SYSTEM APPROACH TO PLANNING URBAN UNDERGROUND DEVELOPMENT

Nataliya Pankratova, Illia Savchenko, Hennadii Haiko, Viktor Kravets

Abstract: *A system approach to planning urban underground construction is considered as a tool for sustainable development concept for megapolises. The foresight methodology, which is viewed as a decision-making process regarding behaviour of complex systems in desirable future, is proposed for evaluating prospects of urban underground construction. The morphological analysis method was applied for estimating suitability of urban territories for underground development. The conducted studies using this method allowed to propose a number of solutions for assessing advisability of underground construction on selected sites, considering highlighted groups of geological and technogenic factors, uncertainties of various nature and risk factor groups. The employed technique is a new tool for evaluating various risks, likelihoods of negative scenarios and related additional expenses, as early as a pre-project stage of underground construction.*

Keywords: *urban underground development, foresight methodology, system analysis, uncertainty, multi-factor risks, decision-making, information technology*

ACM Classification Keywords: *H.4.2. Information System Application: type of system strategy*

Introduction

High tech developments, including underground development of megapolises, where innovations are the base for competitiveness, as well as global ecological, economic, demographic challenges have produced a novel world model – sustainable planetary development.

As the experience of leading states shows, the management system for developing underground space should be based on a master plan for underground development [Gilbert P.H. et all, 2013, Vähäaho I., 2014]. Unlike general urban development plans, a master plan sets goals for meanings (implications) and coordinated objectives of future city development. It envisages significantly larger periods of planning (long-term planning), larger conceptualization degree (along with finer detalization of objects) and engaging not only narrow specialists, but also broader groups of experts and public organizations in the planning process. This approach significantly enhances the sphere of issues and influence factors that are considered in the planning process, and requires active involvement of applied system analysis method [Zgurovsky and Pankratova, 2011]. Various directions of implementing system approach for planning urban surface construction in large cities are known [Resin V.I. and Popkov, 2013]; as for the underground development, the studies went no further than general task setting and analysis of research methods [Kartoziya, 2015].

This paper proposes a system approach for planning underground development, which is based on the foresight methodology, as a tool for creating concepts of sustainable development of megapolises.

The concepts of urban studies and sustainable development in the context of underground construction

The concept “urbanistics” originates from Latin urbanus – related to the city. Urban study as a separate science is relatively young – it originated approximately in the second half of XX century. However, the emergence of urban studies can be attributed to the first ancient cities. Even Plato’s works, which described an ideal city model, can be regarded as the works in the field of urban studies, although the science itself didn’t exist at that time. The appearance of scientific approach to urban development may be referred to the beginning of XX century, when in 1909 the world’s first chair of city planning was opened in London, and different fields of urban studies appeared shortly after.

We will consider urban development as a global supersystem in the form of an ordered set of structurally interrelated and functionally interdependent global systems. A global system is an ordered set of structurally interrelated and functionally interdependent superlarge systems. A superlarge system is an ordered set of structurally interrelated and functionally interdependent large systems. A large system is an ordered set of structurally interrelated and functionally interdependent complex systems. A complex system is an ordered set of structurally interrelated and functionally interdependent systems of different types, that are connected by different types of relations. A system is an ordered set of structurally interrelated and functionally interdependent uniform systems, that are connected by uniform relations. Thus, a city, and its underground space, is not a set of stand-alone objects, but a complex supersystem, containing a variety of nested complex systems that constantly and harmoniously interact with each other. This interaction is the subject of urban studies.

The modern concept of sustainable development regarding the city planning should take into account the future needs, which implies the capability to satisfy current needs of society without causing harm to future generations. The important aspect of sustainable development is the potential for timely reaction to possible environmental changes, and minimization of technogenic and ecological impacts. This concept changes the common strategy for engineering projects and replaces the traditional vision of local problems with the position of systemic consideration of large natural-technical and social problems (system approach).

