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Quantitative Risk Analysis: Expected Monetary Value, Monte Carlo, and Decision Tree - Systematic Literature Review

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ABSTRACT

Quantitative risk analysis (QRA) is an important approach to support decision-making under conditions of uncertainty, particularly in the fields of project management, business, and finance. This study aims to systematically analyze the development of the application of three main methods in quantitative risk analysis, namely Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA), and to identify research trends, advantages, limitations, and opportunities for integration of these three methods. The study uses a Systematic Literature Review (SLR) approach with reference to the PRISMA guidelines. The literature search process was conducted through the Scopus, Web of Science, ScienceDirect, Google Scholar, Portal Garuda, Neliti, and Indonesia OneSearch databases for the 2020–2025 publication period. From the results of the identification process of 84 articles, 12 articles were obtained that met the inclusion criteria and passed the quality assessment for further analysis. The synthesis results show that Monte Carlo Simulation is the most dominant method because it is able to model uncertainty probabilistically, while Expected Monetary Value is effective for decision-making with measurable probabilities, and Decision Tree Analysis excels in visualizing decision alternatives and their consequences. Furthermore, recent research shows a trend toward a hybrid approach that integrates EMV, MCS, and DTA to produce a more comprehensive risk analysis. This study also identifies three main gaps: limited integration between methods, minimal application in the information technology and digital finance sectors, and low utilization of advanced simulation software in the Indonesian context. The research findings are expected to serve as a reference for academics and practitioners in selecting and developing quantitative risk analysis methods that are appropriate to the characteristics of the uncertainty faced and encourage the development of more adaptive and integrated risk analysis models in the future.

INTRODUCTION

The evolving global business environment, characterized by digital transformation, economic dynamics, regulatory changes, and increasing project complexity, has caused organizations to face increasing levels of uncertainty. This uncertainty not only impacts the achievement of operational goals but also directly impacts the long-term success of organizational strategies. These risks can stem from various sources, such as market fluctuations, technological changes, supply chain disruptions, economic instability, and changes in government policy. These conditions require organizations to implement more systematic, objective, and evidence-based risk management practices so that every strategic decision can be made based on a comprehensive understanding of the opportunities, consequences, and levels of uncertainty faced. Thus, risk management is no longer viewed solely as an operational function but has evolved into an integral part of the organizational governance process that supports value creation and organizational sustainability.

As risk complexity increases, risk analysis approaches have also undergone significant development. While organizations initially relied primarily on subjective qualitative risk analysis, quantitative approaches are now increasingly used because they provide more objective, measurable, and scientifically accountable risk measures. Quantitative Risk Analysis (QRA) utilizes mathematical, statistical, and probabilistic models to quantify the likelihood of a risk occurring and its impact. Through this approach, organizations are not only able to identify the level of risk but also evaluate various decision alternatives based on the magnitude of the probability and potential consequences. Therefore, quantitative risk analysis has become a crucial tool in supporting the strategic decision-making process, particularly in business environments characterized by high levels of uncertainty.

In practice and research, various methods are used in quantitative risk analysis. Among these methods, Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA) are the three most widely used approaches due to their complementary characteristics. Expected Monetary Value (EMV) is a method used to calculate the expected monetary value based on the probability of an event occurring and the magnitude of its potential financial consequences, making it highly suitable for use in investment evaluation and risk-based decision-making. On the other hand, Monte Carlo Simulation (MCS) allows organizations to simulate thousands to millions of possible outcomes through a random sampling process based on the probability distribution of risk variables. This approach provides a more realistic picture of the range of possible outcomes, the level of variability, and the probability of success of a decision compared to a deterministic approach. Meanwhile, Decision Tree Analysis (DTA) facilitates the decision-making process by developing a decision structure that describes various alternative actions along with their consequences and associated probabilities. The combination of these three methods allows organizations to obtain a more comprehensive picture of risk, thereby improving the quality of decision-making.

