Especially important to compare a multitude of alternatives. This renders a clearer representation of their location.

The notion to link the principles of PROMETHEE and AHP has been previously explored by other researchers and we compare our recommendations with those of Turcksin et al. (2011). They described the integrated AHP-PROMETHEE approach with an eight step methodology: Step 1, the alternatives are selected; step 2, key objectives of the decision-makers were identified and translated into criteria on which the alternatives are evaluated; step 3, the hierarchical structure is created; step 4 the criteria weights are calculated using AHP method; step 5 covers evaluation table construction; step 6, alternatives are evaluated and ranked by means of the partial ranking with PROMETHEE I and complete ranking with PROMETHEE II and the GAIA plane with D-SIGHT software to perform sensitivity analyses and to confirm

the robustness of the results, step 7, and finally recommendations towards the best compromise are formulated, step 8.

Our two-stage weighted PROMETHEE method uses the same first 3 steps described by Turcksin et al. (2011), but step 4 is different as our criteria weights are equal but it is possible to use AHP instead for the weights' calculation. Steps 5 and 6 we use in our first stage to evaluate alternatives, regions, according to the selected criteria. The difference is in the inclusion of the time series, that is the calculations are repeated for several years. Steps 7 and 8 are covered in our method, but we recommend to use Visual PROMETHEE software for the sensitivity analysis and for the results comparison to formulate the final recommendation. The main difference is in our second stage where the weighted sum of the previous results, net flows from PROMETHEE method for each year and each alternative/region, is calculated. The results of each year may have the same weights or, as we present in this paper, a simple arithmetic delay is incorporated in the sense that the previous year has a smaller weight than the following. This approach demonstrates that it is possible to perform time-series analysis using MCDM method combination. Therefore, we can refute the claim of Martincik (2008) that the MCDM methods do not make it possible to capture the dynamics of the development of individual alternatives over time.

The presented method is suitable for similar analysis of the regions and countries, but also products, services or companies, if the alternatives ranking and time-weighted aspects are important. In addition, the inclusion of a time factor permits the method to be used for panel data.

5 Data availability and material

Open source (<http://czso.cz/>).

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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