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RISK BUDGET AND EFFECTIVENESS OF PROJECT IMPLEMENTATION MONITORED WITH BUSINESS INTELLIGENCE TOOLS

Marcin CHABIOR[1], Anna BLUSZCZ[2*]

[1] Silesian University of Technology, Doctors' School; marcin.chabior@polsl.pl,
ORCID: 0000-0001-5289-055X
[2] Department of Safety Engineering, Silesian University of Technology; anna.bluszcz@polsl.pl,
ORCID: 0000-0001-9724-5706
* Correspondence author

Purpose: The purpose of this paper is to analyze the relationship between risk budget definition and the type of project, its total budget, and the level of success of implementation in a public sector entity, using a university as an example. In addition, the paper aims to demonstrate the benefits of using Business Intelligence (BI) tools in the risk budget management process.
Design/methodology/approach: The paper presents the results of an analysis of the impact of defining a risk budget on the success of project implementation, based on data from a broader survey aimed at assessing the potential of applying business intelligence solutions to improve project management processes in public institutions. The analysis included 32 organizational and administrative projects, as well as 16 investment projects (infrastructure and construction), implemented in a higher education institution between 2018 and 2024.
Findings: The inclusion of a risk budget in project planning has a significant and positive impact on the success of projects. Nevertheless, this practice is not widely used in the surveyed organizations, largely due to the rules of financing projects from external sources. The implementation of business intelligence solutions in the area of project management can provide significant support in the processes of analyzing and monitoring the impact of financial risks on project implementation.
Practical implications: The article demonstrates the legitimacy of defining a budget for managing project risks and points out the need to make it mandatory to estimate such budgets in all projects, including those financed from external sources. The use of business intelligence solutions as effective tools in the process of estimating risk budgets is also indicated.
Originality/value: The study is a valuable contribution to both the theory and practice of project managers. The results presented can be used as a universal argument to support public entities in justifying the need to estimate risk budgets at the project planning stage, and as a guideline for the development of management based on the Data Driven Model using Business Intelligence solutions.
Keywords: project management, risk budget, Business Intelligence, risk management, Data Driven.
Category of the paper: academic article**.**

1. Introduction

The implementation of projects in public sector organizations is subject to many restrictions arising both from internal institutional regulations and from the provisions of public procurement law (Andała-Sępkowska, Bereszko , 2021). Particularly noteworthy are projects financed from external public sources, including EU, ministerial or local government grants, where this is associated with significant financial risk resulting from underestimation or omission in the structure of expenditure budgets of risk management for unpredictable costs (Kerzner, 2017).Uncertainty and volatility of business conditions in a dynamically changing environment create significant operational risks in all sectors of the economy. As a result, project risk management is becoming increasingly important as a key component of effective project planning, execution and control. As a result, Business Intelligence tools, which are largely aimed at predicting events, must have adequate information resources for effective predictive analysis. The use of BI systems to analyze trends related to the occurrence of unanticipated expenses, the structure of project costs, and the correlation between the use of budget reserves and the ultimate success of a project is one of the factors that builds a company's competitive advantage. The implementation of effective project solutions for contingency planning creates the opportunity for the future development of effective algorithms to support both planning processes and mitigate the risks associated with project financing. The budgeting phase of project management in public institutions is one of the most important planning stages of a project proposal (Norkowski, 2015). When estimating the value of services and assets in projects, public organizations often rely on market analysis and bids from potential contractors. If public price lists are available, the responsible persons in the institution analyze them and prepare the corresponding valuation documentation. In practice, however, the implementation of projects - both capital and operational - is subject to the risk of unforeseen costs that may arise despite careful budget planning. In response to this risk, public project budgets should include contingency funds to cover unexpected expenses and allow for flexible adjustment to changing implementation conditions. Accordingly, it is reasonable to include in the project budget a financial reserve whose primary function is to minimize the effects of financial uncertainty and increase flexibility in managing the implementation of the project. Therefore, it is reasonable to include in the project budget the so-called budget reserve, the primary function of which is to protect against the effects of financial uncertainty and allow flexible response to changing implementation conditions (Saunders, Millon Cornett, 2017). A budget reserve is defined as a specific amount of funds set aside in the project budget to cover unforeseen expenses. There are two basic types of reserves: general reserves, which operate at the level of the entire project, and specific reserves, which are allocated to specific tasks or stages of implementation (Vasche, Williams, 2003). Unfortunately, most contracts for projects co-financed by external funds - including EU funds, ministerial or regional grants - do not

provide for the formal possibility of creating contingency budgets. The evaluation of the contractual objects, both in terms of services and fixed assets, is based on the aforementioned market analyses, which provide evidence of the rationality of planning and economy in the expenditure of public funds. Applications for funding, especially for EU projects, are generally highly standardized to ensure transparency, comparability and efficiency in the evaluation process. Each budget item must be clearly defined and the introduction of a separate budget item for the risk reserve, which by its nature is difficult to estimate clearly, may raise doubts on the part of the institution evaluating the grant application. In addition, projects co-financed by public funds - including EU funds - are settled only on the basis of actual and properly documented expenses. Risk-related expenses are usually difficult to substantiate (A Guide…, 2021). Based on the experience of project management in public institutions, it is pointed out that there is a research gap in the practice of taking into account budget reserves at the project planning stage. In many cases, despite changing external and internal conditions, public institutions do not provide for budget reserves in the process of preparing long-term projects. The purpose of the research presented in this article is to demonstrate the impact of risk budget estimation and its inclusion in planning on the effectiveness of public project implementation, especially projects co-financed by external funds. The research confirms that consideration of the risk budget in the planning process is a necessary condition for increasing the probability of successful project implementation. In addition, appropriate business intelligence IT solutions have been identified to optimize budgeting control processes and comprehensive project implementation management. Although budget reserves allow projects to adapt to changing conditions and reduce potential disruptions to project tasks, it is not always easy or possible to include them in the overall project budget. This makes it difficult for project managers to effectively respond to problems and minimize the negative impact of unforeseen events on schedule and cost. While it is not difficult to determine the amount of such a contingency budget, which is most often done using a percentage estimate with the participation of experts, the fact that it is not possible to include it in the project directly affects the success of the project.

The originality of the research is a valuable contribution to both the theory and practice of project management. The presented results can serve as a universal argument supporting public institutions in justifying the need to estimate budget reserves at the project planning stage and as a guideline for developing management based on a data-driven model using Business Intelligence solutions.

2. Literature review

The transformation of the organization to a Data-driven **model** is largely driven by the need to quantify processes and select the appropriate tools, which is also true in the area of project management (Mandinach, Jackson, 2012). Separating the elements that have a direct impact on the success of project implementation from the numerous components requires the use of advanced multivariate analysis. Tools that effectively support such processes are Business Intelligence solutions, especially predictive analytics, which allow estimating future values and results based on the analysis of historical data. This is especially true in areas related to financial risk, which is an integral part of most project ventures (Magdoń, Tchórzewski, 2015). The implementation of a data-driven organizational culture in the public sector, including higher education, through investment in training and development of data analytics skills, enables more effective use of available information through BI tools (William, 2002).