Advances in computing technology, simulation software, and data analysis in recent years have further expanded the use of quantitative risk analysis in various organizational sectors. Expected Monetary Value, Monte Carlo Simulation, and Decision Tree Analysis methods have been widely applied in construction, energy, manufacturing, healthcare, finance, information technology, and project management due to their ability to support more rational, probability-based decision-making (Nabawy & Khodeir, 2020; Hulett, 2022). Furthermore, advances in simulation software also enable risk analysis processes to be performed with a higher degree of accuracy and in increasingly efficient computing time, thus encouraging the increased application of quantitative methods in various industrial sectors (Kwak & Smith, 2021; Xu, 2023).

Nevertheless, various previous studies indicate that the implementation of these three methods is still developing partially and exhibits significant variation in terms of approach, assumptions, and scope of application. Some studies use Expected Monetary Value as the basis for evaluating decision alternatives without considering more complex probability distributions, resulting in deterministic analysis results. Other studies implement Monte Carlo Simulation to depict uncertainty probabilistically, but have not integrated the simulation results with a systematic decision-making structure through Decision Tree Analysis. On the other hand, there are also studies that combine the two methods simultaneously, but have not conducted an in-depth evaluation of the effectiveness of the integration, model assumptions, or implementation limitations in organizational practice. These differences in approach have resulted in diverse research results, thus not providing a complete understanding of the advantages, limitations, and relationships between the methods in supporting quantitative risk analysis.

In addition to methodological variations, most previous research is still oriented towards specific sector contexts, such as construction, energy, investment, and finance, so that cross-sector synthesis regarding the application of Expected Monetary Value, Monte Carlo Simulation, and Decision Tree Analysis is still relatively limited. As a result, the development of research on quantitative risk analysis has not been comprehensively documented, particularly regarding publication trends, methodological developments, integration patterns between methods, and opportunities for developing risk analysis approaches that are more adaptive to the dynamics of modern organizations. This condition indicates a research gap that needs to be bridged through systematic studies that can integrate the results of previous research to produce a more comprehensive understanding of the development of quantitative risk analysis.

Furthermore, the increasing complexity of risk in the era of digital transformation has given rise to various new forms of uncertainty, not only related to financial aspects but also encompassing technological risks, cybersecurity, sustainability, artificial intelligence, and data-driven decision-making. This situation encourages organizations to no longer rely on a single risk analysis method in isolation, but rather to develop approaches that integrate various analytical techniques to produce more comprehensive and accurate information. Therefore, understanding the characteristics, advantages, limitations, and opportunities for integrating Expected Monetary Value, Monte Carlo Simulation, and Decision Tree Analysis is becoming increasingly important for both the development of risk management theory and practice.

Based on these conditions, this study uses a Systematic Literature Review (SLR) approach to synthesize various studies on the application of Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA) in quantitative risk analysis. The SLR approach was chosen because it is able to provide a systematic, transparent, and replicable process of identification, selection, quality evaluation, data extraction, and synthesis of literature, resulting in more objective conclusions than conventional literature reviews. In addition to summarizing research developments, this approach also allows for the identification of research gaps, mapping publication trends, and developing recommendations for further research.

This research focuses on scientific articles published during the period 2020–2025, considering that this time period represents the latest developments in the application of quantitative risk analysis following the increasing use of simulation technology, data analytics, and computer-based decision support systems. Through a systematic synthesis of relevant literature, this study aims to analyze the development of the application of Expected Monetary Value, Monte Carlo Simulation, and Decision Tree Analysis, identify the characteristics, advantages, and limitations of each method, map emerging research trends, and uncover opportunities for integrating the three methods to support risk-based decision-making. In addition, this research is expected to provide theoretical contributions by strengthening the conceptual foundation of quantitative risk analysis, while also providing practical contributions for academics, practitioners, and policymakers in selecting the risk analysis approach that best suits the characteristics of the organization and the level of uncertainty faced. Thus, the results of this study are expected to serve as an important reference in the development of quantitative risk analysis models that are more adaptive, comprehensive, and oriented towards improving the quality of organizational decision-making in the future.

METHODOLOGY

This study uses a Systematic Literature Review (SLR) approach as the primary method to identify, evaluate, and synthesize research findings addressing the application of Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA) in quantitative risk analysis (QRA). The SLR approach was chosen because it is capable of producing a systematic, transparent, objective, and replicable literature synthesis, thus providing a higher level of reliability than conventional literature reviews. In addition to summarizing research developments, this approach also allows for the identification of research trends, research gaps, and future research development directions. This study refers to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which are widely used in literature synthesis-based research because they provide a systematic and well-documented article selection procedure.

