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On the reliability of investment risk assessments

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Abstract. *The paper examines the reliability of investment risk estimates based on probabilistic realizations of purpose-designed scenarios. The calculations of the probabilities of scenario realization were based on logical and probabilistic methods. The reliability of risk assessment is understood as the probability of successful completion of a project, fulfillment of all contractual obligations: construction in compliance with the architectural and engineering design and quality requirements, within the contractual period and approved budget. Investment risks were estimated based on eight primary scenarios. The realization of the risks of the main group depended on the realization of the various numbers of risk scenarios of each subgroups in the main group. For instance, the first scenario of the main group consisted in the risk of faulty project ROI analysis and the risk of underestimated construction budget. The second one consisted in the risk of underestimated construction budget and risk associated with the selection of the basic flowsheet and primary process parameters, etc. The risks of each subgroup could be obtained by means of expert estimations or, in case of sufficient statistical data, based on the actual distributions. A mathematical model was developed for the purpose of a computerized solution. The mathematical model also allowed identifying such dependability factors as "weight", "significance" and "contribution" of each risk in the success of an investment project (reliability structure of investment risk estimation). The analysis of calculation data enabled the identification of the probability of successful project completion (reliability), the risks that are the most important, significant and having the largest contribution to the successful implementation of investment projects. Also, the risks were identified that have the least pronounced effect on the successful implementation of an investment project.*

Keywords: *probability, investment, model, dependability, risks, system, scenarios.*

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This paper examines the reliability of the estimates of investment risks based on probabilistic realizations of purpose designed scenarios. The calculations of the probabilities of scenario realization were based on logical and probabilistic methods.

The reliability of risk assessment is understood as the probability of successful completion of a project, fulfillment of all contractual obligations: construction in compliance with the required architectural and engineering design, quality, within the contractual period and approved budget.

In order to solve the problem, let us identify the following risks that make the main group that consists of eight scenarios (Table 8).

1. Q_1, the effect of design errors, including errors in the design and estimate documentation, incomplete detailed documentation;
2. Q_2, the effects of construction errors that define the quality of construction and installation works, possibility of industrial accidents, etc.;
3. Q_3, the effects of investment management errors that define the project execution period, possibility of contracts execution failures, etc.;
4. Q_4, the effects of negative economic fluctuations, including economic sanctions, sudden foreign exchange rate fluctuations, changes in other market indicators;
5. Q_5, the effects of unstable political situation, deterioration of social situation (strikes, environmental events, etc.);
6. Q_6, the effects of cataclysms (earthquakes, floods, etc.);
7. Q_7, the effects of financial risks.

In turn, the realization of the risks in each group depends on the realization of the scenarios of the subgroups of risks in such groups. Thus, the first subgroup of risks that take into consideration the effects of errors in design and estimate documentation, incomplete detailed documentation, includes:

1.1. $Q_{1\text{-}1}$, the risk of ROI analysis errors;
1.2. $Q_{2\text{-}1}$, the risk of underestimation of project budget;
1.3. $Q_{3\text{-}1}$, the risk associated with the selection of the basic flowsheet and primary process parameters;
1.4. $Q_{4\text{-}1}$, the risk caused by architectural solution and design solution errors;
1.5. $Q_{5\text{-}1}$, the risk caused by errors in the inquiry specifications and cost estimates;

Table 1

	$Q_{1\text{-}1}$	$Q_{2\text{-}1}$	$Q_{3\text{-}1}$	$Q_{4\text{-}1}$	$Q_{5\text{-}1}$	$Q_{6\text{-}1}$	$Q_{7\text{-}1}$	$Q_{8\text{-}1}$	$Q_{9\text{-}1}$
$C_{1\text{-}1}$	1	1	0	0	0	0	0	0	0
$C_{2\text{-}1}$	0	1	1	0	0	0	0	0	0
$C_{3\text{-}1}$	0	0	0	1	1	0	0	0	0
$C_{4\text{-}1}$	0	0	0	0	1	1	0	0	0
$C_{5\text{-}1}$	0	0	0	1	0	0	1	0	0
$C_{6\text{-}1}$	0	0	0	1	0	0	0	1	0
$C_{7\text{-}1}$	0	0	0	1	0	0	0	0	1

1.6. $Q_{6\text{-}1}$, the risk caused by delays in engineering documentation development;
1.7. $Q_{7\text{-}1}$, the risk of biased design solutions;
1.8. $Q_{8\text{-}2}$, the risk of the use of unique materials;
1.9. $Q_{9\text{-}1}$, the risk of underestimation of the construction period;

The scenarios for the risks of the first subgroup are shown in Table 1.

