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

J. Tussupov, L. La, A. Mukhanova

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 an 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 $\mu_F: M \to [0,1]$. We say that F is a fuzzy subset of the set M.

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

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

Let's describe the method.

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

J.A. Tussupov is from L.N. Gumilyev Eurasian National University, Astana, Kazakhstan (corresponding author to provide phone: +7 701 789 27 10; e-mail: tussupov@mail.ru).

L.L. La is from L.N. Gumilyev Eurasian National University, Astana, Kazakhstan (e-mail: lira_la@hotmail.com)

A.A. Mukhanova is from L.N.Gumilyov Eurasian Natinal University, Astana, Kazakhstan (corresponding author to provide phone: +7 775 530 59 77; e-mail: ayagoz198302@mail.ru)

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

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

$$\mu_{ij}(x_i) = \begin{cases} \dfrac{|x_i - y_{i_j}|}{|y_{i_{j-1}} - y_{i_j}|}, & \text{if} \quad y_{i_{j-1}} \le x_i < y_{i_j} \\ 0, & \text{in the contrary case.} \end{cases}$$

The values $\mu_{ij}(x_i)$ turn diverse values of properties of x_i, $i = 1, \dots, n$ of the object $\boldsymbol{S}$ into homogenious, belonging to the segment of [0,1].

Let $\boldsymbol{S} = (x_1, \dots, x_n)$. The first level of the model of the synthetic fuzzy evaluation is described by the equation

$$\boldsymbol{w} \cdot \boldsymbol{R} = \boldsymbol{b}$$

where $\boldsymbol{w} = (w_1, \dots, w_n)$, $0 \le w_i \le 1$ is a weight vector, $\boldsymbol{R} = (r_{ij})_{n \times m}$, $r_{ij} = \mu_{i,j}(x_i)$, $\boldsymbol{b} = (b_1, \dots, b_m)$, $b_j = \sum_{i=1}^{n} w_i r_{ij}$, $j = 1, \dots, m$. 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 $\boldsymbol{S}$ by one factor, let be given c factors $\Phi_1, \dots, \Phi_c$ on which the evaluation of $\boldsymbol{S}$ is made and $\boldsymbol{w}^i \cdot \boldsymbol{R}^i = \boldsymbol{b}^i$, $i = 1, \dots, c$ be the equations describing the first level of the model of the synthetic fuzzy evaluation on the factor Φ_i, where $\boldsymbol{w}^i = (w_1^i, \dots, w_{n_i}^i)$ is a weight vector of ith factor, $\boldsymbol{R}^i$ is a matrix made of values of membership functions for fuzzy sets μ_{kj} for ith factor, $\boldsymbol{b}^i = (b_1^i, b_2^i, \dots, b_m^i)$ is a resultant vector of the first level of model for ith factor, $\boldsymbol{R}^i = (r_{kj}^i)_{n_i \times m}$.

Let $\boldsymbol{B} = (b_{ij})_{c \times m}$,

$$b_{ij} = b_j^i = \sum_{k=1}^{n} w_k^i r_{kj}^i, \qquad i = 1, \dots, c, \qquad j = 1, \dots, m.$$

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

Let $I = (i_1, \dots, i_m)$ is a resultant vector of the last level of the model of synthetic fuzzy evaluation, $i_k = \max\{i_s | s = 1, \dots, m\}$. Then we believe that the object $\boldsymbol{S}$ belongs to kth 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 system of cells which can do requests, store and use the empirical knowledge gained as a result of operation.

Let $M = \{S_1, \dots, S_t\}$ be a finite set of evaluated objects, $\boldsymbol{S} = (x_1, \dots, x_n) \in R^n$, $L = \langle \{a_1, \dots, a_m\}, < \rangle$ be a finite lattice, where $a_i < a_j$ if $i < j$.

Definition. [4] Map $\mu_A: M \to L$ is called a fuzzy subset A of the set M.

It is believed that μ_A expresses a degree of membership of an element $\boldsymbol{S}$ to a fuzzy set A or, in our case, we suppose that $\boldsymbol{S}$ with a degree of $\mu_A(\boldsymbol{S})$ possesses the estimated property. The task of assessment of object $\boldsymbol{S}$ will consist in determination of $\mu_A(\boldsymbol{S})$.