In addition, the increased awareness of the potential of business intelligence solutions and their importance in building higher quality standards and competitive advantage contributes to the transformation of project management processes towards their full quantification and measurability, while reducing financial and time expenditures compared to traditional management methods. The correct definition of project risks is, from a management perspective, a key element that affects the success of a project, especially with regard to the risks associated with the financing of project tasks. Therefore, the correct definition of the risk budget, which is a response to potential risks that may occur during the project implementation phase, is of particular importance. According to the PMBOK (A Guide…, 2021) standards, project risk management is a key component of effective project management. The process involves the identification, qualitative and quantitative analysis, response planning and monitoring of risks throughout the project life cycle. Kerzner's research (Kerzner, 2017) confirms that effective risk management directly increases the chances of project success and minimizes the negative impact of potential risks. Risk budgeting, on the other hand, as an integral part of risk management, involves allocating funds to cover the costs associated with implementing planned responses to risks (Ward, Chapman, 2011). Hillson (Hillson, 2024) points out that a properly constructed risk budget not only allows for a quick response to emerging risks, but also allows for a more efficient use of project financial resources. This notion is supported by the research of Kliem and Ludin (Kliem, Ludin, 2019), who find that the lack of a dedicated risk budget increases a project's susceptibility to cost overruns and implementation delays. The literature clearly demonstrates the positive impact of risk budget planning on project success. Kerzner's research (Kerzner, 2017) has shown that projects with clearly delineated and properly managed risk budgets are more likely to achieve their objectives, especially in terms of quality, schedule, and reduction of uncontrolled costs. Similar conclusions are drawn by Kendrick (Kendrick, 2015), who emphasizes that projects in which

risk budgeting is neglected have a significantly lower success rate and are more susceptible to financial and organizational crises. The above applies not only to project-only activities, but also to large-scale ventures (Bluszcz, Kijewska, 2016).

Planning processes, including risk budgeting, can be effectively supported by modern and powerful business intelligence tools. The growing popularity of BI technologies in project management is due to their ability to aggregate, analyze, and present large data sets in real time (Larson, Gray, 2014). Chen and others (Chen, Chiang, Storey, 2012) have shown that BI systems significantly facilitate risk identification, assessment, and management through advanced analytics and data visualization. BI tools are also given special attention by authors such as Turban, Pollard, and Wood (Turban, Pollard, Wood, 2018), who argue that the use of BI improves the accuracy of management decisions and the efficiency of risk budgeting processes.

Recent studies show that using business intelligence (BI) tools with risk budgeting processes helps predict and manage financial risks more effectively (Sharda, Delen, Turban, Aronson, Liang, 2014). Systems like Power BI, Tableau, or QlikView help you create models of different situations and watch your budget in real time. A Gartner report (Richardson, Sallam, Schlegel, Kronz, Sun, 2020) says that using BI tools to manage project risk is going to be a big deal for project management in the future. Additionally, business intelligence (BI) systems help monitor compliance with financial regulations. This is done through auditing, change tracking, and reporting functions that are selective and insightful. These types of solutions are very important for making sure that money matters are clear and that rules are followed (Kerzner, 2017). Also, BI tools are often used together with ERP systems and commercial project tools. This helps to manage financial and operational data in a consistent way. This, in turn, supports risk analysis and the coordination of project activities (Kliem, Ludin, 2019). In addition to the above, it is important to know that business intelligence (BI) tools allow you to analyze different situations and manage your projects. This helps you decide how to use your resources and decide which projects are most important. It also helps you manage your budget and avoid risks at the level of the entire organization (Sharda, Delen, Turban, Aronson, Liang, 2014). Digital business analytics are becoming more affordable and easier to use, allowing us to analyze large amounts of data and identify patterns and risks. Specialized AI (Artificial Intelligence) and ML (Machine Learning) algorithms make analytical methods more efficient and precise (Chen, Chiang, Storey, 2012). Integrating the above areas with business intelligence tools improves the analysis of projects. This includes automatically detecting budget problems and predicting cost overruns (Sharda, Delen, Turban, Aronson, Liang, 2014). These solutions help identify financial risks early on, so you can deal with them as they come up (Larson, Gray, 2014). In general, the reasons for including budget reserves in project planning are strongly supported by both project management theory and practice, as reflected in recognized methodological standards. According to the PRINCE2 and PMBOK® Guide (Project Management Body of Knowledge), budget reserves are an important part of managing risk and

the overall budget for a project. The PMBOK® Guide methodology lists two main types of reserves (A Guide…, 2021).

1. Contingency Reserves: Financial resources allocated to cover risks that have been identified and analyzed, with the probability and potential impact of these risks having been estimated.
2. Management Reserves: Financial resources allocated to cover risks that are unidentified, difficult to predict, and outside the scope of basic risk analysis. The oversight of these reserves falls under the purview of project management or senior management.

Additionally, the PRINCE2® (Projects IN Controlled Environments) methodology, another of the key project management standards, underscores the necessity of project reserves as a component to effectively address unanticipated events during the project implementation phase (Managing Successful Projects with PRINCE2®, 2017).. The methodology stipulates that budgetary planning should be executed in accordance with meticulous risk analyses and the discernment of any potential discrepancies between the stipulated plan and the actual circumstances. These reserves play an instrumental role in the effective management of exceptions, while providing the Steering Committee and Project Manager with adequate decision-making flexibility and financial space to implement corrective actions.

It is important to acknowledge that the incorporation of budget reserves is also substantiated within agile project management methodologies, such as Scrum (Elkhatib, Al Hosani, Al Hosani, Albuflasa, 2022). Despite the fact that agile methodologies operate in shorter iteration cycles and are characterized by greater planning flexibility, in practice, so-called "financial buffers" or additional funds allocated to selected groups of tasks are often used. This mechanism enables the continuous adaptation of the scope and budget allocation in response to evolving project requirements and emerging risks. Just as the scope of work is adapted in the Agile approach, the reserve budget can also be dynamically modified and proportionally adjusted to the current project situation, enabling effective management of uncertainty in a highly volatile environment. Another standard that is pertinent to this discussion is ISO 21500, which pertains to the management of projects. This particular standard also indicates the necessity of allocating budget reserves, a process that is inextricably linked to the management of risk and financial planning (ISO 21500:2021 Project Management…, 2021). An analysis of project implementation reveals that the validity of reserve utilization and their optimal quantity are contingent on the unique characteristics of the project, particularly its industry and technological nuances. A general classification of projects into functional categories reveals the following relationships (Stretton, 2014): Innovation and R&D projects are characterized by a high level of risk and significant operational and technological uncertainty. Consequently, the necessity to incorporate a budget reserve appears not merely justified but imperative for this particular context. Furthermore, the allocation of these funds must be meticulously calibrated to the extent of the research domain, the extant base budget, and the proficiency of the project team. Infrastructure and construction projects are prone to

recurrent and predictable risks. However, due to the substantial scale of implementation and the high probability of unplanned events—such as increases in raw material prices, technical difficulties, or implementation delays—meticulous planning of significant budget reserves is also required. IT and technology projects are particularly sensitive to the volatility of requirements from stakeholders, as well as the complexity of the technology and integration environments in which they are implemented. Consequently, it is recommended that adequately high levels of financial reserves be utilized to enable a flexible response to emerging risks and changes in the scope of the project. Organizational and administrative projects are typically characterized by lower levels of complexity and greater cost predictability. Consequently, the necessity for budget reserves in such projects may be comparatively diminished, with their level being adapted to the circumscribed scope of risks.

