Notes on Intuitionistic Fuzzy Sets
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InterCriteria Analysis of data for blood collection in the Transfusion Hematology Department, University Hospital "St. Anna", Sofia

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Abstract: Maintaining a supply of safe blood and blood products is a national priority in many countries in the European Union. Achieving this aim requires the development and implementation of a national policy and the development of guidelines to the departments of transfusion hematology. There are a number of guidelines that spell out how quality and safety can be achieved. One of the most important factors for the improvement of the work of these departments is the number of the blood sample investigations of the donors and patients. In the present

paper application of the InterCriteria Analysis approach to data about the blood collection in the Department of Transfusion Hematology University Hospital "St. Anna", during a period of four years (2014–2018) is presented. The aim is to detect and analyse the dependencies between the investigated years based on the available data.
Keywords: InterCriteria Analysis, Transfusion hematology, Blood sampling.
2010 Mathematics Subject Classification: 03E72.

1 Introduction

Blood sampling and transfusions are an important part of hematologic care. Blood collection is an important preanalytical component of hematological testing and for the future transfusion which is the transfer of blood, its components, or products from one person (donor) into another person's bloodstream (recipient). Blood samples are usually collected daily from different collection points, such hospitals and health centers, and transported to a central laboratory for testing. The blood center is the location for the collection, receipt, processing, testing, storing and distribution of blood [1]. These centers are working according to some well-established standards. Directive 2002/98/EC has set standards of quality and safety for the collection, testing, processing, storage and distribution of human blood and blood components, which were further clarified and augmented by directives Directive 2004/33/EC devoted to the technical requirements, Directive 2005/61/EC focused on the monitoring and reporting of serious adverse events and reactions and Directive 2005/62/2005 which deals with the quality systems requirements [2]. There are a number of factors determining the good and efficient work of such centers. In general, the number of the blood samples and the quality of the performed tests are indicators for the well-organized management of the hematological departments. Any test performed in the laboratory of the blood center is subject to a variety of conditions that may influence the outcome of the result. Some of them include the sample itself, the test method, reagents used, and different operators carrying out the same process. Blood sample tests performed from the donors and patients are divided in two major groups: the laboratory tests of the donors and the immunohematological studies of the patients. The main laboratory tests performed on the collected blood from the donors are:

- Determination of the blood group from the ABO blood group system,
- Determination of Rh phenotype,
- Hemoglobin test.

The immunohematological studies of the patients are:

- Determination of the blood group from the ABO blood group system,
- Determination of Rh D antigen,
- Anti-erythrocyte allo-antibodies tests,
- Immunohematological studies in neonates for CKD (chronic kidney disease),
- Blood compatibility tests,
- Other blood tests (subgroup).

In the present paper application of the InterCriteria analysis approach to data about the blood collection and the number of the performed tests on the collected blood from the donors and the patients in the Department of Transfusion Hematology University Hospital “St. Anna”, during a period of four years (2014-2018) is presented. The aim is to detect and analyse the dependencies between the investigated years, based on the available data.

2 Notes on the InterCriteria Analysis

Let I be a fixed set of indices and $\mathcal{R}$ be the set of the real numbers. By IM with index sets K and L $(K, L \subset I)$, we denote the object:

$$[K, L, \{a_{k_i,l_j}\}] \equiv \begin{array}{c|cccc} & l_1 & l_2 & \dots & l_n \\ \hline k_1 & a_{k_1,l_1} & a_{k_1,l_2} & \dots & a_{k_1,l_n} \\ k_2 & a_{k_2,l_1} & a_{k_2,l_2} & \dots & a_{k_2,l_n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ k_m & a_{k_m,l_1} & a_{k_m,l_2} & \dots & a_{k_m,l_n} \end{array},$$

where $K = \{k_1, k_2, ..., k_m\},\ L = \{l_1, l_2, ..., l_n\},$ for $1 \le i \le m$, and $1 \le j \le n : a_{k_i,l_j} \in \mathcal{R}$.

In [3], different operations, relations and operators were defined over IMs. Here, we shall briefly remind some of them.

