Notes on Intuitionistic Fuzzy Sets
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Software for InterCriteria Analysis: Implementation of a normalization step before data processing

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Abstract: In this research, we present a novel modification to the existing software for InterCriteria Analysis. An automated normalization process has been introduced to handle parameters with varying units of measurement, thereby improving the accuracy and efficiency of the analysis. Additionally, the updated version of the software offers a variety of advanced functionalities for post-analysis once the results have been generated.
Keywords: InterCriteria Analysis, Data normalization, ICrA software.
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1 Introduction

InterCriteria Analysis (ICrA) is a tool that assesses the degree of association between investigated criteria of multivariate objects. It was created at the Institute of Biophysics and

Biomedical Engineering of the Bulgarian Academy of Sciences (IBPhBME-BAS) in 2014 [6]. It is based on two mathematical formalisms: the algebraic apparatus of index matrices for processing data sets of different dimensions [1, 3] and intuitionistic fuzzy sets as a mathematical tool for handling of uncertainty [2]. The reader can find more details about the nature of ICrA in [5, 7–9, 12, 22]. ICrA has an advantage over the other more commonly used method for processing datasets – correlation analysis, in that it can detect positive consonance and negative consonance where the relationship is not linear, whereas correlation analysis detects significant relationships between variables when the relationship between them is linear. For the period 2015–2025, InterCriteria Analysis has been used in over 140 studies [13].

When working with InterCriteria Analysis software with data from various scientific areas and practical domains such as education [11], medicine [14], petroleum industry [19–21], etc., data is always in different types of numerical values (for example: temperature in reactors is denoted by natural numbers, while density is denoted by real numbers). When starting to work with the software of InterCriteria Analysis, first the data set is normalized using the formula (1):

$$X_{new} = \frac{X - X_{min}}{X_{max} - X_{min}} \qquad (1)$$

This preliminary preparation prior to working with the InterCriteria analysis software is quite time consuming, and very often errors are made in the normalization of the data, and working professionals are likely to obtain erroneous results. In order to make it easier for those working with Intercrteria analysis software, we propose to introduce the normalization of the data by formula 1 into the software itself and to perform it automatically. So far we are not aware of anyone who has proposed or implemented this innovation, which is in fact the purpose of this paper.

2 Software for InterCriteria Analysis: Implementation of the normalization step before data processing

InterCriteria Analysis does not require all of the criteria to measure objects on the same scale. However, when the input matrix is transposed and objects are treated as criteria, we are essentially attempting to compare two values measured on potentially very different scales. Therefore, these values need to be normalized to a uniform scale, such that they can be compared both within the realm of their own criterion and with values evaluating the same object by a different criterion [4].

Min-Max normalization (Equation (1)) can be used to convert values measuring objects by a single criterion into numbers between 0 and 1. This is achieved by transforming the minimum value to 0 and the maximum value to 1, while intermediate values are scaled according to their relative distance from these extremes. This normalization allows ICrA to compare values measured against different criteria within the same numerical domain.

In this section, we will describe an extension to the InterCriteria Decision Making (ICDM) software [15–17], which implements data normalization based on the method described above as a preprocessing step before performing ICrA. Figure 1 shows the relevant part of the code, which performs the normalization.

```
std::vector< std::vector<double> > data1_transposed(data1[0].size(),std::vector<double>(data1.size()));

if(flip)
    for(size_t j=0; j<data1.size(); j++){
        for(size_t i=0; i<data1[j].size(); i++){
            data1_transposed[i][j] = data1[j][i];
        }
    }
else
    data1_transposed=data1;

for(size_t x=0; x<data1_transposed.size(); x++){
    std::vector<double>& row=data1_transposed[x];
    double min = *std::min_element(row.begin(), row.end());
    double max = *std::max_element(row.begin(), row.end());

    for(size_t z=0; z<row.size(); z++){
        if(flip) data1[z][x] = (data1_transposed[x][z]-min)/(max-min);
        else data1[x][z] = (data1_transposed[x][z]-min)/(max-min);
    }
}
```

Figure 1. The C++ code called by pressing the normalization button

The ICrA software requires the user to load a table of input data, which can come from either a Microsoft Excel workbook or a text file with tab-separated values. An example input data worksheet is shown in Figure 2.