We suppose that a_i accept values of the natural language, expressing some quality, for example, good, bad, etc.

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

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

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

Further, we suppose that functions μ_{I_k} are either increasing or decreasing, i.e. $\mu_{I_k}(x_i) \le \mu_{I_k}(x_j)$, whereas $x_i \le x_j$ (or $\mu_{I_k}(x_i) \ge \mu_{I_k}(x_j), at\ x_i \le x_j$) which corresponds to the majority of real tasks of objects assessment.

The first level of model is described by the equation of

$$\boldsymbol{w} \cdot \boldsymbol{T} = \boldsymbol{b}$$

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

$$t_{kj} = \begin{cases} \dfrac{|x_k - y^{''}_k|}{|y_k^{'} - y^{''}_k|} & \text{if } \mu_{I_k}(x_k) = a_j \\ 0, & \text{on the contrary.} \end{cases}$$

Finally, we determine the resultant vector $\bar{\boldsymbol{b}} = (\overline{b_1}, \dots, \overline{b_m})$ where $\bar{b}_i = b_i / \sum_{j=1}^{m} b_j$.

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

1. Factors $\Phi_1, \dots, \Phi_c$ for evaluation $\boldsymbol{S}$ are defined.

2. To each factor Φ_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 $\Phi_1, \dots, \Phi_c$ be factors on which the assessment of object $\boldsymbol{S}$ is made, $\boldsymbol{w}^i \cdot \boldsymbol{T}^i = \boldsymbol{b}^i,\ i = 1, \dots, c$ be equations describing the first level of model on a factor Φ_i, where $\boldsymbol{w}^i = (w_1^i, \dots, w_{n_i}^i)$ is a weight vector, $\bar{\boldsymbol{b}}^i = (\bar{b}_1^i, \dots, \bar{b}_m^i)$ is an resultant vector of the first level of model for factor Φ_i, $\boldsymbol{T}^i = (t_{kj}^i)_{n_1 \times m}$.

Let $\boldsymbol{B} = (\bar{b}_{ij})_{c \times m}$, $\bar{b}_{ij} = \bar{b}_j^i$, $i = 1, \dots, c,\ j = 1, \dots, m$.

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

$$\boldsymbol{p} = \boldsymbol{W} \cdot \boldsymbol{B}'$$

where $\boldsymbol{W} = (W_1, \dots, W_c)$ is weight vector of the second level of model, W_i weight of factor Φ_i , $\boldsymbol{p} = (p_1, \dots, p_m)$, $p_j = \sum_{i=1}^{c} W_i b_{ij}^{'}$, normalized vector $\bar{\boldsymbol{p}} = (\bar{p}_1, \dots, \bar{p}_m)$ is the resultant vector of the second level.

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

Let $\bar{\boldsymbol{I}} = (\bar{\iota}_1, \dots, \bar{\iota}_m)$ be an resultant vector of the last level of model of synthetic fuzzy evaluation, let k be closest integer to $\sum_{j=1}^{m} j\, \bar{\iota}_j$. Then we suppose that the object of $\boldsymbol{S}$ 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 x_1, x_2, x_3 on the first factor, on the second, on two properties of h_1, h_2. The lattice of $L = \langle \{a_1, a_2\}, < \rangle$ contains two elements, with $a_1 \ne a_2$. The network looks as follows (see figure below).