When the elements a_{k_i,l_j} are some variables, propositions or formulas, we obtain an extended IM with elements from the respective type. Then, we can define the evaluation function V that juxtaposes to this IM a new one with elements – Intuitionistic Fuzzy Pairs (IFPs) $\langle \mu, \nu \rangle$, where $\mu, \nu, \mu + \nu \in [0, 1]$ (see, [4]). This new IM, called Intuitionistic Fuzzy IM (IFIM), contains the evaluations of the variables, propositions, etc., and may be represented as:

$$V([K, L, \{a_{k_i,l_j}\}]) = [K, L, \{V(a_{k_i,l_j})\}] = [K, L, \{\langle \mu_{k_i,l_j}, \nu_{k_i,l_j} \rangle\}]$$

$$= \begin{array}{c|ccccc} & l_1 & \dots & l_j & \dots & l_n \\ \hline k_1 & \langle \mu_{k_1,l_1}, \nu_{k_1,l_1} \rangle & \dots & \langle \mu_{k_1,l_j}, \nu_{k_1,l_j} \rangle & \dots & \langle \mu_{k_1,l_n}, \nu_{k_1,l_n} \rangle \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ k_i & \langle \mu_{k_i,l_1}, \nu_{k_i,l_1} \rangle & \dots & \langle \mu_{k_i,l_j}, \nu_{k_i,l_j} \rangle & \dots & \langle \mu_{k_i,l_n}, \nu_{k_i,l_n} \rangle \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ k_m & \langle \mu_{k_m,l_1}, \nu_{k_m,l_1} \rangle & \dots & \langle \mu_{k_m,l_j}, \nu_{k_m,l_j} \rangle & \dots & \langle \mu_{k_m,l_n}, \nu_{k_m,l_n} \rangle \end{array},$$

where for every $1 \le i \le m, 1 \le j \le n$: $V(a_{k_i,l_j}) = \langle \mu_{k_i,l_j}, \nu_{k_i,l_j} \rangle$ and $\mu_{k_i,l_j}, \nu_{k_i,l_j}, \mu_{k_i,l_j} + \nu_{k_i,l_j} \in [0, 1]$.

Let us be given a set of objects $O = \{O_1, O_2, ..., O_n\}$ that must be evaluated by criteria from the set $C = \{C_1, C_2, ..., C_m\}$.

Then we can construct the IM :

$$A = \begin{array}{c|ccccccc} & O_1 & \cdots & O_i & \cdots & O_j & \cdots & O_n \\ \hline C_1 & a_{C_1,O_1} & \cdots & a_{C_1,O_i} & \cdots & a_{C_1,O_j} & \cdots & a_{C_1,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_k & a_{C_k,O_1} & \cdots & a_{C_k,O_i} & \cdots & a_{C_k,O_j} & \cdots & a_{C_k,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_l & a_{C_l,O_1} & \cdots & a_{C_l,O_i} & \cdots & a_{C_l,O_j} & \cdots & a_{C_l,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_m & a_{C_m,O_1} & \cdots & a_{C_m,O_i} & \cdots & a_{C_m,O_j} & \cdots & a_{C_m,O_n} \end{array},$$

where for every p, q ($1 \le p \le m\,,\ 1 \le q \le n$):

(1) C_p is a criterion, taking part in the evaluation,

(2) O_q is an object, being evaluated.

(3) a_{C_p,O_q} is a variable, formula or $a_{C_p,O_q} = \langle \alpha_{C_p,O_q}, \beta_{C_p,O_q} \rangle$ is an intuitionistic fuzzy pair, that is comparable about relation R with the other a-objects, so that for each i, j, k:

$$R(a_{C_k,O_i}, a_{C_k,O_j})$$

is defined. Let $\overline{R}$ be the dual relation of R in the sense that if $R(a_{C_k,O_i}, a_{C_k,O_j})$ is satisfied, then $\overline{R}(a_{C_k,O_j}, a_{C_k,O_i})$ is also satisfied. For example, if "R" is the relation "$<$", then $\overline{R}$ is the relation "$>$", and vice versa.

Let $S^{\mu}_{k,l}$ be the number of cases in which

$$\langle \alpha_{C_k,O_i}, \beta_{C_k,O_i} \rangle \le \langle \alpha_{C_k,O_j}, \beta_{C_k,O_j} \rangle \text{ and } \langle \alpha_{C_l,O_i}, \beta_{C_l,O_i} \rangle \le \langle \alpha_{C_l,O_j}, \beta_{C_l,O_j} \rangle$$

or

$$\langle \alpha_{C_k,O_i}, \beta_{C_k,O_i} \rangle \ge \langle \alpha_{C_k,O_j}, \beta_{C_k,O_j} \rangle \text{ and } \langle \alpha_{C_l,O_i}, \beta_{C_l,O_i} \rangle \ge \langle \alpha_{C_l,O_j}, \beta_{C_l,O_j} \rangle$$

are simultaneously satisfied.