	A	B	C	D	E	F	G	H	I	J	K
1		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2	Belgium	344	10,23	11,25	50	14,02	15,9	17,21	77	14,78	17,08
3	Bulgaria	245	1,05	1,96	70	1,78	2,42	1,45	234	1,51	1,7
4	Czechia	2535	5,59	3,77	120	6,7	7,5	7,97	425	7,62	16,43
5	Denmark	646	25,61	22,61	202	20,65	21,67	25,51	34	28,3	31,48
6	Germany	3636	28,25	32,9	124	35,35	30,44	30,82	365	30,86	35,75
7	Estonia	3646	4,38	4,8	244	8,28	17,45	15,3	2463	16,11	19,2

Figure 2. The input data

The data from the Excel file is loaded into the program using the *File* menu, option *Open workbook* (Figure 3). The other *File* menu options are the following:

- *Open without performing the analysis* – the input data is read to memory, but the analysis is not performed,
- *Load a precalculated* result – loads ICrA results from a previous analysis,
- *Exit* – close the software.

The input file contains a series of numerical evaluations of a set of objects according to a set of criteria. The software performs ICrA on the input data and generates intuitionistic fuzzy pairs that represent the calculated degrees of membership and non-membership between each pair of criteria.

After selecting a file, the *Settings* window is displayed (Figure 4). In the section *Input data layout*, the user needs to select whether the criteria in the input file are listed in columns or in rows. If the wrong layout is selected, the objects will be treated as criteria. In the section *When two number pair each give an equality…* the user can select how to treat two equal pairs of values by two different criteria. There are three options: increasing the degree of membership, the degree of non-membership, or both (this is also known as *bias*). When the *Use object priorities* or the *Use criterion priorities* box is checked, the program performs ICrA with weights, where the weights of objects or criteria are given in a separate table, outside the regular input table [10, 18].

