InterCriteria Analysis as an intelligent tool for decision making: Investigation of Polish University Rankings

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Abstract: In the current investigation InterCriteria analysis as a decision making tool is applied to the rankings of Polish Universities aiming at determination of interdependences and influence of the indicators used for their rankings. Public University Ranking, Private University Ranking and Public Vocational Colleges Ranking in Poland for 2023 are in the focus of current investigation, as retrieved from the *Perspektywy University Ranking* website.
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1   Introduction

In the current research the rankings of Polish public and private universities, as well as of public vocational colleges are investigated, based on the Perspektywy University Rankings for 2023, [13]. In a previous authors' work, the university rankings in Poland for 2012–2014 are investigated, [11]. Thus, this is a continuation of the research activities to achieve more sustainable results.

Perspektywy Ranking consists of rankings of Polish public and private universities and public vocational colleges, as well as presents rankings by university types, by subject and by criteria group. Perspektywy University Ranking (Poland) is „IREG Approved" awarded by the IREG Observatory on Academic Ranking and Excellence, [13]. A honorary partner of University Ranking 2023 is the Conference of Rectors of Academic Schools in Poland, which was formed by Polish institutions of higher education having the right to award the doctor's degree (or equivalent) in at least one scientific discipline. Content Partners of University Ranking 2023 are National Information Processing Institute, National Research Institute, Elsevier, The Patent Office of the Republic of Poland, and Erasmus+.

The Perspektywy University Ranking 2023 [13] comprises the rankings of:

1) Academic Schools, called here Public Universities: includes Polish universities that have a right to confer doctoral degree and have minimum 200 enrolled full-time students. The university must have at least two years of graduates that took part in the survey to be included in the Ranking, [12].

2) Private Universities: presents non-public higher education institutions that have the right to master degree and have a minimum two years of graduates. The universities must have 200 full-time and part-time students. The obligatory entry condition is that university conducts full-time studies, [12].

3) Public Academies of Applied Sciences and State Higher Vocational Schools, called here Public Vocational Colleges: includes all universities from the PUZ – state vocational schools group, having at least two years of graduates and minimum 200 enrolled full-time and part-time students, [12].

The ranking system includes information by different number of indicators, which measure different aspects of university activities, aggregated also in criteria groups such as prestige, innovation, academic potential, academic effectiveness, graduates on the labor market, publications, education conditions and internationalization. The methodology of the rankings, as well as the indicators used, are described in [12]. The final assessment is provided in the range from 0 to 100, and 100 points mean the best result within a given indicator [13]. For the purposes of the current investigation, InterCriteria Analysis [5], developed as a decision making tool, is applied to the rankings of Polish universities aiming at determination of interdependences and influence of the indicators used for rankings.

2   Brief remarks on InterCriteria Analysis

InterCriteria Analysis (ICA) is a decision making approach providing capabilities to compare different objects or criteria. Bulgarian researchers Krassimir Atanassov, Deyan Mavrov and Vassia Atanassova have introduced ICA as a new approach for multicriteria decision making about ten years ago, [5]. It is based on the theories of intuitionistic fuzzy sets [2, 6] and index matrices, [3, 14]. ICA algorithm provides the resulting information in the form of intuitionistic fuzzy pairs (IFPs) $\langle \mu, \nu \rangle$, where $\mu, \nu \in [0, 1]$ and $\mu + \nu \leq 1$. The components μ and ν are interpreted as a degree of membership and a degree of non-membership. In the case of $\mu + \nu < 1$, a number $\pi = 1 - \mu - \nu$ appears as a degree of uncertainty. Index matrices (IMs) are the structure used for input and output data in the ICA application. The main algorithm of ICA functioning is described in [5]. Thereafter, several variations of ICA have been introduced: ICA with interval-valued intuitionistic fuzzy evaluations [4], ICA by triples, ICA on intuitionistic fuzzy data, three-dimensional ICA [7], etc. There are numerous applications of ICA in the fields of education, medicine, ecology, industry, artificial intelligence, etc., [7, 10]. The field of education, and especially the university ranking systems, is one of the most investigated by ICA topics. ICA is already applied to university ranking systems of different countries, among which Bulgaria, Poland, Turkey, Slovakia, India, United Kingdom, and Australia, [7, 10, 11].

