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Aspects of risk management in engineering projects based on survey research and the AHP method

Abstract

The aim of this article is to present risk management practices used in large engineering projects and to identify key factors influencing the success of these projects. The article is based on a survey conducted among engineering professionals and a decision analysis performed using the AHP method. The first part discusses selected methods and approaches to risk management. The empirical part presents the results of the survey, which show the awareness and practices of risk management among the respondents. The article concludes with an AHP hierarchical analysis, which identified the most important success factors in project risk management.

Keywords: risk management, engineering projects, AHP, survey analysis, project success.

Aspekty zarządzania ryzykiem w projektach inżynieryjnych na podstawie badań ankietowych i metody AHP

Streszczenie

Celem niniejszego artykułu jest przedstawienie praktyk zarządzania ryzykiem stosowanych w dużych projektach inżynieryjnych i identyfikacja kluczowych czynników wpływających na sukces tych przedsięwzięć. Artykuł opiera się na badaniach ankietowych przeprowadzonych wśród specjalistów z branży inżynieryjnej oraz analizie decyzyjnej przeprowadzonej metodą AHP. W pierwszej części omówiono wybrane metody i podejścia do zarządzania ryzykiem. W części empirycznej zaprezentowano wyniki badań ankietowych, które ukazują świadomość i praktyki zarządzania ryzykiem wśród respondentów. Artykuł kończy się analizą hierarchiczną AHP, która pozwoliła wyłonić najważniejsze czynniki sukcesu w zarządzaniu ryzykiem projektowym.

Słowa kluczowe: zarządzanie ryzykiem, projekty inżynieryjne, AHP, analiza ankietowa, sukces projektu.

1. Introduction

Contemporary engineering projects are characterized by high complexity, a high level of innovation, and significant financial outlays. Risk management plays a key role in their implementation, enabling the minimization of potential losses and maximization of the chances of success. The implementation of effective methods for identifying, analyzing, and responding to risk has become an indispensable part of project management.

The aim of this article is to analyze current risk management practices based on empirical research and to use the AHP method to identify the most important risk factors. The study was conducted among practitioners in the engineering industry, which allows for conclusions based on the professional experience of the respondents.

2. Literature review

Project management is a rapidly developing field of knowledge, particularly important in the context of engineering projects, which are characterized by high complexity, large scope, and strict time and budget constraints. Projects are defined as unique, temporary endeavors aimed at achieving specific goals within limited time, financial, and resource constraints. Figure 1 illustrates the key characteristics that define a project.

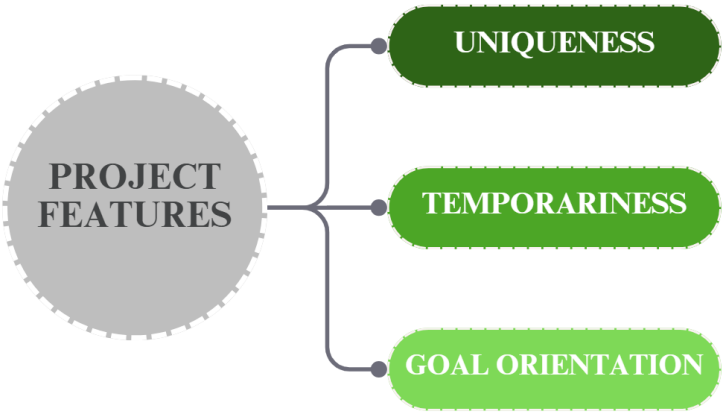

Figure 1. Diagram showing the features of the project

(source: own study based on PMI, 2021)

The first step in project management is to precisely define its objectives. Project objectives must comply with the SMART principle (Figure 2), i.e., they must be specific, measurable, achievable, realistic, and time-bound. Clearly formulating objectives allows for better organization of activities and their monitoring during implementation (Turner, 2016).