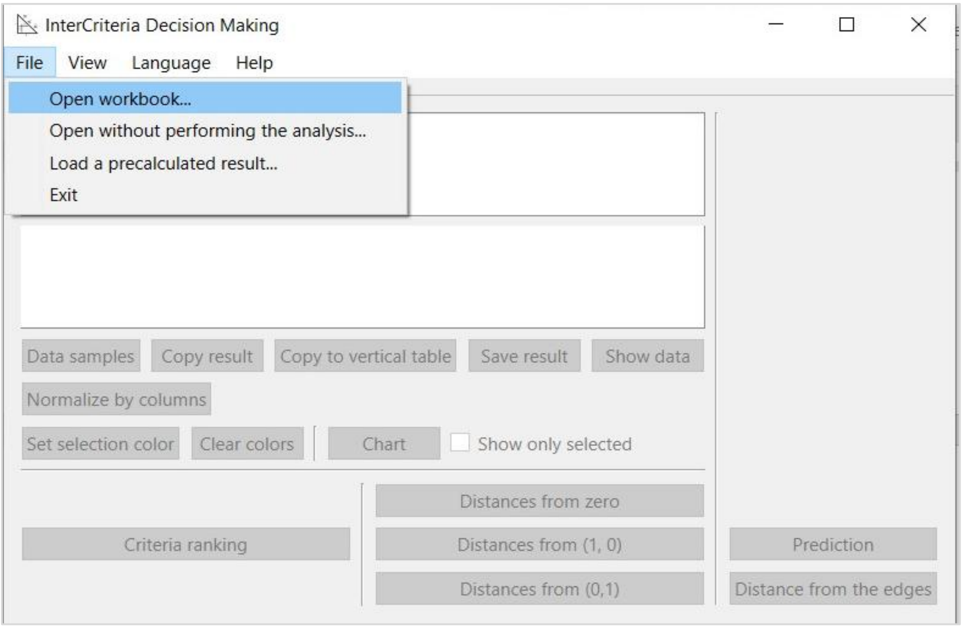


Figure 3. Open a workbook

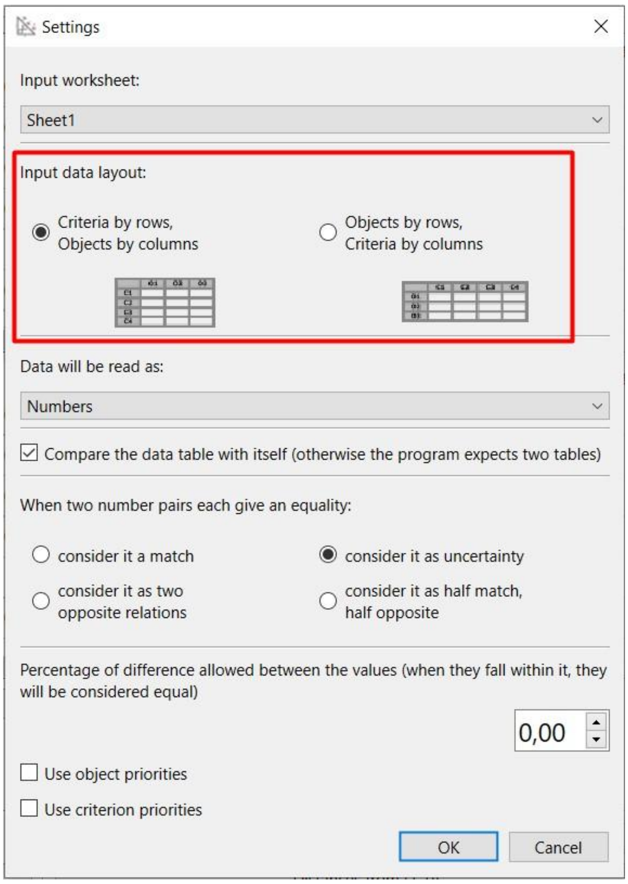
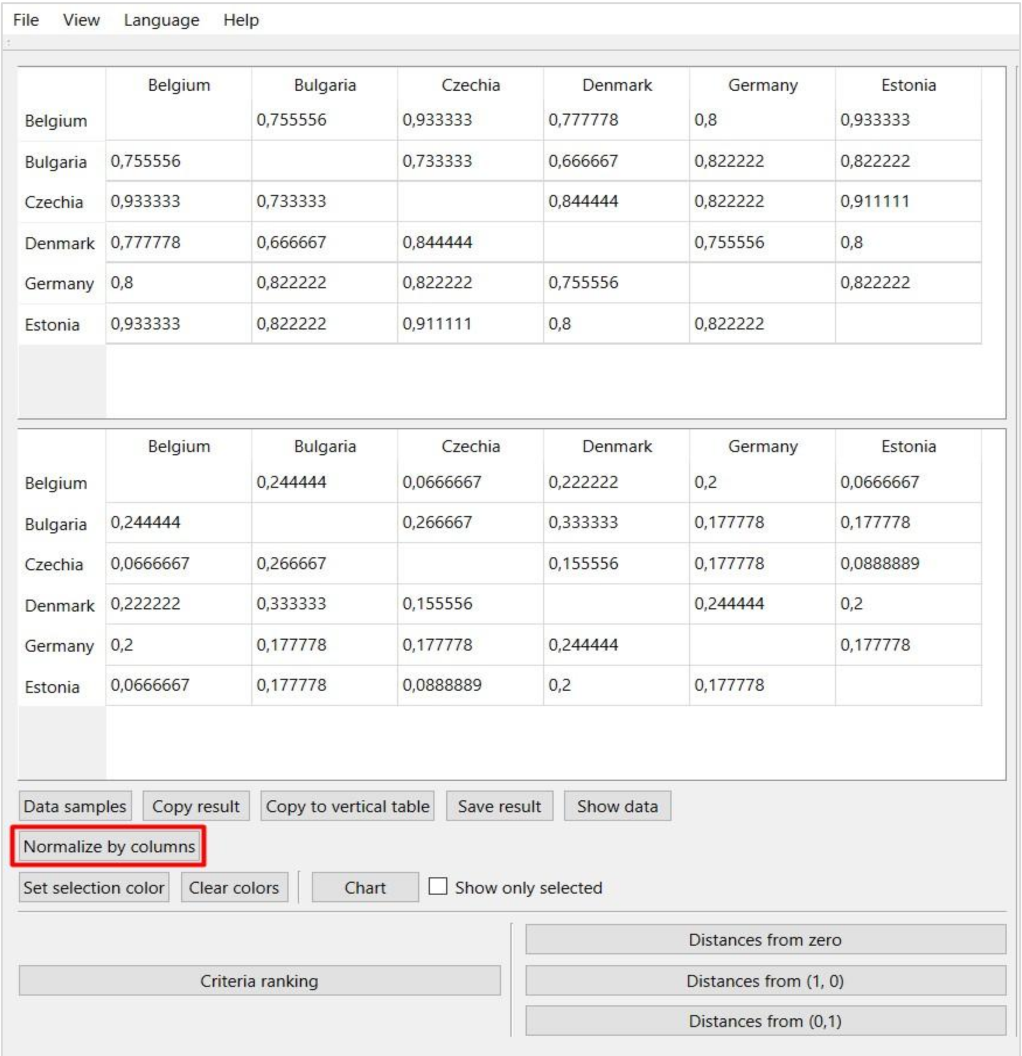


Figure 4. Input settings

After reading the input data, ICrA is applied on it and the results are visualized in two tables, presented in the Figure 5. The first table contains the degrees of memberships, while the second table gives the degrees of non-memberships. The different buttons in the main window perform various functions, which are described in [17].



