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# RISK AND UNCERTAINTY ASSESSMENT IN SOFTWARE PROJECT MANAGEMENT: INTEGRATING DECISION TREES AND MONTE CARLO MODELING

*The evaluation of risk and uncertainty in the context of software project management is the* ***subject of this*** *paper. This paper discusses the difficulties faced by project managers in handling uncertainty brought on by the complex nature of software projects and the ever evolving requirements of technology. A review of the literature, data production, visualization, statistical analysis, and mathematical modeling are included in this study. The* ***goal*** *of this study is to create a methodical approach to assist project managers in making decisions by considering the inherent uncertainty in software development and to find approaches and procedures that may successfully reduce risks, improve decision-making, and eventually result in the implementation of successful projects. The following* ***tasks*** *were carried out: to evaluate risk and uncertainty by examining the state-of-the-art in decision theory and its applications in software project management; to develop an integrated strategy that blends Monte Carlo Simulation with Decision Trees to assess risk and uncertainty in software project management; to generate data, visualize it, and perform statistical analysis to comprehend how project outcomes, costs, and time are affected; to identify important variables affecting project results and decision-making using decision trees; to use Monte Carlo simulation to create project scenarios and weigh the likelihood of each; and to supply project managers with knowledge and suggestions to help them make informed decisions and successfully manage risks.* ***Methods****. To evaluate risk and uncertainty in software project management, this paper analyzes the decision theory approaches currently used as well as Decision Trees and Monte Carlo Simulation techniques.* ***Results****. This study offers thorough insights into how project results, costs, and duration vary among various techniques. The critical factors that have a substantial influence on project success are shown through decision trees. According to the study's findings, combining decision theory and statistical analysis equips project managers to make wise decisions despite uncertainty.* ***Conclusions****. Project managers may improve decision making, risk reduction, and overall project success by applying these cutting-edge approaches. To adapt these techniques to unique software project management contexts and real-world situations, further study and implementation in practice are necessary. With the use of such techniques, the software development sector would be better able to manage the complexity of projects and provide good results within set financial and time parameters.*

***Keywords:*** *software project management; risk assessment; uncertainty; decision theory; Decision Trees; Monte Carlo Simulation; project outcomes; decision-making; statistical analysis; resource allocation; project success.*

## 1. Introduction

Successful project management is essential for delivering high-quality products within budget and time restrictions in the changing world of software development. However, given the inherent complexity of software projects and the constantly evolving demands of technology, there are many uncertainties and hazards that can have a significant influence on how well projects turn out.

### 1.1. Motivation

Software project management decision-makers should use solid methodologies that take risk and uncertainty into consideration in order to successfully handle these issues [1, 2]. Numerous stakeholders frequently interact in complicated ways throughout software projects, and there are also typically strict deadlines and challenging technical specifications. These elements lead to an environment that is characterized by a variety of uncertainties, such as unclear user needs, probable technological difficulties, and the unexpected behavior of software systems. One of the most important aspects of a successful IT project implementation is the quality engineering of the system being built to meet all business objectives, delight the customer, and ultimately satisfy the end user. For a project to be successful through engineering, the level of satisfaction must increase with [3].

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The uncertainty around software initiatives is further increased by external unpredictable factors such as market fluctuations and regulatory changes [4].

Ineffective risk management and decision making in the management of software projects can have serious implications. Uncertainties and risks that are not sufficiently handled can lead to project delays, budget overruns, degraded quality, and eventual project failure [5]. Therefore, a systematic strategy is urgently needed that enables project managers to make educated decisions while considering the inherent uncertainties in the software development process.

### 1.2. State-of-the-art

This section discusses the most recent developments and methods in decision theory used to assess risk and uncertainty in software project management.

Throughout the project life cycle, decisions must be made at least once, regardless of how big or small the project. Increased expenses, dangers, and deadlines are some drawbacks of delays. Project managers might employ methods to make decisive judgments quickly and effectively and the effects of restricted rationality on such decisions [6]. The paper [7] emphasizes that knowledge management is crucial to the success of a project. Despite the many barriers and challenges that stand in the way of effective knowledge management, such as poor motivation, a lack of leadership, inadequate training, and the uniqueness of projects. The importance of knowledge management for enhanced decision making across project management life cycles cannot be underestimated.