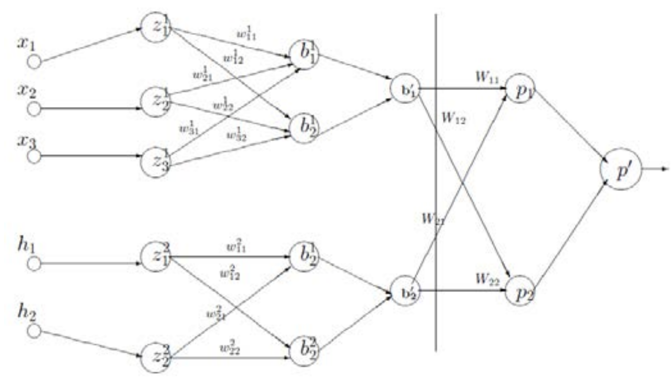

Fig. 1 Network on the example of two factor, two-level models

To calculat the weights of the method of synthetic fuzzy evaluation we'll break the network into two parts corresponding to the first and second levels of model. In figure 1 this splitting is represented by the vertical line. Each of the parts is used for formation of two new networks. The first network realizes one-level model of synthetic fuzzy evaluation, corresponds to the first level of initial model and is applied to calculate weights of the first level. It also consists 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_{ij}^s calculation, $1 \le i \le 3$, $1 \le j \le 2$, $1 \le s \le 2$. 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, $\mu_{I_k}(x_k)$, $z_k^1 = |x_k - y''_k|/|y'_k - y''_k|$, $k = 1,2,3$ are calculated on this layer. The vector (t_{k1}^1, t_{k2}^1) is formed for each neuron as follows. If $\mu_{I_k}(x_k) = a_j$, then $t_{kj}^1 = z_k^1$, $t_{ks}^1 = 0$ for $s \ne j$. The signals t_{kl}^1, $l = 1,2$, $k = 1,2,3$ 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 $b^i = (b_1^i, b_2^i)$, $i = 1,2$, and normalized vector $\overline{\boldsymbol{b}}^i = (\bar{b}_1^i, \bar{b}_2^i)$ where $b_j^i = \sum_{k=1}^{n_i} w_{kj}^i t_{kj}^i$, $n_1 = 3, n_2 = 3$, $j = 1,2$, w_{kj}^i is the weight of line going from kth neuron of the first layer to jth neuron of the second layer of the ith 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'. The layer contains one neuron for each factor. The vector of $(b_1^{i\prime}, b_2^{i\prime})$ is formed for the factor of Φ_i $i = 1,2$, as follows: such t is calculated that t be closest integer to $\sum_{j=1}^{m} j\, \bar{b}_{ij}$ so, $b_t^{i\prime} = \bar{b}_t^i$ and $b_r^{i\prime} = 0$ for $r \ne t$, $i = 1,2$.

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 $(b_1^{i\prime}, b_2^{i\prime})$, $i = 1,2$, calculated on the third layer of the first network are input vectors of the neurons first layer. The signals $b_j^{i\prime}$, $i = 1,2$ move to jth neuron of the second layer.

2 layer. Corresponds to calculation of the output vector of the second level $\boldsymbol{p} = (p_1, p_2)$ and normalized vector $\overline{\boldsymbol{p}} = (\bar{p}_1, \bar{p}_2)$ The 2nd layer consists of two neurons on which $p_j = \sum_{i=1}^{2} W_{ij} b'^{i}_{j}$ are calculated, where W_{ij} are weights corresponding to network lines going from ith neuron of the 1st layer to jth 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 $\sum_{j=1}^{2} j\, \bar{p}_j$. 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 δ-rule is used for training of the both networks [5]. Let's consider training of the first network. The training set consists of pairs $\{\langle (x_1, \dots, x_n), k \rangle\}$, where $\boldsymbol{x} = (x_1, \dots, x_n)$ is an estimated object, k is an integer. It is supposed that for the pair $\langle (x_1, \dots, x_n), k \rangle$ the object $\boldsymbol{S} = (x_1, \dots, x_n)$ 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 l be value of an output for the input $\boldsymbol{S} = (x_1, \dots, x_n)$ from the pair $\langle (x_1, \dots, x_n), k \rangle$. Let's determine

$$\sigma_r = \begin{cases} 0 & \text{if } r = l \\ 1 & \text{if } r \ne l. \end{cases}$$

Then the weights of a network change as follows: $w_{ki}^s(n) = w_{ki}^s(n-1) + \delta_{ik}$ for each of $s = 1, \dots, c$ factors, where $\delta_{ik} = \eta \sigma_i f_k$, n is a step of training, $n = 1, \dots, |\{\langle (x_1, \dots, x_n), k \rangle\}|$, f_k is a value of output signal from kth neuron of the layer 1, η is a coefficient of *training speeds* which allows to control the average size of weights change, δ_i is a correction connected with an output from kth neuron of the layer 1, $w_{ki}^s(n)$ is a value of weight after the correction, $w_{ki}^s(n-1)$ 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 $\langle (x_1, \dots, x_n), k \rangle$, it only changes the weights corresponding to the lines directed to kth 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 $w_{ik} = w_{is} = \max\{w_{ij} | j = 1, \dots, m\}$ for $1 \le k, s \le m$, $1 \le i \le n$. Let's suppose that $w_{ik} = \frac{w_{ik}}{\sum_{j=1}^{n} \sum_{t=1}^{m} w_{jt}}$, $1 \le i \le n, 1 \le k \le m$ is a weight of ith property of a method of synthetic fuzzy evaluation.