To sum up, it can be assumed that the need for budget reserves varies depending on the type of project; in each case, it is crucial to adjust the amount of reserves to the specific risks, the scale of the project and the competences of the team.

The integration of BI in risk management processes is one of the most discussed topics in recent project management literature. BI tools are increasingly being used to identify, assess, and mitigate risks in real time, providing project managers with accurate data to make informed decisions. Choi et al. (2021) highlight that the use of BI in managing project risks involves analyzing historical project data and applying predictive analytics to estimate the likelihood of various risks. This data-driven approach helps in establishing more accurate risk budgets and contingency plans. The authors emphasize the role of BI in managing both financial and non-financial risks, where machine learning algorithms can predict potential budget overruns and project delays with greater precision. Xiahou, X et al. (2025) discuss the simulations with real-time data, project managers can adjust budgets and timelines dynamically, ensuring that resources are allocated appropriately and risks are mitigated effectively. Nahid (2024) examine the role of BI in managing risks in infrastructure and construction projects, where external factors such as material price fluctuations and labor shortages often lead to unpredictable challenges. The authors suggest that BI solutions can offer robust risk forecasting capabilities, allowing project managers to simulate different risk scenarios, optimize risk reserves, and create more resilient project plans.

3. Research methodology

The implementation of the study objective, which entailed an analysis of the relationship between the definition of budget risk and the type of project, its total budget, and the level of success of project implementation, was conducted in the following stages (Figure 1).

1. Selection of a research sample of projects.
2. Classification by project type to distinguish two subsets.
3. Conducting statistical analyses using:
   a. Chi-square independence test - risk budget in relation to project type.
   b. Mann-Whitney U test - risk budget in relation to project total budget and risk budget in relation to project success level.
4. The use of one-way analysis of variance (ANOVA) - the relationship of the level of project success to the type of project in a group of projects with a planned risk budget.

In order to empirically verify the impact of planning and applying project risk budgets on the level of project implementation efficiency, a study was conducted covering a group of 46 projects implemented in 2018-2024 in one of the universities, which is a public sector unit. The analyzed projects were classified into two thematic groups: projects of an organizational and administrative nature and infrastructure and construction projects.

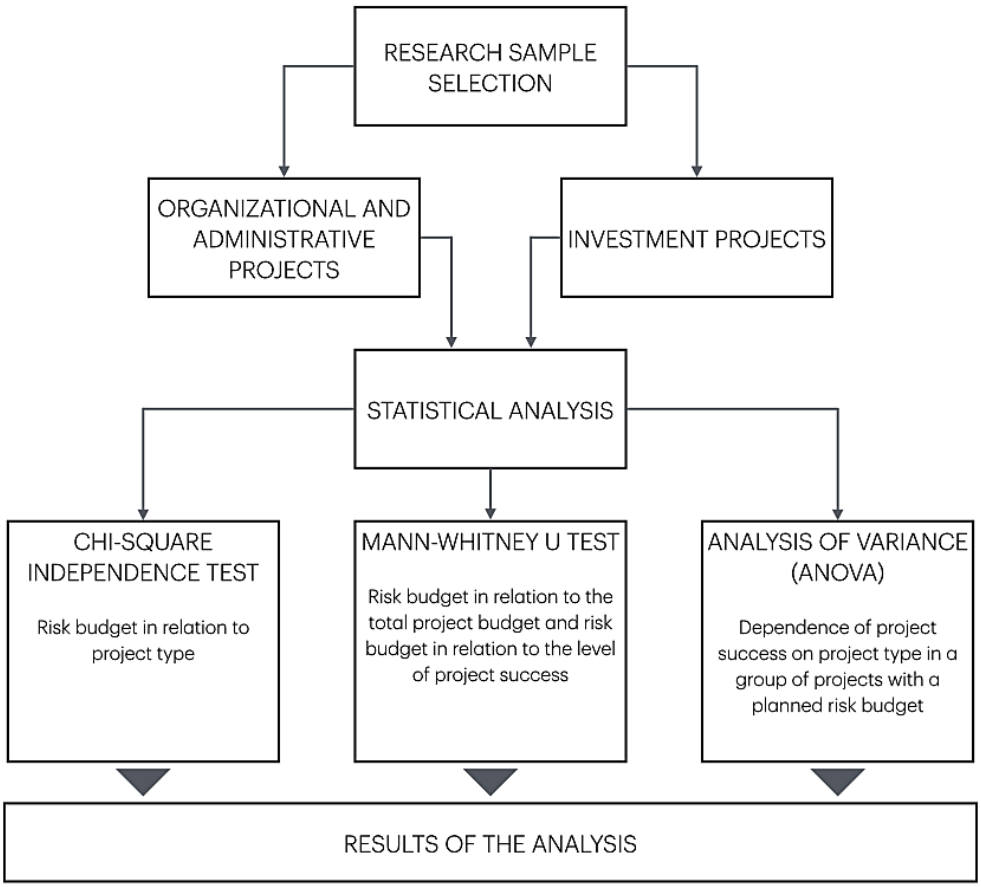

Figure 1. Steps in the implementation of the risk budget impact analysis on the success of project implementation.

This study was part of a broader research project that sought to analyze the potential of applying Business Intelligence solutions in the context of improving project management processes in public institutions. As part of a questionnaire survey administered to project managers within the analyzed organization, data was collected on a total of 114 projects. A comprehensive examination of the repercussions of the implementation of a designated risk

budget on the efficacy of project endeavors has been undertaken. In pursuit of this objective, the subsequent subsets have been identified:

1. A group of 32 organizational and administrative projects is presented herein, including activities in the areas of professional competence development, curriculum development, student support, and implementation of new teaching tools and methods.
2. A group of 16 investment projects, encompassing infrastructure and construction, was executed as a component of investments designed to advance the organization's technical facilities and infrastructure.

For each project, it was ascertained that a reserve budget for covering risks was considered at the planning and implementation stage. The analyses conducted demonstrated that:

1. In the case of projects in the organizational and administrative area, 70% of the projects did not include a planned risk budget.
2. In the group of infrastructure and construction projects, in 75% of cases the risk budget was not specified.

The results presented in Figure 2 indicate a significant gap in terms of a systemic approach to project risk management, regardless of the nature of the project. Despite their divergent risk profiles, the implementation of both soft and investment projects occurred predominantly without the formal allocation of financial contingency reserves.