Let $S^{\nu}_{k,l}$ be the number of cases in which

$$\langle \alpha_{C_k,O_i}, \beta_{C_k,O_i} \rangle \ge \langle \alpha_{C_k,O_j}, \beta_{C_k,O_j} \rangle \text{ and } \langle \alpha_{C_l,O_i}, \beta_{C_l,O_i} \rangle \le \langle \alpha_{C_l,O_j}, \beta_{C_l,O_j} \rangle$$

or

$$\langle \alpha_{C_k,O_i}, \beta_{C_k,O_i} \rangle \le \langle \alpha_{C_k,O_j}, \beta_{C_k,O_j} \rangle \text{ and } \langle \alpha_{C_l,O_i}, \beta_{C_l,O_i} \rangle \ge \langle \alpha_{C_l,O_j}, \beta_{C_l,O_j} \rangle$$

are simultaneously satisfied.

Obviously,

$$S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{n(n-1)}{2}.$$

Now, for every k, l, such that $1 \le k < l \le m$ and for $n \ge 2$, we define

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)}, \quad \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{n(n-1)}.$$

Hence,

$$\mu_{C_k,C_l} + \nu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)} + 2\frac{S^{\nu}_{k,l}}{n(n-1)} \leq 1.$$

Therefore, $\langle \mu_{C_k,C_l}, \nu_{C_k,C_l} \rangle$ is an IFP.

Now, we can construct the IM

$$\begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_m,C_1} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array},$$

that determines the degrees of correspondence between criteria $C_1, \ldots, C_m$. Based on these degrees of correspondence we can measure how close as behavior the criteria are. For further details we refer the interested reader to [5, 6].

3 Application of the InterCriteria Analysis

The ICrA approach was applied to data obtained from the laboratory tests of the donors and the immunohematological studies of the patients during a period of four years in the Department of Transfusion Hematology University Hospital "St. Anna". Eight indicators with a given weight are used:

- Determination of the blood group from the ABO blood group system,
- Determination of Rh phenotype,
- Hemoglobin test,
- Determination of Rh D antigen,
- Anti-erythrocyte allo-antibodies tests (AEAAD),
- Immunohematological studies in neonates for CKD (chronic kidney disease),
- Blood compatibility tests (BCT),
- Other blood tests (subgroup).

We have applied the ICrA to the data summarized in Table 1 and we have obtained the results shown in Tables 2 and 3. The visual interpretation of the results may be seen on Figure 1. The years with greatest positive consonance (in accordance with [5]), for the scale are 2014, 2017 and 2018, indicating that there may have been some difference with regard to 2015-2016 period.

Further we have considered data for the blood donors divided in age-groups for the different years. The data is given in Tables 4 and 5. The results are shown in Figure 2. It is noteworthy that for the male donors the years "2017-2018" are in strongest positive consonance while for the female donors the years that are in strongest positive consonance are: "2014-2015", followed closely by "2017-2018".

Year / Type	2014	2015	2016	2017	2018
ABO	8132	7312	8370	8768	10481
Rh D & P	9323	8454	8370	9999	11942
AEAAD	19692	12863	14352	15077	18037
CKD	118	146	154	182	177
BCT	18003	13285	17214	14841	15159
Other	4091	3818	4257	4525	5387

Table 1. Types of tests per different years

	2014	2015	2016	2017	2018
2014	1.0000	0.9333	0.8667	1.0000	1.0000
2015	0.9333	1.0000	0.9333	0.9333	0.9333
2016	0.8667	0.9333	1.0000	0.8667	0.8667
2017	1.0000	0.9333	0.8667	1.0000	1.0000
2018	1.0000	0.9333	0.8667	1.0000	1.0000

