A method for evaluating geo-environmental technologies based on a weighted convolution of partial performance criteria in the Mathlab environment.

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Abstract

The present paper proposes a model for evaluating geo-ecological protection technologies based on multi-criteria optimization and weighted convolution criteria, on the basis of which the method of calculation is developed, allowing to determine the PQ factor for different objects according to the selected technologies using the Mathlab environment. The work demonstrated the application of the technique in the case of materials made of ash foam concrete with densities and ash content from the incineration of sewage sludge. The determination of the optimum composition of solopenobeton is relevant for the design of noise shields in railway transport. The proposed simulation algorithm in the Matlab environment makes it possible to use the procedure of processing the raw data, using several options of their input: in the form of tables of the format. csv or manual input.

Keywords

multi-criteria optimization, collation of criteria, Matlab, geo-ecoprotective technologies, PQ index

1. Introduction

In today's world, the development of waste-free and low-waste technologies in industrial sectors and transport infrastructures against the backdrop of the crises in economic development is particularly important: An environmentally and economically sound approach to the development of new waste management technologies[1]. [1], [2]. Methodologies for assessing such waste management technologies are also necessary [3], [4].

Existing methods for the assessment of geo-environmental protection technologies [5], [6] do not provide a complete picture of the technologies proposed and often address only one group of criteria. This approach does not provide an objective assessment of all possible groups of criteria to be taken into account by decision makers when using the technology.

Therefore, along with the development of new geo-environmental protection technologies, an integrated assessment model based on the full set of existing criteria (environmental, technological and other) is needed to provide an objective assessment of the technology.

A current problem is the creation of recycling technologies and materials from waste products and their further use in various industrial and transport sectors. Waste ash from the incineration of sewage sludge is one of the types of municipal waste that are currently under-managed. The ash has an elevated natural radiation background and is a source of dust in landfills [4], [7].

The recycling of such ash is therefore an important issue in the housing and utilities sectors and affects the environmental group of criteria for the use of technologies [8].

The percentage of sand content substituted by ash, i.e. the replacement of one material - sand, with

Models and Methods for Researching Information Systems in Transport , December 11–12, 2020, Saint-Petersburg, Russia
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another - with ash, is taken into account in the assessment of the technology to be developed for the recycling of ash from the incineration of sewage sludge. The new material received the name ash foam concrete [9], [10], [11], [12].

This produced material (ash foam concrete) is tested according to different process criteria. [13], [14]. The use of recyclable material (ash) in the next production cycle is also taken into account. The use is to protect the public from noise in the railway industry [15].

The present paper proposes a model for evaluating geoecoprotective technologies based on multi-criteria optimization and weighted convolution criteria. On the basis of this model, a calculation methodology has been developed, which makes it possible to determine the PQ factor for different objects according to the selected technologies using the Mathlab environment.

The work demonstrated the application of the technique in the example of materials made of ash foam concrete, which are dense and containing ash from incineration of sludge in an amount of 50% of sand. The definition of the optimum composition of ash foam concrete is relevant for the application in the design of noise shields in railway transport [4].

The entire chain of technology is suggested as a sequence of processes: ash recycling, neutralizing its harmful properties and reducing noise in populated areas. [19].

2. Problem statement

Let's define by $\mathbf{W} = \{W_s\}_{s=1}^{k}$ the set of possible groups of criteria. Here is $W_s = \{w_{s1},\dots,w_{sj_s}\} - s -$я the group of criteria; $w_{sj_s} - j_s -$ й критерий $s -$й группы. After that, $\Theta = \{\theta_1,\dots,\theta_m\}$ we mark the number of objects to be examined using a group of criteria $\mathbf{W}$. Каждому элементу множества Θ – исследуемому объекту сопоставим матрицу размерности k строк и p столбцов. Здесь p – наибольшее количество критериев по всем k группам ($p = \max\limits_{1\le s\le k} s$). The elements of the matrix are the value of the characteristics of the subject of the study according to natural scale criteria. The rows of the matrix are the values of the characteristics of the object on natural scales of groups of criteria.