Significant portion of territorial, ecological, transport and power supply problems of large cities can be solved by efficient utilization of underground space. Urban underground development, which is an integral part of modern megapolises, has transcended the scale of separate local objects and became a systemic factor of urban development. Historically established approaches to developing underground space include resource-based, directive-based, city construction-based, and complex approaches. The complex approach is shown in [Konykhov, 2010] to allow the devising of the most optimal and rational system of utilizing underground space. Prediction of future changes, the capability to swap functions of underground objects, the corresponding urban policy, planning and management of megapolises development should be based on a sound scientific-methodological base, devised to provide systemic surface and underground urban development as a whole [Gayko G.I., 2018, Pankratova et all, 2019].

Application of morphological analysis method for assessing suitability of urban territories for underground construction

The foresight methodology, which is viewed as a decision making process regarding behavior of complex systems in desirable future, is proposed for evaluating prospects of urban underground construction [Zgurovsky and Pankratova, 2011]. One of the quality analysis methods, which is currently efficiently used for generating scenario alternatives, is the morphological analysis method.

The potential for applying morphological analysis method for assessing suitability of urban territories for developing underground space is deemed as quite prospective, and this method may be in turn involved in creating the master plan for an “underground city”.

Evaluating territories from the underground construction standpoint implies several factors with uncertainty of various nature, and has certain specific aspects:

- exact estimating of all influence factors requires significant expenses of time and resources caused by conducting engineering or geological works, and accurate measurements, that are rarely expedient at the stage of selecting a construction site;
- most of the sites have heterogeneous structure, so their characteristics change in space and time.

To obtain estimates in conditions of uncertainty, one can involve experts that make decisions based upon experience, intuition and relatively scarce information about the construction site.

The framework for this tool set is based on the modified morphological analysis method (MMAM) [Savchenko, 2015], which was well proven for the tasks of modeling objects with a multitude of alternative configurations, spawned by combining different parameter values of the object.

Constructing MMAM models requires several steps:

- determining objects (entities), which will be described by morphological tables, and relations between them;
- constructing morphological tables (MT) for each of the objects;
- estimating dependencies between the table parameters.

This procedure creates a fully formed model that can be employed to evaluate the parameter alternatives of a specific object, based on the given expert information regarding this object. In this paper a two-stage MMAM procedure was used [Pankratova and Savchenko, 2015, Savchenko, 2015], i.e. two MT were involved with a causal link between them. First MT described the potential construction site (geological and technogenic environment), and the second MT described the structure and alternatives of a decision regarding this construction site.

Constructing a MT requires classification of an object by different characteristics, relevant for the decision. Each classification section becomes a MT parameter, and the different values or ranges of values become the alternatives of this MT parameter. Should be noted that the number of parameters often becomes exceedingly large for successful MMAM operation, which is why several sets of characteristics that provide similar influence on the decision were aggregated into single parameters. The final form of the MT is shown in Table. 1.

Table 1. Morphological table for a construction site

Parameter	Alternatives of the parameter
1. Level of dynamic load	1.1. Low (46 – 53 dB)
	1.2. Medium (53 – 73 dB)
	1.3. Increased (73 – 96 dB)
	1.4. High (over 96 dB)
2. Static load from surface buildings	2.1. Insignificant (Ksl<1)
	2.2. Medium (1< Ksl <2)
	2.3. Increased (2< Ksl <3,5)
	2.4. High (Ksl >3,5)
3. Static load from soil	3.1. Insignificant (Кmas<0,05, MPa)
	3.2. Medium (0,05< Кmas <0,3, MPa)
	3.3. High (0,3< Кmas <0,5, MPa)
	3.4. Very high (Кmas >5, MPa)
4. Influence of existing	4.1. Absent (distance over 50 m)

underground objects	4.2. Slight (distance 20 – 50 m)
	4.3 Significant (distance 10 – 20 m)
	4.4 Hazardous (distance less than 10 m)
5. Genetic type and lithologic composure of soil	5.1. Unweathered clays and average density sands
	5.2. Technogenic deposits (alluvial and bulk types)
	5.3. Deluvial clay soils (water-saturated), water-saturated overfloodplain sands
	5.4. Sedentary soils, soils with special properties (loess, peat, silt)
6. Effective soil strength	6.1. Very strong soils >300 kPa
	6.2. Strong soils 200-300 kPa
	6.3. Average strength soils 150-200 kPa
	6.4. Relatively strong soils <150 kPa
7. Influence of aquifers and perched groundwater	7.1. Water-bearing horizons at P-N1np
	7.2. Groundwater depth > 3 m, pressurized groundwater > 10 m