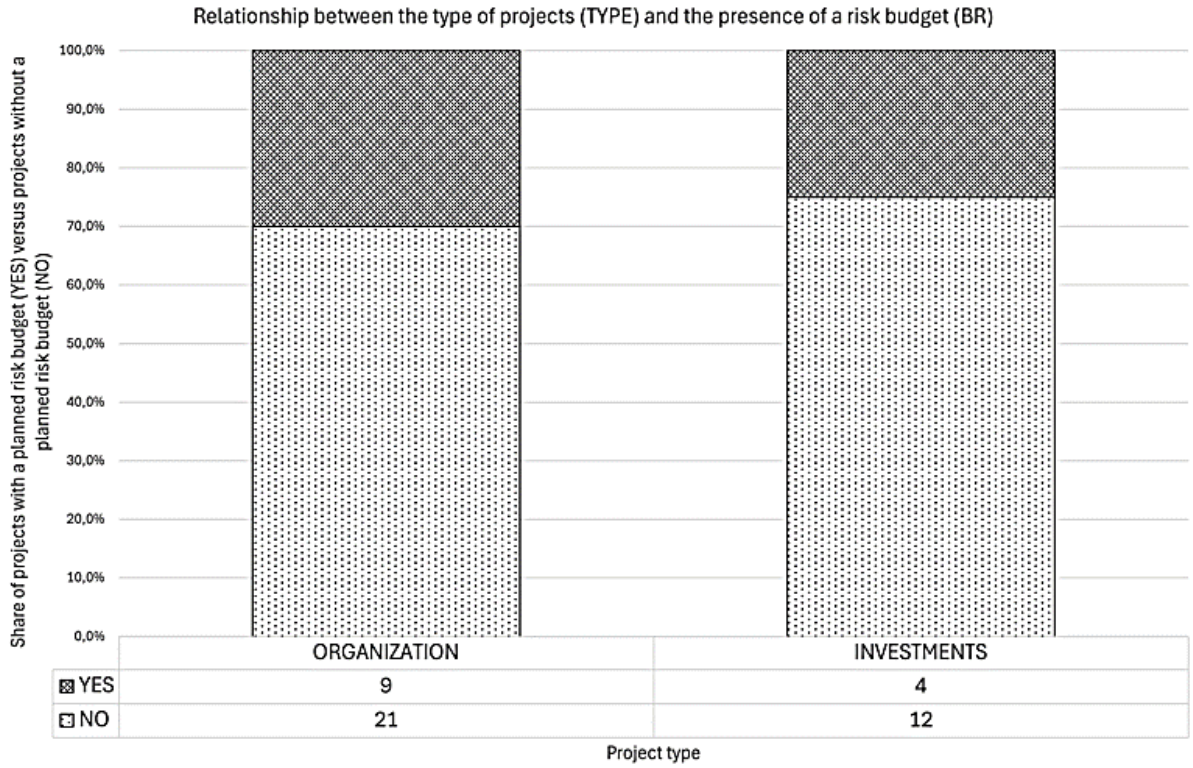

Figure 2. The relationship between the type of project being implemented and the risk budget planned for that project.

The results of the analyses conducted indicate that reserve budget planning in the studied organization is not a systematic or common practice. This phenomenon manifests in a limited number of cases, which may be attributable to the absence of a formally implemented project management standard within the organizational structures of the institution. In the context of the aforementioned points, it should be noted that if planning reserve budgets were a mandatory activity—analogous to routinely implemented processes such as planning the overall budget, schedule, or scope of project deliverables—the share of projects with a risk budget included would likely be significantly higher. Therefore, it is reasonable to hypothesize that the percentage of projects with a reserve budget included (30% for organizational-administrative projects and 25% for infrastructure-construction projects, respectively) is due to the involvement of personnel with broader project management knowledge or practical experience from previous implementations. These individuals were able to observe the significant impact of the existence (or absence) of budget reserves on the final outcome of projects, which translated into greater awareness of financial risk management.

4. Results

4.1. Risk budget in relation to project type

The relationship between the type of project and the presence of a reserve budget was analyzed using the chi-square test of independence. This test was selected because it is an appropriate statistical method for analyzing the relationship between nominal or categorical variables (Jóźwiak, Podgórski, 2022). This test enables the determination of whether the observed relationship between variables is statistically significant or is attributable solely to the random distribution of the data. The chi-square statistic is calculated as the sum of the differences between the observed (O) and expected (E) values.

$$x^2 = \sum \frac{(O-E)^2}{E} \tag{1}$$

where:
O – values observed in the study,
E – expected values, assuming no relationship.

In a further step of the analysis, a p-value was calculated, which determines the probability of obtaining results as extreme or more extreme than the results observed in the study, assuming the null hypothesis is true (Jóźwiak, Podgórski, 2022). The null hypothesis (H0) assumes no effect or no relationship between the analyzed variables, while the alternative hypothesis (H1) indicates the existence of a relationship between them.

The statistical significance level of α = 0.05 was assumed for the dataset, which means that the risk of making an error of the first kind (i.e., rejecting the true null hypothesis) was set at 5%. In accordance with the established criteria:

1. if $p < 0.05$, the null hypothesis is rejected, which means that there are grounds for considering the relationship between the analyzed variables statistically significant,
2. if $p \geq 0.05$, there are no grounds to reject the null hypothesis, which means that the observed relationship may be the result of chance.

Furthermore, the analysis encompassed the number of *degrees of freedom* (*df*), which is defined as the number of independent values in the crosstab that can vary while maintaining constant boundary values. In the case of a two-dimensional table (also known as a cross table), the number of degrees of freedom is calculated according to the following formula:

$$df = (r - 1) \times (c - 1) \tag{2}$$

where:
r – number of rows in the table,
c – number of columns in the table.

Therefore, the p-value can be interpreted as the extent to which our results align with the scenario in the absence of a relationship or discrepancy. The subsequent calculations yielded the results presented in Table 1.

Table 1.
The results of the analysis of the link between the type of project and the assumption of the financial risk budget in the project

Statistical operation	Result of calculations
Chi-square statistic	0.00022 (very low value)
p-value	0.988 (Very high, well above the typical significance threshold 0.05)
Degrees of freedom	2

Based on the calculations, it was shown that in the analyzed group of projects carried out within the studied organization, there was no statistically significant relationship between the variable determining the type of project (TYPE) and the variable describing the decision to plan the risk budget (BR). The expected counts, determined on the basis of the model assuming the independence of the variables, were close to the observed values, providing further evidence of the lack of a significant relationship between the studied variables. Although visual analysis of the data distribution suggested some differences in the incidence of reserve budgets between project types, the Chi-square test of independence did not confirm their statistical significance. This means that, in light of the collected data, the decision to include a risk budget is not significantly determined by the type of project being implemented.

This result indirectly confirms the trend observed earlier, according to which the practice of planning reserve budgets in the analyzed organization is not systemic, and their use took place in only 28% of the cases among all projects included in the analysis.

4.2. Risk budget in relation to the total project budget

The study further analyzed the relationship between the total budget for the project and the presence of a planned reserve budget. The results of the descriptive analysis for both variables are shown in Table 2.

