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DEVELOPMENT OF A MORPHOLOGICAL MODEL FOR TERRITORIAL DEVELOPMENT OF UNDERGROUND CITY SPACE

Purpose. Development and testing of a model that formalizes and supports decision-making process regarding the appropriateness of using territory (geological environment) for urban underground construction.

Methodology. Modified morphological analysis of urbanized territories, expert evaluation method.

Findings. A morphological model and a tool set for evaluating construction sites for underground construction were tested; morphological tables were constructed; expert estimate scales for alternative values of construction site parameters were justified. Cross-consistency matrices of influence factors and parameter alternatives were evaluated. Evaluation of two sites for underground construction in Kyiv was performed using the developed model.

Originality. For the first time, a morphological model of territorial development for underground city planning was designed and tested on real construction sites in Kyiv. The modified morphological analysis method was applied for risk estimation of urban development of underground space. Systemic characteristics of urban territories were obtained, which show the favorability of a site for underground construction.

Practical value. Evaluation of the prospect of underground construction on the pre-project stage, capabilities for risk management of urban underground city space development, diminishing of the potential for project flaws caused by neglecting certain factors or specifics of a geological environment and technogenic impacts, convenient form of information generation as tables, charts or graphs.

Keywords: *underground city space, georesources, geological environment, morphological model, risk estimation*

Introduction. Continuous growth of large cities is a display of consistent historical patterns, and leads not only to the increasing size of metropolises, but also to significant complication of their functional and spatial organization as well. Moreover, in many cases the capacity of expanding "upwise and broadwise" is nearly exhausted. Solution of a set of acute problems related to the intensive growth of metropolises, including territorial, transport, power supply, ecological and other problems, can be achieved by developing the urban underground space. The concept of sustainable growth for large cities holds a special place for underground development, as the underground infrastructure increases the quality of life and ecological safety much more than a similar structure on surface [1, 2]. Despite the systemic advantages and significant prospects of developing underground space, the pace of urban underground construction does not satisfy the needs of modern metropolises. One of the main reasons of this situation is that developing underground space holds considerable risks caused by insufficient information about the state and properties of geological environment at the stage of underground infrastructure planning and making decisions regarding the advisability of investment under the conditions of incomplete information. Thus, preliminary estimation of favorability of urban territories for underground development is an urgent issue for increasing volumes of underground construction in cities.

Literature review. Underground construction as an integral part of a modern metropolis has exceeded the scope of local objects and has become a systemic factor of city development. The first methodical approaches to zoning the territories for underground construction considered applying probabilistic methods [3], typification of geological environment and rating it according to favorability for underground development [4]. However, these methods required precursory accumulation of large volumes of geological engineering data which are hard to obtain at the planning stage, without prior financing for the corresponding construction projects. A more flexible tool set for this task involves the applied system analysis [5–7] and expert estimation methods

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[8–10]. Applying system approach has found various implementations for planning surface construction in large cities [11], but for underground construction it did not go further than the problem statement stage and analysis of methods for study [12]. The morphological analysis method has promising capabilities for estimating the suitability of urban territories for underground space development, and in future can be applied for elaboration of a strategic master plan of an "underground city" [13]. The task of assessing favorability of urban territories is suitable for the procedures of the modified morphological analysis method (MMAM) [14], after development and testing of fitting models, constructing morphological tables and evaluating relations between factors of the problem.

Purpose. The purpose of this paper lies in the development of a tool set, designing and testing a model for formalization and support of the decision-making process regarding the suitability of a territory (geological environment) for urban underground construction.

Methods. The basis of the developed tool set is MMAM with the two-stage procedure [15]. The first stage comprises constructing and assessing a morphological table (MT) that describes the considered geological environment. In this study we used ten parameters for its description:

1) level of dynamic load;
2) static load from surface buildings;
3) static load from soil;
4) influence of existing underground objects;
5) genetic type and lithologic composure of soil;
6) effective soil strength;
7) influence of aquifers and perched groundwater;
8) landscape type and morphometrics;
9) geological engineering processes;
10) geotechnologies of underground construction.

For each parameter several possible alternative values or ranges were defined. By using expert estimation both probabilities of all alternatives and the degrees of interrelation between alternatives of different parameters were assessed. Calculation in MMAM algorithms [14] is based on solving a system of equations, the size of which equals the total number of alternatives for all parameters (38 in this study). This procedure allows estimating the probabilities of each parameter value under the conditions of uncertainty for the considered construction site.

