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ENTERPRISE'S RISK ASSESSMENT OF COMPLEX CONSTRUCTION PROJECTS

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The purpose of this article is to present the preparation of Project Risk Assessment Methodology and its mitigation in complex construction projects. The main text provides a summary of the approach, the method used and the findings. The conclusions have been drawn that the proper tools for quantifying risks have to be based on the criteria specific for mathematical statistic and probability or at least fuzziness. Function, which makes possible to categorize any risks into one of the five categories, is a combination of probability and the impact on one of the items: people and their safety or budget, cost, schedule and planning or quality and performance. An attempt was made to express numerically the relationship between risks impacts and their level of likelihood. Also, a method of associating the influence of projects risks impacts on the extent of the likelihood of project risk occurrence which makes possible to determine the direction and the strength of this relationship was presented.

Keywords: project, management, construction, correlation, risk

1. INTRODUCTION

Project risk is defined as an unplanned event or condition that, if occurs, has a negative effect on a Project Objective. Risk management stands for identification, assessment, and prioritization of risks defined in ISO 31000 followed by coordinated and economical allocation of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities. Several risk management standards have been developed in construction management companies for years, enhanced by implementation ISO 9001 standard [2], [12], [14], [16].

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While estimating risks in construction projects, experts face problems of working on the qualitative (immeasurable data) basis rather than on a quantitative one. The decision making theory presents a classical split of such situations that have been presented from three following points of view [8], [15]:

– certainties: the entire information describing the decision making process is deterministic in character;
– risk: the entire information describing the decision making process is probabilistic;
– uncertainties: even the probability distributions are unknown;
– fuzzy state: uncertainties tackle not only the existence of an event appearance but its overall meaning that cannot be described by probabilistic methods [7].

2. PRINCIPLES AND SCOPES OF THE RISK REVIEW

A risk has a cause and, if it occurs, an impact. A project risk is an unplanned event or condition that, if it occurs, has a negative effect on a Project Objective. The following Project Objectives were considered when completing this risk assessment [6]: Safety, Cost, Schedule and Quality.

The risk assessment was structured around the following topics [2], [3], [7], [9], [16]:

Table 1. Project Risk Assessment Topics

No.	Main Topic	Sub-Topic
1.	Project Scope	Scope Definition, Basis of Design, Future Requirements, Public Relations
2.	Project Objectives	Defined Objectives
3.	Project Organisation	Project Team, Roles and Responsibilities, Communications, Continuity Interface with Operations
4.	Confidentiality Information Security	Confidentiality, Information Security
5.	Project Schedule	Overall Schedule, Third Party Deliverables, Project Team, Decision Making, Detailed Design, Procurement, Construction, Commissioning, Qualification
6.	Cost Budget	Funding Approval, Control Budget, Design Development, Value Management, Contingency, Change Control
7.	Contracts Procurement Strategy	Contract Strategy, Procurement Strategy, Insurance, Shipping, Transportation Requirements, Critical Equipment
8.	External Threats Risks	External Threats, Organisational Weaknesses
9.	Project Quality Performance	Quality Strategy, Customer Requirements, Product Contamination
10.	Third Party Regulatory & Approvals	Planning Conditions, Planning Objections, Fire Certification, Building Regulations, Permitting Requirements Regulatory, Insurers Requirements
11.	Design Technical Issues	New Technology, Process Design, Process Equipment, Process Utilities, Automation, IS, Instrumentation, Electrical, IT, Building Services, Fire Engineering, Civil, Structural, Architectural, Piping, Security Systems, Environmental Monitoring, WWTP and Environmental Designs, Design Co-Ordination, Specifications and Standards

No.	Main Topic	Sub-Topic
12.	Safety	Safety Management Systems, Operator Safety, Contractor Safety, Safe access/egress, ATEX, Construction Regulations
13.	Environmental Issues	Waste Management Strategy, Noise, Emissions
14.	Technology Transfer	Technology and Knowledge Transfer
15.	Operational Issues	Operational Issues, Spare Parts Strategy, Vendor Strategy
16.	Construction and Interfaces Operations	Construction Safety, Construction Interfaces with Operations Construction Interfaces with Other Projects IR Issues
17.	Commissioning Qualification	Commissioning, Phased Commissioning, Availability of Utilities, Qualification Strategy
18.	Facilities Logistics	Offices, Space Allocation, IT Support, Document Management