Table 2.
Results of the analysis of the link between the total budget amount and the assumption in the draft budget of financial risk

Statistical operation	BR = 0 Risk budget (NO)	BR = 1 Risk budget (YES)
Budget average	PLN 1.11 million	PLN 857,000
Median	PLN 500,000	PLN 300,000
Statistical spread	From 150 thousand to 4.5 million zlotys	From 150 thousand to 3 million zlotys

The results of the descriptive analysis indicate that projects with no planned risk budget have a higher average total budget value, and a larger budget spread compared to projects that had a separately allocated reserve budget. Median analysis, on the other hand, revealed that the majority of projects with planned risk budgets fell within the range of lower total budget values, which may suggest a different approach to risk management depending on the scale of the project.

Based on the above results, it is possible - with interpretive caution - to formulate the hypothesis that projects with lower budgets have a more conservative and precise approach to risk management, resulting in more frequent planning of reserve budgets. On the other hand, projects with a larger financial scale may be estimated at a higher level of generality, potentially leading to an underestimation of risk and the abandonment of reserve planning, under the assumption that significant budget resources will cover possible unforeseen costs. This kind of assumption, however, can be the result of what is known as *project optimism bias*, understood as the tendency of project teams to make unrealistically favorable estimates of key project parameters, such as cost, schedule, end results or level of risk (Meyer, 2014).

As part of further statistical analysis to verify the relationship between the amount of the project budget and the presence of a reserve budget, the non-parametric *Mann-Whitney U* test was used (Durka, 2003). This test is used to assess the significance of differences between two independent groups when the normality of the distribution of variables cannot be assumed. In the case analyzed, the median values of the project budget were compared for:

1. group of projects without a planned risk budget,
2. group of projects with a planned risk budget.

The *Mann-Whitney U* test is based on comparing the rank sums for the two groups and calculating the value of the U test statistic according to the following formula:

$$U_1 = n_1 \cdot n_2 + \frac{n_1(n_1+1)}{2} - R_1 \tag{3}$$

$$U_1 = n_1 \cdot n_2 + \frac{n_2(n_2+1)}{2} - R_2 \tag{4}$$

where:
n_1, n_2 – the number of groups,
R_1, R_2 – sums of ranks in groups.

The U statistic is the smaller value among U_1 and U_2. As for the previously described case, for a *p-value* < 0.05 we reject the null hypothesis (groups differ significantly) and in the case where the *p-value* ≥ 0.05, then we do not reject the null hypothesis (no significant difference between groups).

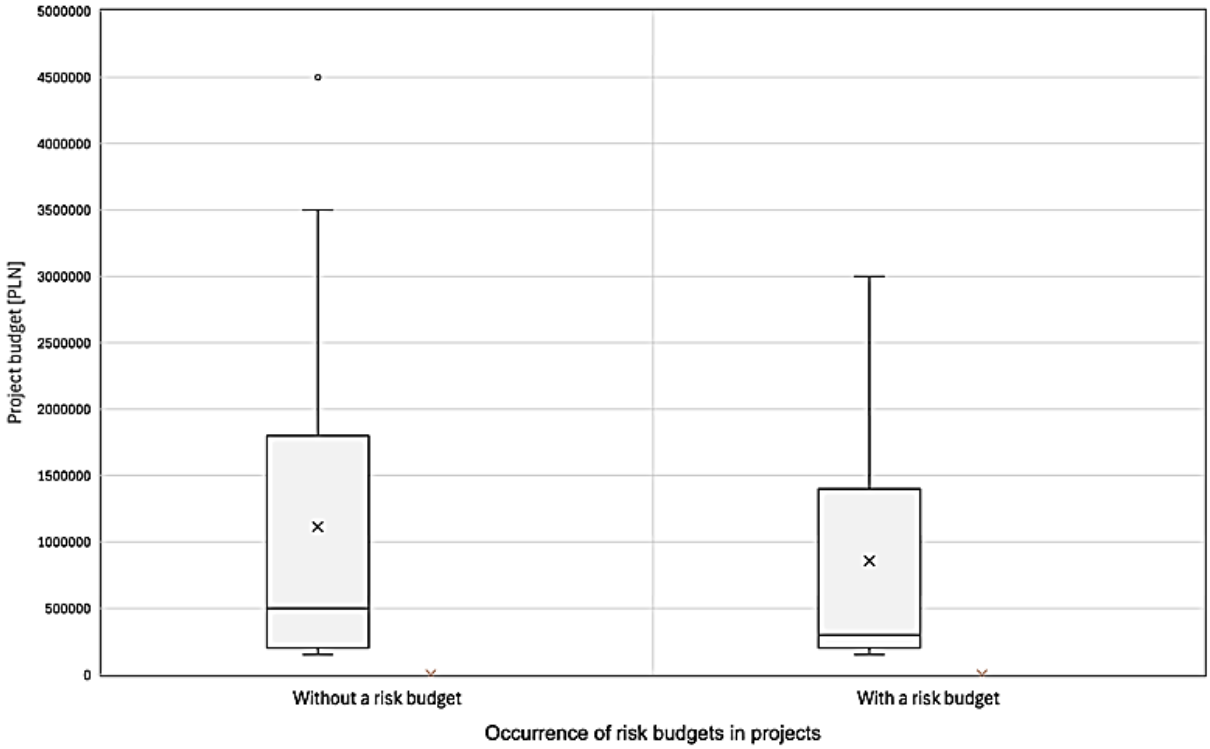

Figure 3. Relationship between the total project budget and the risk budget planned for the project.

A statistical analysis of the relationship between the amount of the project budget (BP) and the presence of a planned risk budget (BR) indicates that projects with risk provisions have a lower median total budget compared to projects with no risk budget (Figure 3). Based on this, it can be hypothesized that projects with smaller financial scale have a higher propensity for formal planning of risk budgets. In addition, outliers, i.e. projects with unusually large budgets, were observed in the group of projects without a planned risk budget. This phenomenon can be interpreted as the result of a common - albeit undesirable from the point of view of project management standards - assumption that a high project budget provides sufficient financial flexibility and allows transfers of funds between cost categories in case of unforeseen situations. Such an approach, while seemingly beneficial, can lead to fraud, irregularities and a lack of transparency in the management of financial resources. In the course of the analysis, the *Mann-Whitney U-test* was applied, yielding the following results:

- Test statistics $U = 255.0$.
- p-value = 0.327 ($p > \alpha = 0.05$).
- Median BP for BR group = 0 (without a risk budget): PLN 500,000.
- Median BP for BR group = 1 (with a risk budget): PLN 300,000.

The resulting *p-value* of 0.327 indicates that the difference between the medians is not statistically significant, which means that the existence of a systematic relationship between the size of the project budget and the decision to plan a risk reserve cannot be confirmed. Despite the discernible difference in the central values (PLN 500,000 vs. PLN 300,000), it does not provide grounds for concluding that the scale of the budget determines the existence of a risk budget in a statistically significant way.