These values were used as input data for the second stage, which evaluates the parameters of a decision regarding the territory. Overall, six crucial decision parameters were chosen for the second stage:

1. "A. Site suitability" (Suitable; not suitable).
2. "B. Object scale" (cross-section up to 10 m^2; cross-section up to 35 m^2; cross-section up to 70 m^2; cross-section up to and over 70 m^2).
3. "C. Construction depth" (0–10; 10–20; 20–50; beneath 50 m).
4. "D. Risk factor" (Construction failure, malfunction; dangerous influence on surface or neighboring underground objects; initiating displacements; underflooding; ecological risks; transport problems; increasing construction and operation cost).
5. "E. Risk degree" (<3; 3–10; 10–20; 20–50; > 50 %).
6. "F. Risk level" (0.1–5; 5–20; 20–50; > 50 % Q). Here Q denotes the total object cost.

The influence of the first stage alternatives on the decision parameters were also assessed by expert estimation. After that, the weights of the second stage parameter alternatives were calculated using MMAM procedures. These weights aggregate the possibilities of any of the 524 288 potential configurations of MT emerging at the first stage. The probabilities of configurations were calculated at the first stage of MMAM.

The described procedures were implemented using the SAS Studio software with C# user modules, compiled in Microsoft Visual Studio 2017 environment. The modules correspond to the main steps of MMAM: MT construction; MT estimation; cross-consistency matrix estimation; weight calculation for one-stage and two-stage MMAM procedures. This tool set allows designing and performing morphological studies for complex tasks, including the task of this research. The interaction between modules that solves the task of evaluating territories for underground construction is shown in Fig. 1.

Using this model requires only inputting the data obtained from expert estimation of the territory parameters via questionnaires, as shown in Fig. 2. The following MMAM procedures are performed automatically giving the sought-for results on both stages of the method.

Performing test calculation using the developed model. To test the functioning of the developed model, two underground parking lot sites in Kyiv with different characteristics were taken.

The first construction site is found at the Shevchenkivsky district at the Peremohy avenue. From a geomorphologic viewpoint the site is placed in the bounds of two geomorphologic elements – first overfloodplain terrace of the Lybid river and its valley slope. Geological composure of the studied site down to the depth of 50 m comprises of alluvial and fluvioglacial deposits including silty sandy loam, sand, peat, low- and medium-clay loam that lie upon bedrock of the Kyiv Paleocene suite represented by marly loam and marly clay. In turn, Kyiv suite soils lie upon sandy loam and sand of the Paleocene Buchak suite. On the surface alluvial and Paleocene deposits are covered by bulk ground. The studied soil characteristics, obtained from 11 boreholes, were used in the morphological model construction.

The second construction site is also found at Shevchenkivskyi district between Bulvarno-Kudriavska and Honchara streets. The studied territory is placed at the left slope of the Lybid river valley. The primary landscape surface is significantly heightened by bulk ground up to Bulvarno-Kudriavska street marks at this place; additionally, the embankment is fenced off by a supporting rubble stone wall. The geological structure of the studied site down to the investigated depth of 36 m comprises of: on the territory surface – modern bulk and Holocene deluvial deposits with underlying Holocene and upper Pleistocene deluvial-shearing deposits that occasionally cover deluvial soils of early Pleistocene. Under a substantial stratum of deluvial and bulk soils, a