3   InterCriteria Analysis applied to Poland's Public University Ranking

In the current investigation, Poland's Public University Ranking 2023 is analyzed based on the data retrieved from the Perspektywy University Rankings website, [13]. Public University Ranking 2023 contains 104 universities assessed against 30 indicators, classified as representatives of reputation, employability, research potential, innovation, research effectiveness, teaching and internationalization. A sample of the first 30 universities is used for current investigation. The aim of the ICA application to the Public University Ranking 2023 [13] is to investigate the interdependences and the influence of the indicators used in the ranking system. ICA is performed by ICrAData [9], as well as by the new implementation for data points interpretation, [8]. The pairs counting and visualizations are made using an additional software for visualizations, [8]. The results of ICA application are presented in Table 1.

The types of correlations in the left column in Table 1 are defined in [1] and the numbers in brackets are related to the degree of agreement. According to the applied scale, there are 1 pair of indicators in strong positive consonance, 1 pair in positive consonance, 14 pairs in weak positive consonance, 60 (30 + 30) pairs in weak dissonance, 174 (93 + 81) pairs in dissonance, 173 pairs in strong dissonance, and 6 pairs in weak negative consonance.

The most noteworthy dependencies are for the pairs of indicators, showing strong positive consonance, positive consonance and weak positive consonance. The strongest relationship (strong positive consonance) is found between the indicators "Rights to confer PhD with habilitation degree – Rights to confer PhD degrees: $\langle 0.96; 0.04 \rangle$". These two indicators can be merged in one common indicator. The second number in the $\langle . \rangle$ brackets represents the degree of

Table 1. Results of ICA applied to investigate the indicators
used in Public University Ranking

Type of correlations	Pairs of indicators (number)
strong positive consonance [0.95; 1,00]	1
positive consonance [0.85; 0.95)	1
weak positive consonance [0.75; 0.85)	14
weak dissonance [0.67; 0.75)	30
dissonance [0.57; 0.67)	93
strong dissonance [0.43; 0.57)	173
dissonance [0.33; 0.43)	81
weak dissonance [0.25; 0.33)	30
weak negative consonance [0.15;0.25)	6
negative consonance [0.05;0.15)	0
strong negative consonance [0.00;0.05]	0

disagreement. In the case when the sum of both numbers in the brackets is less than 1, the difference to 1 is the degree of uncertainties. There is a pair of indicators with strong relationship (positive consonance): "Citations – Field-weighted citation impact[1] : ⟨0.86; 0.13⟩". It is recommended those two indicators to be also combined.

The most noteworthy dependencies are for the pairs of indicators, showing strong positive consonance, positive consonance and weak positive consonance. The strongest relationship (strong positive consonance) is found between the indicators "Rights to confer PhD with habilitation degree – Rights to confer PhD degrees: ⟨0.96; 0.04⟩". These two indicators can be merged in one common indicator. The second number in the ⟨ . ⟩ brackets represents the degree of disagreement. In the case when the sum of both numbers in the brackets is less than 1, the difference to 1 is the degree of uncertainties. There is a pair of indicators with strong relationship (positive consonance): "Citations – Field-weighted citation impact: ⟨0.86; 0.13⟩". It is recommended those two indicators to be also combined.