Show the view shown here $d : \Theta \to Mat(k, p)$:

$$d(\theta_j) = X_j = \begin{pmatrix} x_{11} & x_{12} & \dots & \dots & x_{1p} \\ \dots & \dots & \dots & \dots & \dots \\ x_{k1} & x_{k2} & \dots & \dots & x_{kp} \end{pmatrix} \quad (1),$$

where among the elements $x_{il}(\theta_j)$ occur and zero. This means that there is no feature of the facility in the group of criteria (such element in the matrix e X_j is replaced by zero).

Next, each matrix X_j compares a matrix Y_j, the elements of which are the values of the characteristics of the objects on a single scale for all criteria of the specified groups.

As a single scale set, a segment is selected $[0;1]$. This set is natural for multi-criteria optimization applications, as the characteristics of the objects are compared with the given values of the criteria, which are numerically given by a point per segment $[0;1]$.

2.1. Set of model objects

The objects used are pure ash and molten ash of different densities with 50% ash content from incineration of sewage sludge (instead of sand). Noise-proofing screens along the railways were made of various densities of autoclave ash foam concrete to protect the population from railway noise:

θ_1 – ashes from incineration of sewage sludge;

θ_2 –autoclave ash foam concrete, density of the substance 500 kg/m^3 ;

θ_3 –autoclave ash foam concrete, density of the substance 600 kg/m^3 ;

θ_4 –autoclave ash foam concrete, density of the substance 800 kg/m^3 .

Thus, the set of objects being studied $\Theta = \{\theta_1,\dots,\theta_4\}$ is composed of four elements.

2.2. Groups of criteria and model criteria

In the model of assessment of geo-ecological technologies of manufacture autoclave ash foam concreteya distinguish the following groups of criteria:

W_1 – Environmental group;

W_2 – Technological group;

W_3 –Operational group.

Several of the most relevant criteria for decision makers are identified in each group.

For an environmental group, these are:

w_{11} – content of natural radionuclides

w_{12} – dust content

For the technology group, this is:

w_{21} – thermal conductivity

w_{22} – strength

w_{23} – frost resistance

w_{24} – ash content

w_{25} – sound insulating ability

For the operating group it is:

w_{31} – noise level in built-up area

2.3.Scale of criteria

Consider the display $d:\Theta \rightarrow Mat(k,p)$ (1) from a set of objects to a set of matrices whose elements set the properties of objects according to criteria scales.

Each object θ_j matrix X_j with k strings and p columns (here k – number of groups of criteria,s – number of criteria per group, $p = \max_{1 \le s \le 3} s$. In the rows of the above matrix, the values of the characteristics of the object are arranged according to groups of criteria. In the case $k = 3$, for the set of investigated objects referred to in paragraph 2.1 $\Theta = \{\theta_1, \ldots, \theta_4\}$, we have the following groups of criteria:

first group – $s_1 = 2$ criteria;

second group – $s_2 = 5$ criteria;

third group – $s_3 = 1$ criteria.

Here $p = \max_{1 \le s \le 3} s_k = \max\{2,5,1\} = 5$.

To harmonize the dimensions, we assume that if one or more criteria are not present in a group, the corresponding matrix elements are replaced by 0.

General type of such matrix for the case: $k = 3$, first group – $s_1 = 2$ criteria; second group – $s_2 = 5$ criteria; third group – $s_3 = 1$ criteria; $p = \max_{1 \le s \le 3} s_k = 5$ has the form:

$$d(\theta_j) = X_j = \begin{pmatrix} x_{11} & x_{12} & 0 & 0 & 0 \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \\ x_{31} & 0 & 0 & 0 & 0 \end{pmatrix},$$

$x_{ij} \in [a_{ij(\min)}, b_{ij(\max)}]$.

$a_{ij(\min)}$и $b_{ij(\max)}$ - it is the lower and upper limits of the range of the relevant criterion scale.

2.3.1. The numerical values of criteria characteristics

The numerical values of the characteristics according to the scale of criteria for objects of study - samples from materials 1-4 are given in table 1 below.

