*Journal of Mining and Geological Sciences, Volume 62, Number 3, 2019*

# EVALUATION OF TECHNOLOGICAL SOLUTIONS, GIVEN THE RISKS OF DEVIATION OF INTEGRAL DESIGN INDICATORS

***Inna Bondarenko, Igor Temkin***

*National University of Science and Technology MISiS, 119049 Moscow; innasbondarenko@gmail.com*

**ABSTRACT.** The article deals with the choice of technological solutions for conducting underground works that most adequately meet the conditions of the construction site. At the initial stages of project development the proposed methodology for comparative assessment of integral indicators of the project allows evaluating and selecting a technological solution that enhances the efficiency and safety of the construction of an underground structure. The structure of the methodology includes fuzzy models and algorithms that provide processing of large amounts of information, form the significance of environmental factors (organisational, mining and geological, construction site factors), design and technological parameters of the project and allow the main relationships and interdependencies between them to be identified.

**Key words:** technological solution, project, underground structure, risk, fuzzy model

## ОЦЕНКА НА ТЕХНОЛОГИЧНИ РЕШЕНИЯ, КАТО СЕ ВЗЕМАТ ПРЕДВИД РИСКОВЕТЕ ОТ ОТКЛОНЕНИЕ НА ИНТЕГРАЛНИТЕ ИНДИКАТОРИ НА ПРОЕКТА

***Инна Бондаренко, Игор Темкин***

*Национален университет за наука и технологии “МИСиС”, 119049 Москва*

**РЕЗЮМЕ.** Статията разглежда избора на технологични решения за провеждане на подземни работи, които най-адекватно отговарят на условията на строителната площадка. Предложената методология за сравнителна оценка на интегралните показатели на проекта позволява на началните етапи на разработване на проекта да се оцени и избере такова технологично решение, което да повиши ефективността и безопасността на изграждането на подземна конструкция. Структурата на методологията включва размити модели и алгоритми, които осигуряват обработка на големи количества информация, формират значението на факторите на околната среда (организационни, минни и геоложки, фактори на строителната площадка), проектни и технологични параметри на проекта и позволяват да се идентифицират основните отношения и взаимозависимостите между тях.

**Ключови думи**: технологично решение, проект, подземна структура, риск, размит модел

## Introduction

The construction of underground structures includes a number of geotechnical risks, for which the project participants, funding and performing the construction, require qualitative and quantitative analysis. The adoption of a decision depends on many objective and subjective conditions and factors. It is not always possible to consider all conditions and factors, and then influence them actively, i.e. there is uncertainty of the forecasting situation.

In most cases, the security is provided by the normative models and coefficients that apply to groups of corresponding structures. The project security can be achieved by processing the standards documents for the use of the project. They take into account unusual and random loading: earthquakes, floods, mudslides, strong winds, fires in tunnels, etc. But it is important to perform this analysis during the project preparation stage and choose the design option based on the assessment of uncertainties and their impact on the construction project.

## Methodology

At the initial stages of design, comparison of the project options is impossible without its formalised presentation, including the development of each of the possible technological solutions in the form of engineering design schemes, engineering topological plans, etc. It is a lengthy and not rational procedure for all project participants. It`s extremely important to choose a method for describing the structure of a construction project, provided that, on the one hand, the problem of choosing a design solution is effectively solved, and on the other hand, allowing to take into account the characteristic qualitative features of its constituent elements.

Based on the above conditions for the implementation of construction projects of communication tunnels and analysis of project documentation, a parametric description of the project will be further provided.

Earlier, in scientific papers on the laying of engineering structures (Kulikova et al., 2005; Krivonozhko et al., 2016) the most significant environmental factors were identified, which included the parameters of mining and geological conditions, the parameters of the ground and underground characteristics of the urban environment. They were considered in accordance with the issues related to this problem. As a result, 9 main parameters were identified, and the attributes describing them were also determined (Temkin et al., 2012)

From the entire set of mining and geological conditions ($U_1$), the parameters were identified. The strength of the host rocks ($P_1$) and the water saturation of soils ($P_2$) are the most important parameters in the development of the underground space.

The underground conditions ($U_2$) of the construction site are characterised by the density ($P_3$) of already existing underground utilities and facilities at the construction site. When evaluating the density of the underground structures, three informal categories are usually distinguished: "high", "medium" and "low", depending on the ratio $V_{ps} / V_{ob} \times 100\%$, where $V_{ps}$ is the volume of the underground facilities already in the construction area, $V_{ob}$ is the total volume of the underground space construction of communication tunnels.

The ground conditions ($U_3$) include the most significant parameters for underground construction, the density of the ground structures, road load, environmental condition, type of territory, historical and cultural value. Further, it is necessary to develop algorithms for evaluating the integral parameters that allow comparing design solutions, detailed structuring and model representations of the construction project.