Thus, the first scenario consists in the risk of faulty project ROI analysis and the risk of underestimated construction budget. The second one consists in the risk of underestimation of the construction budget and risk associated with the selection of the basic flowsheet and primary process parameters. And so on.

Thus, the probability of the effect of design errors, including errors in the design and estimate documentation, Q_1, is defined by the realization of scenarios $C_{1\text{-}1}$, *or* $C_{2\text{-}1}$, *or* $C_{3\text{-}1}$, *or* $C_{4\text{-}1}$, *or* $C_{5\text{-}1}$, *or* $C_{6\text{-}1}$, *or* $C_{7\text{-}1}$.

The second subgroup of risks that take into consideration the effects of construction errors that define the quality of construction and installation works (CIW), possibility of industrial accidents, etc. includes:

2.1. $Q_{1\text{-}2}$, the risk of non-fulfillment of obligations by contractors and equipment suppliers;
2.2. $Q_{2\text{-}2}$, the risk of violation of CIW process regulations;
2.3. $Q_{3\text{-}2}$, the risk of the use of materials that do not comply with the design solutions;
2.4. $Q_{4\text{-}2}$, the risk of longer construction time by fault of the general contractor;
2.5. $Q_{5\text{-}2}$, the risk of failure to achieve the project's technical indicators;
2.6. $Q_{6\text{-}2}$, the risk of delayed commissioning of the facility;
2.7. $Q_{7\text{-}2}$, the risk of non-receipt of the required authorizations and approvals.

The scenarios for the risks of the second subgroup are shown in Table 2.

Table 2

	$Q_{1\text{-}2}$	$Q_{2\text{-}2}$	$Q_{3\text{-}2}$	$Q_{4\text{-}2}$	$Q_{5\text{-}2}$	$Q_{6\text{-}2}$	$Q_{7\text{-}2}$
$C_{1\text{-}2}$	1	1	0	0	0	0	0
$C_{2\text{-}2}$	0	1	1	0	0	0	0
$C_{3\text{-}2}$	0	1	0	1	0	0	0
$C_{4\text{-}2}$	1	0	0	0	1	0	0
$C_{5\text{-}2}$	0	0	0	0	1	1	0
$C_{6\text{-}2}$	1	1	1	0	0	0	1

The third subgroup of risks that take into consideration the effects of investment management errors that define the project execution period, possibility of contracts execution failures, etc. includes:

3.1. $Q_{1\text{-}3}$, the of risk of selection of a wrong strategy;
3.2. $Q_{2\text{-}3}$, the risk of wrong prediction;

3.3. $Q_{3\text{-}3}$, the risk of managerial errors;

3.4. $Q_{4\text{-}3}$, the risk of supervision and regulation errors.

The scenarios for the risks of the third subgroup are shown in Table 3.

Table 3

	$Q_{1\text{-}3}$	$Q_{2\text{-}3}$	$Q_{3\text{-}3}$	$Q_{4\text{-}3}$
$C_{1\text{-}3}$	1	1	0	0
$C_{2\text{-}3}$	1	0	1	0
$C_{3\text{-}3}$	0	0	1	1

The fourth subgroup of risks that takes into consideration the effects of negative economic fluctuations including economic sanctions, sudden foreign exchange rate fluctuations, changes in other market indicators, includes:

4.1. $Q_{1\text{-}4}$, the risk of international economic sanctions;

4.2. $Q_{2\text{-}4}$, the risk caused by sudden foreign exchange rate fluctuations;

4.3. $Q_{3\text{-}4}$, the risk of incorrect market assessment: increasing competitiveness, etc.;

4.4. $Q_{4\text{-}4}$, the risk of incorrect market capacity evaluation;

4.5. $Q_{5\text{-}4}$, the risk of incorrect market share assessment;

The scenario for the risks of the fourth subgroup are shown in Table 4.

Table 4

	$Q_{1\text{-}4}$	$Q_{2\text{-}4}$	$Q_{3\text{-}4}$	$Q_{4\text{-}4}$	$Q_{5\text{-}4}$
$C_{1\text{-}4}$	1	0	0	0	0
$C_{2\text{-}4}$	0	1	0	0	0
$C_{3\text{-}4}$	0	0	1	0	0
$C_{4\text{-}4}$	0	0	0	1	0
$C_{5\text{-}4}$	0	0	0	0	1

The fifth subgroup of risks that takes into consideration the effects of unstable political situation, deterioration of social situation (strikes, environmental events, etc.) includes:

5.1. $Q_{1\text{-}5}$, the risk of deteriorating social situation;

5.2. $Q_{2\text{-}5}$, the risk of politically motivated strikes;

5.3. $Q_{3\text{-}5}$, the risk of environmental protests;

5.4. $Q_{4\text{-}5}$, the risk of political demonstrations;

The scenarios for the risks of the fifth subgroup are shown in Table 5.