	7.3. Groundwater depth < 3 m, pressurized groundwater < 10 m
	7.4. Flooded areas with groundwater level up to 1 m present
8. Landscape type and morphometrics	8.1. Flat areas of overfloodplain terraces, morainic-glacial plains
	8.2. Slightly tilted overfloodplain terraces, watershed ares
	8.3. Small river valleys, slightly irregular slopes, high floodplain
	8.4. Slope areas with ravines and steep banks, low floodplain
9. Geological engineering processes	9.1. Absent
	9.2. Stabilized
	9.3. Low displacement processes
	9.4. Active manifestations of subsidence, underflooding, gravitational processes
10. Geotechnologies of underground construction	10.1. Open
	10.2. Underground

The second MT includes the parameters of a decision to be made for the construction site. A total of 6 parameters were defined (Table. 2).

Table 2. A morphological table of a decision for the construction site

General characteristics		
A. Site suitability	B. Object scale	C. Construction depth
A.1. Suitable	B.1. Cross-section up to 10 m^2	C.1. 0–10 m
A.2. Not suitable	B.2. Cross-section up to 35 m^2	C.2. 10–20 m
	B.3. Cross-section up to 70 m^2	C.3. 20–50 m
	B.4. Cross-section up to and over 70 m^2	C.4. beneath 50 m
Construction risks		
D. Risk factor	E. Risk degree	F. Risk level
D.1. Construction failure, malfunction	E.1. <3%	F.1. 0,1–5% Q
D.2. Dangerous influence on surface or neighboring underground objects	E.2. 3–10%	F.2. 5–20% Q
D.3. Initiating displacements	E.3. 10–20%	F.3. 20–50%Q

D.4. Underflooding	E.4. 20–50%	F.4. >50% Q
D.5. Ecological risks	E.5. >50%	
D.6. Transport problems		
D.7. Increasing construction and operation cost		

Parameters A, B, C define the general characteristics. Parameter A (site suitability) is an integral one, with the alternative A.1 (suitable site) encompassing the very favorable, favorable and slightly unfavorable geological environment, and the alternative A.2 (not suitable site) represents the unfavorable environment, that has high risk values (see D…F parameters). Parameter B (object scale) characterizes types of designed underground objects of urban infrastructures, including sewer and power line communications (alternative B.1), transport communications (alternative B.2), multi-functional underground chamber-like facilities (alternative B.2), and large scale underground chambers: underground malls, sports facilities, power stations, manufacturing enterprises etc. (alternative B.4). As the favorability of underground construction can depend on transversal scale of structure in different geological environments, the parameter B (object scale) is important for the choice of construction site in various conditions. The construction depth (parameter C) is related to the functional purpose of the structure and the chosen geoengineering technology, it influences the formation of load on lining from ground pressure, static and dynamic impacts.

Parameters D, E, F refer to the risks of underground construction. The alternatives for risk factors include construction failure or malfunction (D.1), dangerous influence on surface or neighboring underground objects (D.2), initiating displacements on sloping relief (D.3), underflooding (D.4), ecological risks (D.5), transport problems (D.6), and increasing construction and operation cost (D.7). Risk degree (parameter E) describes the probability of unfavorable events (E.1…E.5), and risk level (parameter F) estimates economic loss, caused by unfavorable events, in percent of initial structure cost Q.

Study of two sites in Kyiv for construction of underground parking lots

The developed model was tested on two underground parking lot sites in Kyiv with different characteristics. The first construction site is found at the Shevchenkivsky district at the Peremohy avenue, and the second is also found at the Shevchenkivsky district between the Bulvarno-Kudriavska and Honchara streets. The morphological tables were estimated using the available data of geological and technogenic nature, and the dependencies between parameters were obtained by expert estimation (the cross-consistency matrix of parameter pairs in Table 1 was constructed).