Table 1 Experimentally measured

Samples of materials	$x_{11}(\theta_j$	$x_{12}(\theta_j$	$x_{21}(\theta_j$	$x_{22}(\theta_j$	$x_{23}(\theta_j$	$x_{24}(\theta_j$	$x_{25}(\theta_j$	$x_{31}(\theta_j$
	Bq/kg	mg/m3	W/m2 °C.	MPa	cycles	kg/m3	dB	dB
ash	615	3,51	0	0	0	0	0	0
D500	96	0	12	16,5	15	80	38	65
D600	100	0	14	20	15	115	41	57
D800	107	0	17	25	15	205	43	50

Standard methods conforming to the requirements of the GOST were selected for qualitative and quantitative analysis of the research materials [9], [10].

The data in table 3 are sample averages derived from a series of sample experiments. The statistical processing was done using the Mathlab environment.

All the research was carried out in the centre «Socrates» of the PGUPS; in the test laboratory «Center of testing and certification of SPB»; in the test laboratory of the radiation control of the Test Center «PKTI-Stroistat». All organizations are licensed.

2.3.2. Natural scale of objects according to criteria

The starting point in the search for an optimum object that satisfies the groups of criteria and the decision on the basis of which it can be used in geo-ecological protection technologies is the systematization of natural scales.

Natural scales are to be understood as measurements of the characteristics that determine the physical properties of the materials of the tested samples. Table 2 shows the natural scales with measurement units for the criteria variables.

Units of the international SI system and units of measurement according to the GOST test standards were used as units of change.

Table 2 Natural scales of variables describing criteria

$\overline{x}_1(\theta_j)$	units	$\overline{x}_2(\theta_j)$	units	$\overline{x}_3(\theta_j)$	units
$x_{11}(\theta_j)$	Bq/kg	$x_{21}(\theta_j)$	W/m2 °C	$x_{31}(\theta_j)$	dB
$x_{12}(\theta_j)$	mg/m3	$x_{22}(\theta_j)$	MPa		
		$x_{23}(\theta_j)$	cycles		
		$x_{24}(\theta_j)$	kg/m3		
		$x_{25}(\theta_j)$	dB		

2.3.3. Limit values of the measurement scales

In order to construct a universal scale with an area of variation, the ranges of measurement boundaries for each characteristic were fixed for all criteria.

For all the criteria, the following range boundaries were selected:

1) Natural radionuclides content (NRC) was reviewed at intervals from 29 Bq/kg (the best value of the interval is the background value corresponding to the plaster natural stone as the cleanest) until 740 Bq/kg (the worst value of the interval corresponds to the samples allowed for use in urban construction [9]). Best natural radionuclide content criterion (29 Bq/kg) coincides with the right limit of the universal scale, i.e. 1.

2) The dust content was considered in the range of 0 mg/m3 to 0.3 mg/m3 (norm maximum permissible concentration). The best value (corresponding to the ideal state of the system - total absence of dust)- 0 mg/m3 is assigned a value of 1 in the universal scale, the worst value (0.3 mg/m3) is the value of 0 in the universal scale. The best (0 mg/m3) coincides with the right bound on the universal scale.

3) The thermal conductivity of the samples shall be considered in the range of 0.07 W/m2 °C to 0.20 W/m2 °C. The best value for the heat conductivity criterion (0.07 W/m2 °C) corresponds to the right boundary of the universal scale.

4) The compression strength of the samples shall be considered between 0 MPa and 35 MPa. The best value on the compression strength criterion (35 MPa) corresponds to the right boundary of the universal scale.

5) Frost resistance, the property of the material to damage resistance from the freezing-thaw cycle, is measured in the number of cycles that will withstand the material without damage. The scale of the criterion in natural units of measurement ranges from 5 cycles to 30 cycles. The best value for the cold resistance criterion (30 cycles) corresponds to the left boundary of the universal scale.

6) The ash content of 1 m3 of material is considered in the range of 0 to 500 kg/m3. The best value for the ash content criterion (500 kg/m3) corresponds to the right boundary of the universal scale.

7) The soundproofing capability of sound shields from autoclave ash foam concreteA of different density and thickness is determined by a calculated method. It accepts values on a natural scale from 0 dB to 49 dB. The best value for the soundproofing capacity of the sample (49 dB) corresponds to the right boundary of the universal scale.

8) Noise in populated areas was measured before and after installation of the noise shield. This criterion adopts values on a natural scale ranging from 20 dB to 120 dB. The best value according to the criterion «noise level in populated areas» (20 dB) corresponds to the right border of the universal scale.