The significance of decision theory in software development initiatives has been underlined by earlier research [5]. The authors discovered that project managers who used decision theory were better able to foresee and reduce possible risks, which led to on-time delivery and higher-quality products.

The article [8] provides insight into the application of risk-based fuzzy decision support systems in new product development (NPD) projects. This study highlights the increasing complexity and risk aversion behavior in NPD projects, necessitating effective risk management strategies. The proposed R-VIKOR methodology combines the R-numbers method and fuzzy VIKOR to assess and rank critical risk factors in NPD projects. The article emphasizes the importance of implementing such models to guarantee project success and suggests future research directions for further exploration and improvement in risk management practices.

Research in the field of decision theory in project management has identified three categories of methods: quantitative [9, 10], qualitative [9, 11], and mixed [9, 12] (Figure 1).

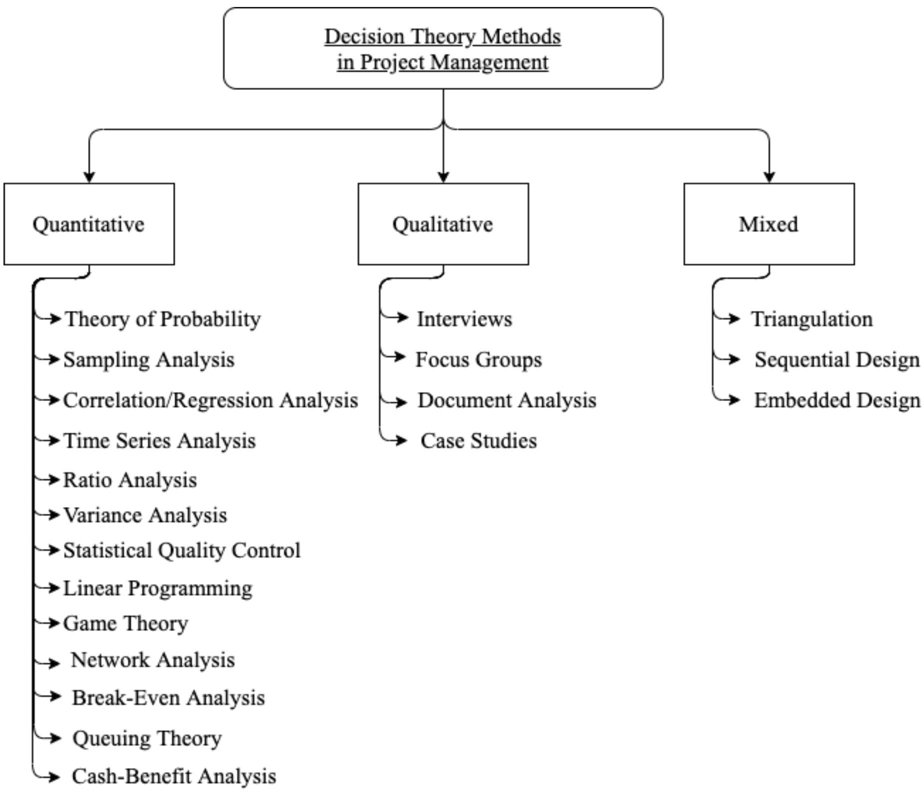


Fig. 1. Methods of decision theory in software project management

In quantitative approaches, numerical data are gathered and examined to generate statistical insights [13] and reach objective choices [14, 15]. Probability analysis uses methods such as Monte Carlo simulations or statistical modeling to quantify the likelihood of risk and calculate its impact. Cost-benefit analysis uses financial metrics to assess the likely costs and benefits of various project options or risk mitigation measures. Statistical analysis examines past software project performance to identify patterns, trends, and correlations that can help inform decision making. Decision tree building enables project stakeholders to view likely project outcomes, assign probabilities to different branches, and choose the best course of action based on the predicted outcomes.