Table 2. The values of μ resulting from the application of ICrA

	2014	2015	2016	2017	2018
2014	0.0000	0.0667	0.0667	0.0000	0.0000
2015	0.0667	0.0000	0.0000	0.0667	0.0667
2016	0.0667	0.0000	0.0000	0.0667	0.0667
2017	0.0000	0.0667	0.0667	0.0000	0.0000
2018	0.0000	0.0667	0.0667	0.0000	0.0000

Table 3. The values of ν resulting from the application of ICrA

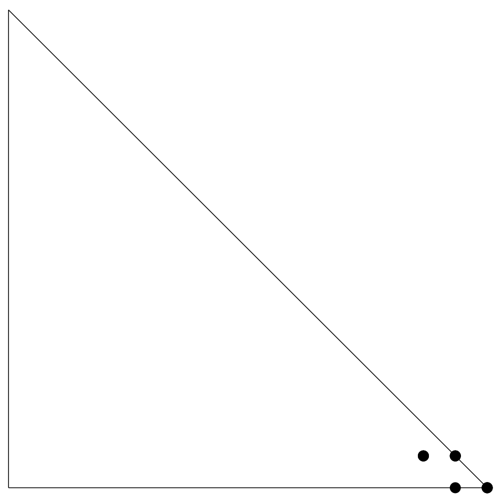

Figure 1. Visual interpretation of the results from ICrA

Year \ Age	Up to 20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	Over 60
2014	113	520	709	669	703	625	476	310	176	60
2015	80	371	630	614	606	617	424	300	167	45
2016	80	400	622	638	668	657	512	336	220	68
2017	102	441	617	694	690	620	477	346	190	67
2018	111	425	688	775	695	637	471	285	189	67

Table 4. Age groups of male donors per year

Year \ Age	Up to 20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	Over 60
2014	30	112	140	167	199	204	177	144	98	32
2015	18	75	122	159	163	167	152	131	73	23
2016	20	60	128	172	206	193	205	153	75	25
2017	26	78	138	119	194	170	185	142	77	42
2018	41	106	142	176	200	243	190	128	112	50

Table 5. Age groups of female donors per year

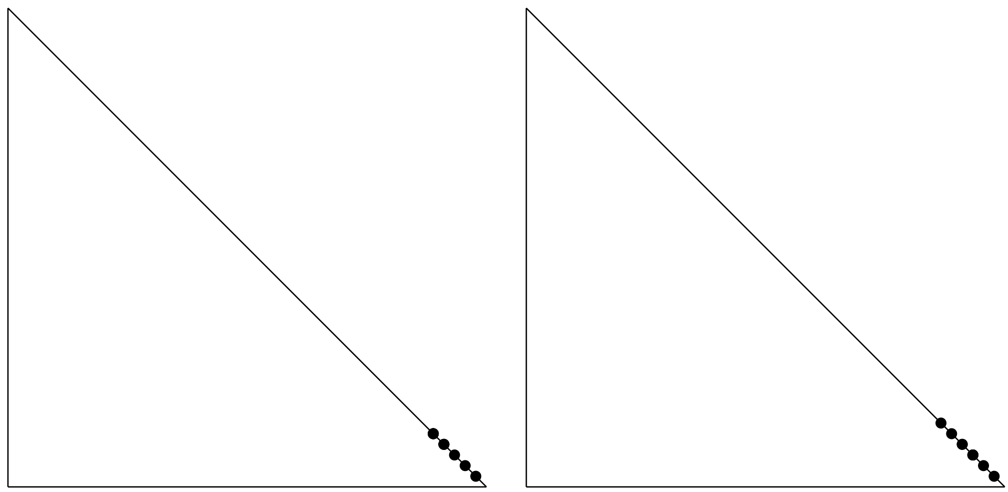

Figure 2. Visual interpretations of the results from ICrA
for the male (left) and female (right) blood donors.

4 Conclusion

From the comparisons of the results obtained during the period of research (2014–2018) the following conclusions can be obtained:
– The year pair "2017-2018" exhibits high degree of consonance for the considered data, which may be viewed as an indicator of stable performance during these years.
– Year pairs "2014-2017" and "2014-2018" usually also exhibit strong positive consonance. – Years 2015, 2016 are usually not in strong consonance with years 2014, 2017 or 2018, which may be interpreted as some deviation in the performance during the said years.

Naturally, given the relatively small size of the considered data it is not possible to claim with absolute certainty that our interpretations are doubtlessly valid but they provide a starting point for further investigations.

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