	Belgium	Bulgaria	Czechia	Denmark	Germany	Estonia
Belgium		0,755556	0,933333	0,777778	0,8	0,933333
Bulgaria	0,755556		0,733333	0,666667	0,822222	0,822222
Czechia	0,933333	0,733333		0,844444	0,822222	0,911111
Denmark	0,777778	0,666667	0,844444		0,755556	0,8
Germany	0,8	0,822222	0,822222	0,755556		0,822222
Estonia	0,933333	0,822222	0,911111	0,8	0,822222	

	Belgium	Bulgaria	Czechia	Denmark	Germany	Estonia
Belgium		0,244444	0,0666667	0,222222	0,2	0,0666667
Bulgaria	0,244444		0,266667	0,333333	0,177778	0,177778
Czechia	0,0666667	0,266667		0,155556	0,177778	0,0888889
Denmark	0,222222	0,333333	0,155556		0,244444	0,2
Germany	0,2	0,177778	0,177778	0,244444		0,177778
Estonia	0,0666667	0,177778	0,0888889	0,2	0,177778	

Figure 5. ICrA results without the normalization step

The new feature in the ICDM software is activated by pressing the *Normalize by columns* button (Figure 6). It applies the implemented normalization formula over the input data and repeats ICrA with the normalized values. The results in Figure 5 show the data after normalization and ICrA application.

Normalization is always performed by column (e.g., per criterion). If the user needs to normalize criteria values by rows, the input file must be reopened and the input layout changed. If the user desires to undo the normalization, they can press the *Initial data* button, which replaces the normalization button after the analysis is complete. Results from ICrA without normalization with normalization are presented in Figure 7 and Figure 8.

