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Abstract. In the paper application of the InterCriteria analysis approach to real dataset with instances of hourly averaged responses from an array of 5 metal oxide chemical sensors embedded in an air quality chemical multisensor device [29, 30] is represented. The InterCriteria analysis is a new method that can be used for multicriteria decision making. The aim is to analyze the correlations between 12 indicators representing the recordings of on field deployed air quality chemical sensor devices responses.

Keywords: Air Quality, InterCriteria analysis, Intuitionistic fuzzy sets, Index matrix, Multicriteria decision making.

1 Introduction

By InterCriteria analysis (ICA) method the so-called tasks of multicriteria decision making can be solved. Not only the criteria themselves, but also the available data, obtained by measurement or evaluation of the objects with respect to the criteria, may be varying and heterogeneous in nature. Sometimes the measurement or evaluation according to some of the criteria may prove time-consuming, cost-ineffective, resource-demanding, etc. In such cases, for the decision maker it will be of significance advantage to ignore in future decision making all or part of these „unfavourable” criteria without this having an adverse effect on the accuracy of the decision. For this aim, it would be beneficial to detect sufficiently high and predictable correlations between the given „unfavourable” criteria and others among the set of criteria which are faster, cheaper and easier to measure or evaluate.

The purpose of this development is to identify the most correlated criteria in a real dataset with measurements of hourly averaged responses from an array of 5 metal oxide chemical sensors embedded in an air quality chemical multisensor device [30, 31]. By applying the ICA approach over extracted data for air quality, we can find the criteria that have the highest dependencies. In this way we can observe the behavior of them in time (several years). Analogously we can receive the opposite indicators or indicators that frequently are independent from each other. In the current observation the dataset with 6934 measurements on hourly averaged concentrations for CO, Non Metanic Hydrocarbons, Benzene, Total Nitrogen Oxides (NOx) and Nitrogen Dioxide (NO_2) recorded in over a year [30, 31] were analyzed.

2 The InterCriteria Analysis

The ICA method was introduced by K. Atanassov, D. Mavrov and V. Atanassova in [3]. Several applications of the method have already been published [1, 2, 8-29, 34]. The method was employed to study the relations between the petroleum properties [32], and between bulk properties and fraction properties of crude oils [33].

The method is based on the theory of intuitionistic fuzzy sets and index matrices. Intuitionistic fuzzy sets were first defined by Atanassov [4, 6] as an extension of the concept of fuzzy sets defined by L. Zadeh [35]. The theory of index matrices was introduced in [5].

The objects can be estimated on the basis of several criteria. The number of criteria can be reduced by calculating the correlations in each pair of criteria in the form of intuitionistic fuzzy pairs of values [4]. The intuitionistic fuzzy pairs of values are the intuitionistic fuzzy evaluations in the interval [0, 1]. The relations can be established between any two groups of indicators C_w and C_t.

Let us have a number of C_q criteria, $q = 1, \ldots, n$, and a number of O_p measurements, $p = 1, \ldots, m$; that is, we use the following sets: a set of group of criteria $C_q = \{C_1, \ldots, C_n\}$ and a set of measurements $O_p = \{O_1, \ldots, O_m\}$.

We obtain an index matrix M that contains two sets of indices, one for rows and another for columns. For every p, q ($1 \le p \le m$, $1 \le q \le n$), O_p in an evaluated object, C_q is an evaluation criterion, and a_{O_p,C_q} is the evaluation of the p-th object against the q-th criterion, defined as a real number or another object that is comparable according to a relation R with all the other elements of the index matrix M.

$$M = \begin{array}{c|cccccccc}
 & C_1 & \ldots & C_k & \ldots & C_l & \ldots & C_n \\
\hline
O_1 & a_{O_1,C_1} & \ldots & a_{O_1,C_k} & \ldots & a_{O_1,C_l} & \ldots & a_{O_1,C_n} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
O_i & a_{O_i,C_1} & \ldots & a_{O_i,C_k} & \ldots & a_{O_i,C_l} & \ldots & a_{O_i,C_n} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
O_j & a_{O_j,C_1} & \ldots & a_{O_j,C_k} & \ldots & a_{O_j,C_l} & \ldots & a_{O_j,C_n} \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
O_m & a_{O_m,C_1} & & a_{O_m,C_k} & & a_{O_m,C_l} & \ldots & a_{O_m,C_n}
\end{array}.$$