In view of the above, it should be noted that decisions to include risk budgets are likely to be made on an individual basis and not explicitly based on the level of the total budget. Procedural and formal constraints, such as:

1. Lack of requirement for risk budget planning at the stage of preparing project documentation.
2. Inability to include reserve items in applications for external funding, the formats of which are strictly defined by funding institutions.

4.3. Risk budget in relation to the level of success of the project

The final stage of data analysis was to verify the relationship between the fact of planning (or not) the risk budget (BR) and the success of the project (SUCCESS). Thus, for the analyzed group of projects, the results were obtained as in Table 3.

Table 3.
The results of the analysis of the link between the assumption of the financial risk budget in the project and the evaluation of the success of project implementation

Statistical operation	BR = 0 Risk budget (NO)	BR = 1 Risk budget (YES)
Average success rating	5.36	8.08
Median success rating	6	8
Range of success ratings	from 2 to 8	from 6 to 10

Based on the analysis, it can be concluded that projects with a planned risk budget achieve, on average, higher success ratings than projects without such a provision. Moreover, the spread of success ratings (the difference between the highest and lowest ratings) was also found to be greater in the group of projects with a risk budget, but what is significant is that the lower limit of ratings in this group was noticeably higher than in the group of projects without a budget reserve. This situation may be indicative of generally better risk management in projects with planned financial reserves.

To verify the statistical significance of the observed differences, the non-parametric *Mann-Whitney U-test* was used to compare the success ratings of two independent groups of projects:

1. without a risk budget (BR = 0).
2. with a risk budget (BR = 1).

The test results are shown below:

- Test statistics *U*: 24.5.
- p-value: 0.00000263 (significantly below the 0.05 threshold).
- Median SUCCESS for projects without a risk budget (BR = 0): 6.
- Median SUCCESS for projects with a risk budget (BR = 1): 8.

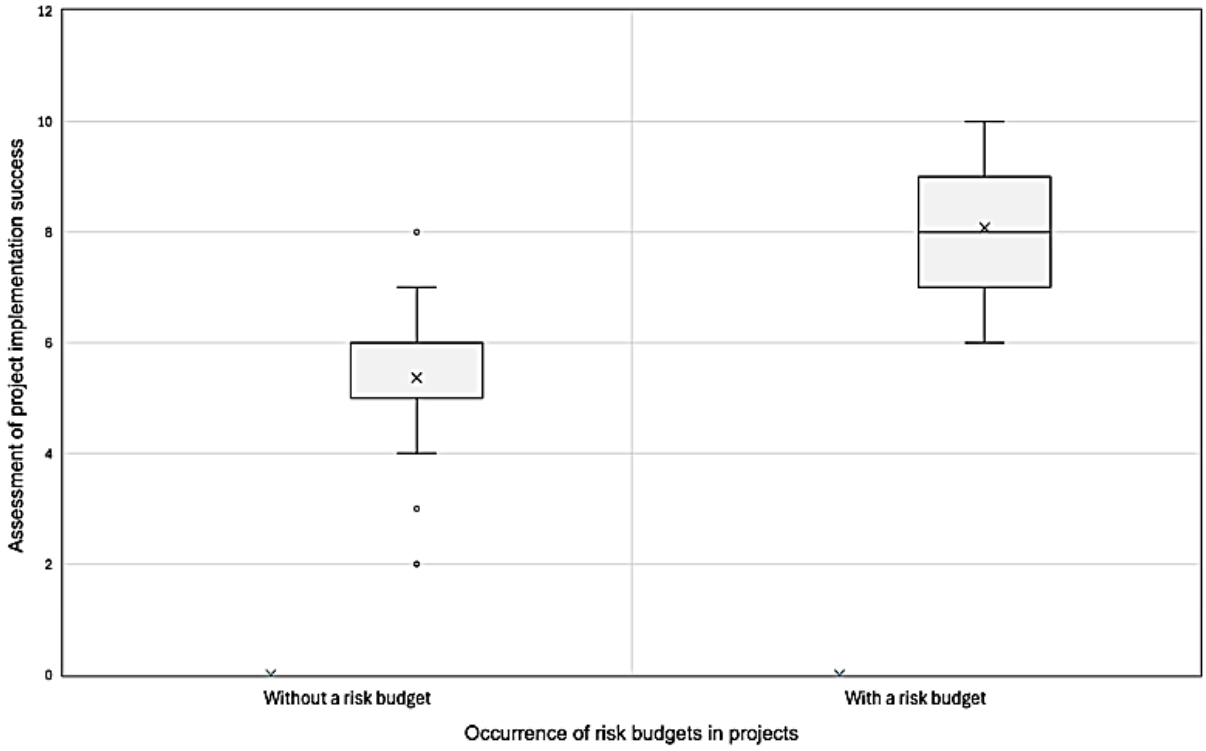

Figure 4. Relationship between the risk budget planned for the project and the assessment of project success.

Analysis of the data obtained clearly indicates that projects for which a risk budget has been provided receive noticeably higher success ratings compared to projects where no such budget has been planned (Figure 4). Also, the median success rating in the group of projects with a risk budget is noticeably higher, suggesting that most of these projects are statistically perceived as more successful. It should be noted here that the study adopted a project success rating scale of 0 to 10, where 0 means total failure and 10 means fully satisfactory achievement of project goals.

In addition, analysis of quartile values confirms the above conclusions:

1. The lower quartile (*Q1*) for projects with a planned risk budget is significantly higher than for projects without such a budget, which means that even the lowest-rated projects in this group perform relatively well.

2. The upper quartile (*Q3*) also takes on a higher value in the group of projects with a risk budget, indicating an overall higher level of success in this group.

The results of the *Mann-Whitney U test* confirm the statistical significance of the observed difference. The very low *p-value* obtained ($p < 0.05$) demonstrates a strong and statistically significant relationship between the planning of a risk budget and the assessment of project success. Therefore, it should be concluded that project risk management, expressed by the establishment of a dedicated reserve budget, has a significant and positive impact on the effectiveness of project implementation.

4.4. Dependence of the level of project success on the type of project in a group of projects with a planned risk budget

In the final step of the statistical analysis, a one-way analysis of variance (ANOVA) was conducted for the subset of projects that included a planned risk budget (BR = 1) (Jóźwiak, Podgórski, 2022). The purpose of the analysis was to compare the average success ratings (SUCCESS) between the two types of projects analyzed (organizational-administrative projects and infrastructure-construction projects).

The results of the ANOVA test are as follows:

- Statistic *F*: 2.01.
- *p*-value: 0.184.
- Types of projects compared: organization, investments.

Based on the results obtained, it was found that at a significance level of $\alpha = 0.05$, the *p-value* of 0.184 does not allow the rejection of the null hypothesis of no differences between the average success ratings in the analyzed groups. This means that the differences in average success ratings between educational and investment projects for which a risk budget was planned are not statistically significant.

Based on the above, it can be concluded that while the mere fact of planning a risk budget has a positive impact on the evaluation of the success of projects, the type of project does not significantly condition the differences in these evaluations, at least in the analyzed dataset. This indicates the potentially universal importance of risk management for the effectiveness of project implementation, regardless of the functional specificity of the project.

