Rocznik Ochrona Środowiska

Volume 24 Year 2022 ISSN 2720-7501 pp. 110-128

https://doi.org/10.54740/ros.2022.009 open access

Received: 05 July 2022 Accepted: 18 July 2022 Published: 14 November 2022

Improving the Environmental Safety Risk Assessment in Construction Using Statistical Analysis Methods

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Abstract: The article aims to assess risk for substantiating the economic and organizational efficiency of construction in the context of ecologic safety. A quantitative risk estimation was made through the Monte Carlo way for negative and positive choices to avoid ecological harm. The simulation algorithm imitated the distribution obtained from the evidence-based fit. The outcomes of a sensitivity investigation are also prepared to verify the suggestion. This risk analysis technique has a digital computer implementation. The simulation data outputs demonstrate the alternative of the general norm of validation and the acceptance of the solution, which is not harmful to the environment. In situations of uncertainty, the decision to select the optimistic flavor with high spending (to retain the reliability of the technics) but less risk pretends to be a decisive factor in the eco-friendly protection strategies of the construction project.

Keywords: ecological risk, environmental safety, Monte Carlo method, risk assessment

1. Introduction

Environmental legislation is associated with the adoption of environmentally sound decisions, the implementation of economic activity, the preclusion of potential unfavorable impacts on the natural ecosystem, and the design of measures to accomplish instruction for ensuring environmental well-being requests. The framework of environmental impact assessment (EIA) is presented in the target federal law "On Environmental Examination" (1995) (https://docs.cntd.ru/document/9014668?section=text; accessed on 12.01.2022) and several articles of the actual act "On Environmental Protection" (2002) (https://docs.cntd.ru/document/901808297; accessed on 12.01.2022), which is the basis of Russian environmental legislation. However, since these laws are not laws of direct action, the new impetus for greening the environment was implemented in numerous by-laws. In this regard, the creation and development of environmental monitoring systems in the construction and operation of building complexes still cannot receive a comprehensive justification and scientific development.

In theory, the Russian law on State Environmental Expertise (SEE), supplemented by EIA procedures, should be aimed at preventing adverse environmental impacts from economic or other activities and, for the first time, provide interested individuals and public organizations to intervene in the process of ensuring environmentally friendly construction.

However, from 1 January 2021, the provision on the EIA ceased to be valid as the only regulatory act on the territory of Russia. The discussion of the EIA materials by interested persons and organizations was questionable. In order to temporarily preserve the EIA procedure, the Natural Resources Ministry drafted a decision of the Government of the Russian Federation on the extension of the period of validity of Order No. 372, dated 16 May 2000, until 1 January 2022. Until now, the issue of EIA remains unresolved to ensure environmental safety if we talk about exploiting natural resources and regulating economic activity in line with energy-efficient, resource-saving, bio-positive solutions. This contribution aims to scrutinize whether the Monte Carlo method (hereinafter MCM) is acceptable for developing sound solutions that form safe construction options and increased environmental protection.

According to ISO/IEC 31010:2009 (Risk assessment methods), ERM/COSO (Enterprise Risk Management - Integrated Framework), and many others, the risk is a consequence of some uncertainty in understanding it for making informed decisions and actions. Uncertainty does not allow us to accurately predict the future consequences of our decisions due to the insufficiency and incompleteness of information, the limited possibilities of its perception and analysis, and the fundamental indeterminacy of nature. If it is known that an event will occur, then this is not a risk, but a fait accompli, so an uncertain event is an occurrence that can happen with some probability. Any risk has two parameters: impact and probability of occurrence. In this definition, the interpretation of risk includes both a negative side and a positive one since risk can be understood as a "chance". As a rule, quantitative research is considered along with qualitative risk analysis, among which brainstorming, Delphi methodology, and interviews potentially and significantly influence the development of competing project requirements. MCM sets the task of stochastic assessment and acceptability of the corresponding level of risk.

Modern software enables function modeling and Monte Carlo simulations, graphically presenting simulation results (Rees 2015). The MCM is to create virtual data from an actual sample (Graham & Talay 2015). However, the method's success depends on the model's ability to reproduce the distribution obtained from the sample data. Nonparametric distributions such as triangular and homogeneous can be used using expert evaluation for modeling in many segments (Thomopoulos 2013). Using Monte Carlo modeling, nonparametric uniform, triangular, and beta (PERT) distributions were verified and confirmed in air, rail, and land transport projects (Salling 2011). A uniform distribution was used to estimate the current service life of a municipal solid waste landfill when the data quality was not sufficient to correct the parametric distributions (Bieda 2013). With the help of @Risk software for Excel, Monte Carlo modeling was used to monitor the efficiency of the welding procedure (Tabim & Ferreira 2015). Based on a hierarchical simulation model, the risk factors are analyzed at the operational level of the tunnel construction (Yu et al. 2018). A simulation model based on a uniform distribution has been developed to correct the heterogeneity of oil production scenarios worldwide (Kasriel & Wood 2013). The stochastic method has proven to be a reliable and effective tool for facilitating decision-making under uncertainty (Chou & Ongkowijoyo 2015).