3. METHOD OF RISK IDENTIFICATION

The method applied to identify and assess "high level" project risks was as follows [2], [3], [5], [6], [10], [16]:

- Identify a potential risk;
- Categorise the expected Impact on the project using the definitions provided in Table 1 as a reference;
- Categorise the Likelihood of the Risk Occurring using the definitions provided in Table 2 as a reference;
- Combine the Impact and Likelihood to determine the Risk using the matrix provided in Table 3;
- Identify a Risk Reduction Strategy for each risk, using the principles outlined in Table 4;
- Identify actions as appropriate;
- At follow-up meetings, determine the status of the identified actions;
- Re-categorise the impact and likelihood on the basis of the actions taken. This is called the "residual risk".

Tables 2, 3, 4 below represent a 5x5 risk matrix approach which represents standard Project Management approach and should be amended as appropriate – figure 2. Alternatives may be used to suit a project or customer; where an alternative to a 5x5 matrix is used, e.g. a 3x3 matrix, 3x2 matrix, customer specific matrix, etc.

Table 2. Impact Categories and Descriptions

Impact	Category	People	Cost (example)	Schedule	Quality
1	Very Low	Slight Injury	< €50K	< 1 week	Minor impact on operation of facility
2	Low	First Aid	€50K - €200K	1-2 weeks	Affecting operation of a non-critical item of equipment
3	Medium	Minor Injury, Restricted Workday Case	€200K - €1M	3-8 weeks	Affecting operation of a critical item of equipment
4	High	Major Injury, Lost Time Injury	€1M - €10M	2-4 months	Affecting operation of a production unit/area
5	Critical	Total Disability, One or More Fatality	> €10M	> 4 months	Affecting operation of the overall facility or ability to meet project user requirement specification

Table 3. Likelihood of Occurrence Categories and Descriptions

Likelihood	Category	Description	
A	Very Low	Incident hardly occurs in industry	< 0.1% (1 in 1000)
B	Low	Incident has occasionally occurred in industry	< 5% (1 in 20)
C	Medium	Incident has occurred previously	< 20% (1 in 5)
D	High	Incident has occurred more than once	< 100%
E	Very High	Incident expected to occur	100%

The above categorisation of risks against their impact and likelihood when appear determine 5 risk management strategies [9], [12], [13]. During the risk review, each topic is considered in terms of its applicability to the proposed development and relevant comments are recorded. When required, actions are identified and recorded with responsibility assigned.

Table 4. Risk Management Strategies

Strategy	Description
Avoid it	Where possible, risks should be eliminated or avoided, e.g. through design change, procedure, etc.
Reduce it	Where it is not possible to eliminate the risk, every effort should be made to minimise/reduce the risk.
Monitor it	In some instances, the most appropriate course of action may be to monitor the situation and only take action if required.
Transfer it	In some instances, risk can be transferred, e.g. insurance cover.
Accept it	In some instances, the project team may be willing to accept the risk. This is generally true only for lower level risk items.

As noted previously, actions were identified during the risk assessment meetings. Actions should be completed by the persons noted as responsible or designated as appropriate. During the review meetings the status of the actions identified is reviewed and the risk re-categorised in each case bears the action taken in mind. The revised risk is referred to as residual risk in the risk assessment record sheets. The expectation for residual risk is that it reduces as actions are completed or as the status of the project changes. In some instances, the risk may become no longer relevant (NLR). Typically, risks become no longer relevant if the possibility of the risk occurring has passed due to, for example, project progress. Risks are also categorised as no longer relevant if the risk consequence has been accepted by the team [4].

4. STATUS OF RISKS IDENTIFIED

The status of the risks identified during the risk assessment meetings is summarised below. Please note that N/A refers to items which were noted for information only and where a categorisation of risk was not appropriate. NLR refers to items that are no longer relevant [4].