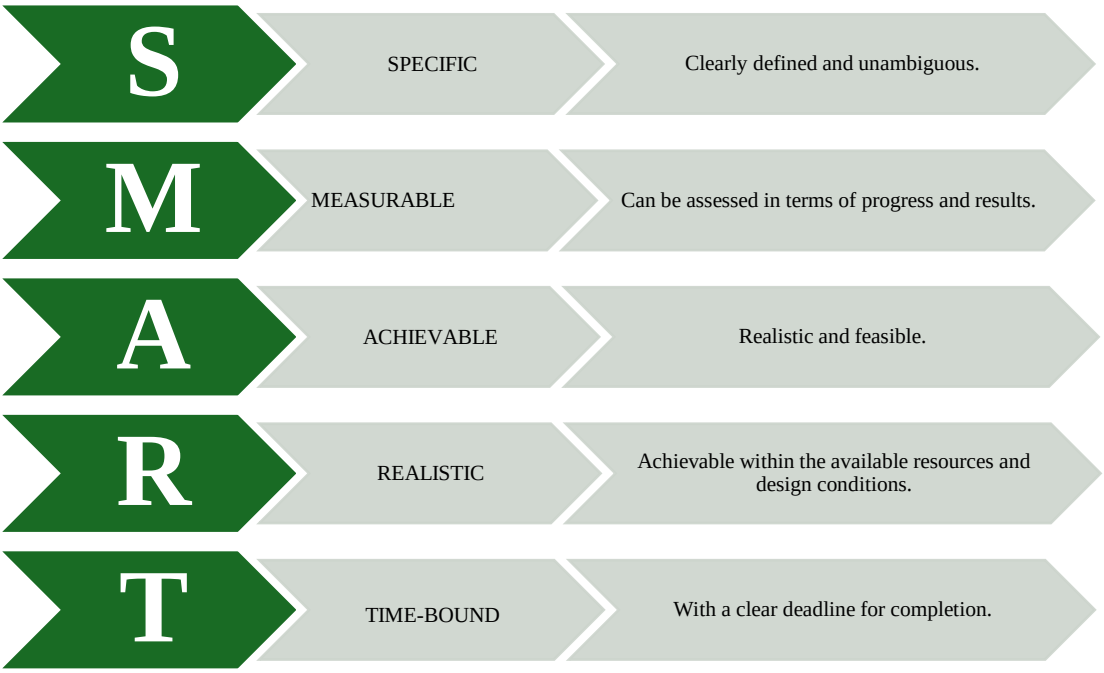

Figure 2. The SMART principle

(source: own study based on Turner, 2016)

In project management literature, risk is defined as an uncertain event or circumstance that, if it occurs, may affect the implementation of a project in both a negative and positive way (PMI, 2021). This means that risk is not only a threat, but can also be an opportunity to improve project performance by taking advantage of favorable circumstances. In the context of project management, risk is an important element of the so-called "iron triangle," which includes time, budget, and project scope. A diagram illustrating the triangle of constraints is shown in Figure 3.

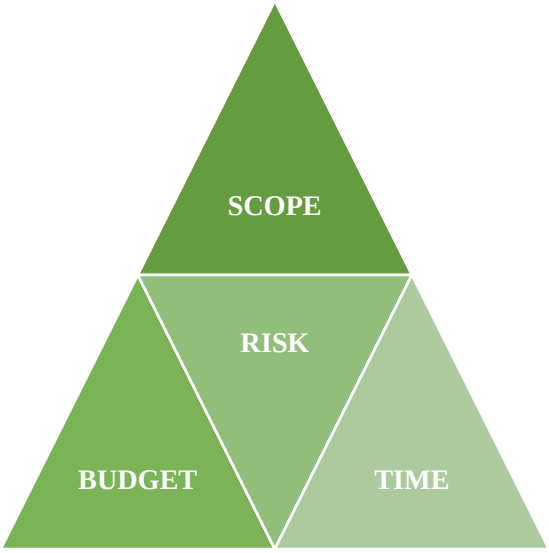

Figure 3. Diagram showing the triangle of constraints

(source: own study based on Petrenko, 2024)

Contemporary approaches to project management emphasize the need for flexibility, iteration, and value orientation, which translates into the selection of appropriate methodologies, including PMBOK, PRINCE2, and Agile. Table 1 presents a summary of the key features of the three most commonly used approaches to project management, with particular emphasis on risk management aspects. This comparison allows us to see both the differences and the potential for combining best practices depending on the nature of the project.