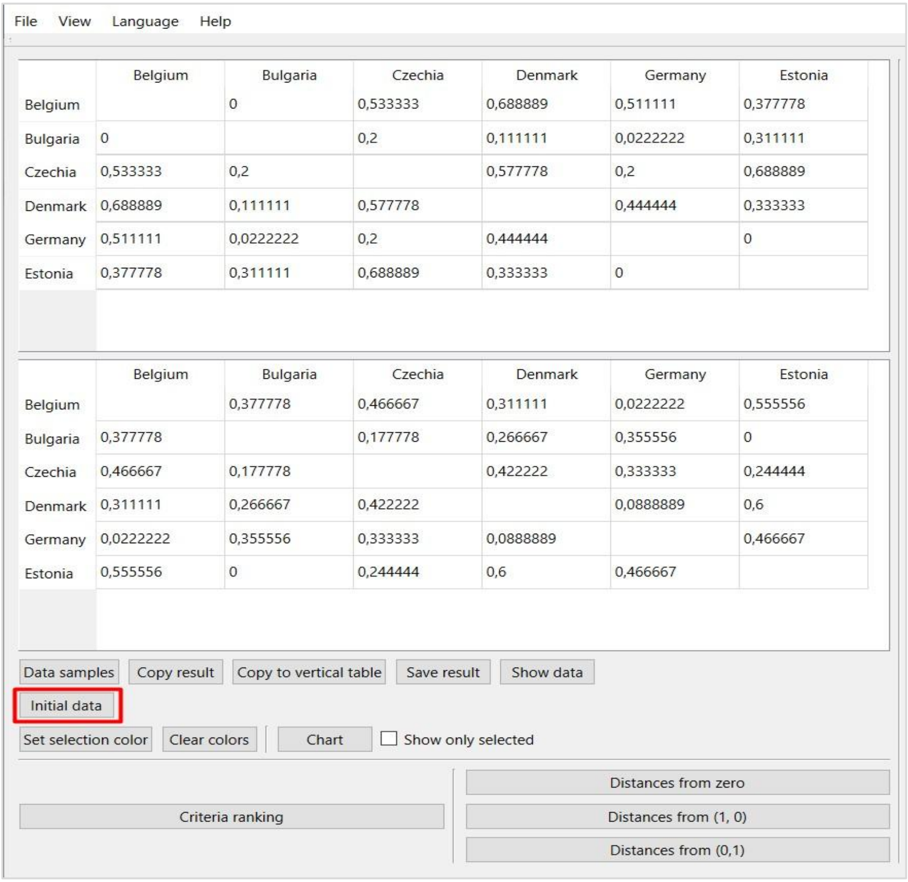


Figure 6. ICrA results with normalization step – ICrA by countries

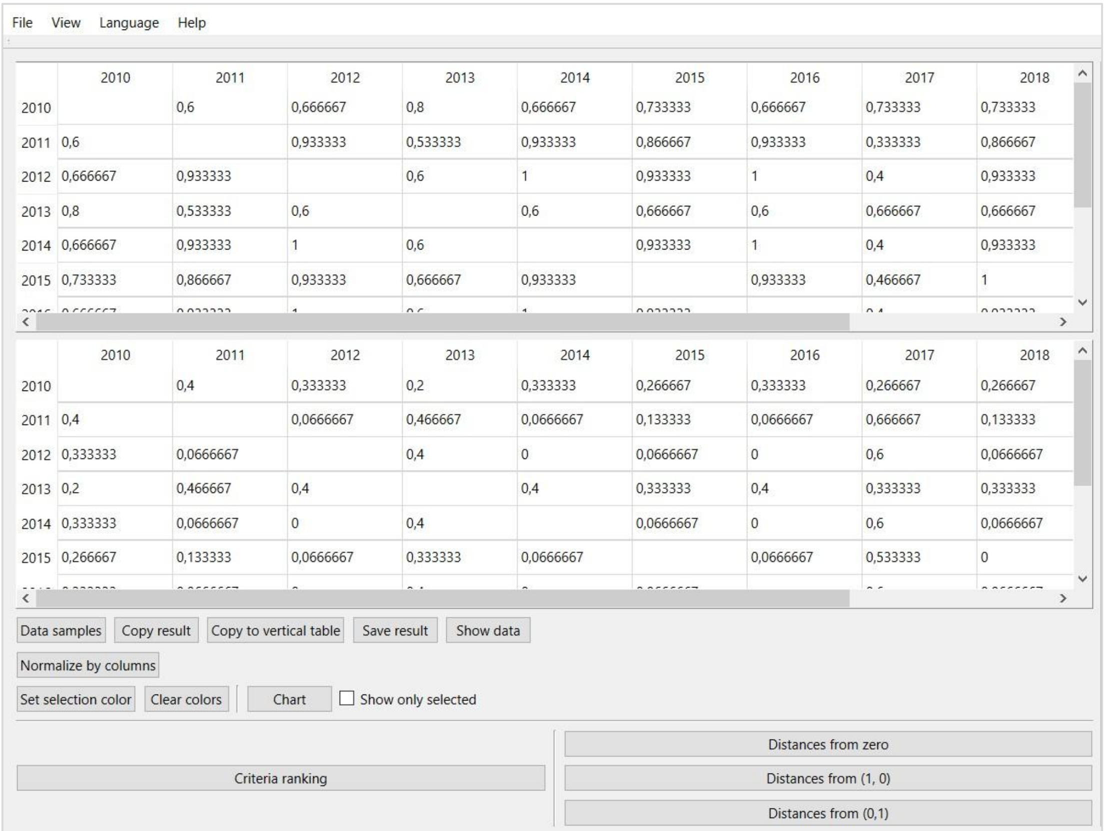


Figure 7. ICrA results without normalization step – ICrA by years

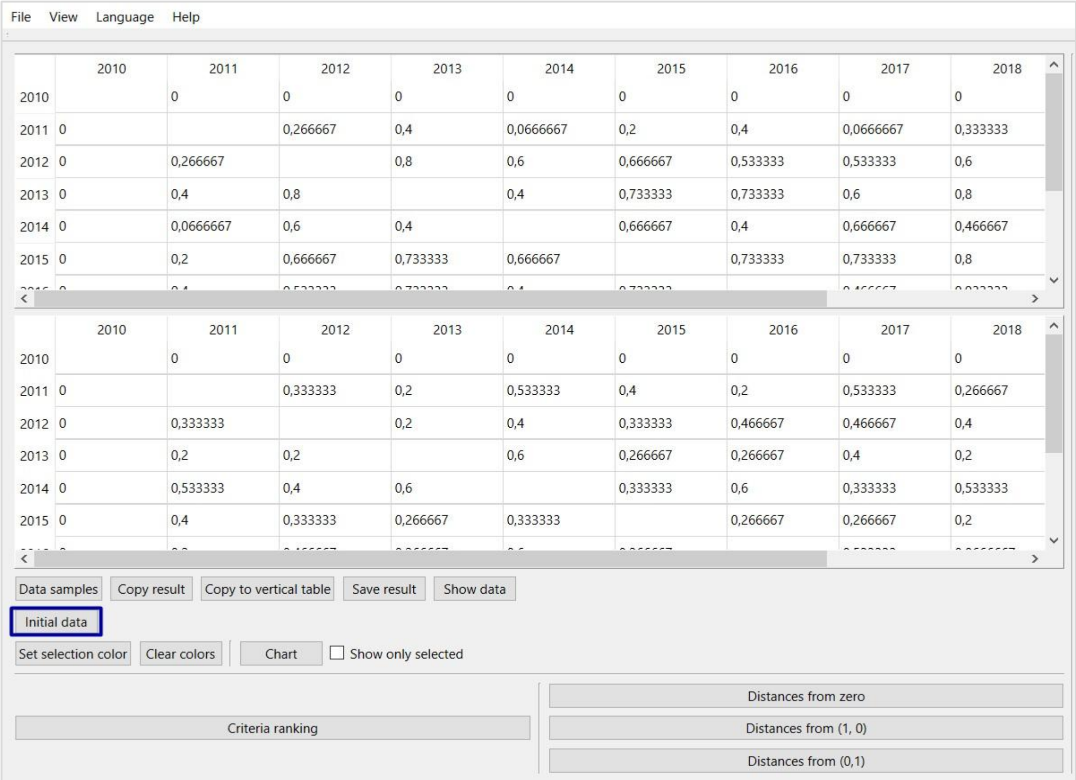


Figure 8. ICrA results with normalization step – ICrA by years

The program provides several options for further analysis after the results are calculated. The first option display the IF pairs in the IF triangle with user-defined colors (Figure 9). The user can select the appropriate points and click the *Set selection color* button to pick a color for a certain IF pair. Then they can push the *Chart* button to visualize the data points.