To obtain a deeper understanding of how decisions are made, qualitative approaches place special emphasis on understanding people's subjective experiences [16], opinions, and viewpoints [17, 18]. Interviews are conducted with project stakeholders, team members, and subject matter experts to obtain opinions, concerns, and suggestions about risk and uncertainty. A focus group with relevant participants was arranged to explore different points of view and obtain qualitative information about decision making in software project management. Examination of project documents, including project plans, risk registers, and lessons learned reports, to identify qualitative trends and insights into risk assessment and decision making. Analyze historical cases or real software projects to understand how risk and uncertainty were managed and the decision-making techniques used.

To fully comprehend a study topic, mixed research methods integrate quantitative and qualitative methodologies [19]. To cross-validate findings and provide a more complete picture, triangulation involves collecting quantitative and qualitative data on risk factors, decision-making processes, and outcomes. Design in sequence means conducting qualitative research to explore decision-making processes and then conducting quantitative research to quantify and examine risk factors and outcomes. By conducting surveys to obtain numerical data and incorporating open-ended qualitative questions to gain additional insights, the embedded design integrates quantitative and qualitative data within a single study.

The key shortcomings in risk and crisis management in the context of engineering projects are identified and analyzed through a study of the literature [20]. Publications by year show that 2016 had the highest concentration of publications. Only 4 publications concerning models for software engineering risk analysis and mitigation were published by the authors, who made up just 1% of the total.

The assessment of risk and uncertainty in software project management is well supported by decision theory. These methods provide project managers with a robust set of tools for making decisions under uncertainty. By implementing these state-of-the-art practices, project managers can improve risk mitigation, enhance decision making, and increase the overall success of software projects. To ensure that these methods are efficient and useful in real-world circumstances, additional studies and practical applications are needed to develop and tailor them to specific software project management contexts.

### 1.3. Objectives and Structure

This paper assesses the risk and uncertainty involved in managing software projects. Analyzing the distribution of project duration and cost across outcomes and techniques is emphasized.

Making rational decisions about duration and cost is a key component of software project management and has a major impact on project success. To better understand the features and possible consequences of the different techniques (Waterfall and Agile), this research compares and analyzes the distributions of project duration and cost.

In the context of this paper, risk is the possibility that a situation or event will adversely affect the project's objectives, including its schedule, budget, quality, or scope, while uncertainty is the lack of knowledge, information, or predictability about upcoming events, outcomes, or conditions.

The paper is structured as follows. The first section of the paper introduces the research and the present state of the art. Next, the approach suggests integrating Decision Trees and Monte Carlo Simulation, two distinct mathematical models, to assess risk and uncertainty in software project management. A combination of data generation, visualization, statistical analysis, decision trees, and Monte Carlo simulation is used to provide a complete assessment of project results, time, and cost. Discussion and interpretation of the obtained results are presented. The last section concludes and discusses future research steps.

## 2. An approach for evaluating risk and uncertainty

In this paper, we propose to combine two different mathematical models for evaluating risk and uncertainty in software project management by integrating Decision Trees and Monte Carlo Simulation. This study creates a data-based methodology to assess risk and uncertainty in software project management. This approach integrates decision theory tools with statistical analysis to provide project managers and stakeholders with useful insights into project outcomes, duration, and cost.

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### 2.1. Description of the approach

Decision trees can be used in software project management to examine several project ways depending on various decision points, such as choosing between various development approaches, calculating project expenses, or allocating resources. By putting probability distributions on various variables, such as task durations, resource availability, or market circumstances, Monte Carlo simulations can be used to model alternative project scenarios. It offers various potential outcomes and the probability associated with them by conducting several iterations.

### 2.2. Procedure of the Approach

This approach includes data generation, visualization, statistical analysis, decision trees, and Monte Carlo simulation. The approach is described in detail in the following sections, with an emphasis on how each step helps achieve the goals of this study:

1. Data generation. This study uses a random project data generation approach to simulate software projects with various outcomes and methodologies. The mean and standard deviation values were used to produce key parameters at random, including project cost and duration. The dataset depicts various software projects with various results and approaches, such as Outcome 1, Outcome 2, Outcome 3, and Outcome 4. To generate random project data, the sample function in R was used. The study will cover various project scenarios and adequately reflect the complexity of real-world projects if the dataset is well generated.