Table 1
Comparison of risk management methods

Criteria	PRINCE2	PMBOK	Agile
Structure	Standardized, process-based	Flexible, modular	Iterative, agile
Approach to risk	Documentation and control	Qualitative and quantitative analysis	Continuous adaptation and communication
Risk identification	Documentation analysis, consultations	Workshops, statistical analyses	Meetings, retrospectives
Risk assessment	Probability and impact	Qualitative and quantitative analysis	Subjective assessment by the team
Response planning	Risk management strategy	Contingency plans, corrective actions	Dynamic adjustment
Monitoring	Construction projects, IT, administration	Engineering projects, large organizations	IT, software development

(source: own elaboration)

The literature points to various approaches to risk analysis, including qualitative and quantitative assessment methods. The most commonly used ones include: SWOT analysis, PESTEL analysis, FMEA method, Monte Carlo analysis, risk matrices, earned value analysis (EVM), decision trees, and brainstorming. The choice of a specific method depends on the specifics of the project, available data, and the level of organizational maturity.

In the context of engineering projects, structural methods are particularly important, as they allow for a systematic approach to the identification and assessment of technical, financial, scheduling, and environmental risks. FMEA (Failure Mode and Effects Analysis) is one of the methods that is highly regarded in technical circles due to its transparency and practicality. Risk matrices, commonly used in qualitative analyses, allow for the assessment of the probability of a given risk occurring and the scale of its potential impact.

Project risk management, although well described in theory in the literature, often encounters organizational barriers in practice. In many cases, risk management procedures are not integrated into day-to-day project management, and actions are only taken after disruptions have occurred. The key factors influencing the effectiveness of risk management remain the organizational culture and the competencies of the project team.

3. Test results and interpretation

An analysis of the responses obtained from 162 respondents allows us to draw several key conclusions regarding the state of risk management in large engineering projects in Poland. Although the overall awareness of risk among the survey participants was high, the actual implementation of formal procedures and tools remains limited. In question 16, respondents were asked to assess the level of risk awareness in the organization where they work. The results are presented in Figure 4. The largest number of respondents, 38.9%, assessed the level of risk awareness as high. Another large group, accounting for 29.6% of the total, indicated a medium level. 21% of respondents described risk awareness in their organization as very high. It is worth noting that only 9.9% of survey participants indicated a low level, while a very low level was indicated by a marginal number of respondents – less than 1%.

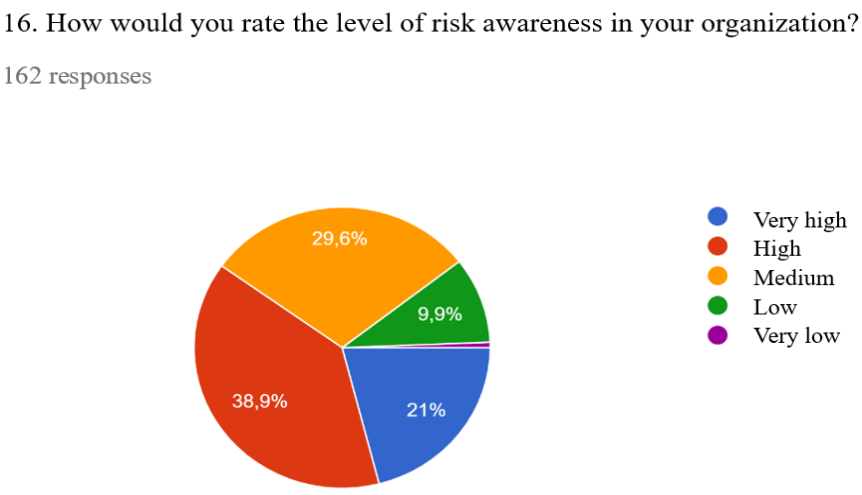

Figure 4. Assessment of risk awareness within the organization

(source: own elaboration)

The collected data indicate that the vast majority of respondents (nearly 60%) perceive the level of risk awareness in their organization as high or very high. This is a positive sign, indicating the growing importance of risk management and probably well-functioning information and education mechanisms for risk identification and assessment.

However, nearly 30% of respondents rate risk awareness as average, and nearly 10% as low, which may suggest the existence of certain barriers or differences in the perception of risk between departments, organizational levels, or depending on the individual experiences of employees. This may also indicate a need for further educational activities and a systematic approach to building a risk management culture.

