A model of fuzzy synthetic evaluation method realized by a neural network

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Abstract— This article is devoted to the development of method of solution for multicriteria problems of decision-making in conditions of uncertainty. A model of fuzzy synthetic evaluation method is proposed. The method is realized by a neural network. Weights of the method and the network coincide.

Keywords— decision making, method of a fuzzy synthetic evaluation, neural networks, multi-criteria tasks.

I. INTRODUCTION

The method of synthetic fuzzy evaluation is a method of the solution of multicriteria problems of decision-making in conditions of uncertainty. It is used for solving various problems when a complete assessment to some object with diverse properties is required [1], [2].

When using the method of synthetic fuzzy evaluation, the most important task is to define a quantitative assessment of the importance of various criteria: weights. Weights are mostly defined by experts, variously set weights lead to different results of estimation. The project involves the modification of the method of synthetic fuzzy evaluation realized by neural network where the method weights are defined at setting weight vectors of network.

Let’s find out a determination for the method of synthetic fuzzy evaluation [1]. Previously we will remind necessary concepts and definitions.

Definition. [3] Let $M$ be arbitrary set and $\mu_F: M \rightarrow [0,1]$. We say that $F$ is a fuzzy subset of the set $M$.

Here $\mu_F(x)$ is a membership function. Sometimes we will write $\mu$ instead of $F$. The value $\mu_F(x)$ is interpreted as a degree of membership of the element $x$ to a set $F$.

Let $M = \{S_1, \ldots, S_l\}$ be a finite set of assessed objects. The objects $S = (s_1, \ldots, s_n) \in \mathbb{R}^n$ are vectors of dimension of $n$. We say that $S$ is defined by $n$ properties or attributes. The value $s_i$ expresses the quantitative value of the $i$th property of the object $S$.

Let’s describe the method.

According each property an object belongs to one of $m$ classes. The object membership to the one of the classes is determined as follows.

Let the object $S = (s_1, \ldots, s_n)$ be set by $n$ properties. By each property of $i$ we can determine fuzzy sets $\mu_{ij}(x_i)$, $j = 1, \ldots, m$ (we will designate them as $\mu_{ij}$ corresponding to $m$ classes as follows.

Let $s_i \in \{y_{i1}, y_{i2}, \ldots, y_{im}\} \subseteq \mathbb{R}$. $[y_{i1}, y_{i2}, \ldots, y_{im}]$ breaks $m$ intervals $[y_{i1}, y_{i2}], [y_{i2}, y_{i3}], \ldots, [y_{im}, y_{i1+1}]$. Then the membership function $\mu_{ij}(x_i) = \mu_{ij}(x_i)$ is defined as follows:

$$
\mu_{ij}(x_i) = \begin{cases} 
\frac{|x_i - y_{ij}|}{|y_{ij+1} - y_{ij}|}, & \text{if } y_{ij+1} \leq x_i < y_{ij} \\
0, & \text{in the contrary case.}
\end{cases}
$$

The values $\mu_{ij}(x_i)$ turn diverse values of properties of $x_i$, $i = 1, \ldots, n$ of the object $S$ into homogenous, belonging to the segment of $[0,1]$. Let $S = (x_1, \ldots, x_n)$. The first level of the model of the synthetic fuzzy evaluation is described by the equation $w \cdot R = b$

where $w = (w_1, \ldots, w_n)$, $0 \leq w_i \leq 1$ is a weight vector, $R = (r_{ij})_{n \times m}$, $r_{ij} = \mu_{ij}(x_i)$, $b = (b_1, \ldots, b_m)$, $b_j = \sum_{i=1}^n w_i r_{ij}$, $j = 1, \ldots, m$. The weight vector is defined by experts of the subject domain of the problem.

Now let’s describe the second level of the model of synthetic fuzzy evaluation. It is supposed that at the first level we estimate the object $S$ by one factor, let be given $c$ factors $\Phi_1, \ldots, \Phi_c$ on which the evaluation of $S$ is made and $w' \cdot R' = b'j$, $j = 1, \ldots, c$ be the equations describing the first level of the model of the synthetic fuzzy evaluation on the factor $\Phi_j$, where $w' = (w'_{1j}, \ldots, w'_{nj})$ is a weight vector of $j$th factor, $R'j$ is a matrix made of values of membership functions for fuzzy sets $\mu_{kj}$ for $j$th factor, $b'j = (b'_{1j}, b'_{2j}, \ldots, b'_{mj})$ is a resultant vector of the first level of model for $j$th factor, $R'j = (r'_{kj})_{n \times m}$.