A large number of modelings of different grades of complication and types, based on mathematical methods, are recommended for use to predict events. However, they are not accurate enough, although we are talking about applying methods recommended in error theory. In this connection, MCM, being flexible to increase the calculation rate (especially using parallel calculations), has the advantage of allowing you to choose any method for analyzing the source data when installed in an interval probabilistic manner (Fathi-Vajargah & Hassanzadeh 2021). Effective network technologies based on MCM to analyze random samples of a particular random value are applied in many engineering applications. MCM effectively coordinates data sharing and problem-solving in dynamically changing virtual organizations with many participants (Branford et al. 2008).

From the point of view of some scientists, MCM is valuable, even if the task is to accurately statistically evaluate infrequent events, analyze the reliability of multivariate variables, solve time-consuming problems, and reduce the amount of computation required to model the objects of interest (Rashki 2021) accurately. This method is a powerful tool for complex engineering problems with many random variables (Peter et al. 2021). Due to its accuracy, this method calculates infinity, while the developed Monte Carlo code gives good predictions about the desired values (Huo 2021).

Mathematical modeling using MCM is used to evaluate the correctness of the modeling procedure and to select the best model parameters based on this method (Coobar et al. 2021). The following estimation tasks are solved: the unknown probability of an event; unknown distribution function; distribution of known parameters; verification of statistical hypotheses about the shape of an unknown distribution or the magnitude of the distribution of known parameters, etc. (Che et al. 2021). Experts are increasingly using this method in various fields of technology, assessing the contribution of uncertainty and sensitivity to model predictions (Pitchai et al. 2021).

MCM procedures have proven to be effective in assessing the risk of exposure to toxic substances in the ecosystem (Toropova & Toropov 2021). MCM is applied in the interests of environmental safety control when it is necessary to determine the conservative fuel depletion limit of a water reactor: forecasting the temperature of the center line, internal pressure deviations, and measurements of the deformation of the reactor (Lee 2021). This method makes it possible to predict changes in the dynamic behavior of an offshore wind turbine during construction since the movement of the seabed is stochastic (Oh & Nam 2021). A probabilistic risk modeling chain with continuous simulation can provide a more comprehensive image of flood risks (Oliver et al. 2009).

However, when it comes to environmental risk assessment, the Monte Carlo method is used quite rarely. The main difficulty is related to the creation of independent samples from the target distribution. The concept of the sampling distribution is the most essential notion of statistics, and it is the cornerstone of building statistical inference. According to the known sample distribution of the studied statistics, we can conclude about the corresponding parameter of the general population. If it is only known that the sample estimate changes from sample to sample, but the nature of this change is unknown, it becomes impossible to determine the sampling error associated with this estimate (Rubinstein 1981).

So, for example, if the uncertainty concerns the ignorance of metal concentrations and the variability of the toxic response among humans, a probabilistic approximation obtained using Monte Carlo simulations should reveal the nature of the negative changes (Kuang et al. 2021). Because the sampling distribution of an estimate describes how it changes from sample to sample, it provides a basis for determining the validity of a sample estimate and can improve understanding of the behavior of pollutants in the environment. Accounting for heavy metal concentrations in surface sediments and samples of marine organisms collected in the Daya Bay of Guangdong serves the purpose of risk analysis in the coastal zone. Monte Carlo simulations helped to identify critical negative impact factors. The obtained sensitivity exploration of variables plays a significant part in assessing their contribution to the total risks of anthropogenic pollution. It was rather difficult for the authors to choose a model for the distribution of random variables and ensure the selection of values randomly from the given distribution of variables and the output of simulation results. As a result, the concentration data for heavy metals follow a log-normal distribution, which helps to draw reliable conclusions about the convergence of the output values. Thus, MCM has been successfully applied to assess the seashore's environmental risk of heavy metal pollution and the risk to public health (Kuang et al. 2021). The average concentration of heavy metals was calculated, and the order of contaminants was set up. The work plan presented by the authors mentioned above can be considered relevant for the study of environmental risk.

Another paper on environmental risk analyzes concentrations of heavy metals in crops (Pirsaheb et al. 2021). The authors also chose a log-normal distribution, which is the best distribution for studying ecotoxicological data. The authors' confidence in the correctness of the conclusions is based on the fact that 95% of all intervals constructed according to the selected sample survey plan contain the actual general mean. In other words, the correctness of the conclusion is due not to some special assessment but accurately to the calculation method. This way is such that for 100 samples for which the sample mean and confidence interval will be designed, in 95 cases, Gaussian premeditated spacing will include the true general value. The accuracy of the sample is determined by the procedure by which the sample was formed. It allows the identification of a characteristic sequence of critical toxicant concentrations for the most sensitive crop types.

As the analysis of works showed, MCM is widely and effectively used in various fields of science and technology. However, its suitability for studying environmental safety data has been little explored. The procedures involved in sampling and determining the initial type of distribution can be controlled by the researcher (for example, the value of the confidence level of the estimate of the general value). However, they are difficult to assess in terms of the result's accuracy and its proximity to the actual value. For example, the larger the standard error of statistics, the higher the degree of scatters of estimates and the lower the accuracy of the procedure.