The next step is to apply the InterCriteria Analysis for calculating the evaluations. The result is a new index matrix M^* with intuitionistic fuzzy pairs $\langle \mu_{C_k,C_l}, \nu_{C_k,C_l} \rangle$ that represents an intuitionistic fuzzy evaluation of the relations between every pair of criteria C_k and C_l. In this way the index matrix M that relates the evaluated objects with the evaluating criteria can be transformed to another index matrix M^* that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_n \\ \hline C_1 & \left\langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \right\rangle & \cdots & \left\langle \mu_{C_1,C_n}, \nu_{C_1,C_n} \right\rangle \\ \cdots & \cdots & \cdots & \cdots \\ C_n & \left\langle \mu_{C_q,C_1}, \nu_{C_q,C_1} \right\rangle & \cdots & \left\langle \mu_{C_n,C_n}, \nu_{C_n,C_n} \right\rangle \end{array}$$

The last step of the algorithm is to determine the degrees of correlation between groups of indicators depending of the chosen threshold for μ and ν from the user. The correlations between the criteria are called „positive consonance", „negative consonance" or „dissonance". Here we use the scale used in previous studies that is shown in Table 1 [7].

Table 1. Scale for determination of the relative values the correlations between the criteria

Type of correlations between the criteria
strong positive consonance [0,95; 1]
positive consonance [0,85; 0,95)
weak positive consonance [0,75; 0,85)
weak dissonance [0,67; 0,75)
dissonance [0,57; 0,67)
strong dissonance [0,43; 0,57)
dissonance [0,33; 0,43)
weak dissonance [0,25; 0,33)
weak negative consonance [0,15; 0,25)
negative consonance [0,05; 0,15)
strong negative consonance [0; 0,05]

3 Application of the ICA over air quality data

We explore real data extracted from UCI Machine Learning Repository i.e., from a site which provide free access to data [30, 31]. Using InterCriteria Analysis approach the behavior of the objects or criteria can be monitoring and optimized.

The ICA method was applied to the 6934 measurements on hourly averaged concentrations. Twelve criteria representing the recordings of on field deployed air quality chemical sensor devices responses are used [30, 31]:

1) True hourly averaged concentration CO in mg/m^3 – CO(GT);
2) PT08.S1 (tin oxide) hourly averaged sensor response – PT08.S1(CO);
3) True hourly averaged Benzene concentration in microg/m^3 – C6H6(GT);
4) PT08.S2 (titania) hourly averaged sensor response – PT08.S2(NMHC);

5) True hourly averaged NOx concentration in ppb – NOx(GT);
6) PT08.S3 (tungsten oxide) hourly averaged sensor response – PT08.S3(NOx);
7) True hourly averaged NO_2 concentration in microg/m^3 – NO_2(GT);
8) PT08.S4 (tungsten oxide) hourly averaged sensor response – PT08.S4(NO_2);
9) PT08.S5 (indium oxide) hourly averaged sensor response – PT08.S5(O3);
10) Temperature in °C – T;
11) Relative Humidity (%) – RH;
12) Absolute Humidity – AH.

The testing matrices which contain μ-values and ν-values from the air quality chemical sensor devices are presented in the Tables 2 and 3. The values in the matrices are colored in shades of gray for the varying degrees of consonance and dissonance from darkest gray (highest values) to white.