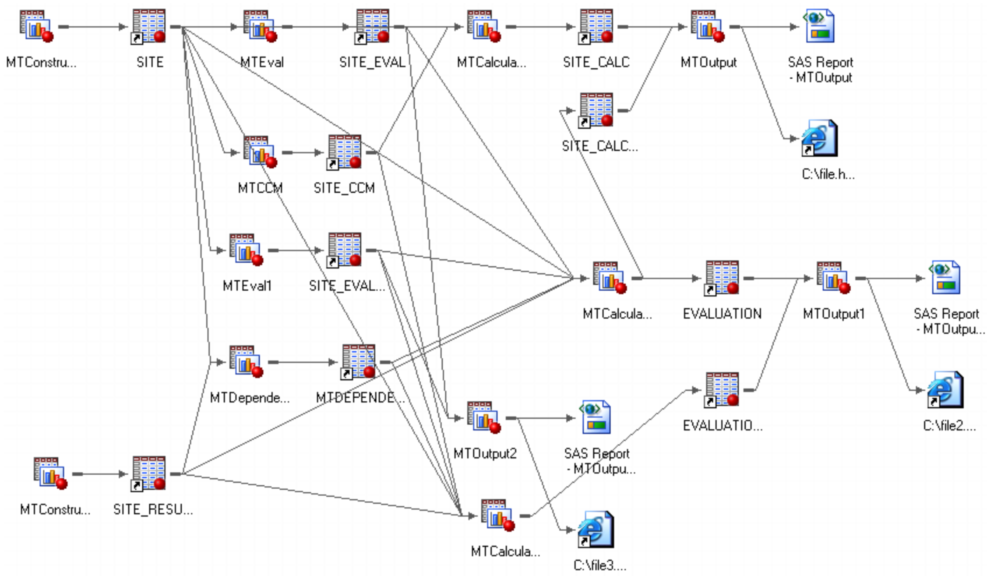
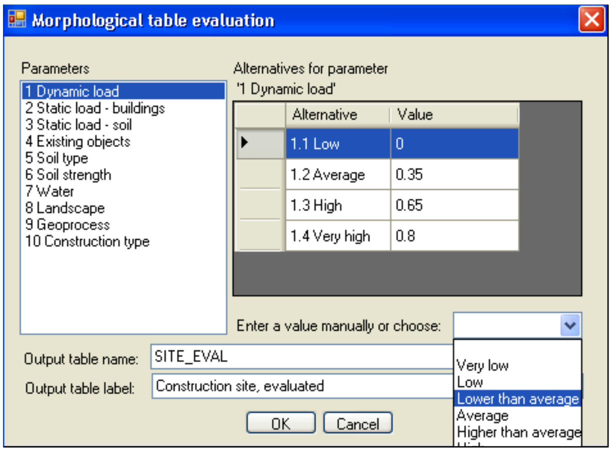


Fig. 1. SAS Studio model for evaluating territories for urban construction

partially washed out stratum of the Poltava series of lower Neocene is found. The investigated slope is comprised of bulk soils with poor filtration properties, which poses a probability of forming individual water lenses in sandy layers of bulk, or even forming perched groundwater spots in upper layers of cross-section in case the natural draining of the slope is interrupted. The studied soil characteristics and technogenic influence were used in the morphological model construction.

The input data from experts and the calculated in the MMAM procedure estimates that take into account the interrelation between parameters, are given in Table 1. The normalized expert estimate (probability) of an alternative $a_j^{(i)}$ is shown in $p_j'^{(i)}$ column; the estimate that was calculated using the cross-consistency matrix is shown in the column $p_j^{(i)}$. The difference between the values demonstrates the influence of other parameters on the probability of choosing a respective alternative.



Morphological table evaluation

Parameters

1 Dynamic load
2 Static load - buildings
3 Static load - soil
4 Existing objects
5 Soil type
6 Soil strength
7 Water
8 Landscape
9 Geoprocess
10 Construction type

Alternatives for parameter '1 Dynamic load'

Alternative	Value
1.1 Low	0
1.2 Average	0.35
1.3 High	0.65
1.4 Very high	0.8

Enter a value manually or choose:

Very low
Low
Lower than average
Average
Higher than average

Output table name: SITE_EVAL

Output table label: Construction site, evaluated

Fig. 2. Entering the input data for the model. The left list contains the parameters of the morphological table; the right list contains the alternatives of the chosen parameter and their initial estimates. An estimate can be entered manually or using the drop-down box below the list

The calculated weights of parameter alternatives for the second MT are shown in Table 2.

The results can be presented in a more intuitive form of charts or graphs (Figs. 5–6).

The pie charts (Fig. 3) demonstrate the most likely risk factors for the construction sites. In both cases the biggest hazard lies in initiating displacements (0.241 and 0.324 respectively), caused by the Lybid river influence and a slope relief for the second site which is prone to landslides. The risk factor of increasing construction and operation cost has the second biggest value for the site 1 (0.202), corresponding to a more difficult geomechanical situation compared to site 2, where the ecological risks have bigger impact (0.3). Both sites also have substantial risks of territory underflooding (0.154 and 0.214 respectively). Other risk factors are less relevant.