As the object of this study, the authors chose the reasons that define the ecological well-being of construction – geographic, hydrologic, geologic, and other features of the building zone. We are discussing risk factors that cause emergencies and threats posed by facilities and technologies used in hazardous waste management. Optimistic and pessimistic scenarios, determination of an environmental safety suitable level, and risk assessment methods were the subject of the study. The authors have identified the following main tasks:

- consider scenarios of risk situations,
- characterize the presented risk scenarios,
- show the most critical risks affecting the scenarios,
- apply logistic and log-normal distributions as risk analysis tools through MCM,

- explore the complete risk assessment algorithm in the area of eco-friendly protection.

So, the authors deliberate the query of the applicability of MCM to assess environmental risks in the construction industry and improve environmental safety in this area.

2. Materials and Methods

The article answers how to optimally allocate funds to (1) reduce the likelihood of emergencies and (2) prevent possible environmental damage. The task of determining the method was solved to assess the construction industry. The authors used a risk minimization formula with controlled parameters for stochastic modeling magnitude of the risk of processes and the creation of a specific methodology for assessing environmental risk.

A log-normal distribution was used with mean and sigma (scale) deviation values. The model of multiplicative interaction of random variables with a log-normal distribution, when the system's condition, which is affected by random factors, is taken into account, made it possible to indicate the expected state of degradation and/or destruction of a building object. The simulation modeling of the scenarios assumed the estimation of the probabilistic distributions of the project parameters and the relationship between their changes.

The method for assessing the quantitative value of risk included: analysis of the given intervals of input variables, types of probability distributions, and correlation coefficients between dependent variables. The resulting indicators were repeatedly calculated. Then, mathematical and statistical methods such as mean, variance, log-normal distribution function, and probability density were used to interpret the simulation results of the given scenarios. The probability of the subsequent indicators dropping into one or another interval and exceeding the boundary values in various project conditions was assessed. Objective functions were also considered to optimize the performance of given anthropogenic impact scenarios.

3. Results

In its quantitative extent (chiefly in the sphere of environmental protection), the risk is characterized as the factum of the examined vulnerability factor and total of damage caused:

$$R = P \times C\,, \tag{1}$$

where R is a quantitative risk value; P is the likelihood of emergency incidence; C is predictable harm and consequences resulting from an accident.

Agreeing to Russian standard GOST R 51898-2002 (“Safety aspects”), risk must be deliberated reasonably regarding an optimum counterpoise between safety and technical requirements. In this case, an iterative process of assessing and lowering the predictable harm follows. The initiators (at the same time, they are also stressors, causing a stressful eco universe) of economic activity are compelled to recompense for the damage caused to the environment. Risk assessment aims to preserve the steadiness of an ecosystem subjected to hazardous effects from outside. Risk assessment tools are used to ensure its reasonable level in construction (Smirnova & Larionov 2020, Larionova 2020).

As a rule, construction must examine the multidimensional character of the impact on ecosystem components. However, the same factor can have both negative (amplify the risk) and positive (reduce the risk) effects on the eco complex. The risk magnitude accompanied by possible damage through the probability of the event occurrence must stay within the margins of normalized acceptable value explicated in quantitative form (Smirnova 2020).

Let us move on to calculative the likely environmental harm, which is estimated as the sum of losses imposed by each environmental pollutant under the resulting formula (Federal service 2016):

$$C = EC_A + EC_G + EC_L + EC_B + EC_W \,, \tag{2}$$

where EC_A is recompense for losses from air pollution; EC_G is return for losses from the pollution of the hydrosphere; EC_L is for damage from soil pollution; EC_B is for impairment from biosphere impurity; EC_W is for harm caused to the terrain by construction waste.

To compute a likely situation, we determine that: the probability P of an accident (A) over time (t) depends on the detailed examination of the conditions for the project, construction, and operation of the objects and the statistical information on the unforeseen contingencies. The exponential distribution of time between accidents is defined by Poisson’s rule, which designates events as a flow of random occurrences in the form of the following formula:

$$P(A,t) = \frac{(\lambda \times t)^A}{N!} \times \exp(-\lambda \times t) \,, \tag{3}$$

$$\text{at } A = 0, 1, 2...; \; \lambda \times t \succ 0 \,,$$

where λ is an average measure of the incidents tensity, mathematical expectation $\mu = \lambda$, and the variance $\sigma^2 = \lambda$ of the random variable in the Poisson’s allocation; $e = 2.718281828$ is the basis of the normal logarithm.