Table 3 presents all boundaries with the specified criteria measurement areas $[x_{min}, x_{max}]$.

Table 3 Areas and boundaries of variable changes

criterion	units	$[x_{min}, x_{max}]$
$\overline{x}_1(\theta_j)$:		
$x_{11}(\theta_j)$	Bq/kg	[29;740]
$x_{12}(\theta_j)$	mg/m3	[0;0,3]
$\overline{x}_2(\theta_j)$:		
$x_{21}(\theta_j)$	W/m2·°C	[0,07;0,20]
$x_{22}(\theta_j)$	MPa	[0;35]
$x_{23}(\theta_j)$	cycles	[5;30]
$x_{24}(\theta_j)$	kg/m3	[0;500]
$x_{25}(\theta_j)$	dB	[0;49]
$\overline{x}_3(\theta_j)$:		
$x_{31}(\theta_j)$	dB	[20;120]

For each criterion with a natural scale and a range of values of a variable criterion, we construct a display F_{kl}, here k – number of groups of criteria, l – number of criteria, the field in a universal for all criteria region-segment [0;1].

Said map exhibits the property of strict monotonicity and compares the lowest (highest) value according to the natural scale of the lowest (highest) according to universal:

$F_{kl}(x_{min}) = 0, F_{kl}(x_{max}) = 1$ – in the case of a strictly increasing function;

$F_{kl}(x_{max}) = 0,\ F_{kl}(x_{min}) = 1$ – in the case of a strict function.

The type of monotony is determined by the physical characteristics underlying the criteria.

2.4.Matrix shapes

Each object $\theta_j$in the set Θ is a comparable matrix Y_j, whose elements are the values of the variables of all model criteria on a universal scale from a segment [0;1]:

$$\theta_j \mapsto Y_j = F(X_j)$$

где $F = (F_{kl})$ – a display introduced in 2.3.3, which has the monotonicity pattern property.

Here, the matrix $X_j = (x_{kl}(\theta_j))$ is the variable matrix for the groups of criteria of an object j.

$$y_{kl}(\theta_j) = F_{kl}(x_{kl}(\theta_j)).$$

For sample 1 material, the matrix will be as follows:

$$Y_1 = \begin{pmatrix} 0{,}249 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0{,}274 & 0 & 0 & 0 & 0 \end{pmatrix}$$

For sample 2 material, the matrix will be as follows:

$$Y_2 = \begin{pmatrix} 0{,}964 & 1 & 0 & 0 & 0 \\ 1 & 0{,}356 & 0{,}213 & 0{,}312 & 0{,}936 \\ 0{,}861 & 0 & 0 & 0 & 0 \end{pmatrix}$$

For sample 3 material, the matrix will be as follows:

$$Y_3 = \begin{pmatrix} 0{,}961 & 1 & 0 & 0 & 0 \\ 0{,}962 & 0{,}520 & 0{,}524 & 0{,}437 & 0{,}944 \\ 0{,}876 & 0 & 0 & 0 & 0 \end{pmatrix}$$

For sample 4 material, the matrix will be as follows:

$$Y_4 = \begin{pmatrix} 0{,}995 & 1 & 0 & 0 & 0 \\ 0{,}740 & 0{,}842 & 0{,}860 & 0{,}685 & 0{,}956 \\ 0{,}891 & 0 & 0 & 0 & 0 \end{pmatrix}.$$

The above matrices show experimental measurement data (table 1) for the subjects of the study, translated into a universal scale.

2.5.Design of criteria target functions

The map $F: Mat_{k,p}(\mathbf{R}_+) \to Mat_{k,p}([0;1])$, built in the preceding paragraphs has a vector character. It compares an object matrix whose elements are characteristic values in natural scales to an object matrix whose elements take values from a segment [0;1] on a universal scale.

$F = (F_{kl})$ –the vector objective function whose components are strictly monotone scalar functions. Monotonicity is determined by the property of the natural physical evaluation of the object (sample).

As scalar target functions $F_{kl}(t)$ the continuous bit-linear functions are selected. The choice of this function class is motivated by the fact that the investigated objects are classified into several applications (e.g., materials in construction). The number of sites where these functions are continuously introduced according to the standards of the application areas of the facilities under study.