The defining factors for risk estimation are the parameters E (risk degree, i. e. the probability of the risk situation) and F (risk level, i.e. the expected financial and economic loss in case the risk situation happens – for example, the cost of repair). The comparison graphs for risk degree (Fig. 4, *a*) point at the largest likelihood of unfavorable scenarios at 3–10 % (with weights 0.502 and 0.625 respectively). Additionally, the likelihood of high risks (20–50 %) is less than 0.072 for the site 1 and nearly equals zero for the site 2, assuming that the conditions are largely favorable for construction. The assessment of possible financial losses in case of unfavorable scenarios (although they have low enough likelihood), can be performed by studying risk level graphs (Fig. 4, *b*). The most probable situation is that the financial risks have the 5–20 % level of construction cost, which is less than the average of the estimation scale. Thus, both sites are favorable for underground construction, which is confirmed by absolute weights of parameter A in Table 2, with "Favorable" alternative having values of 0.688 and 0.993 respectively.

Table 1

Input data and calculated estimates for parameter alternatives of the first MT

Parameter	Alternative	Estimates			
		Site 1		Site 2	
		$p'^{(i)}_j$	$p^{(i)}_j$	$p'^{(i)}_j$	$p^{(i)}_j$
1. Level of dynamic load	1.1. Low (46–53 dB)	0.000	0.000	0.593	0.707
	1.2. Medium (53–73 dB)	0.194	0.388	0.259	0.263
	1.3. Increased (73–96 dB)	0.361	0.286	0.148	0.029
	1.4. High (over 96 dB)	0.444	0.326	0.000	0.000
2. Static load from surface buildings	2.1. Insignificant ($K_{sl} < 1$)	0.000	0.000	0.000	0.000
	2.2. Medium ($1 < K_{sl} < 2$)	0.000	0.000	1.000	1.000
	2.3. Increased ($2 < K_{sl} < 3.5$)	0.000	0.000	0.000	0.000
	2.4. High ($K_{sl} > 3.5$)	1.000	1.000	0.000	0.000
3. Static load from soil mass	3.1. Insignificant ($K_{\text{mas}} < 0.05$, MPa)	0.351	0.030	0.432	0.324
	3.2. Medium ($0.05 < K_{\text{mas}} < 0.3$, MPa)	0.351	0.717	0.351	0.639
	3.3. High ($0.3 < K_{\text{mas}} < 0.5$, MPa)	0.189	0.189	0.108	0.025
	3.4. Very high ($K_{\text{mas}} > 5$, MPa)	0.108	0.063	0.108	0.012
4. Influence of existing underground objects	4.1. Absent (distance over 50 m)	0.000	0.000	0.800	0.714
	4.2. Slight (distance 20–50 m)	0.800	0.479	0.200	0.286
	4.3 Significant (distance 10–20 m)	0.200	0.521	0.000	0.000
	4.4 Hazardous (distance less than 10 m)	0.000	0.000	0.000	0.000
5. Genetic type and lithologic composition of soil	5.1. Unweathered clays and average density sands	0.108	0.107	0.108	0.170
	5.2. Technogenic deposits (alluvial and bulk types)	0.351	0.372	0.351	0.450
	5.3. Deluvial clay soils (water-saturated), water-saturated overfloodplain sands	0.432	0.434	0.432	0.342
	5.4. Sedentary soils, soils with special properties (loess, peat, silt)	0.108	0.087	0.108	0.038
6. Effective soil strength	6.1. Very strong soils >300 kPa	0.000	0.000	0.000	0.000
	6.2. Strong soils 200–300 kPa	0.000	0.000	0.333	0.209
	6.3. Average strength soils 150–200 kPa	0.200	0.352	0.533	0.670
	6.4. Relatively strong soils <150 kPa	0.800	0.648	0.133	0.120
7. Influence of aquifers and perched groundwater	7.1. Water-bearing horizons at P–N$_{1\text{np}}$	0.000	0.000	0.143	0.098
	7.2. Groundwater depth > 3 *m*, pressurized groundwater > 10 *m*	0.121	0.384	0.571	0.672
	7.3. Groundwater depth < 3 *m*, pressurized groundwater < 10 m	0.485	0.552	0.143	0.126
	7.4. Flooded areas with groundwater level up to 1 m present	0.394	0.065	0.143	0.104
8. Landscape type and morphometrics	8.1. Flat areas of overfloodplain terraces, morainic-glacial plains	0.571	0.476	0.000	0.000
	8.2. Slightly tilted overfloodplain terraces, watershed areas	0.143	0.177	0.121	0.382
	8.3. Small river valleys, slightly irregular slopes, high floodplain	0.143	0.275	0.394	0.476
	8.4. Slope areas with ravines and steep banks, low floodplain	0.143	0.072	0.485	0.142
9. Geological engineering processes	9.1. Absent	0.118	0.018	0.000	0.000
	9.2. Stabilized	0.382	0.346	0.256	0.507
	9.3. Low displacement processes	0.382	0.559	0.410	0.467
	9.4. Active manifestations of subsidence, underflooding, gravitational processes	0.118	0.077	0.333	0.025
10. Geotechnologies of underground construction	10.1. Open	0.350	0.281	0.448	0.634
	10.2. Underground	0.650	0.719	0.552	0.366