Figure 5 shows the risk identification methods used in projects implemented by respondents. The question allowed for more than one answer to be selected, which is why the total percentage exceeds 100%.

The most frequently indicated method was SWOT analysis – 35.8% of survey participants declared using this technique. The second most popular was FMEA (Failure Mode and Effects Analysis) with a result of 31.5%, which indicates the widespread use of analytical approaches to assessing technical and operational risks. The Delphi method was indicated by 27.2% of respondents, and the Ishikawa diagram (cause--and-effect) by 22.2%. The relatively least frequently used method was Monte Carlo analysis, which is used by 14.8% of respondents.

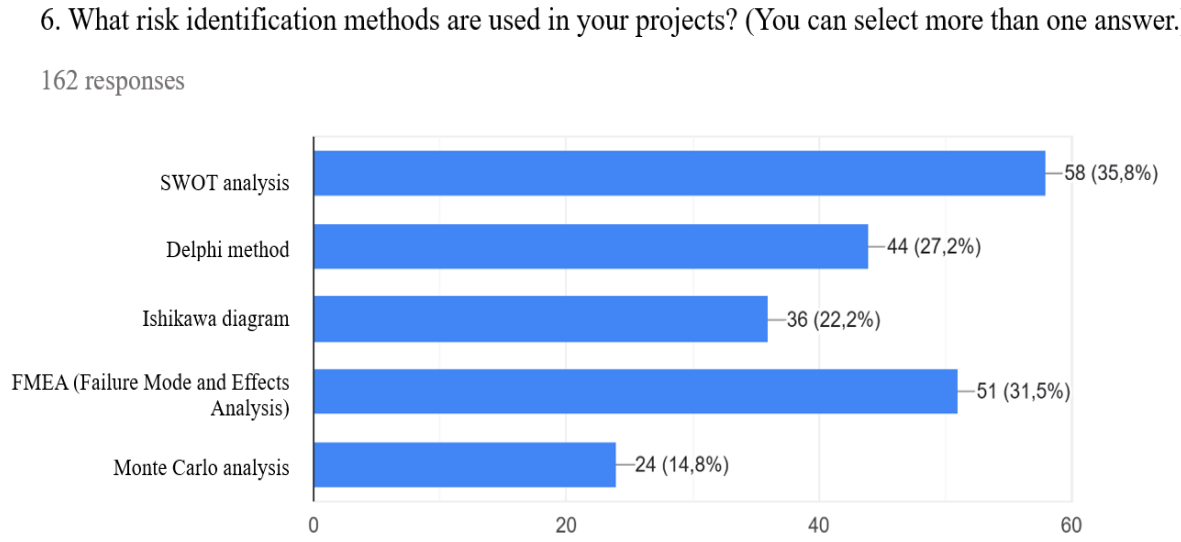

Figure 5. The most commonly used methods of risk identification in projects

(source: own elaboration)

The results show that respondents use a variety of risk identification methods, combining qualitative approaches (SWOT, Delphi, Ishikawa) with quantitative ones (FMEA, Monte Carlo). The popularity of SWOT may be due to its simplicity and versatility, while FMEA and Delphi reflect a desire for a more systematic and expert assessment of risks.

The relatively low use of Monte Carlo analysis may indicate limited availability of specialized tools or a lack of competence in probabilistic methods. The results suggest a need for further training and integration of more advanced analytical methods in project organizations.

Figure 6 shows respondents' answers regarding the most serious barriers to effective risk management in their organizations. The most frequently cited limitation is a limited risk management budget – this factor was indicated by 45.1% of respondents. In second place was insufficient data for analysis – 30.2% of responses.