To describe the project, 6 parameters characterising the constructive solution of communication tunnels and route (S) were identified: the diameter of the communication tunnel, the laying depth, the total length of the route, the geometry of the route, the slope of the route, the shape of the section of the tunnel, category (Temkin et al., 2012).

The main tunnelling technologies (G) were also identified: the mining method (manual labour + combined technology), the semi-mechanised shield, the mining method (manual labour + combined technology), mechanised shield, puncture, punching, directional drilling, microtunnelling (Bondarenko, 2011).

In the construction projects of underground structures an indicator of reliability and safety is the expert assessment of the level of possibility of mutual influence of the developed design solutions and the specific external environment for their implementation.

When implementing a project in real conditions the projected values of the terms and costs may often differ from the actual ones, $\Delta T = | T_f - T_{pr} |$ and $\Delta C = | C_f - C_{pr} |$.

It is impossible to directly relate the Δ value to such characteristics as "project reliability", "project environmental safety". However, for expert designers, the obvious paradigm is that "the project is better, the smaller | Δ |", i.e. in a formalised language: $E \rightarrow \max$ at $\Delta T, \Delta C \rightarrow \min$; $E \rightarrow \min$ at $\Delta T, \Delta C \rightarrow \max$.

Now, based on the foregoing, each project option (Di) can be represented as the following information structure:

$$Di\ \{U_{1i}, U_{2i}, U_{3i}, S_i, G_i, C_i, T_i, E_i\} \quad (1)$$

where:

$U_{1i}$, $U_{2i}$, $U_{3i}$ - the set of parameter values characterising a particular construction site;

$S_i$ - design parameters of the communication tunnel;

$G_i$ - the technology or technologies that form the basis of the project;

$C_i$, $T_i$, $E_i$ - integral indicators of the project: project cost, terms of its implementation, reliability and safety of implementation.

In this task more detailed description of the technologies is not required, because calculations of the parameters of the methods of sinking are in the engineering field. In addition, the most modern technologies have established assessment criteria, regardless of the internal parameters.

When considering engineering and technological features of the construction of communication tunnels, and especially the environment of the project (major city, dense underground and surface development, high population density, etc.) such factors as the geological uncertainty factor ($F_1$), the factor of uncertainty of site conditions ($F_2$) and the structural uncertainty ($F_3$) should be identified.

Assessment of the impact of the uncertainty factors $F_1$,$F_2$,$F_3$ on the integrated project performance $K_j$ (C - the cost of construction, T - construction period, E - reliability and safety implementation) is solved as a comprehensive evaluation of the fuzzy risk (R) ) in the context of the problem.

In this case the fuzzy risk is defined as the subjective probability that is the result of the influence of uncertainty factors. $F_1$,$F_2$,$F_3$ will occur as a deviation of the design value of the integral indicator $K_j^*$ of the total actual $\widetilde{K}_j$.

Evaluation of the fuzzy risk is a combination of the influence (V) of uncertainty factors for integral indices and the degree of this effect (Z).

The possibility of influence of uncertainties on the integral parameters of the construction site`s project under the same conditions is different for the different structural solutions, and the degree of influence of uncertainties on integrated indicators will be different for the different versions of the project implemented under the same conditions, only when these variants differ in construction technology. Thus, it can be argued that there is some dependence of V on the design parameters of the project, and dependence of Z on the technology used and the conditions in which the construction of the communication tunnel is performed:

$$V_{F_iK_j} = f(S); \quad (2)$$

$$Z_{F_iK_j} = f(U, G). \quad (3)$$

In the conditions of the given problem it is not possible to construct an accurate model of dependence because there are no objective estimates and sufficient statistics, so it is only applicable to expert evaluation methods.

According to all uncertainties for all integral indices a comprehensive risk assessment of the design option will be found on the basis of the values of the matrix elements' components of the expert assessment of influence and impact:

$$V = \begin{bmatrix} v_{F_1K_1} v_{F_2K_1} v_{F_3K_1} \\ v_{F_1K_2} v_{F_2K_2} v_{F_3K_2} \\ v_{F_1K_3} v_{F_2K_3} v_{F_3K_3} \end{bmatrix}, Z = \begin{bmatrix} z_{F_1K_1} z_{F_2K_1} z_{F_3K_1} \\ z_{F_1K_2} z_{F_2K_2} z_{F_3K_2} \\ z_{F_1K_3} z_{F_2K_3} z_{F_3K_3} \end{bmatrix} \quad (4)$$

where: $v_{F_iK_j}$– value of influence of the i-th element of uncertainty to the j-th integral parameter; $z_{F_iK_j}$ – the value of the degree of influence of the i-th element of uncertainty to the j-th integral parameter.