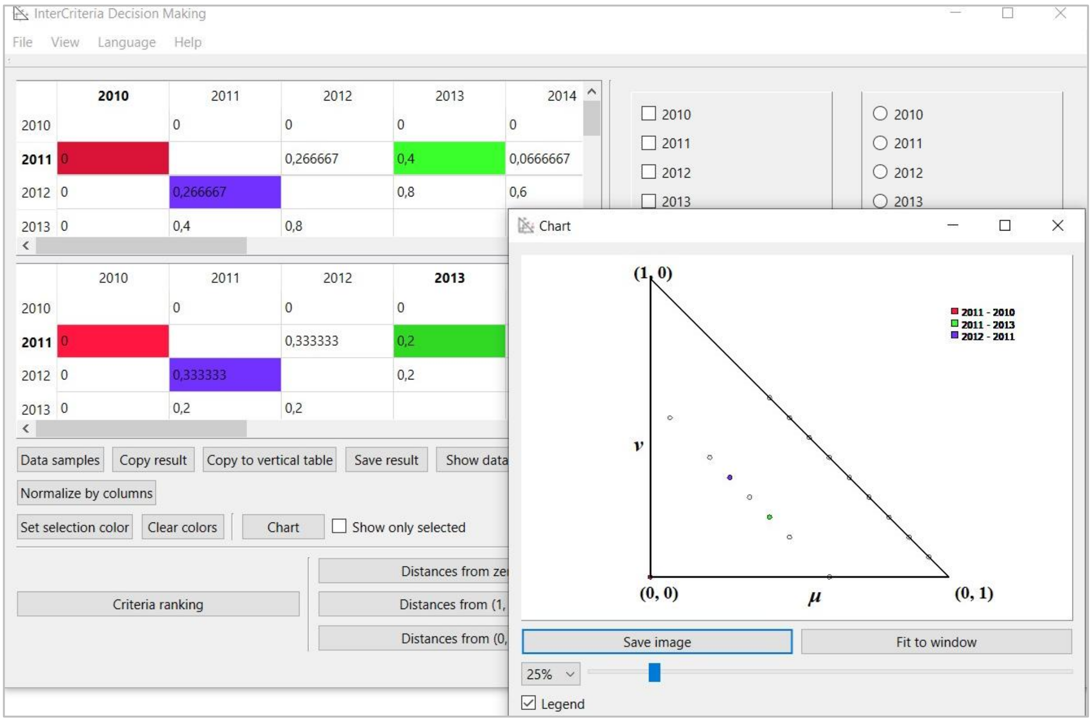


Figure 9. ICrA results visualization – display data points with colors

The second option allows the user to investigate the points' position in the IF triangle. The user can draw a rectangle over the desired point(s) that displayed in the IF triangle and information about them will be displayed in a new window (Figure 10).

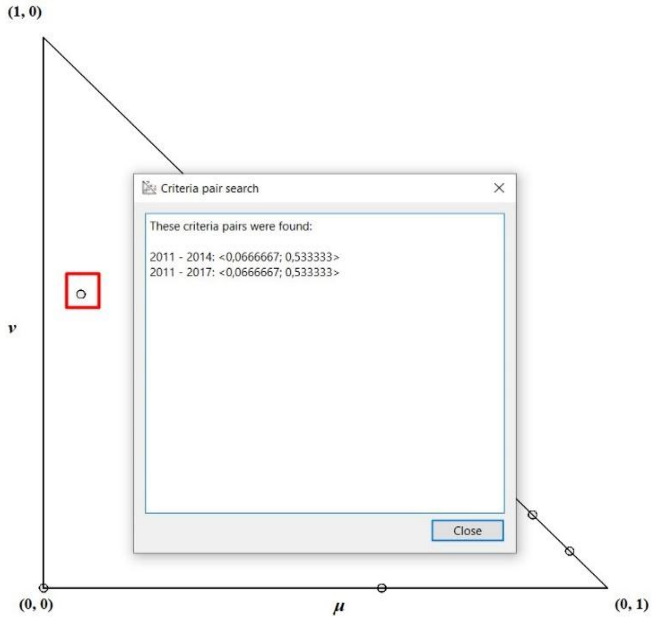


Figure10. ICrA results visualization – information about a selected data point

The third option provides criteria ranking. The results are presented in a list ordered by their degrees of membership and non-membership (Figure 11). The thus obtained results can be used to describe and analyze their correlations.