These are graphically shown on the risk matrix in Figure 3. Due to the format of this diagram, some of the bars are hidden, i.e. low bars hidden behind higher bars, however, the number of issues associated with each bar is indicated on the chart, including the hidden bars [9].

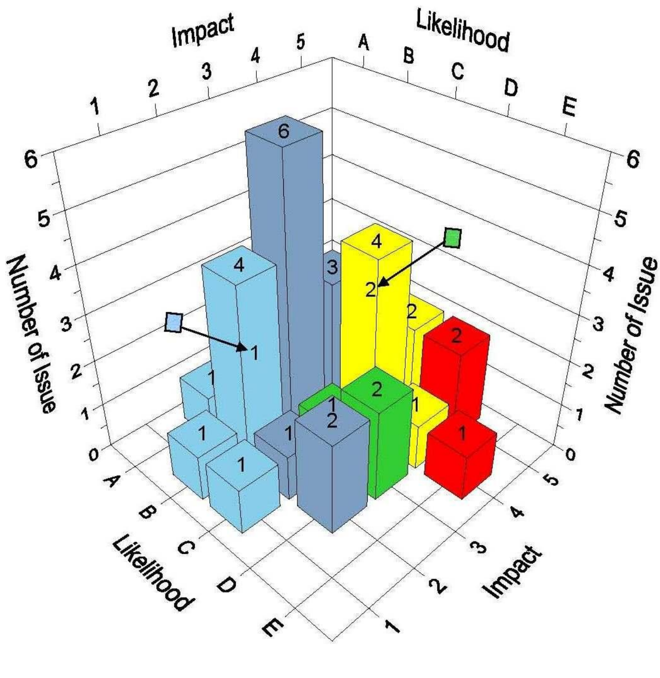

Fig. 1. Number of Issues by Impact and Likelihood

5. ASSOCIATION OF RISKS IMPACTS OCCURRENCE WITH THEIR LIKELIHOOD

An assessment of the risk impact and its likelihood occurrence relies on identification of two types of variables [11], [12]:

- Non-measurable – qualitative variables, i.e. individual project risks impacts i_{ij};
- Measurable – quantitative variables, i.e. likelihood of individual project risk occurrence l_i.

After the types of variables li and i_{ij} have been defined, an attempt was made at the numerical expression of relationship (should such relationships exist) between them, i.e. an attempt at measuring the influence of projects risks impacts on the extent of the likelihood of project risk occurrence. In the calculation of the strength of this relationship, the method of determination of the point bi-serial correlation coefficient (generally marked as r(L)) for the measurable property l_i and the dichotomous property i_{ij}, was used. This is one of a few cases in the statistics when properties of various types are being correlated. The coefficient of correlation value falls within an interval [-1,1]. In the sets of impacts I for each elementary impact i_{ij}=ii (when j=1,2, ... ,m) and the likelihood of project risks L, the following was determined:

- i_i – dichotomous variable that takes on values 0 (i_i0) or 1 (i_i1); i = 1,2, ..., n;
- i_0 – number of observations of the variable i_i marked as 0;
- i_1 – number of observations of the variable i_i marked as 1;

apparently i = $i_0 + i_1$ (if by i, one shall understand the number of all observations i_i), and:

- l_i – measurable variable; values of this variable were divided into two groups distinguished on this basis of: whether l_j takes values 0 or 1; i = 1,2, ..., n;
- l_{i0} – value of the property l_i for these units „i”, for which the property i_{i0} occurs;
- l_{i1} - value of the property l_i for these units „i”, for which them property i_{i1} occurs.