Based on the above conditions, two types of functions are possible to satisfy scalar target functions.

Type 1: Piece-line, rigidly increasing functions

$$F_{kl(r)}(t) = a_{kl(r)} \cdot t + b_{kl(r)},$$

where $a_{kl(r)}, b_{kl(r)}$– positive real numbers, r – range number $r = 1,2, \dots, q$.

Type 2: Piece-by-piece - linear descending functions

$$F_{kl(r)}(t) = b_{kl(r)} - a_{kl(r)} \cdot t,$$

where $a_{kl(r)}, b_{kl(r)}$ – positive real numbers, r – range number $r = 1,2, \dots, q$.

Ratios $\{a_{kl(r)}; b_{kl(r)}\}$ are defined from a system of linear algebraic equations that results from the bilateral continuity of functions $F_{kl(r)}(t)$ at the boundary points of the scale split ranges. Number of equations in the system quantity equal $2q$.

2.6.Weighted consolidation of criteria

The next step in constructing the target function using the criteria consolidation is to determine the folding weights [17],[18],[19].

In each group of criteria, the weight of the criterion α_{kl} is determined taking into account the importance of the criterion in the group.

The relevance of the criterion is determined by the method of peer review, the decision maker based on standards, legislation, worldwide practice and other technical information.

For the weighting coefficients, the natural (additive) normalization condition shall be met:

the sum of all weights in a fixed index α_{kl} shall be one:

$$\sum_{l=1}^{p} \alpha_{kl} = 1.$$

For the four objects considered in the work, for which three groups of criteria are applied, and weights have been determined, the data are listed in table 4.

Table 4 Weight matrix of private criteria

Environmental Criteria Group	α_1	Group of Technology Criteria	α_2	Performance Criteria Group	α_3
content of natural radionuclides α_{11}	0,90	thermal conductivity α_{21}	0,20	noise in settlements α_{31}	1,00
dust content α_{12}	0,10	strength α_{22}	0,13	α_{33}	0
α_{13}	0	frost resistance α_{23}	0,15	α_{34}	0
α_{14}	0	ash content α_{24}	0,35	α_{35}	0
α_{15}	0	sound insulating ability α_{25}	0,35	α_{36}	0

The result of the weighted collation of criteria in each group is the targeted collation function :

$$G_k(t) = \langle \alpha_k, F_k(t) \rangle := \sum_{l=1}^{p} \alpha_{kl} \cdot F_{kl}(t),$$

где $\alpha_k = (\alpha_{k1}, \dots \alpha_{kp})$ – weight vector of criteria in k group, and $F_k(t) = (F_{kl}(t))$– rows of matrix function with bit-linear components.

Each component q_{kl} is defined by linear functions defined on separate ranges of the scales of the corresponding criteria.

The result of applying weighted convolution of criteria to the samples under consideration is given in table 5.

In table 6 the values of the folding functions are specified $G_k(\bar{x}_k, \theta_j)$ for k groups of criteria. Because there are large computations with multivariate datasets in work (k groups, p criteria in the group, q_p line functions, $2q_p$ linear function coefficients), the numerical values of the folding functions were obtained using the Mathlab environment.

Table 5 Grouping of criteria

Environmental Criteria Group	ash	D500	D600	D800
$\bar{x}_1$	0,249	0,968	0,965	0,963
Group of Technology Criteria	ash	D500	D600	D800
$\bar{x}_2$	0	0,535	0,646	0,828
Performance Criteria Group	ash	D500	D600	D800
$\bar{x}_3$	0,244	0,868	0,876	0,891

2.7. Weighted grouping of criteria

Consider the weight vector of the groups of criteria $\omega = (\omega_1, \omega_2, \dots, \omega_k)$, where weights are derived from the ratio

$$\omega_j = \frac{s_j}{\sum_{j=1}^{k} s_j},$$

where s_j - peer review group of criteria number j.

For multiple objects to be considered with three (k=3) the groups of criteria are shown in the table (table 6) weight vector values ω.

Table 6 shows that when materials are used in geo-ecological protection technologies, the environmental group of criteria has the greatest weight. This should be borne in mind by decision makers.