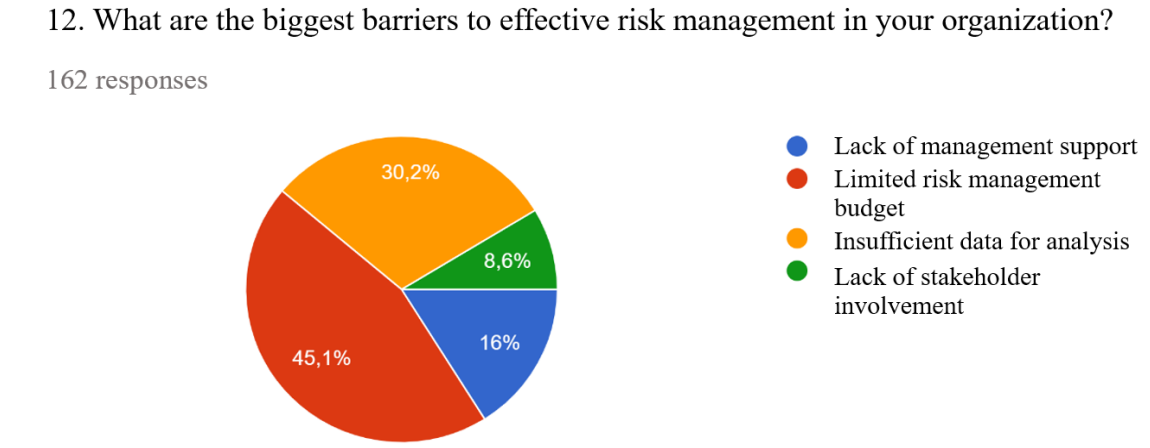

Figure 6. The most common barriers to effective risk management

(source: own elaboration)

The results clearly indicate that the biggest obstacle to implementing effective risk management is financial constraints, which can limit access to training, analytical tools, and human resources. The lack of data is another serious challenge, pointing to inadequate risk monitoring and reporting practices.

The relatively small number of responses indicating a lack of commitment from management or stakeholders may suggest that, although risk management has structural support, its effectiveness is limited primarily by systemic and organizational factors rather than people's attitudes.

In question 26, respondents were asked to indicate how often risk reviews are conducted in engineering projects in their organizations. The distribution of responses is shown in Figure 7.

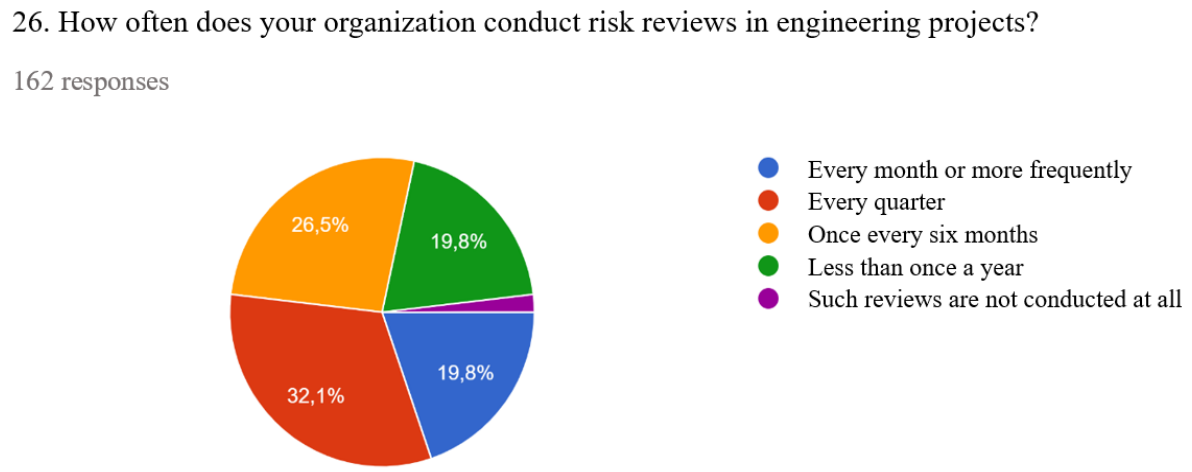

Figure 7. Frequency of risk reviews in engineering projects

(source: own elaboration)

The most frequently indicated answer is a quarterly risk review (32.1%), which can be considered a relatively optimal frequency in the context of large engineering projects, where risks change cyclically, but not necessarily at very short intervals. Slightly fewer, 26.5% of respondents, indicate reviews once every six months, which may be insufficient for dynamic projects. In turn, almost 20% of respondents declare monthly or more frequent reviews, which indicates a high level of commitment and organizational maturity in the area of risk monitoring.