The literature search strategy was conducted systematically, utilizing several international and national scientific databases to ensure a more comprehensive research scope. The international databases used included Scopus, Web of Science (WoS), and ScienceDirect, while the national databases included Google Scholar, Garuda Portal, Neliti, and Indonesia OneSearch. This combination of databases was chosen to obtain scientific articles of high academic quality while also accommodating emerging research in the Indonesian context. The literature search was limited to articles published during the 2020–2025 period, ensuring that the synthesis results represent the most recent developments in quantitative risk analysis methodology.

The search process uses a combination of keywords arranged based on key terms widely used in the literature, namely "Expected Monetary Value" OR "EMV", "Monte Carlo" OR "Monte Carlo Simulation" OR "MCS", and "Decision Tree" OR "Decision Tree Analysis". These three groups of keywords are combined using Boolean operators with the terms "Risk Analysis", "Quantitative Risk Analysis", "Risk Management", as well as contextual words such as "Business", "Finance", and "Project Management". The search strategy is adjusted to the characteristics of each database so that search results remain consistent, relevant, and comparable between sources.

Literature selection was conducted through several stages, adhering to the PRISMA guidelines. The first stage was identification, which involved collecting all articles from various databases along with research metadata, such as title, author, abstract, keywords, publication year, and journal source. All metadata was then managed using reference management software, such as Mendeley or Zotero, to facilitate the identification of duplicate articles. The second stage was screening, which involved filtering articles based on title and abstract to assess their suitability to the research focus. This process was conducted independently by two reviewers to minimize subjectivity in determining which articles were eligible for analysis. Differences in assessment results were resolved through discussion until a mutual agreement was reached. Articles that met the criteria then proceeded to the full-text review stage for a comprehensive evaluation based on methodological suitability, application context, and quality of research reporting. The next stage was quality assessment, which involved assessing quality using a checklist that covered clarity of research objectives, methodology, data quality, transparency of the analysis process, discussion of results, and disclosure of research limitations. Only articles that met all quality criteria were included in the final synthesis process.

Based on the selection process, 84 articles were obtained in the initial identification stage. After removing duplicate articles, 70 articles were declared unique and proceeded to the title and abstract screening stage. At this stage, 40 articles were eliminated because they did not match the research focus, leaving 30 articles to enter the full-text review stage. Evaluation of the full manuscripts showed that 12 articles did not meet the methodological criteria, so only 18 articles proceeded to the quality assessment stage. Furthermore, 6 articles were excluded because their methodological quality did not meet the established threshold. Thus, a total of 12 articles were declared to meet all inclusion criteria and were used as primary sources in the research synthesis process.

Table 2.1 Summary of the Literature Selection Stages (PRISMA Model)

Selection Steps	Process Description	Number of Articles	Status
Identification (Identification)	Initial search using keywords in several major academic databases.	84	Found
Screening (Screening)	Review of titles and abstracts to assess topic relevance.	40	Passed initial screening
Eligibility Check (Eligibility)	*Full-text review*to assess methodological quality and topic relevance.	30	Eligible for analysis
Final Selection (Inclusion)	Selection of the most relevant and high-quality articles.	12	Used in the main analysis

Data obtained from each article was then systematically extracted using a data extraction form. The information collected included the study's identity (author, year, and journal), research objectives, field of application, risk analysis method used, probability distribution, number of simulations (specifically Monte Carlo Simulation), software used, main research findings, and limitations reported by each researcher. All of this information was then compiled into a synthesis matrix to facilitate comparisons between studies and identification of emerging research patterns.

Data analysis was conducted using a qualitative thematic synthesis approach combined with cross-method comparative analysis. The synthesis stage was carried out by grouping the research results into five main themes, namely (1) characteristics of risk analysis methods, (2) areas of application, (3) objectives of risk analysis, (4) software and analysis models used, and (5) main findings and limitations of the research. After grouping, each method was compared based on its characteristics, complexity, effectiveness, and application context. This analysis allowed researchers to identify the advantages and limitations of Expected Monetary Value, Monte Carlo Simulation, and Decision Tree Analysis, while also evaluating opportunities for integrating the three methods to support risk-based decision-making. As a form of validation of the synthesis results, the study also triangulated between international and national literature to gain a more comprehensive understanding of the development of quantitative risk analysis in both the global and Indonesian contexts.