The essential assignment is as follows: either to concentrate on risk in the form of costs for the technical safety engineering, and then the likelihood of an accident is close to zero, or to address assets to avoid the anticipated harm (reliability of the technical base’s failure-free operation), and then the probability of trouble, quite the contrary, will have a tendency to one. The following formula defines the method:

$$P(s) = P(s_1) \times \lfloor 1 - P(s_2) \rfloor, \tag{4}$$
$$\text{at } s = s_1 + s_2,$$

where $P(s_1)$ is the likelihood of an accident in the technical safety engineering, its value is subjected to the sum of funds s_1, allocated at preventing dangers and environmental care dealings (**method 1**); $P(s_2)$ is the likelihood of failure-free operation, which depends on how much s_2 funds are owed to retain the reliability of the means involving the sorts of machines, processes, and materials that are used in industry, transport, and communications, and so decrease the expected harm (**method 2**).

The reduction in the likelihood P of a negative effect on the ecosystem depends on the number of funds s_1 spent on its saving and s_2, allocated to diminish the probable harm C. Based on (1) and (3), it could be written down the functions of altering the probability P and damage C:

$$P(s_1) = 0,01 \times \exp(-a \times s_1), \tag{5}$$

$$C(s_2) = \frac{b}{s_2}, \tag{6}$$

where α is the average cost and b is the remainder of the arranged funds to lessen degradation. Then the solution to the efficient arrangement of funds will be as follows:

$$R(s_{1\min}, s_{2\min}) = \min_{\{s_1, s_2\}} P(s_1) \times C(s_2) = \min_{\{s_1, s_2\}} \left[0,01 \times \exp(-a \times s_1) \times \frac{b}{s_2} \right], \tag{7}$$

As a means to simulate an actual situation and evaluate the option of safety against hazardous troubles, we make the task more difficult by introducing a complementary parameter when the likelihood of an accident is inclined to one. Presume that one of the scenarios given below is possible throughout the construction of an object with a specific value of risk probability P:

Scenario 1. The facility's placing caused a change in the landform, meaning there is a risk of damage by flooding, $P_1 = 0.3$. By formula (7), in the face of an object's low risk, its position must be considered. The sum of funds s_1, intended at preventing accidents and environmental care dealings, does not ensure a low-risk value with apriority due to the opportunity of scenery trouble (for instance, flooding). The investment of s_2 funds in sustaining the safety of the technic processes may be unwarranted due to the damaging impacts of exterior factors, which leads to a pessimistic, unfavorable scenario rather than one with a comparably low-risk charge.

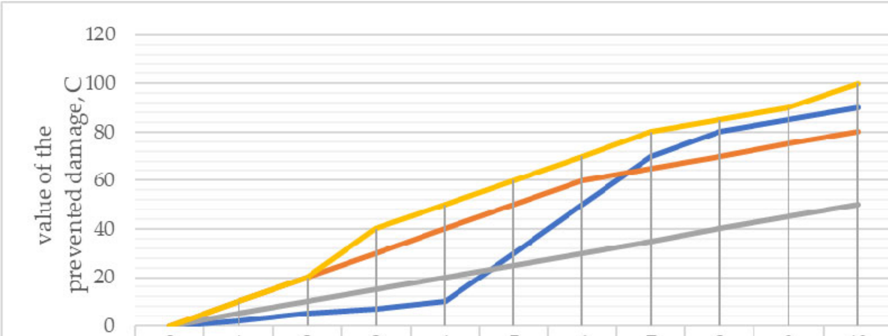
Scenario 2. The building did not meet the parameters of the project documents due to violating fire extinguishing equipment, and the risk of fire is a possibility, $P_2 = 0.6$. In obedience to formula (7), the high risk of accidents permanently rises when plan parameters are broken, despite the high deals s_2 in the safety assurance of the technical means.

Scenario 3. The project cost of building for this area did not deliberate the parameters of seismic safeness; for that reason, there is a risk of harm or obliteration of the facility through an earthquake, $P_3 = 0.1$. Agreeing with formula (7), given the values of s_1 and s_2 and a low-risk rate, it is significant to comprehend what is pertinent in a scenario linked with a place with a likely seismic threat. For example, in St. Petersburg (Russia), there is no possibility of developing occurrences in a seismic safety variant. But, in Tbilisi (Georgia), the harmful factors of a quake can extend the scale of a natural cataclysm.

Scenario 4. The facility is related to an environmentally unsafe technical process and can cause a contingency at any time, $P_4 = 0.7$. Permitting of formula (7), it should be noticed that when in complete obedience with the claims for the technological operation and corresponding funds (s_2) in the care of the technical scheme, emergencies with a high rate of risk are unrealizable, and the progress of this scenario is expected to be optimistic. In preferring between s_1 (funds allocated at preventing accidents and environmental care dealings) and s_2 (assets assigned for the failure-free operations of the technic processes), the optimum scenario will be the one that assures the technic safeness of production.