Table 5

	$Q_{1\text{-}5}$	$Q_{2\text{-}5}$	$Q_{3\text{-}5}$	$Q_{4\text{-}5}$
$C_{1\text{-}5}$	1	1	0	0
$C_{2\text{-}5}$	1	0	1	0
$C_{3\text{-}5}$	1	0	0	1

The sixth subgroup of risks that takes into consideration the effects of cataclysms (earthquakes, floods, etc.) includes:

6.1. $Q_{1\text{-}6}$, the risk of off-design earthquakes;

6.2. $Q_{2\text{-}6}$, the risk of insufficiency of adopted design measures in cases of design-basis earthquakes;

6.3. $Q_{3\text{-}6}$, the risk of flooding;

6.4. $Q_{4\text{-}6}$, the risk of landslides caused by background earthquakes or flooding.

The scenarios for the risks of the sixth subgroup are shown in Table 6.

Table 6

	$Q_{1\text{-}6}$	$Q_{2\text{-}6}$	$Q_{3\text{-}6}$	$Q_{4\text{-}6}$
$C_{1\text{-}6}$	1	1	0	0
$C_{2\text{-}6}$	1	0	1	0
$C_{3\text{-}6}$	1	0	0	1

The seventh subgroup of risks that takes into consideration the effects of financial risks includes:

7.1. $Q_{1\text{-}7}$, the risk of non-availability of financial loan;

7.2. $Q_{2\text{-}7}$, the risk of changing interest rate;

7.3. $Q_{3\text{-}7}$, the risk of investor's insufficient own circulating assets;

7.4. $Q_{4\text{-}7}$, the risk of financial losses as the result of changes in the exchange rate that may occur between the conclusion of contract and the settlement;

7.5. $Q_{5\text{-}7}$, the inflation risk, i.e. the possibility of depreciation of capital (in the form of the company's financial assets), as well as the expected income generated by financial operations amidst inflation;

7.6. $Q_{6\text{-}7}$, tax risk that is characterized by the probability of introduction of new taxes and fees for specific business activities, possibility of increased rates of existing taxes and fees, changes in the terms and conditions of individual taxes, probability of cancellation of existing tax exemptions as regards the company's business activities;

7.7. $Q_{7\text{-}7}$, the systemic risk defined by inefficient funding of the company's current expenditures, which causes a high relative share of the standing costs in the overall sum.

The scenarios for the risks of the seventh subgroup are shown in Table 7.

Table 7

	$Q_{1\text{-}7}$	$Q_{2\text{-}7}$	$Q_{3\text{-}7}$	$Q_{4\text{-}7}$	$Q_{5\text{-}7}$	$Q_{6\text{-}7}$	$Q_{7\text{-}7}$
$C_{1\text{-}7}$	1	1	0	0	0	0	0
$C_{2\text{-}7}$	0	1	1	0	0	0	0
$C_{3\text{-}7}$	0	0	1	1	0	0	0
$C_{4\text{-}7}$	0	0	0	1	1	0	0
$C_{5\text{-}7}$	0	0	0	0	1	1	0
$C_{6\text{-}7}$	0	0	0	0	0	1	1

Shown in Tables 1 to 7 are: Q_i, the probability of realization of the i-th risk; C_i, logical conjunction scenarios.

Company's losses ("failed" investment) are associated with the realization of risk scenarios shown in Table 8: *or* (Q_1 *and* Q_3), *or* (Q_1 *and* Q_6), *or* (Q_2 *and* Q_3), *or* (Q_2 *and* Q_5, *and* Q_6), *or* (Q_1 *and* Q_3, *and* Q_4), *or* (Q_1 *and* Q_3, *and* Q_5), *or* (Q_3 *and* Q_4, *and* Q_5, *and* Q_6), *or* (Q_7).

Table 8

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
C_1	1	0	1	0	0	0	0
C_2	1	0	0	0	0	1	0
C_3	0	1	1	0	0	0	0
C_4	0	1	0	0	1	1	0
C_5	1	0	1	1	0	0	0
C_6	1	0	1	0	1	0	0
C_7	0	0	1	1	1	1	0
C_8	0	0	0	0	0	0	1

The given data for Q_i, $i = 1, \ldots, 7$ are the probabilities identified based on the scenarios given in Tables 1 to 7.