Table 2. Membership part of the intuitionistic fuzzy pairs

μ	CO (GT)	PT08.S1 (CO)	C6H6 (GT)	PT08.S2 (NMHC)	NOx (GT)	PT08.S3 (NOx)	NO2 (GT)	PT08.S4 (NO2)	PT08.S5 (O3)	T	RH	AH
CO (GT)	1,000	0,844	0,895	0,895	0,865	0,128	0,815	0,810	0,824	0,582	0,460	0,543
PT08.S1 (CO)	0,844	1,000	0,883	0,883	0,837	0,095	0,785	0,881	0,871	0,610	0,519	0,629
C6H6 (GT)	0,895	0,883	1,000	1,000	0,887	0,098	0,836	0,850	0,865	0,613	0,463	0,558
PT08.S2 (NMHC)	0,895	0,883	1,000	1,000	0,887	0,098	0,836	0,850	0,865	0,613	0,463	0,558
NOx (GT)	0,865	0,837	0,887	0,887	1,000	0,157	0,857	0,793	0,845	0,561	0,480	0,528
PT08.S3 (NOx)	0,128	0,095	0,098	0,098	0,157	1,000	0,214	0,116	0,130	0,398	0,481	0,379
NO2 (GT)	0,815	0,785	0,836	0,836	0,857	0,214	1,000	0,733	0,788	0,589	0,411	0,489
PT08.S4 (NO2)	0,810	0,881	0,850	0,850	0,793	0,116	0,733	1,000	0,825	0,615	0,566	0,700
PT08.S5 (O3)	0,824	0,871	0,865	0,865	0,845	0,130	0,788	0,825	1,000	0,556	0,521	0,581
T	0,582	0,610	0,613	0,613	0,561	0,398	0,589	0,615	0,556	1,000	0,290	0,586
RH	0,460	0,519	0,463	0,463	0,480	0,481	0,411	0,566	0,521	0,290	1,000	0,704
AH	0,543	0,629	0,558	0,558	0,528	0,379	0,489	0,700	0,581	0,586	0,704	1,000

The representation of the IF pairs as points into the intuitionistic fuzzy triangle is shown in Fig. 1. In Fig. 2, Fig. 3 and Fig. 4 the dependences between criteria during the year are shown.

Table 3. Non-membership part of the intuitionistic fuzzy pairs

ν	CO (GT)	PT08.S1 (CO)	C6H6 (GT)	PT08.S2 (NMHC)	NOx (GT)	PT08.S3 (NOx)	NO2 (GT)	PT08.S4 (NO2)	PT08.S5 (O3)	T	RH	AH
CO (GT)	0,000	0,131	0,080	0,080	0,108	0,846	0,155	0,164	0,151	0,392	0,515	0,431
PT08.S1 (CO)	0,131	0,000	0,117	0,117	0,161	0,904	0,209	0,118	0,128	0,389	0,481	0,371
C6H6 (GT)	0,080	0,117	0,000	0,000	0,110	0,901	0,159	0,150	0,134	0,386	0,537	0,441
PT08.S2 (NMHC)	0,080	0,117	0,000	0,000	0,110	0,901	0,159	0,150	0,134	0,386	0,537	0,441
NOx (GT)	0,108	0,161	0,110	0,110	0,000	0,840	0,135	0,205	0,152	0,436	0,517	0,469
PT08.S3 (NOx)	0,846	0,904	0,901	0,901	0,840	0,000	0,781	0,884	0,870	0,601	0,518	0,621
NO2 (GT)	0,155	0,209	0,159	0,159	0,135	0,781	0,000	0,261	0,206	0,405	0,583	0,506
PT08.S4 (NO2)	0,164	0,118	0,150	0,150	0,205	0,884	0,261	0,000	0,175	0,384	0,433	0,300
PT08.S5 (O3)	0,151	0,128	0,134	0,134	0,152	0,870	0,206	0,175	0,000	0,443	0,478	0,418
T	0,392	0,389	0,386	0,386	0,436	0,601	0,405	0,384	0,443	0,000	0,709	0,413
RH	0,515	0,481	0,537	0,537	0,517	0,518	0,583	0,433	0,478	0,709	0,000	0,295
AH	0,431	0,371	0,441	0,441	0,469	0,621	0,506	0,300	0,418	0,413	0,295	0,000