Table 6 Weights of groups of criteria

Group of criteria	Environmental Criteria Group ω_1	Group of Technology Criteria ω_2	Performance Criteria Group ω_3
ω_k	0,4	0,3	0,3

The target function of a weighted group bundle generally has the form [20],[21],[22]:

$$G(t) = \sum_{j=1}^{k} \omega_j G_j(t) = \sum_{j=1}^{k} \omega_j \langle \alpha_j, F_j(t) \rangle =$$

$$= \sum_{j=1}^{k} \sum_{l=1}^{p} \omega_j \cdot \alpha_{jl} \cdot F_{jl}(t)$$

The intended function in the particular case under consideration is for $k=3$:

$$G(t) = \omega_1 \cdot \langle \alpha_1, F_1(t) \rangle + \omega_2 \cdot \langle \alpha_2, F_2(t) \rangle +$$
$$+ \omega_3 \cdot \langle \alpha_3, F_3(t) \rangle,$$

где $\alpha_j = (\alpha_{j1}, \dots \alpha_{jp})$ - weight vector of criteria in group number j.

Calculations with the specified bundles for different objects are carried out in the Mathlab environment using algorithms for processing multivariate data arrays.

These algorithms allow the data to be used immediately after measurement experiments and to find target function values for any number of experimental samples. It saves time and computational complexity [23].

2.8. Optimal solution

On the Figure 1 shows the weighted totals of the criteria groups as a column chart.

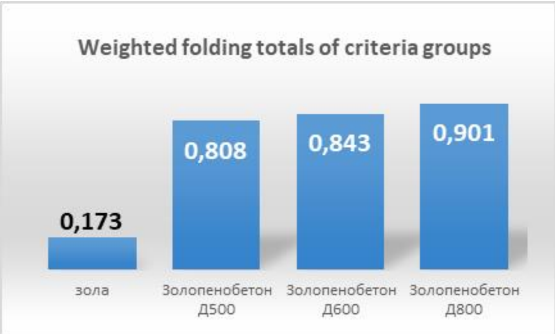

Figure 1: Weighted folding totals of criteria groups

According to the data of the table and the figure, it can be argued that the most effective result of weighted folding of groups of criteria is production of autoclave ash foam concretea with an average density of 800 kg/m3 (D800), since the sum of 0 is the highest - 0.901.

2.9. Conclusions

The proposed model, based on weighted totals of criteria, makes it possible to compile as a method of calculating the target functions of PQ-factors according to individual optimality criteria. And how to calculate the PQ factors of the group of criteria with the aim of constructing an optimal solution for recommending a decision on the use of materials in the creation of geo-environmental protection.

The final result of the work is an algorithm implemented in the Mathlab environment with processing of multivariate data sets, which can be used for a wide class of tasks of estimation of different technologies under conditions of decision-making with full information on different groups of criteria.

3. Acknowledgements

The authors express their gratitude to their colleagues at the University of Petersburg for the communication ways of Emperor Alexander I for many years of fruitful cooperation, which led to the emergence of interesting ideas in approaches to solving various applied problems, particularly relevant in today's environment, such as modelling the reliability and stability of systems/

We also express our gratitude to the departments «Water supply, drainage and hydraulics», «Engineering chemistry and natural history», «Higher mathematics», «Informatics and information security» for the friendly warm atmosphere, Continuous discussion and creative search in solving emerging applications.

We shall mark the high contribution to the organization and holding of the seminar «Models and Methods for Researching Information Systems in Transport» by the employees of the department «Information and computing systems».

References

[1] Svatovskaya L.B., Makarova E.I., Shershnyeva M.V and other. «New eco-protection technologies on railway transport». Monograph/ Moscow, 2007.

[2] Sakharova A.S., Svatovskaya L.B., Baidarashvilly M.M., Petriaev A.V. Building wastes and cement clinker using in the geoecoprotective technologies in transport construction. In: Computer Methods and Recent Advances in Geomechanics. Proceedings of The 14th international Association for computer Methods and regent advances in geomechanics. editors Fusao Oka, Akira Murakami, Ryosuke Uzuoka, Sayuri Kimoto. 2015., pp. 619-622.

[3] Sakharova A., Svatovskaya L., Baidarashvili M., Petriaev A. Sustainable development in transport construction through the use of the geoecoprotective technologies. In: Procedia Engineering. "3rd International Conference on Transportation Geotechnics, ICTG 2016", 2016., pp. 1401-1408.