In Table 9, the following data is given for the example in question. Risks Q_{i-j} (probability of realizations of i risks of the j-th group) in the example in question were obtained by means of expert evaluation. In case of sufficient statistical data, probability Q_{i-j} should be identified based on the actual distributions.

Shown in Table 9 are: Q_i, the probability of realization of the i-th risk; R_i, instead, the probability of non-realization of the i-th risk, i.e. $R_{i-j} = 1 - Q_{i-j}$.

Let us write the probability of successful implementation of an investment project:

$$R_c = 1 - Q_c, \tag{1}$$

Where

$$Q_c = \begin{vmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \end{vmatrix} = \begin{vmatrix} Q_1Q_3 \\ Q_1Q_6 \\ Q_2Q_3 \\ Q_2Q_5Q_6 \\ Q_1Q_3Q_4 \\ Q_1Q_3Q_5 \\ Q_3Q_4Q_5Q_6 \\ Q_7 \end{vmatrix}. \tag{1$'$}$$

Thus, each scenario is a multicriterion value. In order to account for all the risks, the realization of possible "unsuccessful" scenarios should be described, i.e. it must be identified how damage can occur. Table 8 describes the scenarios of model ($1'$).

A mathematical model was developed for the purpose of a computerized solution of problem (1). The probability of successful project completion subject to the above probabilities is 0.93742. Therefore, the probability of "failure" or losses is 6,258%. The mathematical model allows identifying the "weight" (2), as well as the "significance" (3) and "contribution" (4) of each risk to the success of an investment project. The findings are given in Table 10.

$$g_{Q_i} = \frac{G\{\Delta_{Q_i} y(Q_1,\ldots,Q_n)\}}{2^n} = \sum_{j=1}^{l} 2^{-(r_j-1)} - \sum_{f=1}^{k} 2^{-(r_f-1)}, \tag{2}$$

where $f = 1, \ldots, k$; $j = 1, \ldots, l$; r_f, r_j are the ranks of elementary conjunctions; k, l are the number of conjunctions that contain $Q_i^{/}, Q_i$ ($Q_i^{/} = R_i$) and not contain the i-th argument; n is the number of fixed variables of the initial function.

The "weight" of the Boolean difference (2) characterizes the importance of risk Q_i for the reliability of investment. The "weight" of an elements also characterizes the relative number of such critical states, in which the failure of an individual scenario causes the failure of the whole model (and vice versa, the recovery causes the recovery) out of all states of the model with $Q_i = 1$. The criterion of the "weight" of a risk g_{x_i} characterizes the location of such risk Q_i in the model (of the system) ($Q_1, \ldots, Q_n$).

The "significance" of risk Q_i is a partial derivative of mathematical model Q_c ($1'$) with respect to the probability of risk Q_i, i.e.

$$\zeta_{Q_i} = \frac{\partial P\{y(Q_1,\ldots,Q_n)=1\}}{\partial P\{Q_i=1\}} = \frac{\partial Q_c}{\partial Q_i}. \tag{3}$$

The criterion of "significance" characterizes the rate of change of the reliability of investment. The "significance" is the conditional probability under condition of realization of risk Q_i. Additionally, the criterion of "significance" allows identifying the risks that enable the highest increase in the reliability of the chosen model.

The "contribution" of element Q_i to system (risk scenarios) $y(Q_1, \ldots, Q_n)$ is the product of risk Q_i and its "significance", i.e.

$$B_{x_i} = Q_i \frac{\partial Q_c}{\partial Q_i} = Q_i \frac{Q_c - Q_{c0}^{(i)}}{Q_i} = Q_c - Q_{c0}^{(i)}. \tag{4}$$

The criterion of "contribution" characterizes the increase of dependability after recovery of scenario with risk Q_i.

The concept of "specific contribution" is a more general characteristic than simply "contribution". The "specific contribution" of risk Q_i to system (scenario) $y(Q_1, \ldots, Q_n)$ is the standardized "contribution" of such risk, i.e.