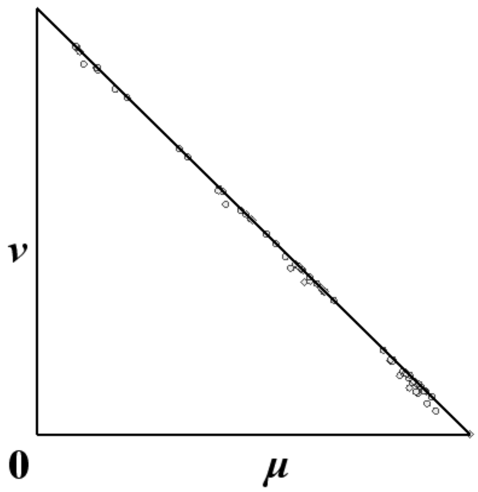

Fig. 1. IF pairs in the intuitionistic fuzzy triangle

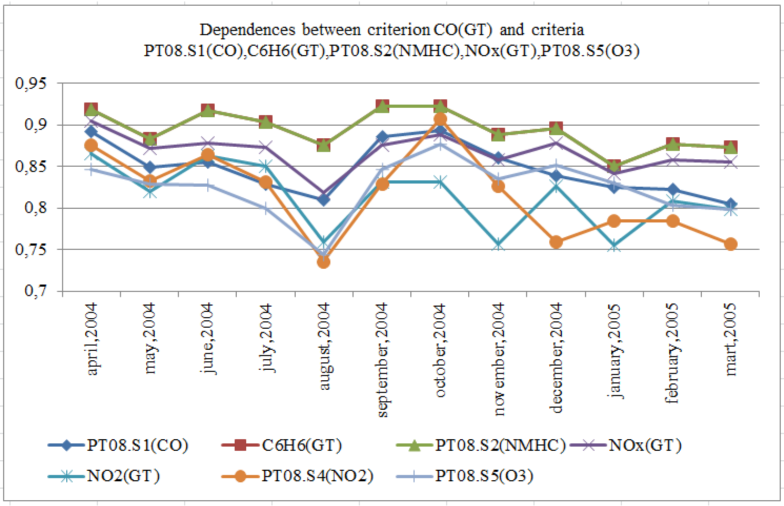

Fig. 2. Dependences between criterion CO(GT) and criteria PT08.S1(CO), C6H6(GT), PT08.S2(NMHC), NOx(GT), PT08.S5(O3)

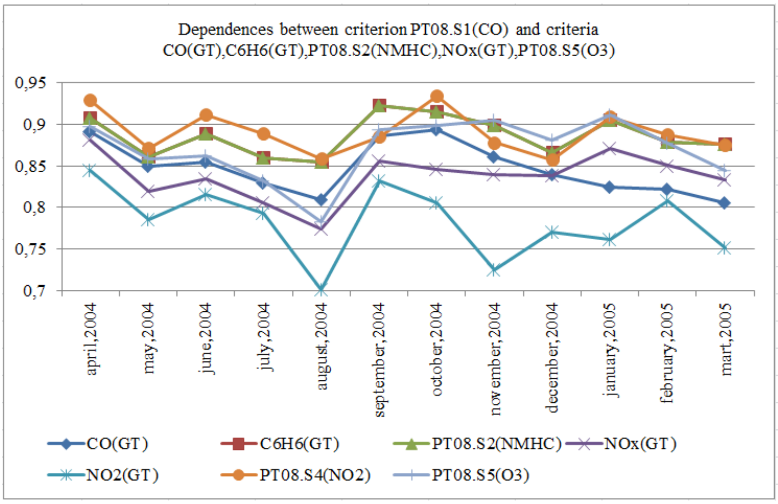

Fig. 3. Dependences between criterion PT08.S1(CO) and criteria CO(GT), C6H6(GT), PT08.S2(NMHC), NOx(GT), PT08.S5(O3)