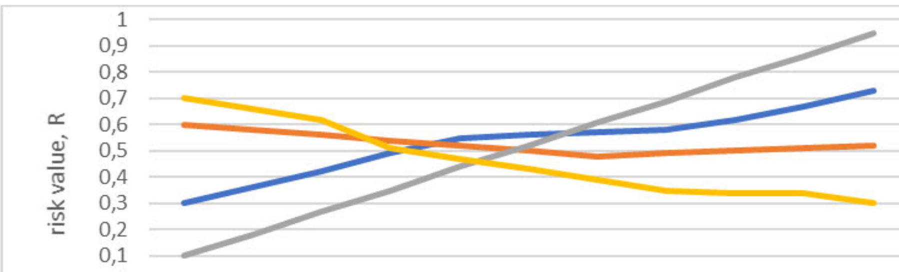
In each of the suggested virtual scenarios, it is undertaken that an object with a likelihood P is a poor success. It is in an emergency, destructively affecting the ecological unit and lowering its eco-protection. An employer can utilize revenue in 100 conventional payment units (I) without hoarding benefits to replace a loss. The chief is handling the task of distributing assets from the returns of his effective activities to develop the environmental care (s_1) and reliability of the technical engineering (s_2), according to the protection actions assured for each of the four scenarios (choosing one of them). The primary data of the virtual scenarios are offered in Fig. 1.

The results for the problem of improving the risk assessment when selecting a specific option were counted up using the formula with restricted variables (I is the annual revenue of the firm in the form of 10 conditional unit costs; D equals ten contributions to each of the 4 options; C is the full amount of averted detriment in dependent units in relative to highest losses – 100 units; $c_i(d)$, i.e., $c_1(d)$, $c_2(d)$, $c_3(d)$, $c_4(d)$, is i-th part of the averted harm in conventional units, P is the certain the assessment of the risk likelihood) for an optimum estimation of environmental hazard.



D	0	1	2	3	4	5	6	7	8	9	10
c1(d)	0	2	5	7	10	30	50	70	80	85	90
c2(d)	0	10	20	30	40	50	60	65	70	75	80
c3(d)	0	5	10	15	20	25	30	35	40	45	50
c4(d)	0	10	20	40	50	60	70	80	85	90	100

Fig. 1. Primary information of scenarios for the target function and the chart of variations in the averted harm



D	0	1	2	3	4	5	6	7	8	9	10
R1(c)	0.3	0.36	0.42	0.49	0.55	0.56	0.57	0.58	0.62	0.67	0.73
R2(c)	0.6	0.58	0.56	0.54	0.52	0.5	0.48	0.49	0.5	0.51	0.52
R3(c)	0.1	0.18	0.27	0.35	0.44	0.52	0.61	0.69	0.78	0.86	0.95
R4(c)	0.7	0.66	0.62	0.51	0.46	0.43	0.39	0.35	0.34	0.34	0.3

Fig. 2. Results of the estimated example for the objective function

In this case, risk level R depends on the costs of avoiding the predictable hurt, so all revenue can be deliberated as yearly wrong got in an unexpected condition. The objective function is the next:

$$R_i(D) = \frac{(1-P_i)\times D}{I} + \frac{P_i\left[C - c_i(D)\right]}{C}, \tag{8}$$

Substituting the values from the table (Fig. 1) and risk likelihood meanings into formula (8), the outcomes offered in Fig. 2 were found.

Charts R_1(c), R_2(c), R_3(c), and R_4(c) are put up via the outcomes of the computational example for the objective function. Fig. 2 confirms that even with a zero-investment set (D = 0), each scheme (scen. 1-4) affords the outlays of ensuring eco-friendly protection. It is required to examine the two possible results of occasions to treat the calculation outcomes for simulated scenarios. The two probable products are pessimistic (1st and 2nd scen.) and optimistic (3rd and 4th scen.). In the first downbeat variation, the lowest rate of risk assessment R is 0.52 at the cost of c in 3.5 conventional units. In the second confidence about the future flavor, the minimum price of risk assessment R will not surpass 0.46 at the cost of 4.2 conventional units. Moreover, when selecting scen. 3 or 4, the business owner will have to deal with even lower risk scores, matching the sums financed.

Precisely under pessimistic conditions, the first scenario overpowers the second sequence preference because assets in the technical means remained large, raising its fail-safety (Fig. 3). In an optimistic situation, investing in the second variant is also vindicated. Scen. 3 has the lowest probability of risk owing to noteworthy charges in the safety of the technical base (70%). Though the general risk value is more significant (5.65) than in the pessimistic scenarios (5.55 and 5.2), the graph demonstrates that the lowermost risk values followed before the investments amounted to 4.2.

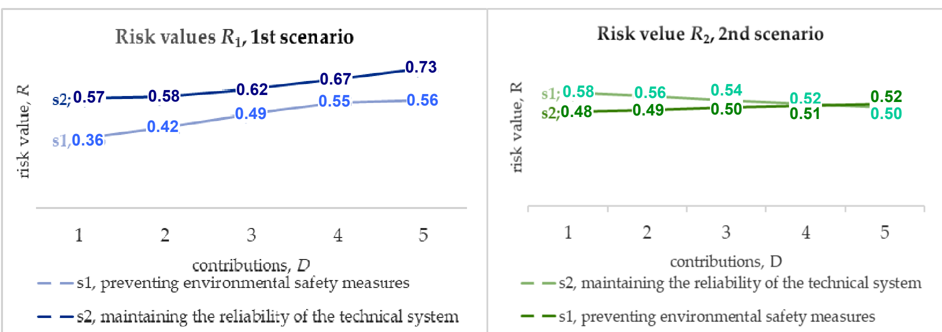


Fig. 3. Investment structure in pessimistic scenarios

Actions connected to environmental protection costs, the payback time-limit of which is longer, likewise have their worth collated to higher costs for raising the reliability of the technical complexity, which has a shorter payback time. This status quo decreases the impact of the risk. Note that in scen. 4, starting from an asset of 4.2, the risk lessens with a decrease in environmental care costs since the payback period is diminished (51.73%) (Fig. 4).