Let $b = (b_{ij})_{c \times m}$, $b_{ij} = \sum_{k=1}^c w_k r_{kij}$, $i = 1, \ldots, c$, $j = 1, \ldots, m$.

Then the second level of the model of synthetic fuzzy evaluation defined by equation $p = W \cdot B$, where $W = (W_1, \ldots, W_c)$ is a weight vector of the second level of the model of synthetic fuzzy evaluation, $p = (p_1, \ldots, p_m)$, $p_j = \sum_{i=1}^c W_j b_{ij}$ is a resultant vector of the second level. Similarly the 3rd, the 4th, etc. model levels are defined.

Let $I = (i_1, \ldots, i_m)$ is a resultant vector of the last level of the model of synthetic fuzzy evaluation, $i_k = \max\{|s| \in I |s| = 1, \ldots, m\}$. Then we believe that the object $S$ belongs to $k$th class.
II. THE MODIFICATION OF A METHOD OF SYNTHETIC FUZZY ASSESSMENT

The given work involves one model of the modified method of synthetic fuzzy evaluation realized by a neural network, where weights of method are defined by network weights. Let’s describe the model and review some definitions.

Definition. [5] The artificial neural systems or neural networks are systems physically organized as a system of cells which can do requests, store and use the empirical knowledge gained as a result of operation.

Let $M = \{S_1, \ldots, S_n\}$ be a finite set of evaluated objects, $S = (x_1, \ldots, x_n) \in R^n$, $a_i = \{(a_{i1}, \ldots, a_{in})\}$ be a finite lattice, where $a_i < a_j$ if $i < j$.

Definition. [4] $\mu_k: M \rightarrow \mathbb{L}$ is called a fuzzy subset $A$ of the set $M$.

It is believed that $\mu_k$ expresses a degree of membership of an element $S$ to a fuzzy set $A$ or, in our case, we suppose that $S$ with a degree of $\mu_k(S)$ possesses the estimated property.

The task of assessment of object $S$ will consist in determination of $\mu_k$. We suppose that $\mu_k$ accepts values of the natural language, expressing some quality, for example, good, bad, etc.

Determination of $\mu_k(S)$ happens at some stages called model levels. Depending on the quantity of levels we will distinguish one, two, etc. level models.

Let’s try to describe the first level of model.

Let $S = (x_1, \ldots, x_n) \in R^n$, $I_k = [y_k, y'_k] \subset R$, $k = 1, \ldots, n$ be segments of a set of the real numbers $R$. The $x_k$ variable takes values in $I_k$. Function $\mu_k, I_k \rightarrow \mathbb{L}$ is defined by experts of subject domain of the problem.

Further, we suppose that functions $\mu_k$ are either increasing or decreasing, i.e. $\mu_k(x_i) \leq \mu_k(x_j)$, whereas $x_i < x_j$ (or $\mu_k(x_i) \geq \mu_k(x_j)$, at $x_i < x_j$) which corresponds to the majority of real tasks of objects assessment.

The first level of model is described by the equation of

$$w \cdot T = b$$

where $w = (w_1, \ldots, w_n)$, $0 \leq w_i \leq 1$, $\sum_{i=1}^n w_i = 1$ is weight vector, $T = (t_{kj})_{n \times m}$, $b = (b_1, \ldots, b_m)$ is output vector, $b_j = \sum_{k=1}^n w_k t_{kj}$, $j = 1, \ldots, m$.

$$t_{kj} = \begin{cases} 1, & \text{if } \mu_k(x_i) = a_j \\ 0, & \text{on the contrary} \end{cases}$$

Finally, we determine the resultant vector $\bar{b} = (\bar{b}_1, \ldots, \bar{b}_m)$

$$\bar{b}_j = b_j/\sum_{i=1}^n b_i.$$ 

The object assessment at the level $k, k \geq 2$ occurs according to the following scheme.