Table 2

Alternative parameter weights for the second MT

Parameter	Alternative	Estimate	
		Site 1	Site 2
A. Site suitability	A.1. Suitable	0.688	0.993
	A.2. Not suitable	0.312	0.007
B. Object scale	B.1. Cross-section up to 10 m^2	0.722	0.454
	B.2. Cross-section up to 35 m^2	0.241	0.303
	B.3. Cross-section up to 70 m^2	0.033	0.201
	B.4. Cross-section up to and over 70 m^2	0.005	0.041
C. Construction depth	C.1. 0–10 m	0.053	0.261
	C.2. 10–20 m	0.143	0.307
	C.3. 20–50 m	0.439	0.309
	C.4. beneath 50 m	0.365	0.123
D. Risk factor	D.1. Construction failure, malfunction	0.047	0.002
	D.2. Dangerous influence on surface or neighboring underground objects	0.049	0.006
	D.3. Initiating displacements	0.241	0.324
	D.4. Underflooding	0.154	0.214
	D.5. Ecological risks	0.185	0.300
	D.6. Transport problems	0.122	0.081
	D.7. Increasing construction and operation cost	0.202	0.073
E. Risk degree	E.1. < 3 %	0.028	0.304
	E.2. 3–10 %	0.502	0.625
	E.3. 10–20 %	0.382	0.068
	E.4. 20–50 %	0.072	0.003
	E.5. > 50 %	0.017	0.000
F. Risk level	F.1. 0.1–5 % Q	0.037	0.562
	F.2. 5–20 % Q	0.789	0.422
	F.3. 20–50 %Q	0.153	0.015
	F.4. > 50 % Q	0.020	0.000