Next, arithmetic averages were calculated in the both groups:

(5.1) $$\overline{l_0} = \frac{1}{i_0}\sum_{i=1}^{i_0} l_{i0}$$

(5.2) $$\overline{l_1} = \frac{1}{i_1}\sum_{i=1}^{i_1} l_{i1}$$

the standard deviation (determined for the correlation r(l) with a relationship defined in a different way):

(5.3)
$$d(L)=\sqrt{\frac{i\sum_{i=1}^{i}l_i^2-(\sum_{i=1}^{i}l_i)^2}{i(i-1)}}$$

and as a result, on the basis of (1-3), the point bi-serial correlation coefficient r(l):

(5.4)
$$r(l)=\frac{\overline{l}_1-\overline{l}_0}{d(L)}\sqrt{\frac{i_1 i_0}{i(i-1)}}$$

The above presented method of associating of the influence of projects risks impacts on the extent of the likelihood of project risk occurrence makes possible to determine the direction and the strength of this relationship shown in figure 3.

6. INDICATIVE RESEARCH. SUMMARY

There were 19 similar projects – industrial green field plants, approximately 10.000 square meters each area, with around 40 mln pln budget – selected, investigated and researched to describe relation between project risks impacts and likelihood of project risks occurrence [9], [11]. The point bi-serial correlation coefficients r(l) have been determined to measure reason-effect relationship 'risks impacts – likelihood of risks occurrence' on the basis of these projects analysis. The results of r(l) chosen coefficients have been presented in table 5.

Table 5. Point Bi-serial Coefficients between Project Risks Impacts and Risks Occurrence

No.	Risks Assessment Topics Occurred	r(l) for Risks Impacts by Categories				
		Very Low	Low	Medium	High	Critical
1.	Project Scope	0.18	0.21	0.29	0.32	0.34
5.	Project Schedule	0.26	0.29	0.39	0.58	0.71
6.	Cost Budget	0.29	0.35	0.46	0.68	0.88
9.	Project Quality Performance	0.16	0.20	0.26	0.31	0.35
11.	Design Technical Issues	0.28	0.31	0.42	0.52	0.73
12.	Safety	0.32	0.40	0.51	0.69	0.95
13.	Environmental Issues	0.15	0.19	0.22	0.31	0.33
16.	Construction and Interfaces Operations	0.20	0.23	0.32	0.39	0.46

Due to the lack of complete information while reporting on the investigated projects and an insufficient number of them, only 8 topics of risks assessment that occurred have been associated with the projects risks impacts [7], [9]. The point bi-serial correlation coefficients r(l) have been determined for all of them and represent interesting conclusions from indicative research – table 5:

- the direction of the relationship is right-hand (positive) for all 8 risks assessed and occurred but the strength of correlation between project risks impacts and likelihood of project risks occurrence shows a considerable span (from 0.18 to 0.95);
- the unanimous trend of bi-serial correlation coefficients r(l) growth has been observed – the higher / more serious project risk impact, the bigger value of r(l) is;
- the trend of r(l) is more significant and the values of coefficients are exceeding 0.5 for projects risks which are more measurable and easier to quantify then others: project schedule, cost budget, design technical issues and safety constrains

This is the simplest method for associating the influence of projects risks impacts on the extent of the likelihood of project risk occurrence which makes possible to determine the direction and the strength of this relationship.

Although the presented approach of projects risks assessment by linking risks impacts with their likelihood occurrence is quite well described in accessible literature [2], [3], [4], [6], [10], [13], [14], [16] but there is an insufficient number of construction projects reported and tested in measurable way. The data of enterprises in construction industry are under confidentiality agreements and well protected by global clients, project management companies and credit bank analysts. To make thing worse some of the projects risks may or may not occur, therefore their nature is moved to fuzzy sets categories [7] rather than belonging to probabilistic area where models of likelihood risks impacts may be determined easily. However, the approach, the research and the conclusions presented in the article – even indicative ones – are worth further investigations and exploring. This will make more possible pinpoint, determine, monitor and mitigate the most impactful risk appearing in construction projects.