1. Factors $\Phi_1, \ldots, \Phi_c$ for evaluation $S$ are defined.

2. To each factor $\Phi_i$ corresponds $n_i$ properties for an object assessment.

3. At each level, starting from the second, factors of the previous level appear as properties of the current level.

Now we will describe the second level of model. Let $\Phi_1, \ldots, \Phi_c$ be factors on which the assessment of object $S$ is made, $w' = (w'_{i1}, \ldots, w'_{ic})$ is a weight vector, $\bar{b}' = (\bar{b}'_{i1}, \ldots, \bar{b}'_{ic})$ is a resultant vector of the first level of model for factor $\Phi_i$, $t' = (t'_{ij})_{n_1 \times m}$.

Let $b = (b_{ij})_{cxm}$, $\bar{b}_{ij} = \bar{b}'_i$, $i = 1, \ldots, c, j = 1, \ldots, m$.

Form a matrix $B = (b_{ij})_{cxm}$ as follows. Let $t$ be closest integer to $\sum_{i=1}^m b_{ij}$ then $b'_{it} = \bar{b}'_t$ and $b'_{ir} = 0$ for all $r \neq t, i = 1, \ldots, c$. Then the second level of model is defined by the equation

$$p = W \cdot B'$$

where $W = (W_{ij})_{1 \times c}$ is weight vector of the second level of model, $W_{ij}$ weight of factor $\Phi_j$, $p = (p_1, \ldots, p_m)$, $p_j = \sum_{i=1}^c W_{ij} b_{ij}$, normalized vector $\overline{p} = (\bar{p}_1, \ldots, \bar{p}_m)$ is the resultant vector of the second level.

The 3rd, the 4th, etc. model levels are defined by the same way.

Let $T = (t_1, \ldots, t_m)$ be an resultant vector of the last level of model of synthetic fuzzy evaluation, let $k$ be closest integer to $\sum_{i=1}^m t_i$. Then we suppose that the object of $S$ with a degree of $a_k \in L$ possesses estimated property.

III. DEFINITION OF WEIGHT VECTORS

Determination of weights is an important task when using the method of synthetic fuzzy evaluation. Weights are usually defined by experts, variously defined weights lead to different results of assessment. The article also offers to realize the given method of assessment by neural network where the weights of the method are defined by the network weights.

Let’s give the network determination on the example of two factor, two-level models where the objects are estimated on three properties of $h_1, h_2$ on the first factor, on the second, on two properties of $h_1, h_2$. The lattice of $L = \{(a_1, a_2), <\}$ contains two elements, with $a_1 \neq a_2$. The network looks as follows (see figure below).

![Fig. 1 Network on the example of two factor, two-level models](image-url)
of two subnets, each of which estimates an object on one of
the factors. Let’s describe it.

0 layer. The signals corresponding to the values of
properties of an estimated object are given to the input layer
\((x_1, x_2, x_3)\) for the first factor and \((h_1, h_2)\) for the second one.
Weights from the 0 layer to the first are absent.

1 layer. \(t^i_{kj}\) calculation, \(1 \leq i \leq 3, 1 \leq j \leq 2, 1 \leq s \leq 2\).
It contains 5 neurons corresponding to the input signals
of \(x_1, x_2, x_3\) for the first factor, \(h_1, h_2\) for the second. The values
for the first factor, \(\mu_{ik}(x_s)\), \(z^i_k = |x_k - y''_k|/|y'_k - y''_k|\),
\(k = 1, 2, 3\) are calculated on this layer. The vector \(t^i_{kj}\) is
formed for each neuron as follows. If \(\mu_{ij}(x_k) = a_j\), then
\(t^i_{kj} = z^i_k\), \(t^i_{k5} = 0\) for \(s \neq j\). The signals \(t^i_{k1}, l = 1, 2, k = 1, 2, 3\)
go to \(l\) neuron of the second layer. The similar calculations
are made for the second factor.

2 layer. Contains 2 neurons for each factor. Neurons
correspond to values \(a_1, a_2\) of the lattice \(L\).
These are calculated in the second layer \(b^j_l = (b^j_1, b^j_2)\), \(i = 1, 2, 3\),
and normalized vector \(\bar{b}^j_l = (\bar{b}^j_1, \bar{b}^j_2)\) where \(b^j_l = \sum_{k=1}^{q_j} w^j_{kl} b^j_k\),
\(n_1 = 3, n_2 = 3, j = 1, 2, w^j_{kl}\) is the weight of line
going from \(k\)th neuron of the first layer to \(j\)th neuron of the second
layer of the \(t\)th factor. The weights from the second layer
to the third are absent.