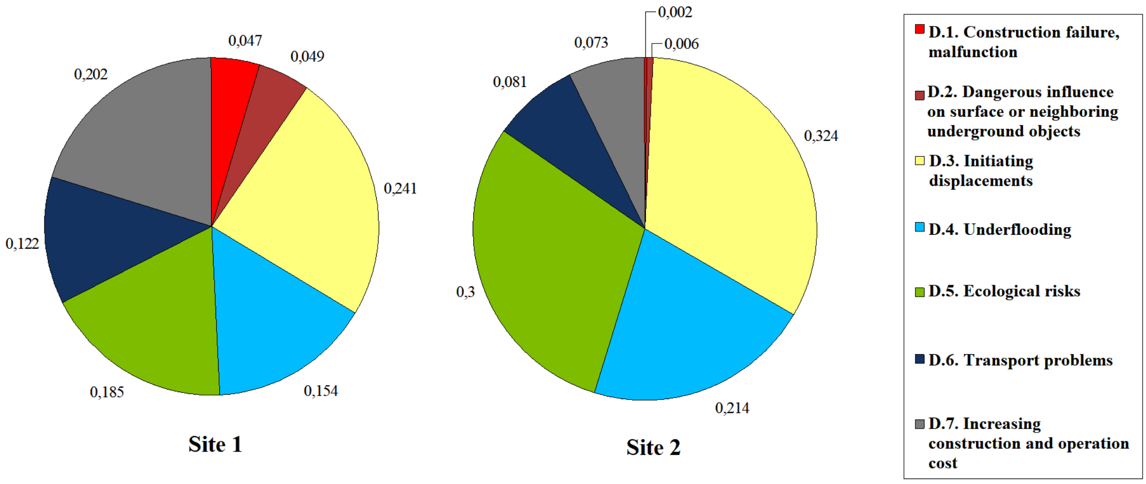


Fig. 3. Chart for parameter "D. Risk factor" of the first and second sites

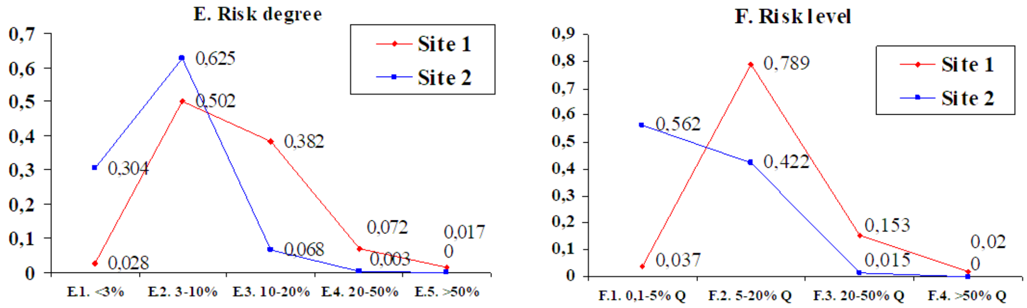


Fig. 4. Comparison of weights for alternatives of parameters "E. Risk degree", "F. Risk level" for both sites

Conclusion. The tool set for analysis of favorability of urban territories for underground construction was developed on the base of modified morphological analysis method which was established as a highly effective modeling method for problems having objects with a large multitude of possible configurations formed by combining different parameter values of these objects. Using the selected groups of geological and technogenic factors, this method allowed considering a multitude of decisions and risk groups for underground space development on the studied construction sites. The technique applied in this research allows assessing various risks, the likelihoods of unfavorable scenarios and potential financial losses related to them, as early as at the pre-project stage of underground construction. This provides the investors and city administrations with a powerful tool for managing risks and investments when developing urban underground space of metropolises. The developed technique and tools will be used for creating strategic master plans of developing "underground Kyiv" and other large cities in Ukraine.

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Reference.

1. National Research Council of the National Academies (2013). *Underground Engineering for Sustainable Urban Development*. Washington: The National Academies Press. DOI: 10.17226/14670.

2. Vähäaho, I. (2014). Underground space planning in Helsinki. *Journal of Rock Mechanics and Geotechnical Engineering, 6*(5), 387-398. DOI: 10.1016/j.jrmge.2014.05.005.

3. Babets, D. V., Sdvyzhkova, O. O., Larionov, M. H., & Tereshchuk, R. M. (2017). Estimation of rock mass stability based on probability approach and rating systems. *Visnyk Natsionalnoho Hirnychoho Universytetu, 2*(158), 58-64.

4. Gayko, G. I., & Kril, T. V. (2015). Typization of geological environment of urbanized territories when developing underground space. In *XIV international scientific-practical conference "Modern information technologies of managing ecological safety, natural resource usage, emergency measures"* (pp. 173-180), Kyiv. Retrieved from http://journals.uran.ua/geoeco/article/download/39-51/133440.

5. Zgurovsky, M. Z., & Pankratova, N. D. (2015). *System analysis: problems, methodology, applications* (2^{nd} ed.). Kyiv: Naukova dumka.

6. Gorelova, G. V., & Pankratova, N. D. (Eds). (2015). *Innovative development of socioeconomic systems based on foresight and cognitive modeling methodologies*. Kyiv: Naukova dumka.

7. Pankratova, N. D., & Malafeeva, L. Yu. (2014). Knowledge information model of the scenario analysis. *Journal of Automation and Information Sciences, 46*(2), 56-66. DOI: 10.1615/JAutomatInfScien.v46.i2.50.

8. Tsyganok, V., Kadenko, S., Andriychuk, O., & Roik, P. (2017). Usage of multicriteria decision-making support arsenal for strategic planning in environmental protection sphere. *Journal of Multi-Criteria Decision Analysis, 24*(5-6), 227-238. DOI: 10.1002/mcda.1616.

9. Pankratova, N. D., & Nedashkovskaya, N. I. (2014). Hybrid Method of Multicriteria Evaluation of Decision Alternatives. *Cybernetics and Systems Analysis, 50*(5), 701-711. DOI: 10.1007/s10559-014-9660-2.

10. Nedashkovskaya, N. I. (2015). Method for evaluation of the uncertainty of the paired comparisons expert judgements when calculating the decision alternatives weights. *Journal of Automation and Information Sciences*, *47*(10), 69-82. DOI: 10.1615/JAutomatInfScien.v47.i10.70.