To assess the impact of these factors on the integral characteristics of the construction project (such as, for example, the depth of the tunnel lining, slope, alignment, diameter, etc.) the expert rules and the methodology for project evaluation were developed based on the calculation of the influence $V_{F_iK_j}$ of the uncertainty factor (Fi) and the degree of influence $Z_{F_iK_j}$ of the uncertainty factor (Fi) on the integral indicator (Kj) (Temkin et al., 2013) .

When the expert rules are used to describe the parameters and their estimates, it is proposed to use fuzzy formalisms. Each of the rule elements is described using several Boolean variables (3÷5): "high," "upper average", "average", "below average", "low". Figure 1 shows an example of a membership function for linguistic variable "high," "medium" and "low" for the rock strength.

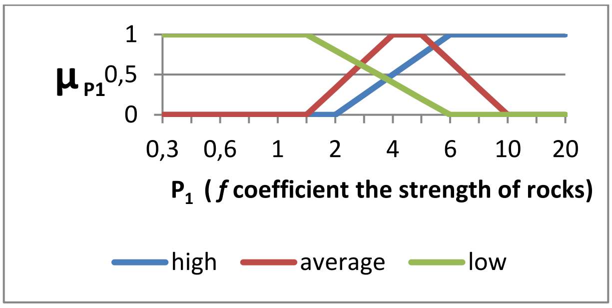

**Fig. 1. The membership functions of linguistic variables "high", "average" and "low" for the rock strength**

Thus, the model of fuzzy risk (R), integral index $K_j$ of the construction project of a communication tunnel is determined by calculating a fuzzy risk for each uncertainty factor, which, in turn, is obtained by evaluating the influence and impact of uncertainty on $K_j$:

$$\left.\begin{array}{l} V_{F_1K_j} \wedge Z_{F_1K_j} \rightarrow R_{F_1K_j} \\ V_{F_2K_j} \wedge Z_{F_2K_j} \rightarrow R_{F_2K_j} \\ V_{F_3K_j} \wedge Z_{F_3K_j} \rightarrow R_{F_3K_j} \end{array}\right\} R_{K_j} \qquad (5)$$

Figure 2 shows the general scheme of the fuzzy risk assessment model for the integral index of the project in the form of a block diagram.

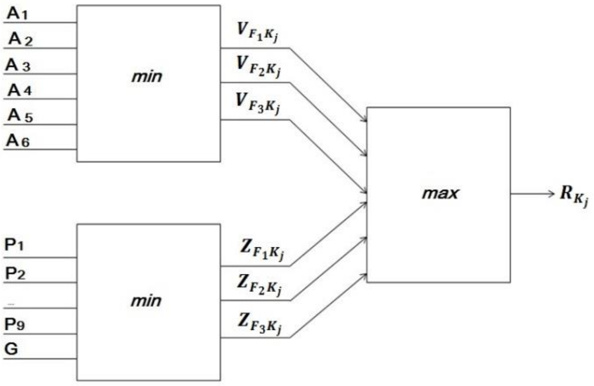

**Fig. 2. The general scheme of the model of fuzzy risk assessment for the integral indicator of the construction project of CT**

Identifying the impact of factors on the overall risk to the integral index is based on the fuzzy associative matrix (Table 1).

Table 1. *The possibility and degree of influence factor*

| | | | | | | |
|---|---|---|---|---|---|---|
| **The possibility of the influence factor** | high | average | average | above average | high | high |
| | above average | below average | average | average | above average | high |
| | average | below average | below average | average | average | above average |
| | below average | low | below average | below average | average | average |
| | low | low | low | low | below average | average |
| **The degree of influence factor** | | low | below average | average | above average | high |

In the future, when the rule will be difficult to operate with facts that are represented in linguistic form, it will be needed to encode the original set of the rules and generate the source of inductive table.

According to the chosen risk factors based on a formalised description of the project, a training table was developed for building a fuzzy rule base, where on the basis of expert opinions the possibility of the influence of the uncertainty factor ($F_i$) on the integral indicator ($K_j$) – $V_{F_iK_j}$ (table 2) and the degree of influence of the uncertainty factor (Fi) on the integral indicator ($K_j$) - $Z_{F_iK_j}$ (Table 3) will be determined.