This methodology provides a strong foundation for the literature synthesis process because it applies systematic steps, starting from identification, selection, quality assessment, data extraction, and thematic synthesis. Therefore, the research results are expected to have a high level of validity, transparency, and replicability, and to provide a comprehensive overview of the development of the application of Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA) in quantitative risk analysis during the 2020–2025 period.

RESULTS AND DISCUSSION

Description of the Research Results Obtained

Based on the process of identifying, selecting, and assessing the quality of literature using the Systematic Literature Review (SLR) approach referring to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, this study successfully identified 12 articles that met all inclusion and quality criteria for further analysis. All articles were published during the 2020–2025 period and discussed the application of Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA) in various quantitative risk analysis contexts, including project management, investment, construction, energy, information technology, and the financial sector. The synthesis results show that the development of quantitative risk analysis over the past five years has experienced significant progress, both in terms of methodology, the complexity of the analysis models, and the expansion of application areas. These findings demonstrate that quantitative approaches are increasingly positioned as strategic instruments in supporting organizational decision-making facing high levels of uncertainty.

In general, all the articles analyzed share a common view: Quantitative Risk Analysis (QRA) is an approach capable of increasing the objectivity of decision-making through the use of probabilistic models, numerical simulations, and the evaluation of various decision alternatives based on quantitative risk measures. Unlike qualitative approaches, which rely more on the perceptions and experiences of decision-makers, quantitative risk analysis allows organizations to evaluate the probability of a risk occurring while estimating the magnitude of its possible consequences in a more measurable manner. This situation indicates a paradigm shift in modern risk management practices, from a reactive approach to a predictive approach supported by mathematical modeling and data-driven analysis.

The synthesis results show that Monte Carlo Simulation (MCS) is the most dominant method used in the analyzed studies. Nearly all international studies place Monte Carlo Simulation as the primary approach in modeling uncertainty because it is able to generate probability distributions of various possible outcomes through a random sampling process. Research by Nabawy and Khodeir (2020) shows that Monte Carlo Simulation can improve the accuracy of cost and time risk estimates in construction projects by modeling various stochastic variables. These findings are reinforced by Hulett (2022), who explains that the use of probabilistic simulation allows decision-makers to understand the range of project outcome variations, identify the probability of failure, and determine the confidence level of project cost and duration estimates.

Monte Carlo Simulation's dominance in the literature stems from its ability to accommodate the complexity of intervariable relationships that are difficult to analyze using deterministic approaches. Unlike conventional methods that produce a single-point estimate, Monte Carlo Simulation produces a probability distribution that more realistically depicts the level of uncertainty. This allows organizations not only to determine the expected value of a risk but also to understand the probability of the best-case, most likely, and worst-case scenarios occurring. Therefore, Monte Carlo Simulation provides a stronger foundation for risk-based decision-making than approaches that rely solely on average values or single estimates.

However, the synthesis results also indicate that most studies still utilize Monte Carlo Simulation solely as a probabilistic analysis tool without integrating the simulation results into the decision-making process or ongoing risk mitigation strategies. Most studies stop at the risk distribution identification stage without explaining how the simulation results are used as a basis for developing risk management policies. This condition indicates that the implementation of Monte Carlo Simulation still tends to be oriented towards technical aspects rather than developing a strategic decision-making framework. These findings indicate that there is still room for research regarding the integration of probabilistic simulation with organizational decision-making processes.

In addition to Monte Carlo Simulation, Decision Tree Analysis (DTA) also showed significant progress during the research period. The study results indicate that Decision Tree Analysis is widely used to help decision-makers evaluate various alternative courses of action through the development of a systematic decision structure. Research by Zaku and Uysal (2022) demonstrated that Decision Tree Analysis can visualize the relationship between decision alternatives, the probability of occurrence, and the potential financial consequences, making it easier for organizations to choose strategies that provide the best expected value. Similar findings were presented by Williams et al. (2021), who explained that the use of decision trees is highly effective in situations involving sequential decision-making with high levels of uncertainty.