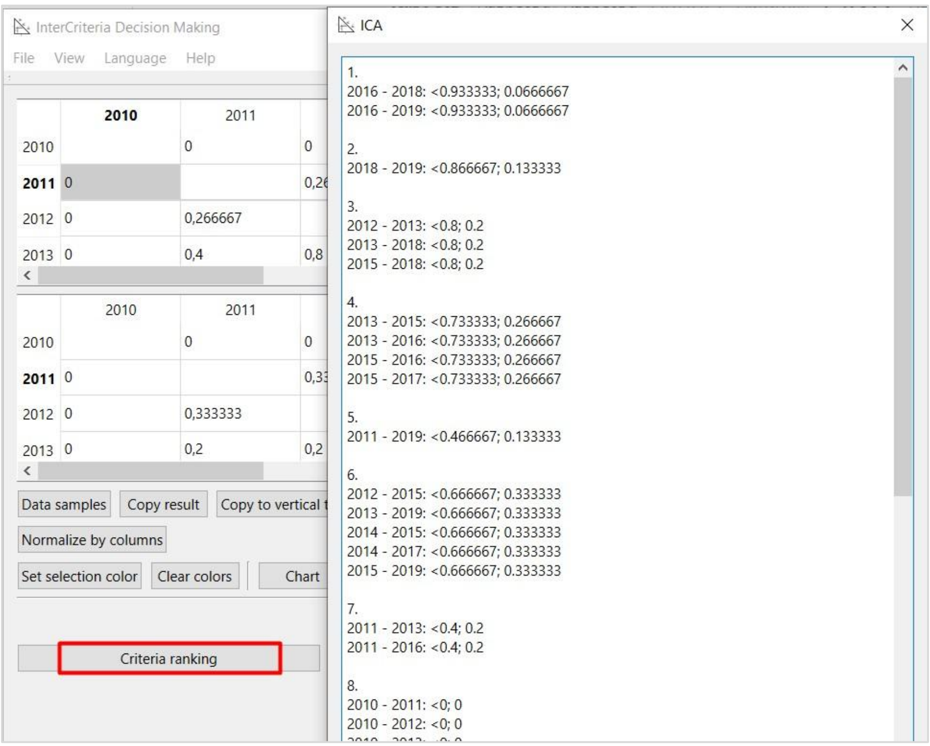


Figure 11. ICrA results visualization – criteria ranking

3 Conclusion

This paper introduces an innovative implementation of a normalization procedure within the InterCriteria Analysis (ICrA) software, aimed at improving the reliability and comparability of input data before computational processing. The normalization of diverse numerical data is an essential step in modifying the effects of inequality, thus ensuring that the analysis dependably reflects the intrinsic relationships among criteria, rather than being slanted by differences in units or scales of measurement. Including the proposed normalization mechanism directly into the software's workflow enhances user accessibility and reduces the likelihood of preprocessing errors that may occur when such transformations are performed externally. Furthermore, these improvements could enhance the accuracy of ICrA evaluations and extend its applicability in fields that require a sophisticated assessment of solid criteria, such as engineering, environmental management, economics, and biomedical research.

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References

[1] Atanassov, K. (1987). Generalized index matrices. *Comptes rendus de l'Academie Bulgare des Sciences*, 40(11), 15–18.

[2] Atanassov, K. (2012). *On Intuitionistic Fuzzy Sets Theory*. Springer, Berlin.

[3] Atanassov, K. (2014). *Index Matrices: Towards an Augmented Matrix Calculus*. Springer, Cham.

[4] Atanassov, K., Atanassova, V., Chountas, P., Mitkova, M., Sotirova, E., Sotirov, S., & Stratiev, D. (2016). Intercriteria analysis over normalized data. *Proceedings of 2016 IEEE 8th International Conference on Intelligent Systems*, pp. 564–566.

[5] Atanassov, K., Atanassova, V., & Gluhchev, G. (2015). InterCriteria Analysis: Ideas and problems. *Notes on Intuitionistic Fuzzy Sets*, 21(1), 81–88.

[6] Atanassov, K., Mavrov, D., & Atanassova, V. (2014). Intercriteria decision making: A new approach for multicriteria decision making, based on index matrices and intuitionistic fuzzy sets. *Issues in Intuitionistic Fuzzy Sets and Generalized Nets*, 11, 1–8,

[7] Atanassov, K., Ribagin, S., Sotirova, E., Bureva, V. Atanassova, V., & Angelova, N. (2017). Intercriteria analysis using special type of intuitionistic fuzzy implications. *Notes on Intuitionistic Fuzzy Sets*, 23(5), 61–65.