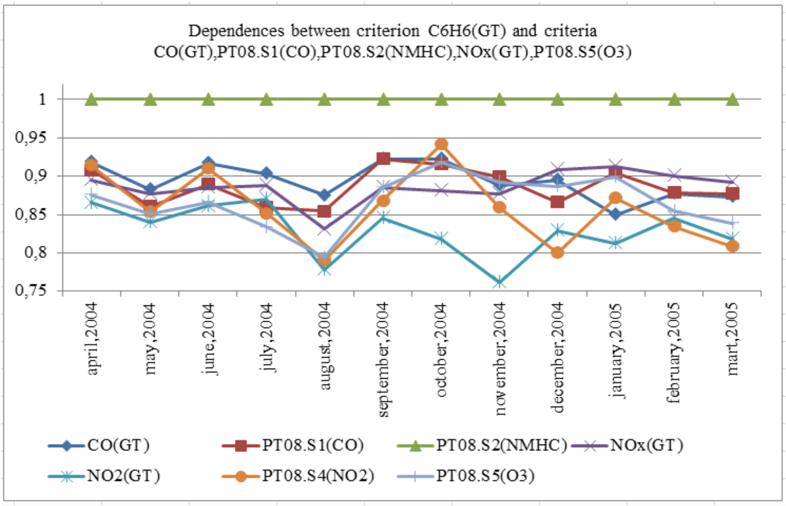

Fig. 4. Dependences between criterion C6H6(GT) and criteria CO(GT), PT08.S1(CO), PT08.S2(NMHC), NOx(GT), PT08.S5(O3)

4 Analysis of the results

Via the comparison of the results during the period of research the following outcomes are obtained:

- One pair of criteria is in strong positive consonance during the all period of research and we can ignore one of them: C6H6(GT)–PT08.S2(NMHC) ⟨1,000; 0,000⟩;
- Fourteen pairs of criteria are in positive consonance: CO(GT)–C6H6(GT), CO(GT)–PT08.S2(NMHC), C6H6(GT)–NOx(GT), PT08.S2(NMHC)–NOx(GT), PT08.S1(CO)–C6H6(GT), PT08.S1(CO)–PT08.S2(NMHC), PT08.S1(CO)–PT08.S4(NO_2), PT08.S1(CO)–PT08.S5(O3), C6H6(GT)–PT08.S5(O3), PT08.S2(NMHC)–PT08.S5(O3), CO(GT)–NOx(GT), NOx(GT)–NO_2(GT), PT08.S2(NMHC)–PT08.S4(NO_2), C6H6(GT)–PT08.S4(NO_2);
- Thirteen pairs of criteria are in weak positive consonance: NOx(GT)–PT08.S5(O3), CO(GT)–PT08.S1(CO), PT08.S1(CO)–NOx(GT), C6H6(GT)–NO_2(GT), PT08.S2(NMHC)–NO_2(GT), PT08.S4(NO_2)–PT08.S5(O3), CO(GT)–PT08.S5(O3), CO(GT)–NO_2(GT), CO(GT)–PT08.S4(NO_2), NOx(GT)–PT08.S4(NO_2), PT08.S1(CO)–NO_2(GT), NO_2(GT)–PT08.S5(O3), NO_2(GT)–PT08.S4(NO_2);
- The rest thirty-eight criteria are in weak dissonance, dissonance or in negative consonance;
- The correlation between criteria appears periodically;
- The dependences between criteria are relatively constant, but there is a very slight decrease over the time.

5 Conclusion

In the research reported here the authors have applied the ICA method to the data of the real dataset with measurements of hourly averaged responses from an array of 5 metal oxide chemical sensors embedded in an air quality chemical multisensor device. There is reasonable consistency across the criteria for period of the research. This would seem to indicate that the criteria and their measurements are reasonably reliable. The observations can thus help to determine the behavior of the criteria and relations among them over time.

In order to determine the behavior of each criteria over time we should observe the results of the application of ICA method for several years. If this criterion has a strong correlation, again, in the next step we can try to ignore it in future decision making without this having an adverse effect on the accuracy of the decision.

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