2. Data visualization. The project duration (Figure 2) and cost (Figure 3) distributions can be analyzed using density plots to identify prominent features. The 'ggplot2' package in R [21] is used to visualize these distributions.

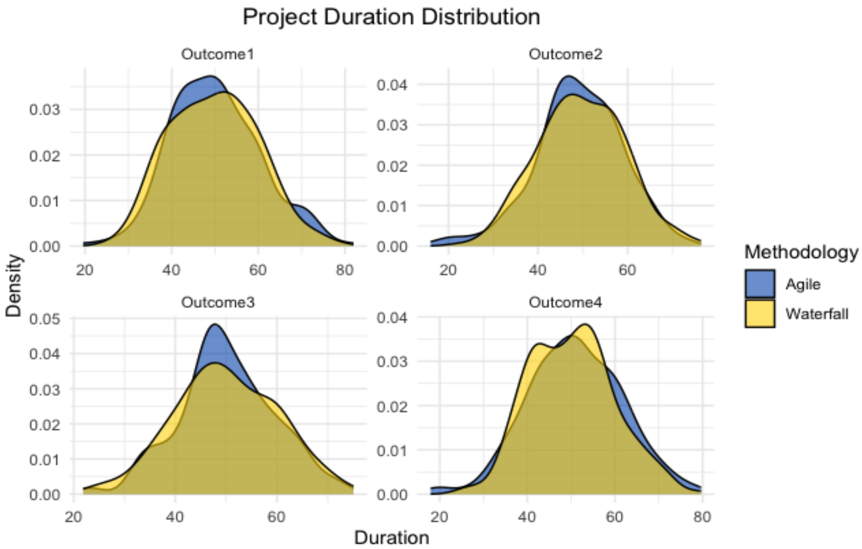


Fig. 2. Project duration distribution

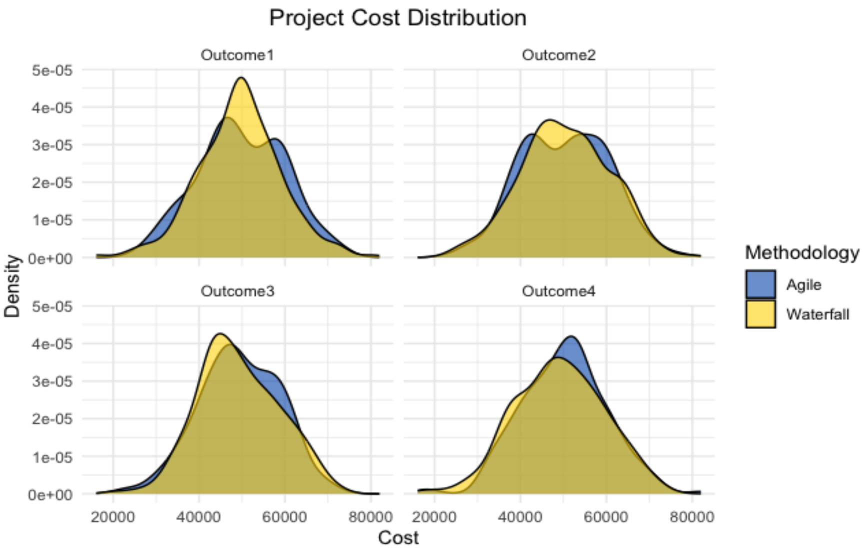


Fig. 3. Project cost distribution

A first comprehension of the properties and trends of the dataset is provided by visualizing the project duration and cost distributions. These illustrations provide a starting point for additional data analysis and interpretation. Based on various results and approaches, they direct the identification of prospective trends, outliers, and disparities in project performance.