[8] Atanassova, V. (2015). Interpretation in the intuitionistic fuzzy triangle of the results, obtained by the intercriteria analysis. In: *Proceedings of 16th World Congress of the International Fuzzy Systems Association and 9th Conference of the European Society for Fuzzy Logic and Technology (IFSAEUSFLAT-15)*. Atlantis Press, pp. 1369–1374.

[9] Atanassova, V., & Roeva O. (2018). Computational complexity and influence of numerical precision on the results of intercriteria analysis in the decision making process. *Notes on Intuitionistic Fuzzy Sets*, 24(3), 53–63.

[10] Bureva, V., Atanassov, K., Mersinkova, Y., & Stratiev, D. (2023). Evaluating the performance of catalyst and feedstocks in the fluid catalytic cracking process: Application of InterCriteria Analysis with weight coefficients of the objects. *Notes on Intuitionistic Fuzzy Sets*, 29(2), 166–177.

[11] Bureva, V., Petrov, P. R., Atanassova, V., Umlenski, I. (2022). InterCriteria Analysis as a tool for analyzing Big Data datasets: Case study of 2021 national statistics of Bulgarian system of higher education. *Notes on Intuitionistic Fuzzy Sets*, 28(4), 464–474.

[12] Bureva, V., Sotirova, E., Atanassova, V., Angelova, N., & Atanassov, K. (2018). Intercriteria Analysis over intuitionistic fuzzy data. In: *Lirkov, I., Margenov, S. (Eds.). Large-Scale Scientific Computing. LSSC 2017.* Lecture Notes in Computer Science, Vol. 10665, pp. 333–340. Springer, Cham.

[13] Chorukova, E., Marinov, P., & Umlenski, I. (2021). Survey on Theory and Applications of InterCriteria Analysis Approach. In: *Atanassov K.T. (Ed.). Research in Computer Science in the Bulgarian Academy of Sciences. Studies in Computational Intelligence*, Vol. 934, pp. 453–469. Springer, Cham.

[14] Ignatova, V. G., Todorova, L. P., Haralanov, L. H., & Vassilev, P. M. (2024). Early clinical predictors of long-term disability progression in patients with multiple sclerosis. *Indian Journal of Medical Specialities*, 15(1), 48–52.

[15] Mavrov, D. (2015). Software for InterCriteria Analysis: Implementation of the main algorithm. *Notes on Intuitionistic Fuzzy Sets*, 21(2), 77–86.

[16] Mavrov, D. (2015-2016). Software for InterCriteria Analysis: Working with the results. *Annual of "Informatics" Section Union of Scientists in Bulgaria* 8, 37–44.

[17] Mavrov D., & Bureva V. (2022/2023). Software for intercriteria analysis: Implementation of the algorithm of intercriteria analysis with weight coefficients of objects or criteria. *Annual of "Informatics" Section, Union of Scientists in Bulgaria,* 12, 95–104.

[18] Mavrov, D., Popov, S., Nenov, V.; Stratiev, D. (2023). Evaluating the performance of catalyst and feedstocks in the fluid catalytic cracking process: Application of InterCriteria Analysis with weight coefficients of the criteria. *Notes on Intuitionistic Fuzzy Sets*, 29(2), 178–196.

[19] Shishkova, I., Stratiev, D., & Sotirov, S. (2024). *Petroleum Chemistry and Processing Investigated by the use of InterCriteria Analysis*. "Professor Marin Drinov" Publishing House of Bulgarian Academy of Sciences, ISBN 978-619-245-487-6.

[20] Stratiev, D., Shishkova, I., Dinkov, R., Kolev, I., Argirov, G., Ivanov, V., Ribagin, S., Atanassova, V., Atanassov, K., Stratiev, D., Nenov, S., Pilev, D., & Yordanov, D. (2022). Intercriteria analysis to diagnose the reasons for increased fouling in a commercial ebullated bed vacuum residue hydrocracker. *ACS Omega*, 7(34), 30462−30476.

[21] Stratiev, D., Shishkova, I., Kolev, I., & Palichev, G. (2022). Conversion variation in a commercial vacuum residue hydrocracker investigated by intercriteria analysis and pilot plant tests. *Proceedings of 13th International Symposium on Heterogeneous Catalysis.* 1–5 September 2024, Burgas, Bulgaria.

[22] Zoteva, D., & Roeva, O. (2018). InterCriteria analysis results based on different number of objects. *Notes on Intuitionistic Fuzzy Sets*, 24(1), 110–119.