However, it is worth noting that a total of almost 22% of organizations review risks less than once a year or not at all, which may indicate insufficient supervision of risks in design processes or a lack of a systematic approach to their management.

Analysis of the survey results enabled the formulation of important observations regarding risk management practices in engineering projects. The research sample included a diverse group of respondents in terms of professional experience, project roles, and industries, which strengthens the reliability and multifaceted nature of the data obtained.

Most participants in the study confirmed the existence of formal risk management policies in their organizations, but their actual application is sometimes limited. This indicates a discrepancy between the declarative and operational levels of risk management. The respondents emphasized that the effectiveness of these activities depends not only on the choice of methodology (e.g. FMEA, PRINCE2, PMBOK), but also on its consistent implementation and support from the organization.

The main barriers to effective risk management identified include: limited resources (budget, time), lack of specialized tools, resistance from teams, and insufficiently rapid response to threats. The role of organizational culture proved to be equally important – open communication and team involvement are prerequisites for the effectiveness of the entire process.

Respondents most often use general tools such as spreadsheets or Microsoft Project, while specialized software (e.g., Primavera Risk Analysis, Tableau) is used sporadically. Nevertheless, there is a noticeable trend toward digitization – many organizations are planning to implement new technologies to support risk management, including solutions based on predictive analytics and artificial intelligence.

Key findings:

- Risk management is present in most organizations, but its practical implementation can be inconsistent.
- The most commonly used methodologies are FMEA, PRINCE2, and PMBOK, which are particularly valued in technical projects.
- The main obstacles are lack of resources, organizational resistance, limited tools, and slow response times.
- Organizational culture and open communication are essential for effective risk management.
- There is a widespread belief in the need to improve current practices.
- Digital technologies, including automation, predictive analytics, and Big Data, are considered key areas for development.

Practical recommendations:
- Enforce the application of risk management procedures in project practice.
- Invest in modern IT tools that support risk analysis and monitoring.
- Develop the competencies of project teams, including in the areas of communication and working in conditions of uncertainty.
- Ensure organizational flexibility to enable rapid response to threats.
- Build a culture of openness to risk by encouraging active reporting of uncertainty.
- Standardize the approach to risk management within the organization, especially in multi-disciplinary projects.

The collected data clearly indicate that although the importance of risk management is recognized by most survey participants, its implementation remains selective, strongly dependent on the specific nature of the organization, the type of project, and the awareness of management. The results justify the need for further support for organizations – both through training and the selection of appropriate tools and system procedures.

4. Analysis of risk management methods using the AHP method

This chapter presents a comparative analysis of four popular risk management methodologies: PRINCE2, PMBOK, Agile, and FMEA, using the Analytic Hierarchy Process (AHP) method. The aim of the study was to determine which of the analyzed methodologies best meets the criteria for effective risk management in projects.

The analysis adopted six key criteria that are essential for effective risk management:

1. Methodology structure – transparency, completeness, and consistency of the methodology structure,
2. Approach to risk – systematic actions and compliance with best practices,
3. Risk identification – effectiveness in recognizing potential threats,
4. Risk assessment – depth and accuracy of risk analysis,
5. Response planning – flexibility and adequacy of remedial actions,
6. Monitoring – effectiveness in tracking and reporting risks.

The Saaty scale (1-9) was used to assign weights to individual criteria. Based on expert assessment, the following comparison matrix was created in Table 2.

Table 2
Criteria pair comparison matrix

Criteria	Structure	Approach	Identification	Assessment	Response planning	Monitoring
Structure	1	0,5	1	1	2	1
Approach	2	1	2	2	2	2
Identification	1	0,5	1	1	2	1
Assessment	1	0,5	1	1	2	1
Response planning	0,5	0,5	0,5	0,5	1	0,5
Monitoring	1	0,5	1	1	2	1
Sum	6,5	3,5	6,5	6,5	11	6,5

(source: own elaboration)

Based on expert assessments, a matrix of comparisons of pairs of criteria was developed in accordance with Saaty's scale. The results were normalized and the following AHP weights were determined in Table 3.