4.5. Business Intelligence (BI) in project portfolio risk management

Focusing on the role of business intelligence solutions in estimating and managing risk budgets, special attention should be paid to tools that enable automatic data collection, processing and recommending the appropriate level of financial reserves for projects. This makes the risk management process faster, more precise and reduces the risk of errors due to the human factor, such as excessive project optimism or incomplete identification of risks. A prerequisite for the effectiveness of this process is the aggregation of data from previous projects implemented in the organization - both successful projects and projects that

encountered budget problems (Nambiar, Mundra, 2022). This data should include: the total project budget, the budget allocated for handling risks, the financial risks present, the percentage use of the budget reserve, the reasons for budget deviations and the final results of the project implementation.

Subsequently, it is reasonable to apply methods such as expected value analysis (EMV), Monte Carlo simulations and predictive models based on machine learning techniques (Reshi, Khan, 2014). The implementation of these tools in business intelligence ecosystems enables the analysis of collected data and the construction of mathematical models tailored to the specifics of the organization, the purpose of which is to estimate the probability of occurrence of certain types of risks and predict their potential financial impact. This approach allows users of BI systems to obtain information about the required level of budget reserve (most often expressed as a percentage of the total budget), to allocate financial reserves appropriately to individual project tasks, and to obtain recommendations for risk response strategies (such as risk avoidance, acceptance or transfer). A key advantage of implementing this type of solution is that the results of the analysis are automatically updated in real time, making it possible to dynamically determine the level of recommended reserves and to keep the project manager informed of the need for possible budget adjustments.

The analysis of available and popular Business Intelligence solutions supporting business risk analysis and management allows defining the significant benefits of automating these processes (Table 4). First of all, attention should be paid to modern ERP systems equipped with BI modules, supporting all financial processes and a significant part of project processes (Chomuszko, 2016). Direct integration of BI with ERP systems makes it possible to retrieve data on budgets, schedules, project costs and changes in expenditures on an ongoing basis. Automatic reading of project expenditure data in real time, comparing actual expenditures with assumed reserves, and suggesting changes in the reserve budget in case of changes in the level of risk translate directly into an increase in the probability of successful project implementation.

Implementing simulation methods such as Monte Carlo simulations in a BI environment is particularly applicable to infrastructure projects, such as building construction or laboratory upgrades, where the variability of material and service costs is significant. These simulations make it possible to predict cost ranges by drawing different risk scenarios, defining probabilities of cost increases, running alternative project implementation scenarios, and determining the probability with which the budget (including the reserve) will be sufficient to cover all implementation costs.

Additional budget risk management automation features are based on activities such as:

1. Ongoing reporting of threshold exceedances.
2. Suggesting corrective actions such as reviewing risks, updating schedule or renegotiating contracts.
3. Automatically assigning expenses to appropriate cost categories.
4. Generating complete reports (eg. Excel, PDF) with documentation of expenditures.

5. Real-time monitoring of project KPIs (e.g., schedule deviations, number of changed project requirements).
6. Presentation of actual analysis results and recommendations on BI dashboards with the needs and context of the roles, e.g., project manager and sponsor.

Table 4.
Relationship between the risk budget planned for the project and the assessment of project success

No.	Scope of BI automation	BI Tools	Functionality description
1	BI platform to integrate data with SAP/ERP	SAP Analytics Cloud, Microsoft Power BI, Qlik Sense	Integration of financial data from ERP systems in real time, ability to build consistent management and analytical dashboards
2	Monte Carlo simulation in Power BI for infrastructure projects	Microsoft Power BI + DAX/What-If Analysis, Tableau + R Extension	Ability to design simulations for multiple cost scenarios using "What-If" query tools and statistical scripts
3	Automatic notifications of exceeding the budget reserve	Power BI Alerts, Tableau Notifications, Qlik Alerting	Create automatic alerts (e.g., email or system alerts) when set budget thresholds are exceeded
4	Automatic generation of audit reports for funding institutions	Power BI Report Builder, Tableau Report Server, SAP Crystal Reports	Automatic generation of formalized financial reports required during audits or during project/grant settlement
5	Dynamic recommendation of reserve size based on current risk indicators	Power BI + Azure ML, Tableau + Einstein Discovery, Qlik AutoML	Integration of BI with ML algorithms, dynamic generation of recommendations for the amount of budget reserves based on current risk indicators
6	Automatic prediction of project execution delays based on schedule analysis	Power BI + Azure Machine Learning, Tableau + Python Integration, Qlik Sense	Predictive models based on analysis of Gantt schedules and milestones for early warning of possible delays
7	Automatic classification of project risks based on historical data	Power BI + Dataflows, Tableau Prep + AutoML, Qlik AutoML	Machine learning on historical data to classify risks by impact, probability, and risk handling priority

In summary, the implementation of Business Intelligence solutions in the process of estimating and managing budget reserves allows for the automation of many key activities, which significantly increases the precision, efficiency and flexibility of risk management. Thanks to integration with ERP systems and the use of advanced analytical methods, such as Monte Carlo simulations or predictive models based on machine learning, organizations can dynamically adjust the level of budget reserves, which leads to greater certainty in project implementation and minimizing the risk of unforeseen expenses.

To sum up the results chapter, several important conclusions can be indicated that bring new value to both the theory and practice of project management, especially in the context of the public sector. The research confirms that including a risk budget in project planning has a significant impact on the success of their implementation. Although this practice is beneficial, it is still not widely used in the organizations studied. This is particularly visible in projects financed from external sources, where the applicable financing rules often make it difficult to allocate funds for risk reserves. Application of Business Intelligence in risk budget

management: A novelty in the research is the demonstration of how BI tools can support financial risk management processes in projects. BI enables the collection and analysis of data in real time, which allows for precise monitoring of financial risks and adjustment of budgets to changing conditions. The analyses conducted indicate that BI can significantly improve the processes of risk forecasting and estimating appropriate budget reserves, as well as provide recommendations on risk response strategies (e.g. avoidance, acceptance, transfer). The research reveals that despite the positive impact of defining a risk budget on the success of project implementation, in public institutions (e.g. universities) it is still a rarely used practice. This is mainly due to the regulations regarding financing projects from external funds.

5. Discussion

The analysis of the relationship between risk budget definition and project success in a public sector context, specifically within a university, provides several valuable insights into the importance of incorporating risk management strategies at the planning stage. The study highlights a significant positive correlation between the inclusion of a risk budget and the successful implementation of projects. However, it also points out the limitations of this practice in public sector entities, particularly in projects financed through external sources. These findings raise several important questions and offer opportunities for further investigation into the broader implications for public sector project management.

First and foremost, the study's conclusion reinforces the critical role that defining and allocating a risk budget plays in project success. By including financial reserves specifically for risks, projects are better equipped to manage unforeseen events or cost overruns. This approach aligns with established project management literature, which stresses the need for adequate contingency planning and proactive risk management to ensure project objectives are met. The findings of this study, therefore, support the notion that a well-defined risk budget can help mitigate the impact of uncertainty and enable more flexible responses to emerging challenges, ultimately contributing to project success.