3. Summary statistics calculation. Summary statistics are computed for the project duration and cost to provide a quantitative overview of the project data. For each result category, the mean and standard deviation of project duration and cost were calculated, providing information on the data's central tendency and variability (Table 1).

Table 1

Summary statistics for project duration and cost

| № | Outcome | Duration | Cost |
|---|---|---|---|
| 1 | Outcome 1 | 49.96387 | 49668.29 |
| 2 | Outcome 2 | 49.34296 | 50346.10 |
| 3 | Outcome 3 | 50.04849 | 49312.05 |
| 4 | Outcome 4 | 50.52879 | 49606.95 |

The summary statistics are computed in R using the aggregate function. Project duration and cost are estimates of the average project length and associated expenses for different outcome categories. The standard deviation of duration and cost reflects the variability or spread around the mean, indicating the level of uncertainty or risk associated with the project. These statistics provide a quantitative understanding of the central tendency and variability of project duration and cost across different outcomes.

4. Decision tree modeling. The correlation between project outcomes, project management approaches, and project features is investigated by applying decision trees to the project data. The 'rpart' package in R [22] is used to build a decision tree model that predicts the Outcome column based on the Methodology, Duration, and Cost columns (Figure 4).

The decision tree model illustrates the relationships among project outcomes, project management methodologies, and project features. The decision tree with nodes denoting the splits and leaf nodes denoting the anticipated outcomes will be displayed in the final plot. Each leaf node reflects the anticipated outcome, and each split indicates a choice made in response to a specific characteristic. Interpretation of the decision tree allows project managers to make informed decisions based on the criteria and paths within the tree.

5. Monte Carlo simulation. Monte Carlo simulation is used to generate several scenarios based on predetermined parameters to assess project risk and uncertainty. The task duration is multiplied by the resource availability, and the result is then divided by 10000 to obtain the project duration and cost for each sample. Figure 5 displays the distribution of the mean project durations obtained from the simulation, while

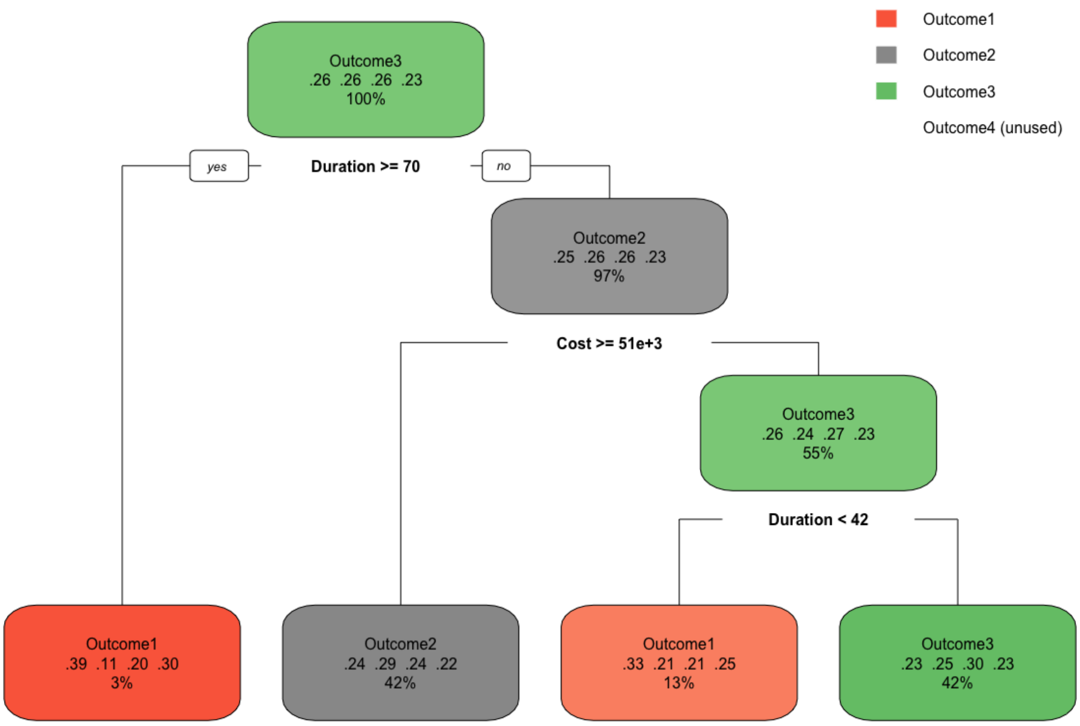


Fig. 4. The decision tree

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Figure 6 displays the distribution of the mean project costs for one of the methodologies.