There are a lot of pairs of indicators in weak dependencies. In a weak positive consonance are the following 14 pairs: "Academic reputation (teaching) – Accreditations: ⟨0.81; 0.17⟩", "International students – Students studying in foreign language: ⟨0.81; 0.19⟩", "Rights to confer PhD degrees – SDG[2] : ⟨0.80; 0.13⟩", "Rights to confer PhD with habilitation degree – SDG: ⟨0.79; 0.14⟩", "ICI[3] – International teaching staff: ⟨0.79; 0.21⟩", "TOP 10 – International teaching staff: ⟨0.78; 0.21⟩", "SDG – Accreditations: ⟨0.77; 0.21⟩", "Academic reputation (teaching) – TOP 10: ⟨0.76; 0.23⟩", "Rights to confer PhD with habilitation degree – TOP 10: ⟨0.76; 0.17⟩", "Faculty development – Academic titles awarded: ⟨0.76; 0.24⟩", "Academic reputation (teaching) –

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[1] Indicator "Field-weighted citation impact" – measured by the ratio of citations of the publication to the average number of citations obtained by similar publications indexed in the SCOPUS database for 2018–2022. Source: SciVal.

[2] Indicator "SDG" – contribution of research to the implementation of the UN Sustainable Development Goals (2030 agenda). Source: SCOPUS.

[3] Indicator "ICI" (Collaboration on Impact) – measured by the number of citations in publications with a foreign co-author in 2018–2022. Self-citations are not included. Source: SciVal.

International recognition: ⟨0.75; 0.25⟩", "Academic reputation (teaching) – SDG: ⟨0.75; 0.25⟩", "International recognition – Accreditations: ⟨0.75; 0.23⟩", "Students mobility (outbound) – Students mobility (inbound): ⟨0.75; 0.25⟩". These pairs of indicators have similar behavior and have to be monitored simultaneously.

The pairs in weak negative consonance "Parametric evaluation – Membership in a European university: ⟨0.24; 0.27⟩", "Rights to confer PhD degrees – Students studying in foreign language: ⟨0.23; 0.7⟩", "Faculty development – Strategic partnership projects: ⟨0.23; 0.67⟩", "Teaching staff – Membership in a European university: ⟨0.23; 0.28⟩", "Academic titles awarded – Strategic partnership projects: ⟨0.16; 0.74⟩", "Citations – Membership in a European university: ⟨0.16; 0.35⟩" have rather opposite influence. The rest pairs of indicators in strong dissonance, dissonance and weak dissonance have independent behavior.

The results presented in Table 1 are visualized as points on the intuitionistic fuzzy interpretational triangle, as shown in Figure 1.
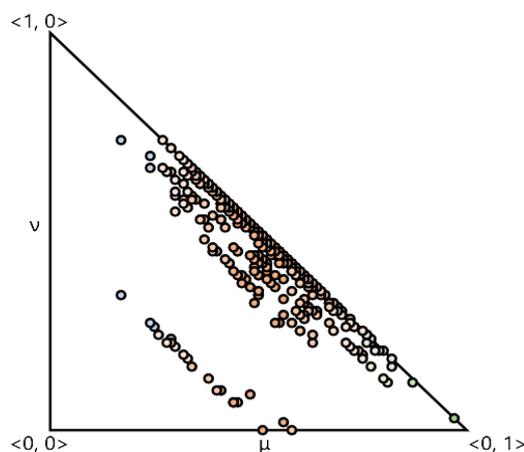

Figure 1. Results of ICA application to the Public University Ranking
to investigate the indicators interdependences and influence

4 InterCriteria Analysis applied to Poland's Private University Ranking

Private University Ranking 2023 is analyzed based on the data retrieved from the Perspektywy University Rankings website, [13]. The Ranking contains 44 universities assessed against 20 indicators, classified as representatives of reputation, employability, academic potential, didactic potential, innovation and cooperation with the economy and internationalization. By analogy to previous section, the aim of the ICA application to the Private University Ranking 2023 is to investigate the interdependences and influence of the indicators used in the ranking system. The results of ICA application are presented in Table 2.

As seen from Table 2, there is 1 pair of indicators in strong positive consonance, 5 pairs in positive consonance, 15 (5 + 10) pairs in weak dissonance, 58 (25 + 33) pairs in dissonance, 100 pairs in strong dissonance, and 7 pairs in weak negative consonance.

Again, the most noteworthy dependencies are for the pairs of indicators in strong positive consonance and positive consonance. The strongest relationship (strong positive consonance) is found between the indicators "Rights to confer PhD with habilitation degree – Rights to confer PhD degrees: $\langle 0.96; 0.02 \rangle$". Those two indicators have been in strong positive consonance in the investigation of Public Universities as well. Obviously, they can be merged in one common indicator.