Nevertheless, the limited use of risk budgets in the surveyed university projects suggests a gap between theoretical best practices and their practical application. A key barrier identified is the complexity of financing mechanisms, particularly when external sources, such as grants or public funding, are involved. External financing often comes with strict guidelines, timelines, and budgetary constraints, which may make the inclusion of a separate risk budget challenging. The study suggests that this issue could be mitigated by making the estimation of risk budgets mandatory, even in externally funded projects. This recommendation not only addresses the financial uncertainty inherent in such projects but also promotes greater project resilience and long-term success.

Another significant contribution of this study is its exploration of the potential of Business Intelligence (BI) solutions in the project management process, specifically in the area of risk budget estimation and monitoring. The results clearly indicate that the integration of BI tools can streamline the risk management process, providing real-time data analysis and predictive modeling to support decision-making. The use of BI systems can help project managers track risks more effectively, allocate financial reserves in alignment with actual project conditions, and adjust budgets dynamically as new risks emerge. This technological approach offers substantial improvements over traditional methods, which often rely on manual data collection and forecasting, thereby reducing the risk of errors and biases that could affect project outcomes.

In particular, the application of Monte Carlo simulations and predictive models based on machine learning, as discussed in the paper, presents a promising avenue for improving risk management in complex projects. These advanced techniques can help organizations forecast potential risks more accurately, assess their financial impact, and develop strategies to mitigate them. The integration of these methods within a Business Intelligence framework allows for a more nuanced and data-driven approach to project management, moving away from reactive measures to proactive, real-time decision-making.

Despite these promising findings, several challenges remain in fully integrating BI tools into project management practices, particularly in public sector institutions. One challenge is the potential resistance to adopting new technologies and methodologies, especially in organizations with limited digital infrastructure or a lack of familiarity with advanced analytical tools. Additionally, the costs associated with implementing BI solutions may be prohibitive for some public institutions, particularly those with constrained budgets. Therefore, future research could explore the cost-benefit analysis of adopting BI solutions in public sector projects, as well as strategies for overcoming barriers to technology adoption.

Moreover, while the study provides valuable insights into the benefits of BI in risk budget management, it is important to note that the findings are based on data from a specific higher education institution, which may limit the generalizability of the results to other sectors or countries. Future studies should consider expanding the sample size to include a broader range of public institutions, thereby providing a more comprehensive understanding of how BI solutions can be utilized in diverse project contexts.

6. Conclusions and recommendations

Based on the analyses, it can be concluded sequentially that:

1. The inclusion of a risk budget in projects has a significant and positive impact on their success, which was confirmed by both descriptive analyses and statistical tests, including the *Mann-Whitney U* test. Projects with a planned risk budget provision achieved higher success ratings compared to projects that did not have such a provision.
2. Despite the confirmed need for a risk budget in project implementation, the analysis showed that this practice is not commonly implemented in the surveyed organization, especially in projects financed with public funds or external funds (e.g., EU). The lack of dedicated budget items for risk is due to the current legal regulations and public funding guidelines, which require a high level of transparency, precise planning and strict documentation of expenses.
3. The results of the Chi-square independence test showed no statistically significant relationship between the type of project and the decision to plan a risk budget, which in turn indicates that the project category (project type) has no influence on the use of financial risk management mechanisms. This thus means that the decision to include a risk budget is independent of project characteristics, at least for the administrative-organizational and investment-construction project categories.
4. Estimating the risk budget for a specific project is not a very complicated task and the methods already available, such as the percentage method, the expected value method (EMV), Monte Carlo simulation, the Delphi method and benchmarking, are effective tools to support this process, which in turn translates into support in decision-making processes. The tools mentioned in the study enable improvements in the precision of financial uncertainty management and increase the likelihood of project success.
5. Projects with lower total budgets were slightly more likely to include a risk budget in the sample, which may indicate a more cautious approach to risk management for projects with limited financial resources, more exposed to the effects of possible budget deviations.
6. The phenomenon of excessive project optimism, which involves unrealistic estimates of costs as well as schedules or end results, poses a significant threat to the credibility of project planning. It can lead to underestimation of risks, resulting in inadequate financial reserves to cover unforeseen expenses.
7. International project management standards, such as PMBOK®, PRINCE2® and ISO 21500, clearly indicate the need to include budget reserves as an integral component of risk management. This confirms the validity of institutionalizing this practice in all types of projects, regardless of their nature, scale and funding source.

8. Business Intelligence can play a key role in the process of effective financial risk management of projects. BI tools enable automatic aggregation of project data, dynamic estimation of risk levels, forecasting of reserve costs and real-time monitoring of budget execution.
9. Modern BI ecosystems, integrating functions of simulation, cost prediction, scenario analysis and project portfolio management, allow for better resource planning, increased efficiency of project execution and effective planning of risk budgets.

The introduction of formalized standards for project risk management in public organizations should be a priority, especially in the context of the implementation of projects financed by public funds and external funds such as EU grants. In particular, it is recommended to introduce mandatory risk budgeting as an integral part of the budgeting process. The development of own project standards that meet the requirements of the organization should be based on good practices derived from recognized project management methodologies such as PMBOK®, PRINCE2® and ISO 21500. It is recommended to use a variety of methods for estimating the risk budget, appropriately adapted to the specificity and nature of projects. The use of planning tools in the budget area allows for increased precision in forecasting the cost of unforeseen events and effective management of financial risks. It is reasonable to strengthen the competence of project teams and project managers in risk management. Such activities should be an important part of organizational policy due to the extent of the impact of effectiveness in project implementation on the efficiency of public sector units. Increasing the awareness and practical knowledge of managers directly translates into higher quality of project management and their more effective planning of resources, including primarily financial. Systematic analysis of historical data of completed projects and documentation of risk countermeasure cases should become standard practice in organizations such as universities, where the number of completed projects is significant. Creating and updating project knowledge bases can enable better estimation of future risk budgets and will serve to support decision-making processes. Given the formal constraints on the ability to plan risk budgets in application documentation, especially in projects co-financed by EU funds, it is necessary to develop internal mechanisms to accommodate them. This may include, among other things, documentation of risk estimation methods and internal procedures for approval and monitoring of financial reserves. For projects with a high total budget or significant complexity, the mandatory use of advanced analytical tools such as Monte Carlo simulation or the expected value method (EMV) is recommended. These methods provide greater accuracy in forecasting the impact of risks and allow for more precise planning of reserve resources. In order to reduce the impact of the phenomenon of excessive project optimism, it is advisable to implement planning quality control mechanisms, such as critical analysis, internal or external audit and expert consultation at the project preparation stage. These activities promote realistic estimation of risks and ensure adequate financial preparation for their potential occurrence. Developing automatic alert functions and proper selection of management and analytical

dashboards in BI environments, can ensure that project managers respond quickly to changes in risk and update their strategies for managing project budgets.

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