Summary data were calculated, including mean duration, mean cost, standard deviation of duration, and standard deviation of cost (Table 2 and Table 3).

Simulated project durations and costs represent potential outcomes under different combinations of variables. The mean duration and cost provide estimates of expected values for project completion time and associated expenses, whereas the standard deviation of duration and cost represents variability or uncertainty. This simulation enables project managers to assess the potential risks and uncertainties associated with different project scenarios, thus facilitating informed decision-making.

This approach can be used to gain a thorough understanding of risk and uncertainty in software project management. The detailed assessment of project outcomes, time, and cost provided by the combination of data generation, visualization, statistical analysis, decision trees, and Monte Carlo simulation provides invaluable insight for strategic decision making and risk mitigation.

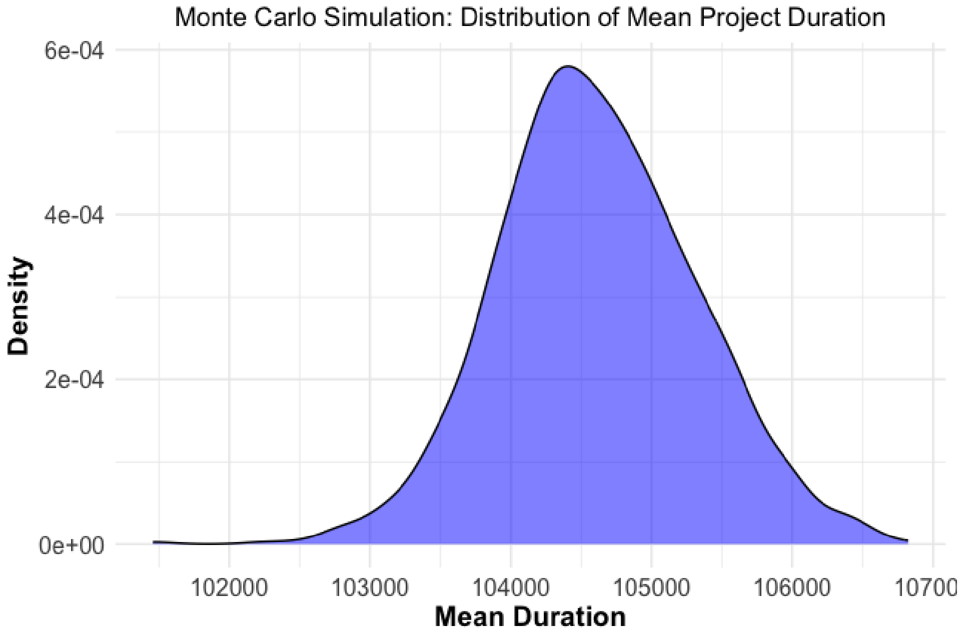


Fig. 5. The distribution of mean project durations

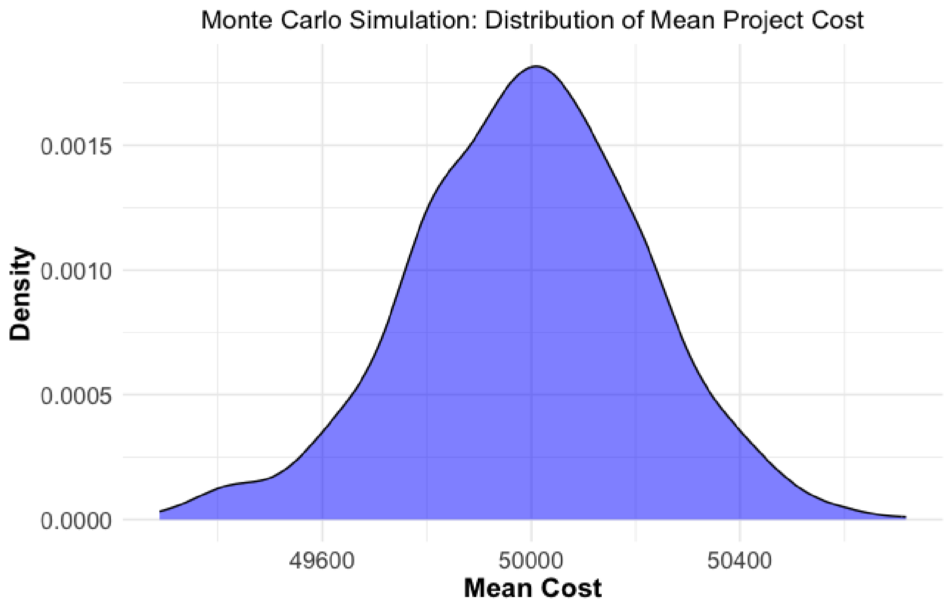


Fig. 6. The distribution of mean project cost

Table 2

Monte Carlo Summary Statistics for Duration

| Min | 1st Quartile | Median | Mean | 3rd Quartile | Max |
|---|---|---|---|---|---|
| 101458 | 104144 | 104576 | 104610 | 105062 | 106825 |

Table 3

Monte Carlo Summary Statistics for Cost

| Min | 1st Quartile | Median | Mean | 3rd Quartile | Max |
|---|---|---|---|---|---|
| 49289 | 49841 | 50001 | 49993 | 50141 | 50717 |

## 3. Discussion and Interpretation of the Obtained Results

The project duration and cost density graphs show how different outcomes and methodologies are distributed and vary. By way of illustration, it is possible to see that Agile methodology often has lower costs and higher duration for any outcome. Outcome 2 is shorter than the other outcomes. This suggests that specific outcomes could be connected to more difficult undertakings that require more effort and money.

Decision trees provide insightful information about the variables that affect project outcomes. By examining the decision rules and circumstances, it is possible to identify the most critical factors and their thresholds that influence specific outcomes. For example, the decision tree shows that choosing the waterfall approach and having less than 70 units are critical variables for Outcome 3. This underscores the importance of project duration and approach selection in achieving positive outcomes.