Table 2. Results of ICA applied to investigate the indicators
used in Private University Ranking

Type of correlations	Pairs of indicators (number)
strong positive consonance [0.95; 1,00]	1
positive consonance [0.85; 0.95)	5
weak positive consonance [0.75; 0.85)	0
weak dissonance [0.67; 0.75)	5
dissonance [0.57; 0.67)	25
strong dissonance [0.43; 0.57)	100
dissonance [0.33; 0.43)	33
weak dissonance [0.25; 0.33)	10
weak negative consonance [0.15;0.25)	7
negative consonance [0.05;0.15)	0
strong negative consonance [0.00;0.05]	0

Other 5 pairs of indicators with strong relationship (positive consonance) are determined as follows: "Rights to confer PhD degrees – Multicultural composition of student body: $\langle 0.94; 0.04 \rangle$", "Rights to confer PhD with habilitation degree – Multicultural composition of student body: $\langle 0.92; 0.05 \rangle$", "Parametric evaluation – Rights to confer PhD with habilitation degree: $\langle 0.91; 0.04 \rangle$", "Parametric evaluation – Rights to confer PhD degrees: $\langle 0.9; 0.05 \rangle$", "Parametric evaluation – Multicultural composition of student body: $\langle 0.89; 0.07 \rangle$". Obviously, 4 indicators appear in aforementioned dependencies. Thereafter, these indicators can be investigated and replaced with an aggregated indicator. Most of the indicators are assessed by strong dissonance, dissonance and weak dissonance and as such they possess independent information.

Seven pairs of indicators are in weak negative consonance: "Strategic partnership projects – Student exchange (inbound): $\langle 0.23; 0.1 \rangle$", "External funding for research – Strategic partnership projects: $\langle 0.22; 0.1 \rangle$", "Academic reputation – Strategic partnership projects: $\langle 0.21; 0.09 \rangle$", "International students – Strategic partnership projects: $\langle 0.21; 0.09 \rangle$", "Academic staff with highest qualifications – Strategic partnership projects: $\langle 0.18; 0.12 \rangle$", "Postgraduate studies – Strategic partnership projects: $\langle 0.18; 0.12 \rangle$", "Alumni's earnings – Strategic partnership projects: $\langle 0.16; 0.13 \rangle$". Obviously, the indicator "Strategic partnership projects" has weak opposite relationship towards the indicators "Student exchange (inbound)", "External funding for research", "Academic reputation", "International students", "Academic staff with highest qualifications", "Postgraduate studies", and "Alumni's earnings".

The distribution of the indicators' dependencies is presented onto the intuitionistic fuzzy triangle (Figure 2).
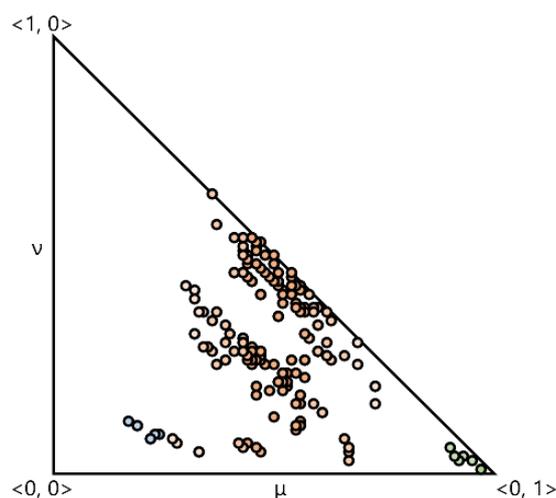
Figure 2. Results of ICA application to the Private University Ranking
to investigate the indicators interdependences and influence

5   InterCriteria Analysis Applied to Poland's Public Vocational Colleges Ranking

Public Vocational Colleges Ranking 2023 is analyzed based on the data retrieved from the Perspektywy University Rankings website [13]. The Ranking contains 14 entities assessed against 15 indicators, classified as representatives of reputation, employability, academic potential, didactic potential, cooperation with the economy and internationalization. By analogy to previous sections, the aim of the ICA application to the Public Vocational Colleges 2023 is to investigate the interdependences and influence of the indicators used in the ranking system. The results of ICA application are presented in Table 3.