3 layer. The third layer is output for the first level and
corresponds to the calculation of a matrix of \(B^t\). The layer
contains one neuron for each factor. The vector of \((b^i_1, b^i_2)\)
is formed for the factor of \(\Phi_i\), \(i = 1, 2\), as follows: such \(t\) is
calculated that \(t\) be closest integer to \(\sum_{j=1}^{m_i} \bar{b}^i_j\) so, \(b^{i}_1 = \bar{b}^{i}_1\)
and \(b^{i}_2 = 0\) for \(r \neq t\), \(i = 1, 2\).
The second network consists of the third layer of the first
network and the second part of the general network. It will be
used for finding weights of the second level. Let’s try to
describe it.

1 layer. Consists of two neurons, one for each factor. The
vectors \((b^i_1, b^i_2)\), \(i = 1, 2, 3\), calculated on the third layer of
the first network are input vectors of the neurons first layer.
The signals \(b^i_1, i = 1, 2\) move to \(j\)th neuron of the second layer.

2 layer. Corresponds to calculation of the output vector of
the second level \(p = (p_1, p_2)\) and normalized vector \(\bar{p} = (\bar{p}_1, \bar{p}_2)\).
The 2nd layer consists of two neurons on which \(p_j = \sum_{i=1}^{q_j} W_{ij} b^i_j\) are calculated, where \(W_{ij}\)
are weights corresponding to network lines going from \(i\)th neuron of the
1st layer to \(j\)th neuron of the 2nd layer. Weights from the second
layer to the third are absent.

3 layer. Finds out the \(k\) that is the closest integer to
\(\sum_{j=1}^{2} \bar{p}_j\). The 3rd layer contains one neuron. The number \(k\)
is output of the network. We suppose that the object with a
degree of \(a_k\) possesses the estimated property.

IV. NETWORK TRAINING
The modification of generalized \(\delta\)-rule is used for training
of the both networks [5]. Let’s consider training of the first
network. The training set consists of pairs \(\{(x_1, \ldots, x_n, k)\}\),
where \(x = (x_1, \ldots, x_n)\) is an estimated object, \(k\) is an integer.
It is supposed that for the pair \(\{(x_1, \ldots, x_n, k)\}\) the object
\(S = (x_1, \ldots, x_n)\) with a degree of \(a_k\) possesses the estimated property.
Let’s attach to all weights of a network some values close to
"0". Let \(b\) be value of an output for the input \(S = (x_1, \ldots, x_n)\)
from the pair \(\{(x_1, \ldots, x_n, k)\}\). Let’s determine
\(\sigma_r = \begin{cases} 0 & \text{if } r = l \\ 1 & \text{if } r \neq l \end{cases}\)
Then the weights of a network change as follows:
\(w_{kl}^n(n) = w_{kl}^n(n - 1) + \delta^i_{kl} \) for each of \(s = 1, \ldots, c\) factors,
where \(\delta^i_{kl} = \eta \sigma f_k\). \(n\) is a step of training.
\(n = 1, \ldots, |\{(x_1, \ldots, x_n, k)\}|\). \(f_k\) is a value of output signal
from \(k\)th neuron of the layer 1, \(\eta\) is a coefficient of training
speeds which allows to control the average size of weights
change, \(\delta^i_{l}\) is a correction connected with an output from
\(k\)th neuron of the layer 1, \(w_{kl}^n(n)\) is a value of weight after the correction,
\(w_{kl}^n(n - 1)\) is the value of weight before the correction.
Note the following.
1. At each step of training if there is a pair on the input
\(\{(x_1, \ldots, x_n, k)\}\), it only changes the weights corresponding to
the lines directed to \(k\)th neuron and on which nonzero signals
from neurons of the first layer flow.
2. Upon the completion of the process of training let’s put
\(w_{kl} = w_{ik} = \max\{|w_{ij}|, 1 \leq i, s \leq m, 1 \leq l \leq n\}\). Let’s suppose that
\(w_{ik} = \frac{w_{ik}}{\sum_{j=1}^{m_i} \sum_{r=1}^{n_i} w_{jr}}\) for \(1 \leq i \leq n, 1 \leq k \leq m\)
is a weight of \(i\)th property of a method of
synthetic fuzzy evaluation.
Let \(\{(x_1, \ldots, x_n, k)\}\) be a a training set. From 1 it follows
that in the received trained network on input \((x_1, \ldots, x_n)\)
we will get output \(i\).
Training of the second subnetwork is performed similarly.
After the completion of the training process both
subnetworks are united so that the output layer of the first
subnetwork, which consists of neurons on which \((b^i_1, b^i_2)\),
\(i = 1, 2\) are calculated will coincide with the first layer of the
second subnetwork and form the 3rd layer of the network.
The received network realizes offered two-level model of
the method of synthetic fuzzy evaluation.