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LIST OF FIGURES AND TABLES:

OCENA RYZYKA INWESTYCYJNEGO W ZŁOŻONYCH PRZEDSIĘWZIĘCIACH BUDOWLANYCH

Słowa kluczowe: przedsięwzięcie, zarządzanie, budownictwo, korelacja, ryzyko

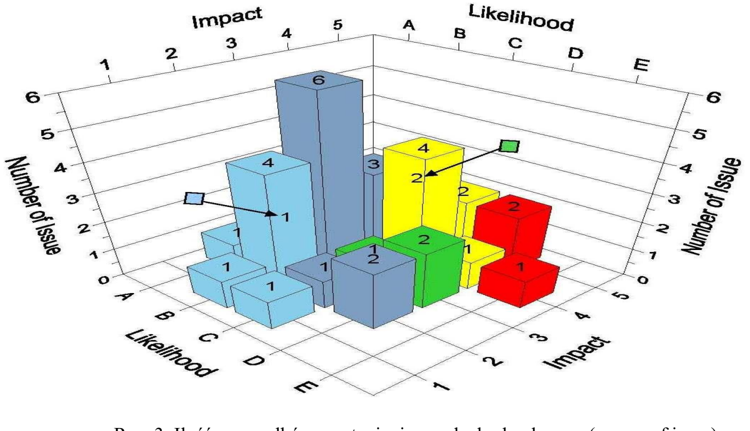
STRESZCZENIE

Ryzyko przedsięwzięcia budowlanego jest definiowane jako nieplanowane zdarzenie, które – jeśli wystąpi – ma negatywny wpływ na cel zadania inwestycyjnego. Na podstawie tej definicji przedstawiono narzędzia do kwantyfikacji ryzyk, oparte na założeniach matematycznych i kryteriach probabilistycznych. Funkcja - która umożliwia kategoryzowanie wszelkich ryzyk w jedną z pięciu kategorii - jest kombinacją prawdopodobieństwa wystąpienia ryzyka i jego wpływu na: ludzi i ich bezpieczeństwo, budżet i nakłady inwestycji, planowanie i harmonogramowanie przedsięwzięcia oraz jakość realizacji robót budowlanych. W artykule przedstawiono próbę liczbowego wyrażenia relacji pomiędzy wielkością ryzyk a prawdopodobieństwem ich wystąpienia. Zaprezentowano metodę powiązania wpływu wagi ryzyka z prawdopodobieństwem jego wystąpienia jako zdarzenia losowego oraz wyznaczenia kierunku i siły tego związku w przedsięwzięciach budowlanych.

Metoda została zastosowana do identyfikacji i szacowania wysokiego poziomu ryzyka inwestycyjnego i polega na:

- identyfikacji potencjalnego ryzyka;
- kategoryzacji oczekiwanego wpływu ryzyka na przedsięwzięcie budowlane;
- kategoryzacji prawdopodobieństwa występowania ryzyka w zadaniu inwestycyjnym;
- powiązaniu wpływu różnych ryzyk i prawdopodobieństw ich wystąpienia w celu zbudowania macierzy ryzyk inwestycyjnych;
- przyjęciu strategii redukcji wpływu ryzyka na najważniejsze obszary zarządzania przedsięwzięciem budowlanym;
- ustaleniu działań wynikających ze strategii redukcji wpływu ryzyka;
- ponownej kategoryzacji wpływu ryzyk i ich prawdopodobieństw po wdrożonych działaniach zapobiegawczych, co prowadzi do określenia pozostałej części ryzyka budowlanego

Trzy główne parametry tej metody zostały zobrazowana na rysunku 3.



Rys. 3. Ilość przypadków wystąpienia ryzyka budowlanego (numer of issue)
w funkcji jego wpływu (impact) i prawdopodobieństwa wystąpienia (likelihood)

Punktowy, dwuszeregowy współczynnik korelacji cech różnego rodzaju r(l):

(4)
$$r(l) = \frac{\overline{l}_1 - \overline{l}_0}{d(L)} \sqrt{\frac{i_1 i_0}{i(i-1)}}$$

stwarza możliwość skojarzenia wpływu ryzyka inwestycyjnego z prawdopodobieństwem jego występowania, jak również określenia kierunku i siły tego związku.