[4] Rusanova E.V.«Technologies of recycling of some industrial and transport waste and their integrated assessment.» Thesis for Candidate of Technical Sciences / Saint Petersburg, 2005.

[5] Svatovskaya L.B., Maslennikova L.L., Yakimova N.I. and other. Complex technologies of waste disposal of railway transport, Moscow, 2007.

[6] Titova T.S. Methodology of Integrated Assessment of Environmental Protection Technologies and Quality. Index IEQ News of Petersburg University of Communications. 2005. 2 (4)., pp. 98-105.

[7] Sakharova A., Baidarashvili M., Petriaev A.. Transportation structures and constructions with geoecoprotective properties. In: Procedia Engineering. 2017., pp. 569-575.
[8] Rusanova, E., Abu-Khasan, M., Sakharova, A. The Control Waste of Communal ServicesIOP Conference Series: Earth and Environmental Science, 2019, 272(2), p.022109.
[9] Sakharova A.S., Petriaev A.V., Kozlov I.S. New construction solutions for geoenvironment protection of transport infrastructure. In: IOP Conference Series: Earth and Environmental Science. 2019., p. 022220.
[10] Svatovskaya L., Sychova A., Sychov M., Okrepilov V. New parameter of geoecological protective ability of construction articles. In: MATEC Web of Conferences. Editor V. Murgul. 2016., p. 01024.
[11] Svatovskaya L., Sychov M., Sychova A., Gravit M. New geoecoprotective properties of the construction materials for underground infrastructure development. Procedia Engineering,. 2016. Part 165, pp. 1771-1775.
[12] Sycheva A.M., Hitrov A.V., Shershneva M.V., Rusanova E.V. «Autoclave ash foam concrete with the use of ashes of sludge of wastewater» Cement and its use. 2006. 3., pp. 64.
[13] Titova T.S., Makarova E.I., Dudkin E.P. Use in the construction of an autoclave noise protection foam. Technospheric security technologies. 2014. 2 (54)., p. 35.
[14] Rublevskaya O.N., Vasilyev B.V., Protasovsky E.M., Petrov S.V. Treatment and disposal of sewage sludge at saint petersburg treatment plants: experience and prospects. Water and sanitation. 2018. 10., pp. 47-51.
[15] Svatovskaya L.B., Titova T.S., Rusanova E.V. «Autoclave ash foam concrete and its application in transport» Science and technology of transport. 2005. 2. pp. 36-39.
[16] Rusanova E.V., Abu-Khasan M.S., Egorov V.V. The Complex Evaluation of Geo Eco-Protective Technologies Taking into Account the Influence of Negative Temperatures/ IOP Conference Series: Materials Science and Engineering, 2020, 753(2), p. 022042.
[17] Nogin V.D. «Linear collation of criteria in multi-criteria optimization» Artificial intelligence and decision making. 2014. 4., pp. 73-82.
[18] Sigal A.V., Remesnik E.S. Weighting factor vector estimation В compendium: System analysis and information technology SAIT-2019. Proceedings of the Eighth International Conference. 2019., pp. 478-486.
[19] Kozlova E.A., Rudenko L.I. Linear generalized criteria in the problem of multi-criteria optimization In the compendium: Mathematics, computer science, modeling, education. Collection of scientific works of the scientific-practical conference MIKMO-2017 and the Tauri Scientific Conference of students and young specialists in mathematics and informatics. Taurist Academy (structural subdivision) FGAO VO «KFU im. V.I. Wernadsky» Pod. V.A. Lukyanenko. 2017., pp. 138-143.
[20] Vincke Ph. Multicriteria decision aid. - Chichester : Wiley, 1992.
[21] Yu P. L. Multiple criteria decision making: concepts, techniques, and extensions. - New York: Plenum Press, 1985.
[22] Hwang Ch.-L. Group decision making under multiple criteria. Methods and applications/ Ch.-L.Hwang, M.-J.Liп. - Berlin : SpringerVerlag, 1987.
[23] Rykov A. C. Models and methods of systems analysis: decision-making and optimization. - M.: MISIS, Publishing house «Rud and Metals», 2005.