**Application of probability theory in risk analysis for optimal business decision making**

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**Abstract**

This study discusses the application of probability theory in risk analysis to support more optimal business decision making amidst market uncertainty. The methods used include probability distribution, Bayes' Theorem, and Monte Carlo Simulation to identify and measure risks in various business scenarios, including market volatility, investment decisions, and profit projections. This approach allows quantitative modeling of uncertainty, so that risks can be evaluated more accurately and measurably. The results show that risk analysis based on probability theory provides deeper insight into possible business outcomes, enables more effective risk mitigation, and improves the accuracy of strategies in dealing with market changes. Based on the analysis results, it can be concluded that the application of probability theory plays a significant role in managing business risks and uncertainties. Monte Carlo simulation, Bayes' Theorem, and probability distribution analysis allow companies to make more accurate predictions regarding future events, leading to more data-driven decision making. In addition, a probabilistic approach enables businesses to clearly identify patterns of risk and opportunity, optimize resource management, and enhance operational, marketing, and investment planning strategies. However, challenges remain in its implementation, especially regarding the understanding of probability concepts and the need for accurate data. Therefore, stronger integration between probability theory and analytical technology is essential to optimize risk management strategies. With the right approach, probability theory becomes a valuable tool for supporting sustainable and competitive business growth in a dynamic market environment.

**Keywords:** probability theory, risk analysis, Bayes’ Theorem, Monte Carlo Simulation, decision making

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1. **Introduction**

Risk is something that cannot be predicted when it will occur. Although not expected, risk always needs to be prepared with careful planning to deal with it (Suriyadi & Azmi, 2022). Uncertainty is a condition that arises due to a lack of information about an event, including the possibility of it occurring and the impact it will have. Uncertainty that is beneficial is known as an opportunity, while the detrimental is called a risk. In a business context, risk and uncertainty can affect various operational and strategic aspects, so the right approach is needed to identify and manage it effectively.

Risk arises as a consequence of uncertainty, where the higher the level of uncertainty, the greater the potential negative impact that can occur on the company. Risk can be understood as an event that has the potential to cause losses to individuals and companies. Therefore, a systematic approach is needed in managing risk, which includes identification, grouping, finding solutions, controlling, and evaluating risks. This approach aims to minimize the negative impact of risk and optimize the achievement of company goals (Yoewono & Prasetyo, 2022).

Risk plays an important role in the business world, not only as a challenge, but also as a driver of innovation and growth. Every strategic step, such as market expansion or new product development, always involves risks that must be managed wisely. Without risk, there would be no innovation, change, or development that would allow businesses to continue to grow and compete in a dynamic market. Therefore, risk is not something to be avoided, but rather understood and utilized as an opportunity to achieve progress (Nazara, Le, & Oktoriza, 2024).

In a business world full of uncertainty, risk management plays an important role in ensuring the stability and profitability of a company. Risks that are not managed properly can hinder the achievement of business goals and cause significant losses. Therefore, the implementation of risk management policies, from identification to control, is a strategic step in mitigating negative impacts. With the right approach, risks can be minimized, while the company's operational effectiveness and financial performance can be improved. In addition, a structured risk management system allows companies to be more adaptive in dealing with change and make more accurate decisions (Arsyadona et al; 2025).

In the face of risk and uncertainty, proper decision making is a key element that must be considered. Effective decisions are highly dependent on the availability of relevant and quality information. Accurate information is the basis for evaluating various options and predicting the results of each decision taken. Decision making based on inaccurate or incomplete data can result in failure to anticipate risks, which can ultimately result in major losses for the company (Sari, Masviansyah, & Hidayat, 2024).

In addition, risk-based decision making is also an important aspect in managing complex and uncertain projects. Risk in project management refers to uncertainty that can affect various elements such as cost, time, quality, and scope of the project. If these risks are not managed properly, they can lead to failure or deviation from the stated objectives. Therefore, a risk-based approach allows decision makers to identify potential risks, evaluate their impact, and develop effective mitigation strategies in dealing with these challenges (Alawdin et al., 2024).