Compared to Monte Carlo Simulation, Decision Tree Analysis has advantages in terms of visualizing the decision-making process. This method allows the cause-and-effect relationships between decision alternatives to be displayed hierarchically, making it easier for decision-makers to interpret the results. However, the synthesis results show that most studies still use Decision Tree Analysis as a conceptual tool without adequate empirical validation. Some studies only present decision models based on certain probability assumptions without testing the model's sensitivity to changes in risk parameters. Consequently, the ability of Decision Tree Analysis to support strategic decisions still depends heavily on the quality of the probability estimates used as input for the analysis.

Meanwhile, Expected Monetary Value (EMV) remains a widely used method due to its conceptual simplicity and ease of implementation. Studies show that EMV is most commonly applied in investment analysis, project evaluation, and the selection of decision alternatives with relatively predictable probabilities and financial consequences. Research by Pratama and Ilham (2024) shows that EMV has been widely used in national projects in Indonesia as a basis for evaluating investment risks and project cost planning. This method is considered effective because it produces a risk measure that is easy to understand and can be directly used in managerial decision-making.

However, compared to Monte Carlo Simulation and Decision Tree Analysis, Expected Monetary Value (EMV) is relatively limited in its ability to describe the complexity of uncertainty. This method essentially only generates expected values, and therefore cannot explain the distribution of possible outcomes or the sensitivity to changes in risk parameters. Consequently, EMV is more appropriate for situations with relatively low levels of uncertainty and well-known event probabilities. These findings suggest that the effectiveness of EMV is significantly influenced by the quality of the probability estimates used in the calculation process.

In addition to comparing the characteristics of each method, the synthesis results also indicate an expansion in the context of quantitative risk analysis applications. While initially these methods were primarily used in the construction and investment sectors, recent studies have shown that the application of Quantitative Risk Analysis has expanded to various other fields, such as information technology, cybersecurity, data management, digital finance, and artificial intelligence-based decision support systems. Research by Xu (2023) shows that advances in analytical technology allow Monte Carlo Simulation to be integrated with machine learning-based modeling to improve the accuracy of risk predictions in digital systems. Meanwhile, research by Mustafian et al. (2024) shows that quantitative approaches are beginning to be applied in information technology risk management, which requires analysis of large and dynamic data volumes.

This expansion of application areas demonstrates that quantitative risk analysis is no longer viewed as an analytical tool relevant only to construction or investment projects, but has evolved into an integral part of an organization's data-driven decision support system. This shift also reflects the growing need for organizational risk analysis methods that can accommodate the complexities of the modern business environment, including developments in digital transformation, artificial intelligence, and increased reliance on information systems.

Overall, the synthesis of twelve articles shows that the development of Quantitative Risk Analysis during the 2020–2025 period is moving towards an increasingly comprehensive, adaptive, and technology-based approach. Monte Carlo Simulation still dominates as the primary method due to its ability to model uncertainty probabilistically, while Decision Tree Analysis makes a significant contribution in visualizing complex decision-making processes, and Expected Monetary Value remains an effective method for risk conditions with relatively measurable probabilities and impacts. The synthesis results also show that no single method can optimally address all organizational risk characteristics. Therefore, the latest research trend is moving towards the development of an integrative approach that combines the advantages of these three methods to produce a more comprehensive, realistic risk analysis that can support strategic decision-making more effectively. These findings also strengthen the argument in the introduction that the development of quantitative risk analysis is no longer oriented towards the use of a single method, but is moving towards an integrated analysis model in accordance with the complexity of risks faced by modern organizations.

Current Research Trends

A synthesis of twelve articles that met the inclusion criteria shows that research on Quantitative Risk Analysis (QRA) has experienced very dynamic development during the 2020–2025 period. This development is not only evident in the increasing number of studies examining Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA) methods, but also in the shifting paradigm of risk analysis, which is moving from the use of a single method to a more integrative, adaptive, and technology-based approach. This shift reflects the increasing need for organizations to have risk analysis models capable of handling the complexity of the modern business environment characterized by high uncertainty, rapid technological change, and the increasing volume of data that must be analyzed in the decision-making process.