Table 2.*The estimation of the influence of the uncertainty factor ($F_i$) on the integral indicator ($K_j$)*

| LS | $A_1$ | … | $A_6$ | $V_{F_iK_j}$ |
|---|---|---|---|---|
| 1 | $a_{11}$ | … | $a_{61}$ | $V_{LS\ 1}$ |
| 2 | $a_{12}$ | … | $a_{62}$ | $V_{LS\ 2}$ |
| … | … | … | … | … |
| n | $a_{1n}$ | … | $a_{6n}$ | $V_{LS\ n}$ |

Table 3. *Assessment of the degree of influence of the uncertainty factor ($F_i$) on the integral indicator ($K_j$)*

| LU | $P_1$ | … | $P_9$ | $h_{GFi}$ | $Z_{F_iK_j}$ |
|---|---|---|---|---|---|
| 1 | $p_{11}$ | … | $p_{91}$ | $h_1$ | $z_{LU\ 1}$ |
| 2 | $p_{12}$ | … | $p_{92}$ | $h_2$ | $z_{LU\ 2}$ |
| … | … | … | … | … | … |
| z | $p_{1z}$ | … | $p_{9z}$ | $h_z$ | $z_{LU\ n}$ |

where:
$LS_x$ – line training table, by definition;
$P_{F_iK_j}$ (= 1 rule), $x = \overline{1,n}$;
$LU_y$ – line training table, by definition, $Z_{F_iK_j}$ (= 1 rule), $y = \overline{1,z}$;
$h_{GFi}$ - resistant technology to the uncertainty factor $F_i$, defined by the experts.
The number of training tables (i×j)×2.

## Results from the calculations

The example of expert reasoning can serve as the following rules assessment of the geological influence factor on the construction time:

| | |
|---|---|
| LS 1: | If the diameter is<2 and depth[3-8] and track length>600 and geometry of the route (number of turns)>3 and slope of the route (number of turns in the cut)[1-3] and shape sections III,IV => $V_{F_1T}$→average |
| LU 1: | If the fortress[3-6] and water saturation<0.1 and the density of underground structures [high], and the density of surface facilities [average] traffic load [high] and the environment [normal] view site [residential] and historical and cultural value [is] complex and the significance of the [required] and hGFi [low] => $Z_{F_1T}$→ below average |

## Conclusion

Thus, each rule is built on a set of formal parameters and the project gives an expert estimation of the influence and degree of influence of the uncertainty factor ($F_i$) on the integral indicator ($K_j$) for each possible combination of values for these parameters.

As an example of the use of this mechanism, the choice of two design options for the construction of a communication tunnel (D1 and D2) was considered based on risk assessment of the uncertainty geological factor (F1) for the integral indicator of "construction time" (T) for the conditions of the construction site of a sewer tunnel under the Moscow railway, Savelovsky direction on the site "Reconstruction of Lianozovsky passage from Dmitrovsky sh. to Cherepovetskaya street".

From the calculations, the following results were obtained:

$V_{F_1T}(D_1) = 1.55$ and $Z_{F_1T}(D_1) = 6.59$ → RT(D1)=3.63
$V_{F_1T}(D_2) = 1.79$ and $Z_{F_1T}(D_2) = 4.76$ → RT(D2)=2.74

These results show that the risk for deviation of the actual value of the integral indicator (timing of implementation) from the design value under the given conditions of the construction site for the second project is smaller, i.e., the risk that they will violate the terms of project implementation is smaller than in the case of chosen technological solution D2.

The study was implemented under a grant by the Russian Scientific Foundation (project No. 17-11-01353).

The resulting model provides a choice of the design options for the construction of the tunnel communication in conditions of uncertainty for many integrated indicators (economic, organisational, technological), which is implemented with minimum risk.

## References

Belopushkin, V. I., I. S. Bondarenko. 2008. The method of choosing the optimal technology for the construction of a communication tunnel. – *Software products and systems, 3*, 10–13.

Bondarenko, I. S. 2011. The methodology of choosing the technology for driving the collector tunnel. *Mountain Information and Analytical Bulletin, 6*, 108–114.

Bondarenko, I. S. 2015. Ecological-economic analysis of project solutions in the construction of communication tunnels based on the methodology of the assessment of deviations of integral indicators of the project. – *Materials 11-th International Conference on Problems of Mining, Construction and Energy. Socio-economic and environmental problems of mining, construction and energy. Tula-Minsk-Donetsk*, 268–279.

Granichin, O. N., V. I. Comedy. 2008. Information technology in management. *INTUIT,* Moscow.

Kaufman, L. L. 2009. Geotechnical risks in underground construction. – *Nord-Press,* Donetsk.

Krivonozhko, V. E., F. Forsund, A. V. Lychev. 2016. Improving the Frontier in DEA Models. – *Mathematics*, *94,* 3, 715–719.

Kulikova, E. Yu., A. V. Korchak, A. N. Levchenko. 2005. Strategy risk management in urban underground construction. – *Moscow State Mining University,* Moscow.

Temkin, O. I., S. I. Bondarenko. 2013. Risk assessment of the construction of communication tunnels based on expert analysis of design decisions. – *Heavy machinery,* 9, Moscow, 38–40.

Temkin, I. O., I. S. Bondarenko, I. V. Barannikova. 2012. Evaluation of the integral parameters of the project based on the neural network models for forecasting the cost and timing of the project. – *Mountain Information and Analytical Bulletin* 6, 95–101.