19 podobnych przedsięwzięć budowlanych – nowo wznoszonych, przemysłowych zakładów o powierzchni około 10.000 m2 każdy, z budżetem inwestycyjnym około 40 mln złotych – wyodrębniono jako próbę badawczą do określenia parametrów asocjacji wpływu ryzyka inwestycyjnego z prawdopodobieństwem jego występowania w każdej zrealizowanej inwestycji w latach 2010 - 2014. Punktowy, dwuszeregowy współczynnik korelacji „wpływ ryzyka – prawdopodobieństwo wystąpienia ryzyka" dla wybranych 8 z 18 zidentyfikowanych ryzyk inwestycyjnych wyznaczono i przedstawiono w tablicy 5.

Tab. 5. Punktowy, dwuszergowy współczynnik korelacji wpływu ryzyka i prawdopodobieństwa jego wystąpienia

Nr	Obszar ryzyka, które może wystąpić	r(l) dla wpływu ryzyk wg kategorii				
		b. niskie	niskie	średnie	wysokie	krytyczne
1.	Zakres przedsięwziecia budowlanego	0.18	0.21	0.29	0.32	0.34
5.	Harmonogram inwestycji	0.26	0.29	0.39	0.58	0.71
6.	Budzet inwestycji	0.29	0.35	0.46	0.68	0.88
9.	Jakość realizacji zadania	0.16	0.20	0.26	0.31	0.35
11.	Projektowanie techniczne	0.28	0.31	0.42	0.52	0.73
12.	Aspekty BHP	0.32	0.40	0.51	0.69	0.95
13.	Warunki środowiskowe	0.15	0.19	0.22	0.31	0.33
16.	Działania operacyjne w realizacji	0.20	0.23	0.32	0.39	0.46

Wyniki badania tego związku punktowym, dwuszeregowym współczynnikiem korelacji cech różnego rodzaju r(l) prowadzą do następujących wniosków:

- kierunek związku jest prawostronny (dodatni) dla wszystkich 8 badanych ryzyk budowlanych, ale siła korelacji pomiędzy występującym wpływem ryzyka, a prawdopodobieństwem jego wystąpienia wykazuje znaczną rozpiętość (od 0,18 do 0,95);
- zaobserwowano jednoznaczny trend zmiany współczynnika korelacji r(l) dla wszystkich 8 badanych obszarów ryzyk – im większy wpływ ryzyka inwestycyjnego tym większe prawdopodobieństwo jego wystąpienia;
- trend współczynnika r(l) jest szczególnie wyraźny i znaczący kiedy przekracza wartości 0.5, co ma miejsce w przypadku łatwiej mierzalnych I kwantyfikowalnych obszarów ryzyk w przedsięwzięciu budowlanych: harmonogram inwestycji, budżet zadania, projektowanie techniczne i względy BHP.

Zaprezentowana w artykule metoda korelacji wpływu wielkości ryzyka w budowlanym procesie inwestycyjnym z prawdopodobieństwem jego wystąpienia pozwala w prosty sposób wyznaczyć kierunek i siłę tego związku.
Pomimo faktu, że metody badania zjawisk przyrodniczych punktowym, dwuszeregowym współczynnikiem korelacji cech różnego rodzaju są szeroko opisane w dostępnej literaturze to ich aplikacja w modelowaniu przedsięwzięć budowlanych jest utrudniona z uwagi na niedoskonałość ich opisu parametrami mierzalnymi. Ponadto dane liczbowe zrealizowanych zadań inwestycyjnych są szczególnie chronione przez inwestorów korporacyjnych, firmy menedżerskie i departamenty kontroli ryzyka banków kredytowych. Trzeba również pamiętać, że nie ma pewności co do wystąpienia niektórych obszarów ryzyk budowlanych, a zatem ich natura leży bliżej rozmytości niż probabilistyki, z lepiej rozwiniętym aparatem matematycznym do modelowania procesów inwestycyjnych. Jednakże, podejście i wnioski zaprezentowane w artykule powinny skłaniać do prowadzenia dalszych badań, nawet w niedoskonałych próbach badawczych. Identyfikacja ryzyka budowlanego w przedsięwzięciach budowlanych, wyznaczenie siły jego wpływu i możliwości wystąpienia oraz jego monitorowanie i eliminowanie działaniami zapobiegawczymi są nie do przecenienia w prawidłowym zarządzaniu procesem inwestycyjnym w budownictwie.