The synthesis results show that Monte Carlo Simulation remains the most dominant method in current research. Nearly all international articles place this method as the primary approach in modeling uncertainty because it can generate probability distributions of various possible outcomes through random sampling. This dominance is due not only to Monte Carlo Simulation's ability to accommodate stochastic risk variables but also to the increasing availability of simulation software that allows for faster and more accurate analysis. Research by Nabawy and Khodeir (2020), Hulett (2022), and Xu (2023) shows that Monte Carlo Simulation is increasingly used in highly complex projects because it can generate information on risk distribution, variable sensitivity, confidence levels, and project success probabilities more comprehensively than deterministic methods.

However, recent research developments indicate that the use of Monte Carlo Simulation is no longer a stand-alone approach, as was often found in research before 2020. Most studies have begun to integrate probabilistic simulation with other methods, resulting in more comprehensive analysis models. This phenomenon indicates a paradigm shift from an approach solely focused on risk quantification to one that also considers the decision-making structure and evaluation of alternative courses of action. Thus, the focus of research is no longer solely on answering questions about the magnitude of potential risks, but also on identifying the best decision based on the resulting probability distribution.

This paradigm shift is reflected in the increasing research developing hybrid risk analysis models, namely analysis models that integrate Expected Monetary Value, Decision Tree Analysis, and Monte Carlo Simulation within a single, complementary analytical framework. Research by Zaku and Uysal (2022), Williams et al. (2021), Xu (2023), and Truong and Hara (2024) shows that this integration provides more realistic analysis results than using a single method. In the hybrid approach, Decision Tree Analysis is used to structure decisions and identify alternative actions that an organization might take. Furthermore, Expected Monetary Value is used to calculate the expected financial value for each decision branch based on the probability of occurrence, while Monte Carlo Simulation is used to simulate the uncertainty inherent in each risk parameter, generating a probability distribution of all decision alternatives. This approach is able to simultaneously integrate structural, financial, and probabilistic aspects, thereby improving the quality of the decision-making process.

The synthesis results also indicate a shift in the context of Quantitative Risk Analysis application. While in the previous decade, most research focused on construction, energy, and investment projects, research during the 2020–2025 period shows an expansion of its application to more complex and technology-based sectors. Research by Xu (2023) shows that the Monte Carlo Simulation method is beginning to be applied to information system and cybersecurity risk analysis involving large volumes of data and dynamically changing risk characteristics. Research by Mustafian et al. (2024) also shows that quantitative approaches have been used in information technology risk management through the integration of probabilistic analysis with digital data processing. This expansion of context indicates that quantitative risk analysis has evolved from a project evaluation tool to a critical component of data-driven organizational decision support systems.

Another notable development is the increasing use of computing technology in risk analysis processes. Much of the latest research utilizes simulation software such as @Risk, Oracle Crystal Ball, MATLAB, R, Python, and various simulation libraries that support more efficient numerical computation. This software enables organizations to conduct thousands to millions of simulations in a relatively short time, thereby increasing the accuracy of risk estimates. Furthermore, several studies have begun combining probabilistic simulation with machine learning algorithms and predictive analytics techniques to enhance models' ability to project risk based on historical and real-time data. This integration demonstrates the growing link between quantitative risk analysis and digital transformation and the development of modern analytical technologies.

However, the review also shows that the adoption of simulation technology still shows a gap between developed and developing countries. International research has generally utilized complex simulation software supported by large amounts of historical data, enabling the development of more accurate probabilistic models. In contrast, research in the Indonesian context is still dominated by the use of relatively simple models with limited data, software, and quantitative analysis capabilities. Research by Pratama and Ilham (2024) and Mustafian et al. (2024) shows that limited quantitative literacy, access to licensed software, and data quality remain major challenges in implementing quantitative risk analysis methods in various national organizations. This condition has resulted in the implementation of methods such as Monte Carlo Simulation and Decision Tree Analysis not being optimally utilized despite their conceptual potential.