Let $\{\langle (x_1, \dots, x_n), k \rangle\}$ be a a training set. From 1 it follows that in the received trained network on input $(x_1, \dots, x_n)$ 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 $(b_1^{i\prime}, b_2^{i\prime})$, $i = 1,2$ 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 aplication 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 latice L consists of 5 elements $L = \langle a_1, \dots, a_5; < \rangle$ that corespond 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/m^3). 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/m^3)

III. Concentration of microorganisms producers, bacterial preparations and their components (mg/m^3). This factor is characterized by the following 15 properties: maintenance of Acetobacter methylicum, Actinomyces roseolus, Alcaligines denitrificans, Aspergillus awamori, Bacillus amyloliquefaci ens, Bacillus licheniformis, Bacillus licheniformis, Bacillus polymyxa, Bacillus subtilis, Brevibacterium flavum, Candida tropicalis, Clostridium acetobutilicum, Penicillium canescens, Trichoderma viride, Yarrowia lipolytica.

At the first level we form matrixes $R = (r_{ij})_{n\times m}$ according to formulas given in first section. For example, for the first factor it will be the matrix of $(r_{ij})_{15\times 5}$ calculated according to table below. We will show only some part of the table.

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

Criteria	Attributes	Linguistic assessment				
		VP	P	A	D	VD
Concntytation of harmful chemicals (мг\\m^3)	Epichlorohydrin	[0-0,05)	[0,05-0,1)	[0,1-0,2)	[0,2-0,3)	[0.3-0,5]
	Toluene	[0-0,2)	[0,2-0,4)	[0,4-0,6)	[0,6-0,8)	[0,8-1,0]
	Phenol	[0-0,001)	[0,001-0,002)	[0,002-0,003)	[0,003-0,004)	[0,004-0,005]
	Aniline	[0-0,01)	[0,01-0,02)	[0,02-0,03)	[0,03-0,06)	[0,06-0,1]
	Formaldehyde	[0-0,001)	[0,001-0,002)	[0,002-0,003)	[0,003-0,004)	[0,004-0,005]
	Alcohol butyl	[0-0,02)	[0,02-0,05)	[0,05-0,1)	[0,1-0,2)	[0,2-0,5]
	Metil anhydride	[0-0,01)	[0,01-0,03)	[0,03-0,05)	[0,05-0,1)	[0,1-0,2]
	Alcohol isopropyl	[0-0,2)	[0,2-0,4)	[0,4-0,6)	[0,6-0,8)	[0,8-1,0]

The vector of an evaluation is calculated by a formula $\boldsymbol{b}^i = \boldsymbol{w}^i\boldsymbol{T}^i$, $i = 1,2,3$ and correspondig normalized vectors $\overline{\boldsymbol{b}}^i$. At the second level the matrix $\boldsymbol{B}$ consists of three lines corresponding to vectors of evaluation for three factors. The resulting vector $\overline{\boldsymbol{p}}$ of the second level can be obtained by normilizing $\boldsymbol{p}$, $\boldsymbol{p} = \boldsymbol{w}\boldsymbol{B}'$, here $\boldsymbol{w}^i, \boldsymbol{w}$ are weight vectors. As a result of evaluation we get number $k \in \{1, \dots ,5\}$, and air purity will be estimated by value a_k , that is as Very Pure or Pure or Average and so on.

VI. Conclusion

This article is devoted to the problem of automatic determination of weights for method of fuzzy synthetic evaluation. The modification of the method of synthetic fuzzy evaluation realized by neural network is offered. Weights of the method and the network coincide. The proposed method is multilevel and multifactor one.

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

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Tussupov Jamalbek is Doctor of physic and mathematical science, full professor, chair of information systems department, L.N.Gumilyov Eurasian Natinal University, Astana, Kazakhstan

La Lira is associated professor, L.N.Gumilyov Eurasian Natinal University, Astana, Kazakhstan

Mukhanova Ayagoz is third year doctoral student, master of Information systems, L.N.Gumilyov Eurasian Natinal University, Astana, Kazakhstan