Project durations and costs can be viewed from a probabilistic perspective using Monte Carlo simulation. The probability of different outcomes based on the simulated samples can be determined by examining the histograms. Project managers can use these data to determine the likelihood that project goals will be met and allocate the right resources.

By analyzing and interpreting the data, the risk and uncertainty aspects of software project management were clarified. Visualizations, decision trees, and Monte Carlo simulations were used to illustrate the distribution of project costs and durations, as well as the factors that affect project outcomes. These results help project managers and other stakeholders make informed decisions to select the best methodology, efficiently allocate resources, and successfully complete their projects. They also help project managers and stakeholders better understand the risks.

## Conclusion

This research article highlights the need for effective project management in the dynamic field of software development. Project outcomes can be greatly affected by the inherent complexity of software projects and the ever-changing demands of technology. Software project management decision makers should adopt sound risk and uncertainty management techniques to successfully overcome these obstacles.

Poor risk management and decision making can have serious consequences, including project delays, budget overruns, and eventual project failure. Therefore, it is essential to use a methodical approach that enables project managers to make decisions while considering the uncertainties inherent in software development.

This study proposes a method for assessing risk and uncertainty in software project management that combines decision trees with Monte Carlo simulation. This method provides project managers and stakeholders with useful insights into project outcomes, scope, and costs. It enables them to identify critical elements that affect a project's success, manage resources wisely, and make informed decisions to reduce risk.

The study concludes by emphasizing that decision theory, along with statistical analysis, provides project managers with reliable methods to successfully manage risk and uncertainty in software project management. Project managers can improve decision making, enhance risk mitigation, and improve overall project performance by implementing these cutting-edge approaches. However, adapting these techniques to specific software project management contexts and real-world situations requires further research and practical application. With the implementation of such techniques, the software development industry can more successfully manage project complexity and deliver effective results while adhering to budget and schedule constraints.