Table 3
Comparison matrix and criteria weights

Criteria	AHP weight
Approach to risk	0,2393
Risk assessment	0,1764
Response planning	0,1490
Methodology structure	0,1451
Risk identification	0,1451
Monitoring	0,1451

(source: own elaboration)

Each methodology was assigned a score based on a subjective expert assessment in Table 4.

Table 4
Scoring of methods against criteria (scale 1-5)

Criteria	PRINCE2	PMBOK	Agile	FMEA
Methodology structure	5	4	3	3
Approach to risk	4	5	3	4
Risk identification	4	5	4	5
Risk assessment	4	5	3	5
Response planning	4	5	5	5
Monitoring	4	5	3	4

(source: own elaboration)

The preference index was calculated using the following formula:

$$W = \sum_{Y=1}^{n} P_{XY} \cdot W_Y \quad (1)$$

where:
P_{XY} – point assessment of method X in relation to criteria Y,
W_Y – weight assigned to the criteria Y.

PMBOK=4×0.1451+5×0.2393+5×0.1451+5×0.1764+5×0.1490+5×0.1451=4.8549
FMEA=3×0.1451+4×0.2393+5×0.1451+5×0.1764+5×0.1490+4×0.1451=4.3254
PRINCE2=5×0.1451+4×0.2393+4×0.1451+4×0.1764+4×0.1490+4×0.1451=4.1451
Agile=3×0.1451+3×0.2393+4×0.1451+3×0.1764+5×0.1490+3×0.1451=3.4431

The final values are as follows:
- PMBOK – 4.85
- FMEA – 4.33
- PRINCE2 – 4.15
- Agile – 3.44

The AHP analysis shows that PMBOK is the most comprehensive and effective risk management methodology. It received the highest final score, which proves its strong process-based approach, broad scope of risk assessment, and well-developed planning and monitoring mechanisms.

Second place went to the FMEA method, which stands out for its excellent effectiveness in identifying and analyzing threats. Its specialized nature makes it particularly useful in engineering and manufacturing environments, despite its less complex management structure compared to PMBOK.

The PRINCE2 methodology took third place, offering a well-organized approach to risk, especially in the context of administrative and infrastructure projects.

Agile methodology came last in the ranking. Although very flexible and agile, it focuses less on formal and systematic risk management. Its approach works better in environments requiring rapid iterations than in projects requiring precise risk analysis.

The use of the AHP method enabled a transparent, multi-criteria analysis to be carried out, which can support project managers in selecting the most appropriate risk management methodology, tailored to the specific nature of the organization or industry.

5. Conclusions

The aim of this article was to analyze the risk management methods used in engineering projects, with particular emphasis on the level of organizational awareness, the effectiveness of the tools used, and their compliance with applicable standards. The empirical research conducted allowed us to assess the degree of risk management implementation in practice and identify areas requiring improvement.

The results indicate the growing popularity of tools such as FMEA, PRINCE2, PMBOK, and SWOT analysis, with FMEA gaining particular recognition for its simplicity and effectiveness in the context of technical risk. At the same time, as many as 90.7% of respondents expressed the need to improve current practices, confirming the growing awareness of the importance of effective risk management. Despite this, only 30.2% of respondents rated the level of risk awareness in their organization as very high, indicating a need for further educational and organizational measures.

Some organizations do not conduct systematic risk reviews, which increases the vulnerability of projects to disruptions. In response to these challenges, a comparative analysis of four risk management methodologies (PMBOK, PRINCE2, Agile, and FMEA) was also carried out using the AHP method. Six decision criteria were taken into account, which enabled an objective assessment and selection of an approach tailored to the specific nature of the project.

Based on the analyses, the following practical recommendations were formulated:

- implementing regular and cyclical risk reviews at all stages of the project;
- integrating risk management with scheduling and cost control (e.g., through EVM);
- developing a risk management culture through training and team communication;
- using a variety of tools, such as risk matrices, FMEA, and Monte Carlo simulations.

In summary, risk management should be viewed not as a formal obligation, but as a strategic tool supporting project decision-making. Effective identification, assessment, and response to risk increase the chances of completing projects within budget, on schedule, and within scope. The findings of this article can serve as a starting point for further research and practical support for organizations seeking mature solutions in the area of risk management.

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