The calculation procedure contained the following general steps:

1) obtaining the information from an expert using a questionnaire;
2) conversion of the expert's responses to a numerical form, and calculation of estimates for alternatives of the first MT, taking into account the interdependencies between them;
3) calculation of weights for alternatives of the second MT, based on the whole multitude of possible configurations of the first MT, and the dependency matrix.

The estimates (probabilities or weights) for factors in morphological tables 1, 2 were calculated and the results were presented in the form of pie charts (Fig. 1).

The pie charts demonstrate the risk factors that are most likely for the considered construction sites. In both cases the biggest danger lies in initiating displacements, which is caused by influence of the Lybid river and a sloping 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 the 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.

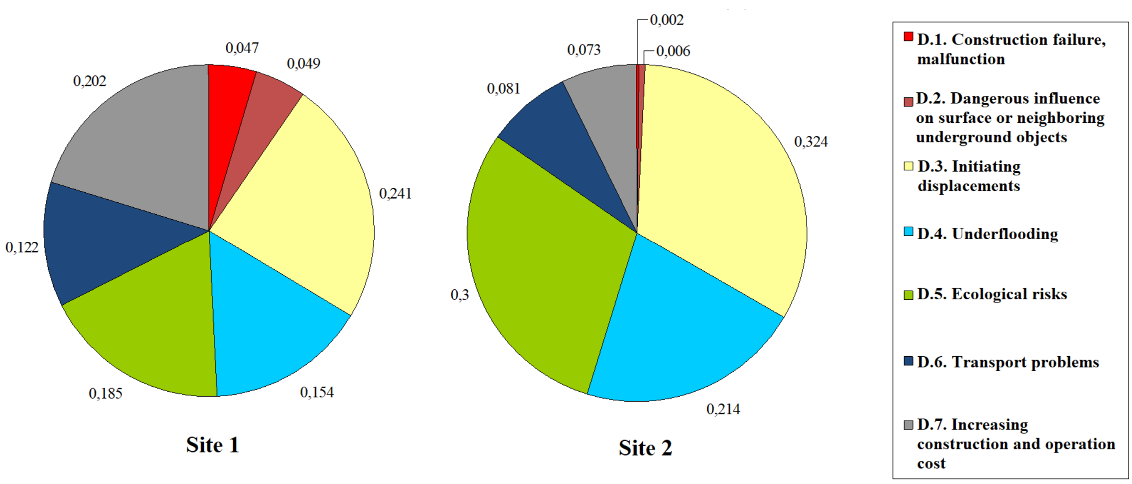


Figure 1. Pie charts for parameter «D. Risk factor» of the two construction sites

The defining factors for risk estimation are the parameters E and F (risk degree and risk level). The likelihood of unfavorable scenarios for both sites lies in 3–10% range (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) show 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, with “Favorable” alternative having values of 0,688 and 0,993 respectively.

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 to consider a multitude of decisions and risk groups for underground space development on the studied construction sites. The technique applied in this research allows to assess various risks, the likelihoods of unfavorable scenarios and potential financial losses related to them, as early as 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 megapolises according to the conceptual approaches of sustainable urban development.

Bibliography

[Gayko G.I., 2018] Gayko G.I. Developing underground space in the concept of sustainable development for large cities // Geotechnologies. – 2018. – №1. – P. 60-64. (in Ukrainian)

[Gilbert P.H. et all, 2013] Underground Engineering for Sustainble Urban Development/ P.H. Gilbert and others. – Washington: The National Academies Press, 2013. – 230 p.