The examination proposes that if the probability of risk P tends to 0 or 1 in unfavorable circumstances, though the costs are minor, then the decision-making risk is relatively high. Therefore, the finance charges may turn out to be unwarranted. In a favorable situation, higher costs (actually in the amount of annual returns) will be acceptable as the decision-making risk is lower. A quantitative risk assessment or risk analysis (QRA) can be grounded on deterministic or stochastic modeling handling.

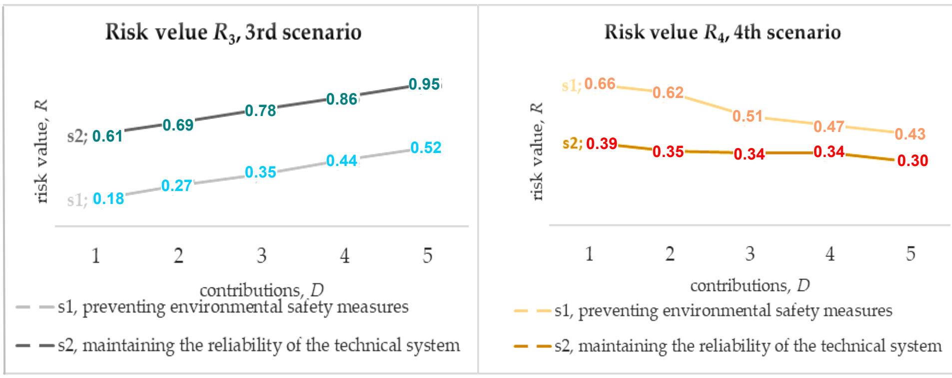


Fig. 4. Investment structure in optimistic scenarios

The distinction between both attitudes is connected with two matters, exactly risk, and uncertainty. Risks are quantitative assessments of the predictable likelihood of actual events occurring. Their outcome in any given condition is subjected to uncertainty or randomity. The uncertainty described above is disregarded in the deterministic model, while it is really reckoned in the stochastic making by means of the MCM. The deterministic model will produce only one value for the outcome parameter, whereas the stochastic pattern will create a probability distribution of likely results.

Modeling by the MCM must be conducted (Smirnova 2021). It is required to make a probability distribution for the predictable risk degrees in the range from 0.1 to 0.95 using the particular boundaries of the logistic (for the pessimistic option) and log-normal distributions (for the optimistic development) via PC simulation (Table 1).

With many random variables, it is reliably known that their arithmetic average as a random variable differs infinitely little from a non-random (standard) variable if we talk about the value of its average mathematical expectation. In other words, the action of a combination of random factors gives a result almost independent of chance. Here there is a well-known approximation of the calculations of probable quantities to a constant. The random variable “level of expected risk” is the average expected value of the environmental risk of the project. Let’s denote it as X.

Next, we use the Crystal Ball program based on MCM algorithms. In our case, the logistic and log-normal probability distributions are the most appropriate for the given data (Figures 5 and 6).

The logistic distribution is similar to a normal distribution in shape, but the ends are "heavier". It permits customers to determine density, probability, and quantiles and create pseudo-random numbers allocated agreeing with a logistic rule. The mean and scale (sigma) is its limiting condition. It characterizes various laws of change in biology, physics, economics, and other areas.

Table 1. Data on the parameters of the probability distribution

$\frac{(1-P_i)\times D}{I}$				$R_i(D)=\frac{(1-P_i)\times D}{I}+\frac{P_i\left[C-c_i(D)\right]}{C}$				$\frac{P_i\left[C-c_i(D)\right]}{C}$			
D_1	D_2	D_3	D_4	R_1(c)	R_2(c)	R_3(c)	R_4(c)	P_1	P_2	P_3	P_4
0	0	0	0	0.3	0.6	0.1	0.7	0.3	0.6	0.1	0.7
0.07	0.04	0.09	0.03	0.36	0.58	0.185	0.66	0.27	0.54	0.095	0.63
0.14	0.08	0.18	0.06	0.42	0.56	0.27	0.62	0.24	0.48	0.09	0.56
0.21	0.12	0.27	0.09	0.49	0.54	0.355	0.51	0.18	0.42	0.085	0.42
0.28	0.16	0.36	0.12	0.55	0.52	0.44	0.47	0.15	0.36	0.08	0.35
0.35	0.2	0.45	0.15	0.56	0.5	0.525	0.43	0.12	0.3	0.075	0.28
0.42	0.24	0.54	0.18	0.57	0.48	0.61	0.39	0.09	0.24	0.07	0.21
0.49	0.28	0.63	0.21	0.58	0.49	0.695	0.35	0.06	0.21	0.065	0.14
0.56	0.32	0.72	0.24	0.62	0.5	0.78	0.345	0.045	0.18	0.06	0.105
0.63	0.36	0.81	0.27	0.67	0.51	0.865	0.34	0.03	0.15	0.055	0.07
0.7	0.4	0.9	0.3	0.73	0.52	0.95	0.3	0	0.12	0.05	0