Table 3. Results of ICA applied to investigate the indicators
used in Public Vocational Colleges Ranking

Type of correlations	Pairs of indicators (number)
strong positive consonance [0.95; 1,00]	2
positive consonance [0.85; 0.95)	2
weak positive consonance [0.75; 0.85)	3
weak dissonance [0.67; 0.75)	4
dissonance [0.57; 0.67)	8
strong dissonance [0.43; 0.57)	29
dissonance [0.33; 0.43)	31
weak dissonance [0.25; 0.33)	11
weak negative consonance [0.15;0.25)	13
negative consonance [0.05;0.15)	0
strong negative consonance [0.00;0.05]	0

As seen from Table 3, there are 2 pairs of indicators in strong positive consonance, 2 pairs in positive consonance, 3 pairs in weak positive consonance, 15 (4 + 11) pairs in weak dissonance, 39 (8 + 31) pairs in dissonance, 29 pairs in strong dissonance and 13 pairs in weak negative consonance.

Again, the most worth to note dependencies are for the pairs of indicators in strong positive consonance, positive consonance and weak positive consonance. One of the strongest relationships (strong positive consonance) is found between the indicators "Rights to confer PhD with habilitation degree – Rights to confer PhD degrees: $\langle 0.99; 0.00 \rangle$". Those two indicators have been in strong positive consonance in the previous two sections as well. In this case there is one more pair of indicators in strong positive consonance, namely "Parametric evaluation – Rights to confer PhD degrees: $\langle 0.95; 0.03 \rangle$". In positive consonance are the pairs of indicators: "Parametric evaluation – Rights to confer PhD with habilitation degree: $\langle 0.93; 0.03 \rangle$" and "Parametric evaluation – Strategic partnership projects: $\langle 0.86; 0.02 \rangle$". In weak positive consonance are the following 4 pairs of indicators: "Rights to confer PhD with habilitation degree – Strategic partnership projects: $\langle 0.84; 0.03 \rangle$", "Rights to confer PhD degrees - Strategic partnership projects: $\langle 0.84; 0.04 \rangle$", "Academic reputation – Academic staff with highest qualifications: $\langle 0.81; 0.18 \rangle$". It might be concluded that aforementioned indicators have strong relationships between each other. The results of ICA application are presented onto the intuitionistic fuzzy triangle (Figure 3).
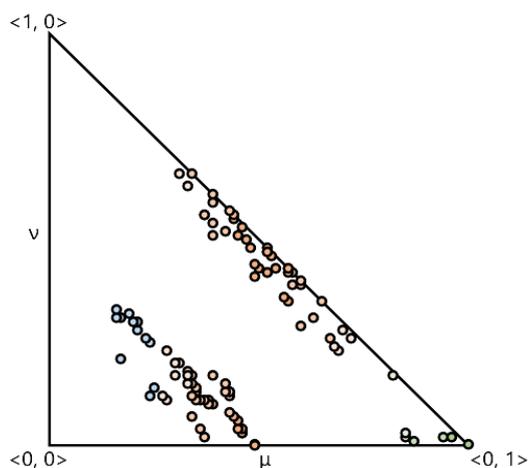

Figure 3. Results of ICA application to the Public Vocational Colleges Ranking
to investigate the indicators interdependences and influence

6   Conclusion

In the current research an investigation of the Polish University Rankings is performed. ICA is applied to determine the interdependences and influence of indicators used for the rankings of Public Universities, Private Universities and Public Vocational Colleges, respectively. In general, indicators found to be in strong positive consonance in different rankings might be subjected to a combination/aggregation, as well as to be considered with a bigger weight in a further deeper analysis.

Acknowledgements

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