In addition to changes in methodology and technology, recent research also indicates a shift in the orientation of risk analysis. Previously, most studies emphasized the process of risk identification and measurement as the primary objective of analysis. However, recent research has begun to focus on how risk analysis results can be integrated with decision support systems and organizational governance. Thus, quantitative risk analysis is no longer positioned solely as a predictive tool, but also as a strategic instrument that supports the ongoing processes of risk planning, control, mitigation, and evaluation. This shift indicates that the risk analysis function is evolving toward a more proactive approach rather than simply being reactive to emerging risks.

From a methodological perspective, the synthesis also demonstrates a growing trend toward the use of multidisciplinary approaches in risk analysis research. While previously risk analysis was primarily influenced by engineering and project management, recent research has begun to integrate concepts from computer science, artificial intelligence, statistics, economics, and data science. This cross-disciplinary integration enables the development of risk analysis models that are more adaptive to the increasingly complex characteristics of modern organizations. Thus, the development of quantitative risk analysis is influenced not only by advances in statistical methods but also by advances in information technology and organizational needs for more intelligent decision support systems.

Overall, the synthesis of twelve articles indicates that research trends in Quantitative Risk Analysis during the 2020–2025 period are moving in three main directions. First, the increasing use of hybrid approaches that integrate Expected Monetary Value, Decision Tree Analysis, and Monte Carlo Simulation as a single risk analysis model. Second, the increasingly widespread application of quantitative risk analysis in technology-based sectors, such as information systems, cybersecurity, digital finance, and data analytics. Third, the growing use of computing technology, simulation software, and integration with artificial intelligence and machine learning to support risk analysis processes. These three trends indicate that research on quantitative risk analysis has moved toward a new paradigm that is more comprehensive, adaptive, and data-driven. These findings also confirm that the future of Quantitative Risk Analysis development no longer lies in perfecting a single method, but rather in the ability to integrate various analytical approaches within a decision support system that can respond to the complexity of organizational risks more effectively and sustainably.

CONCLUSION

Based on the results of a Systematic Literature Review (SLR) of twelve articles published between 2020 and 2025, it can be concluded that Quantitative Risk Analysis (QRA) has undergone significant developments in terms of methodology, application areas, and technological support. The three main methods, namely Expected Monetary Value (EMV), Monte Carlo Simulation (MCS), and Decision Tree Analysis (DTA), have complementary characteristics and advantages in supporting risk-based decision-making. Monte Carlo Simulation is the most dominant method because it is able to model uncertainty probabilistically through a more realistic distribution of possible outcomes. Expected Monetary Value is effectively used to evaluate decision alternatives based on expected financial values under conditions of well-estimated probabilities, while Decision Tree Analysis provides advantages in visualizing the decision structure and consequences of each alternative action. The synthesis results show that no single method can optimally accommodate all organizational risk characteristics, so the choice of method must be adjusted to the complexity of the risk, data availability, and analysis objectives.

This study also demonstrates a paradigm shift in the development of quantitative risk analysis, moving from a single method to a hybrid approach that integrates EMV, Monte Carlo Simulation, and Decision Tree Analysis into a more comprehensive analytical framework. Furthermore, the application of quantitative risk analysis has expanded from the construction and investment sectors to other areas, such as information technology, cybersecurity, digital finance, and data-driven decision support systems. The development of simulation software, numerical computing, and integration with big data, machine learning, and artificial intelligence further strengthens risk analysis capabilities in addressing the complexities of the modern business environment. However, the review also identified several research gaps, including the limited simultaneous integration of the three methods, the limited research in technology-based sectors in developing countries, and the low utilization of advanced simulation software in the Indonesian context.

Overall, this study provides a theoretical contribution through the preparation of a comprehensive synthesis regarding the development of Quantitative Risk Analysis methods, while also providing practical contributions for academics, practitioners, and policy makers in selecting a risk analysis approach that is appropriate to the characteristics of the organization and the level of uncertainty faced. The findings of this study confirm that the direction of the development of quantitative risk analysis in the future needs to be focused on the development of integrated, adaptive, data-driven models supported by digital technology, so as to be able to produce a more accurate, effective, and sustainable decision support system in dealing with the dynamics of organizational risk in the era of digital transformation.

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