The log-normal distribution is usually applied if values are affirmatively skewed (most values take place around the least one). The factors for the log-normal distribution are the mathematical expectation and standard deviation. The logarithmically normal distribution is grounded on three settings: 1) the indefinite variable can grow infinitely, but it is restricted to below by a finite worth; 2) the indefinite variable demonstrates a distribution with affirmative skewness; 3) the natural logarithm of the indefinite variable provides a standard curve.

As expected, in each of the four scenarios, we are talking about emergencies unfavourably affect the natural environment. Construction project managers must monitor the protection of the ecosystem within the framework of environmental legislation. Therefore, a share of funds from the budget is allocated to specific areas of safety: reducing the likelihood of environmental accidents (s_1) and maintaining the reliability of technical systems (s_2).

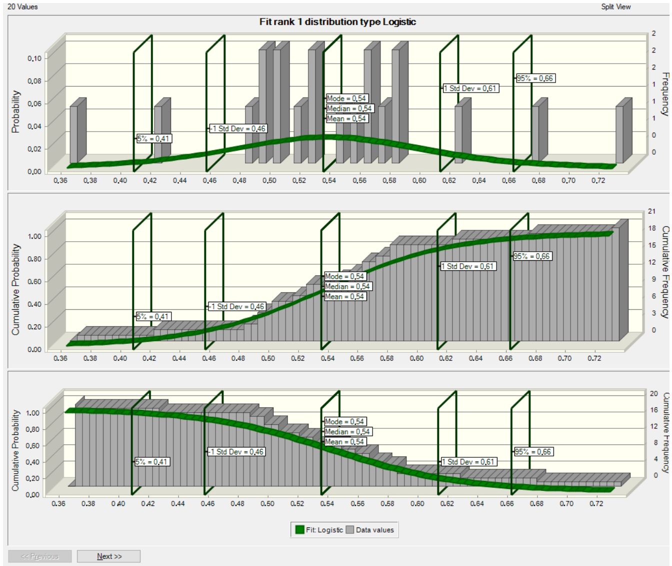


Fig. 5. Logistic distribution with: μ = 0.54 and s = 0.8 (for scen. 1 and 2)

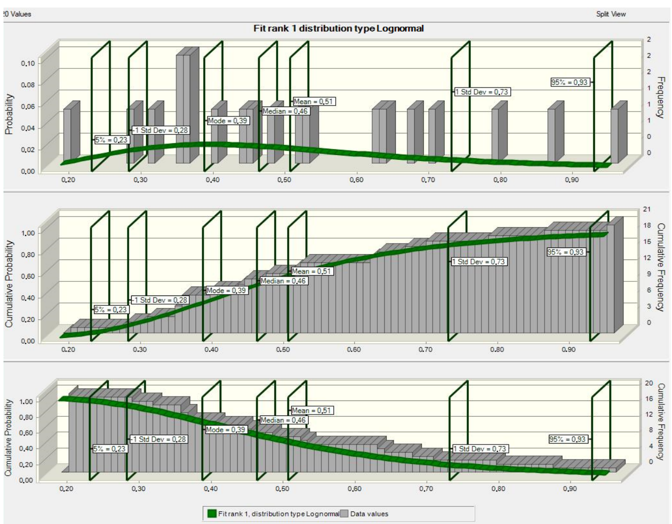


Fig. 6. Lognormal distribution with: Mode = 0.46, $\mu_L = 0$, and $\sigma_L = 1$ (for scen. 3 and 4)

The priority task is deliberated to be the entrepreneur's choice of a scenario with investments in the prevention of possible environmental damage or risk minimization. This study showed that stochastic modeling using MCM fully confirms the hypothesis about the probability and degree of risk in the perspective of the pessimistic (scen. 1 and 2) and positive (scen. 3 and 4) options.

In the pessimistic variant, the minimum value of the risk assessment *R* is 0.52, and in the optimistic variant, *R* does not exceed 0.46. Even in pessimistic conditions, the first scenario is preferable to the second because investments in updating technical means are more significant, increasing their reliability.

In pessimistic scenarios, insufficient investment for the renewal and reliability of technical means leads to a higher risk. On the contrary, the more assets are allocated to reduce the expected damage to the natural environment, the lower the risk is.

However, this type of risk prevention activity is not profitable for entrepreneurs in the short term because the payback period for investments in technical means is shorter than for environmental measures. Despite the high value of the risk probability of 0.7, option 4 is optimistic since the funds s_2 allocated for the trouble-free operation of the technical system reduce the likelihood of an emergency.