V. AN APPLICATION FOR THE METHOD OF SYNTHETIC
FUZZY EVALUATION TO EVALUATION OF AIR QUALITY
In this section one application of the method of synthetic
fuzzy evaluation is offered: evaluation of air quality. We will
give the description of the method on the example of two-level
model.
Our model consists of three factors. The first and third
factors include 15 properties each, the second factor only one
property. As a result of an evaluation the object will belong to
one of five classes corresponding to the following degrees of
purity of air Very Pure, Pure, Average, Dirty, Very Dirty. That
is lattice \(L\) consists of 5 elements \(L = \{a_1, \ldots, a_5; <\}\) that
correspond to these degrees of purity.
The data have been taken according to the State Standards
of the Republic of Kazakhstan No. 14-5-2244/I from
31.03.2011 about “Sanitary and epidemiologic requirements to
atmospheric air", and interstate standard of pure rooms and
related controlled environments, part 1. Classification of air
purity” State Standard 14644-1-2002, the appendices of
hygienic standards 2.1.6.2177-07 “The Maximum Permissible
Concentration (MPC) of microorganisms - producers, bacterial
preparations and their components in atmospheric air in the settlements”. Let’s describe the factors.

I. Content of harmful chemicals (mg/m³). This factor is characterized by the following 15 properties: content of epichlorohydrin, toluol, phenol, aniline, formaldehyde, butyl alcohol, methyl anhydride, isopropyl alcohol, acetone, CO carbon oxide, dioxide of sulfur, hydrogen sulfide, oxide of nitrogen, nitrogen dioxide.

II. Concentration of particles (particles/m³)

III. Concentration of microorganisms producers, bacterial preparations and their components in atmospheric air in the concentration of nitrogen, nitrogen dioxide.

At the second level the matrix is formed according to the content of harmful chemicals and the components in preparation and their components (mg/m³). This factor is characterized by the following 15 properties: maintenance of Acetobacter methylicum, Actinomyces roseolus, Alcaligines denitrificans, Anasargillus awamori, Bacillus amyloliquefaciens, Bacillus licheniformis, Bacillus licheniformis, Bacillus polymyxa, Bacillus subtilis, Brevibacterium flavum, Candida tropicalis, Clostridium acetobutlicum, Penicillium canescens, Trichoderma viride, Yarrowia lipolytica.

The vector of an evaluation is calculated by a formula \( V_B = \mathbf{w}^T \mathbf{T}^i \), corresponding normalized vectors \( \mathbf{B}^i \) are obtained by normalizing \( \mathbf{p}, \mathbf{p} = \mathbf{w} \mathbf{B}^i \), here \( \mathbf{w}, \mathbf{w} \) are weight vectors. As a result of evaluation we get number \( k \in \{1, \ldots, 5\} \), and air quality will be estimated by value \( a_k \), that is as Very Pure or Pure or Average and so on.

### Table. Criteria of an evaluation of air purity of the room according to the content of harmful chemicals

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Linguistic assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epichlorohydri</td>
<td>([0-0.05] )</td>
</tr>
<tr>
<td>Toluene</td>
<td>([0-0.2] )</td>
</tr>
<tr>
<td>Phenol</td>
<td>([0-0.001] )</td>
</tr>
<tr>
<td>Aniline</td>
<td>([0-0.01] )</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>([0-0.001] )</td>
</tr>
<tr>
<td>Alcohol butyl</td>
<td>([0-0.02] )</td>
</tr>
<tr>
<td>Alcohol anhydride</td>
<td>([0-0.01] )</td>
</tr>
<tr>
<td>Alcohol isopropyl</td>
<td>([0-0.2] )</td>
</tr>
</tbody>
</table>

The two-level, multiple-factor model modified for air quality assessment is developed.

REFERENCES


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