[Kartoziya, 2015] Kartosiya B.A. Developing underground space of large cities. New tendencies / B.A. Kartosiya // Mining information-analytical bulletin (scientific technical journal). – 2015. – № 1. – P. 615 – 629. (in Russian)

[Konykhov, 2010] Konykhov S.S. Systematization of approaches for developing underground city space // Vestnik MGSU. №4. - 2010. P. 56–61 (in Russian)

[Pankratova and Savchenko, 2015] Pankratova N.D., Savchenko I.O. Morphological analysis. Problems, theory, applications. Textbook. – Kyiv: Naukova dumka. – 2015. – 245 p. (in Ukrainian)

[Savchenko, 2015] Savchenko I.O. Methodological and mathematical support of solving foresight problems using modified morphological analysis method // Innovative development of socioeconomic systems based on foresight and cognitive modeling methodologies / Editors G.V. Gorelova, N.D. Pankratova. – Kyiv: Naukova dumka, 2015. – P. 427–441. (in Russian)

[Pankratova et all, 2019] Pankratova N.D. Evaluating Perspectives of Urban Underground Construction Using Modified Morphological Analysis Method/ N.D. Pankratova, I.O. Savchenko, G.I. Gayko, V.G. Kravets // Problems of Control and Informatics. – Vol. 5. – 2018. – P. 91-102. (in Russian)

[Pankratova N. et all, 2016] Pankratova, G. Gayko, V. Kravets, I. Savchenko Problems of Megapolises Underground Space System Planning/ N. / Journal of Automation and Information Sciences. – Tom 48. – 2016. – № 4. – P. 32-38.

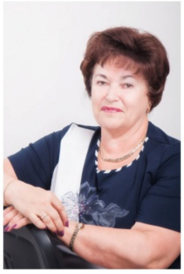
[Resin V.I. and Popkov, 2013] Resin V.I., Popkov Yu.S. Development of large cities under conditions of transitional economy. System approach / V.I. Resin, Yu.S. Popkov. – M.: Bookhouse «LIBROKOM», 2013. – 328 p. (in Russian)

[Semenov V.T. and Shtompel N.E., 2014] Semenov V.T. and Shtompel N.E. Sustainable development of megapolises. Urbanistic aspects // A.N. Beketov Kharkiv National University of City Economy. – Kh.: KhNUGKh, 2014. – 339 p. (in Russian)

[Vähäaho I., 2014] Vähäaho I. Underground space planning in Helsinki // Journal of Rock Mechanics and Geotechnical Engineering. 2014. № 6. P. 387–398.

[Zgurovsky and Pankratova, 2011] Zgurovsky M.Z., Pankratova N.D. System analysis: problems, methodology, applications. – K.: Naukova dumka, 2011. – 728 p. (in Russian)

Authors' Information



Nataliya D. Pankratova – *DTs, Professor, Corresponding member of NASU, Deputy director of Institute for applied system analysis, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Av. Pobedy 37, Kiev 03056, Ukraine;*
e-mail: natalidmp@gmail.com
Major Fields of Scientific Research*: System analysis, Theory of risk, Decision-making, Applied mathematics, Applied mechanics, Foresight, Scenario analysis, Strategic planning, Information technology*

Illia O. Savchenko – *CTs, Researcher, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Av. Pobedy 37, Kiev 03056, Ukraine;*
e-mail: savil.ua@gmail.com
Major Fields of Scientific Research*: System analysis, Decision-making, Applied mathematics, Data analysis, Foresight, Scenario analysis, Morphological analysis*

Hennadii I. Haiko – *Doctor of Technical Sciences, Doctor of Construction, Professor, Corresponding Member of the Academy of Construction of Ukraine, Professor at the Department of Geoengineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Av. Pobedy 37, Kiev 03056, Ukraine;*
e-mail: gayko.kpi@meta.ua
Major Fields of Scientific Research: geoengineering, underground construction, urban planning, renovation of old underground objects.

Viktor G. Kravets – *Doctor of Technical Sciences, Professor,Corresponding Member of the Academy of Mining Sciences of Ukraine, Professor at the Department of Geoengineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Av. Pobedy 37, Kiev 03056, Ukraine;*
e-mail: kravets@geobud.kiev.ua
Major Fields of Scientific Research*: geoengineering, underground construction, urban planning.*