Indeed, scenario 3 has the lowest risk probability due to significant funds in the safety of the technic composition (70%). Together with scenario 4 (with a sufficiently high-risk probability), they indicate even lower risk values than 0.46. It is stipulated for the circumstance that a high level of risk is made for the volume of "lost" investments in maintaining "green" technologies.

4. Discussion

In a situation of choice, when only a set of possible outcomes is known, to which probability values cannot be assigned, the best options will be those that are associated with high costs for maintaining the reliability of the technical operation but with a lower risk of adverse environmental impact (P_3 with a value of 0.1 and P_4 with a value of 0.7). This forecast plays a decisive role in the environmental safety strategy of a construction project.

It is clear that the MCM deals with random variables that take on numeric values and cannot be predicted with utter certainty. On the other side, these quantities can be taken with some probability as one of the values of a certain set of the reals. The fact that the model itself is uncertain remains a significant difficulty in risk investigation. The approach is to define the distribution with the highest entropy according to the existing knowledge, which constrains its potential figure. Without any assumptions about the quantity, this methodology allows the input distribution to be optimally chosen using only limited information about the variables (Bieda 2012).

It can be argued that despite the high-risk probability of 0.7, option 4 is preferable because the assets are distributed to preserve the technical sources' reliability and prevent the expected damage, diminishing the possibility of an impending disaster in increased danger. The best available techniques (BAT), based on modern scientific achievements and the best criteria set for accomplishing eco-friendly safety goals (according to Directive 2010/75/EU of 24 November 2010), are aimed at the full-scale eco-protection and minimizing of the destructive effect on the ambient medium per unit of time or volume of goods made, work executed; profitable efficiency of adoption and operation of installed technologic objects; application of resource-saving techniques of work. Investments in technology develop the environmental and source efficiency of construction, reliably dropping the harmful effect on the environmental situation.

Thus, under the optimal distribution of funds (s_1, reducing the likelihood of an environmental accident and s_2, ensuring technical safety on the base of the BAT), as modeling shows, we mean, first of all, a block of technical measures and investments in technologies to ensure environmental safety, reliable safety of equipment excluding the possibility of an emergency.

However, estimating the degree of probability of rare events is highly problematic. Since large deviations, called "Extremistan" (Taleb 2007), are extremely rare, their contribution to the forecast result is minimal, so they are neglected. Uncertainty scaling based on a Gaussian curve ignores the possibility of jumps. When calculating according to the log-normal probability distribution, excluding such deviations is also the main disadvantage of MCM (Smirnova 2021). A critical factor in risk analysis is ensuring the output's validity. But the disadvantage associated with the assumption that the future will not be severely different from the earlier is also apparent when employing the MCM. The opportunity to forecast events comes to be very restricted.

In terms of analysis, complex methods such as MCM do not ineludibly give more precise outcomes than the simplest ones. The main conclusion that follows from the risk analysis is obvious. No risk is acceptable when considered in seclusion. A rational individual will not yield to any risk except in exchange for a collateral benefit. Even if the risk is tolerable on a specific base, it is still intolerable if the same benefit could be gained by another means with less risk. It is considered unacceptable if the risk could be reduced at little cost. However, a much greater risk may be acceptable if it entails a significant cost reduction or an increase in benefits.

Any assessment of the risk level should consider both quantitative aspects and the results of a qualitative evaluation to obtain a more complete picture of the forecast (Aven 2009). In this regard, the scenario approach to studying risks and their likelihood is a broad qualitative (semi-quantitative) consideration highlighting possible hazards and accident scenarios.

5. Conclusions

A quantitative risk assessment was carried out using MCM for pessimistic and optimistic choices for preventing environmental damage. The simulation results are combined with a visual representation of the general evaluation principle and optimal decision-making. This method of risk analysis has dealings with computer implementation.

The result of the Monte Carlo simulation was the logistic and log-normal distributions of the probable parameters of the given scenarios, which are represented graphically in the form of curves. The model reproduced the distribution established using actual data. MCM can be used to assess environmental risks to improve environmental safety in the construction sector.

In the study, the following conclusions are presented:

- The method associated with the allocation of investments is used (1) to develop the technical safety of construction and thereby escape conceivable harm to the environment, as well as (2) to afford ground for an effective process to diminution the risk of an anthropogenic effect on the eco medium.
- Calculations show that the development of an optimistic or pessimistic scenario depends on external reasons, the exact implementation of project parameters, the location of the facility, and complete adherence to the specifications for the construction's environmental safety.
- Further, the high risk in the case of an optimistic scenario can be explained by the effect of external causes and sufficiently high investment in avoiding ecological destruction.
- The reason for the low risk in the case of a pessimistic scenario can be called a violation of the set parameters of the project, despite investments in environmental safety.
- The MCM increases the flexibility of assessing the environmental situation in various activities and environmental conditions and screening and scoping project zones subject to mandatory environmental certification, which increases their environmental safety.

Additional improvement of the method is aimed at generating a methodology that could assess environmental risks in the construction sector.

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