$$b_{Q_i} = B_{Q_i} / \sum_{i=1}^{n} B_{Q_i}. \tag{5}$$

Table 9

R_{1-1}	R_{2-1}	R_{3-1}	R_{4-1}	R_{5-1}	R_{6-1}	R_{7-1}	R_{8-1}	R_{9-1}
0.850	0.850	0.850	0.800	0.750	0.250	0.900	0.900	0.750
Q_{1-1}	Q_{2-1}	Q_{3-1}	Q_{4-1}	Q_{5-1}	Q_{6-1}	Q_{7-1}	Q_{8-1}	Q_{9-1}
0.150	0.150	0.150	0.200	0.250	0.750	0.100	0.100	0.250
R_{1-2}	R_{2-2}	R_{3-2}	R_{4-2}	R_{5-2}	R_{6-2}	R_{7-2}	–	–
0.900	0.900	0.900	0.850	0.850	0.850	0.990	–	–
Q_{1-2}	Q_{2-2}	Q_{3-2}	Q_{4-2}	Q_{5-2}	Q_{6-2}	Q_{7-2}	–	–
0.100	0.100	0.100	0.150	0.150	0.150	0.010	–	–
R_{1-3}	R_{2-3}	R_{3-3}	R_{4-3}	–	–	–	–	–
0.950	0.900	0.900	0.800	–	–	–	–	–
Q_{1-3}	Q_{2-3}	Q_{3-3}	Q_{4-3}	–	–	–	–	–
0.050	0.100	0.100	0.200	–	–	–	–	–
R_{1-4}	R_{2-4}	R_{3-4}	R_{4-4}	R_{5-4}	–	–	–	–
0.850	0.850	0.950	0.950	0.850	–	–	–	–
Q_{1-4}	Q_{2-4}	Q_{3-4}	Q_{4-4}	Q_{5-4}	–	–	–	–
0.150	0.150	0.050	0.050	0.150	–	–	–	–
R_{1-5}	R_{2-5}	R_{3-5}	R_{4-5}	–	–	–	–	–
0.650	0.750	0.950	0.800	–	–	–	–	–
Q_{1-5}	Q_{2-5}	Q_{3-5}	Q_{4-5}	–	–	–	–	–
0.350	0.250	0.050	0.200	–	–	–	–	–
R_{1-6}	R_{2-6}	R_{3-6}	R_{4-6}	–	–	–	–	–
0.950	0.950	0.990	0.850	–	–	–	–	–
Q_{1-6}	Q_{2-6}	Q_{3-6}	Q_{4-6}	–	–	–	–	–
0.050	0.050	0.010	0.150	–	–	–	–	–
R_{1-2}	R_{2-2}	R_{3-2}	R_{4-2}	R_{5-2}	R_{6-2}	R_{7-2}	–	–
0.950	0.977	0.990	0.750	0.850	0.950	0.900	–	–
Q_{1-2}	Q_{2-2}	Q_{3-2}	Q_{4-2}	Q_{5-2}	Q_{6-2}	Q_{7-2}	–	–
0.050	0.023	0.010	0.250	0.150	0.050	0.100	–	–

Table 10

g_1	g_2	g_3	g_4	g_5	g_6	g_7
0.203	0.141	0.234	0.016	0.047	0.172	0.453
ξ_1	ξ_2	ξ_3	ξ_4	ξ_5	ξ_6	ξ_7
0.03445	0.02019	0.31606	0.00003	0.00050	0.27474	0.98754
B_1	B_2	B_3	B_4	B_5	B_6	B_7
0.00998	0.00130	0.00901	0.00001	0.00008	0.00276	0.05011
b_1	b_2	b_3	b_4	b_5	b_6	b_7
0.136	0.018	0.123	0.000	0.001	0.038	0.684

Calculation data in the form of differential characteristics of risks $g_{Q_i}, \zeta_{Q_i}, b_{Q_i}$ shown in Table 10 clearly demonstrates the distribution of the role of all primary risks over the given dependability structure in the context of various problems.

Table 11 shows relative values of risk parameter p_i ($i = 1, \ldots, 7$) that were obtained:

$$p_i = p_i / p_{max}. \quad (6)$$

Table 11

g_1	g_2	g_3	g_4	g_5	g_6	g_7
0.45	0.31	0.52	0.03	0.10	0.38	1.00
ξ_1	ξ_2	ξ_3	ξ_4	ξ_5	ξ_6	ξ_7
0.03	0.02	0.32	0.00	0.00	0.28	1.00
b_1	b_2	b_3	b_4	b_5	b_6	b_7
0.20	0.03	0.18	0.00	0.00	0.05	1.00

The analysis of calculation data allows for the following *conclusions*.

The probability of successful project completion (reliability) under the Table 8 scenarios is 93.7%. Therefore, the probability of "failure" is 6.3%.

Q_7 and Q_3, i.e. the effects of the financial and managerial risks are the most important, significant and contributing factors of the investment risks.

Q_4, the effect of negative economic fluctuations, and Q_5, i.e. the effect of political instability in the country, have *the least* effect on the probability of an investment project completion.

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