**Contributions of authors:** conceptualization – **Anastasiia Strielkina, Artem Tetskyi**; modeling – **Anastasiia Strielkina, Vladyslava Krasilshchykova**; analysis – **Anastasiia Strielkina**; writing – original draft preparation – **Anastasiia Strielkina, Artem Tetskyi, Vladyslava Krasilshchykova**; writing – review and editing – **Artem Tetskyi**.

All the authors have read and agreed to the published version of this manuscript.

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# ОЦІНЮВАННЯ РИЗИКІВ ТА НЕВИЗНАЧЕНОСТЕЙ В УПРАВЛІННІ ПРОГРАМНИМ ПРОЄКТОМ: ІНТЕГРУВАННЯ ДЕРЕВ РІШЕНЬ І МОДЕЛЮВАННЯ МЕТОДОМ МОНТЕ-КАРЛО

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**Предметом дослідження** є оцінювання ризиків та невизначеностей у контексті управління програмними проєктами. Обговорюються труднощі, з якими стикаються менеджери проєктів при подоланні невизначеності, викликаної складною природою програмних проєктів і вимогами технологій, що постійно змінюються. До цього дослідження включено огляд літератури, генерацію даних, візуалізацію, статистичний аналіз та математичне моделювання. **Мета роботи** полягає у створенні методичного підходу, який допоможе менеджерам проєктів приймати рішення з урахуванням невизначеності, властивої розробленню програмного забезпечення, і знайти підходи та процедури, які можуть успішно знизити ризики, покращити процес прийняття рішень та зрештою призвести до реалізації успішних проєктів. Були виконані такі **завдання**: оцінити ризики та невизначеності шляхом вивчення сучасного стану теорії прийняття рішень та її застосування в управлінні програмними проєктами; розробити інтегровану стратегію, що поєднує моделювання Монте-Карло з деревами рішень для оцінки ризиків та невизначеностей в управлінні програмними проєктами; згенерувати дані, візуалізувати та виконати їх статистичний аналіз для розуміння результатів проєкту, витрат та часу; виявити важливі змінні, що впливають на результати проєкту та прийняття рішень, використовуючи дерева рішень; використати моделювання методом Монте-Карло для створення сценаріїв виконання проєкту та оцінити ймовірність кожного з них; надати менеджерам проєктів знання та пропозиції, які допоможуть їм приймати обґрунтовані рішення та успішно керувати ризиками. **Методи.** Для оцінювання ризиків і невизначеностей в управлінні програмними проєктами аналізуються підходи теорії прийняття рішень, що використовуються в даний час, а також методи дерев рішень і моделювання методом Монте-Карло. **Результати.** Дослідження пропонує детальне представлення того, як результати, витрати та тривалість проєкту різняться залежно від різних методів. Критичні чинники, які суттєво впливають на успіх проєкту, показані за допомогою дерев рішень. Згідно з висновками дослідження, поєднання теорії прийняття рішень та статистичного аналізу дозволяє менеджерам проєктів приймати зважені рішення в умовах невизначеності. **Висновки.** Менеджери проєктів можуть покращити процес прийняття рішень, знизити ризики та підвищити загальний успіх проєкту, застосовуючи ці передові підходи. Щоб адаптувати ці методи до унікальних контекстів управління програмними проєктами та реальних ситуацій, необхідні додаткові дослідження та впровадження на практиці. Використовуючи такі методи, сектор розроблення програмного забезпечення зможе краще управляти складністю проєктів та забезпечувати задовільні результати в рамках встановлених фінансових та часових параметрів.

**Ключові слова:** управління програмними проєктами; оцінка ризиків; невизначеність; теорія прийняття рішень; дерева рішень; моделювання Монте-Карло; результати проєкту; прийняття рішень; статистичний аналіз; розподіл ресурсів; успіх проєкту.

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