11. Resin, V. I., & Popkov, Yu. S. (2013). *Development of large cities under conditions of transitional economy. System approach*. Moscow: Bookhouse "LIBROKOM".

12. Kartosiya, B. A. (2015). Developing underground space of large cities. New tendencies. *Mining information-analytical bulletin (scientific technical journal), 1*, 615-629.

13. Pankratova, N., Gayko, G., Kravets, V., & Savchenko, I. (2016). Problems of Megapolises Underground Space System Planning. *Journal of Automation and Information Sciences, 48*(4), 32-38. DOI: 10.1615/JAutomatInfScien.v48.i4.40.

14. Pankratova, N. D., Savchenko, I. O., Gayko, G. I., & Kravets, V. G. (2018). Evaluating Perspectives of Urban Underground Construction Using Modified Morphological Analysis Method. *Problems of Control and Informatics, 5*, 91-102.

15. Ritchey, T. (n.d.). *Futures Studies using Morphological Analysis*. Adapted from an Article for the UN University Millennium Project: Futures Research Methodology Series, Version 3.0 Retrieved from http://swemorph.com/pdf/futures.pdf.

Розробка морфологічної моделі територіального розвитку підземної урбаністики

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Мета. Розробка й тестування моделі, що формалізує та супроводжує процес прийняття рішення щодо доцільності використання території (геологічного середовища) для міського підземного будівництва.

Методика. Модифікований метод морфологічного аналізу урбанізованих територій, метод експертних оцінок.

Результати. Апробована морфологічна модель та інструментарій оцінювання ділянок будівництва підземних об’єктів, розроблені морфологічні таблиці, обґрунтована оцінка альтернативних станів і шкала експертних оцінок. Побудовані матриці взаємозв’язків факторів впливу та параметрів. Із використанням розробленої моделі проведене оцінювання двох ділянок території м. Київ, призначених для будівництва підземних об’єктів.

Наукова новизна. Уперше розроблена морфологічна модель територіального розвитку підземної урбаністики та проведене її тестування на реальних будівельних ділянках м. Київ. Застосовано модифікований метод морфологічного аналізу для оцінки ризиків урбаністичного освоєння підземного простору. Отримані системні характеристики міських територій, що показують ступінь сприятливості підземному будівництву.

Практична значимість. Оцінка перспектив підземного будівництва на передпроектній стадії, можливості управління ризиками розвитку підземної урбаністики, зменшення вірогідності проектних помилок через неврахування певних факторів або особливостей геологічного середовища й техногенних впливів, зручна форма подання інформації для прийняття управлінських рішень у вигляді таблиць, діаграм або графіків.

Ключові слова: *підземна урбаністика, георесурси, геологічне середовище, морфологічна модель, оцінка ризиків*

Разработка морфологической модели территориального развития подземной урбанистики

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Цель. Разработка и тестирование модели, формализующей и сопровождающей процесс принятия решения о целесообразности использования территории (геологической среды) для городского подземного строительства.

Методика. Модифицированный метод морфологического анализа урбанизированных территорий, метод экспертных оценок.

Результаты. Апробированы морфологическая модель и инструментарий оценивания участков строительства подземных объектов, разработаны морфологические таблицы, обоснована оценка альтернативных состояний и шкала экспертных оценок. Построены матрицы взаимосвязей факторов влияния и параметров. С использованием разработанной модели проведено оценивание двух участков территории г. Киев, предназначенных для строительства подземных объектов.

Научная новизна. Впервые разработана морфологическая модель территориального развития подземной урбанистики и проведено ее тестирование на реальных строительных участках г. Киев. Применен модифицированный метод морфологического анализа для оценки рисков урбанистического освоения подземного пространства. Получены системные характеристики городских территорий, отражающие степень благоприятности подземного строительства.

Практическая значимость. Оценивание перспектив подземного строительства на предпроектной стадии, возможности управления рисками развития подземной урбанистики, уменьшение вероятности проектных ошибок из-за неучета определенных факторов или особенностей геологической среды и техногенных воздействий, удобная форма представления информации для принятия управленческих решений в виде таблиц, диаграмм или графиков.

Ключевые слова: *подземная урбанистика, георесурсы, геологическая среда, морфологическая модель, оценка рисков*

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