Thus, to manage risk and uncertainty effectively, probability theory is an important tool in measuring the level of risk that may occur and in formulating more targeted mitigation strategies. In the context of business decision making, probability theory allows companies to make more accurate predictions of the various possibilities that may occur. Thus, the formulated mitigation strategies become more effective in reducing potential losses and optimizing the achievement of business goals.

Probability Theory is a branch of mathematics that is widely applied in everyday life. Consciously or unconsciously, almost all aspects of human life are filled with probability theory. Probability theory is related to uncertainty, just as human life is always filled with uncertainty (Sianturi, 2023). The concept of probability is used to identify, measure, and manage risks that arise due to uncertainty. In risk management, probability is the basis for estimating potential risks that may occur and measuring their impact more accurately.

Probability theory includes various concepts such as conditional probability, addition rules, and multiplication rules, which are used to analyze uncertainty more accurately. In addition, the concept of probability theory includes sample space and events, calculating sample points, probability of occurrence, conditional probability and Bayes' rule, as well as random variables and probability distributions (Sianturi, 2023). By using these concepts, various risk scenarios can be evaluated mathematically, allowing decision makers to estimate the likelihood of an event occurring and its impact on the goals to be achieved. This mathematical approach is an important foundation in formulating more optimal and effective mitigation strategies in dealing with existing uncertainty.

The application of probability theory allows decision makers to develop mitigation strategies based on measurable estimates. For example, in operational planning, probability is used to assess the likelihood of system failure or uncertainty in market demand. This analysis then becomes the basis for formulating effective mitigation measures. Furthermore, the use of probability in data analysis and statistics allows for more accurate decision-making based on empirical evidence. Therefore, a deep understanding of the concept and law of probability is very important in managing risk and uncertainty and optimizing the decision-making process in various business contexts. However, the problem that is often faced in business decision-making is how to manage risk and uncertainty with the right method. The use of probability theory in identifying and measuring emerging risks is still often ignored or not optimally applied. Therefore, this study aims to examine the application of the concept and law of probability in risk and uncertainty analysis for optimal business decision-making. This study also aims to show how the application of probability theory can help reduce potential losses and optimize the achievement of business goals through a more systematic and measurable approach.

1. **Research Design and Method**

This study uses theoretical and empirical approaches to understand the concept of opportunity in business decision making. The theoretical approach is carried out through a review of literature related to probability theory, probability laws, and their applications in risk management and business mitigation strategies. Meanwhile, the empirical approach is carried out by examining various case studies and previous research to illustrate how probability theory is applied in the business world. The combination of these two approaches allows the study to not only discuss the concept of probability theoretically but also show its application in managing uncertainty and strategic decision making.

One of the main probabilistic methods studied in this study is Monte Carlo Simulation. This method is used to estimate the likelihood of various business scenarios by considering random variables that can affect the outcome. In investment management, Monte Carlo Simulation helps evaluate portfolio risk based on the probability distribution of historical data. In addition, in supply chain planning, this method is used to predict market demand and adjust logistics strategies to be more adaptive to changes in external conditions. With its ability to manage uncertainty, this method is an important tool in improving the accuracy of predictions and business decision making.

In addition, this study also examines the application of Bayes' Theorem in business, which allows companies to update the probability of an event based on the latest information. In marketing, for example, this theorem is used to evaluate the effectiveness of a campaign based on customer responses so that marketing strategies can be adjusted in real time. In risk management, this approach helps reassess risk levels based on new data, allowing for more accurate mitigation decisions. In addition, this study discusses Probability Distributions, such as the normal, exponential, and poisson distributions, which are often used to analyze market trends, predict product demand, and evaluate the likelihood of operational disruptions. To provide a more comprehensive picture, this study uses descriptive analysis techniques to explain the application of probability theory as well as quantitative analysis to measure risk with statistical methods. Probabilistic analysis in measuring market volatility, for example, helps companies estimate the level of investment risk. Meanwhile, statistical techniques are used in business trend analysis to identify demand patterns and develop more efficient production strategies. With this approach, this study confirms that the application of probability theory can improve the effectiveness of business strategies and the competitiveness of companies in facing market uncertainty.

1. **Results and Discussion**

***Application of the Concept and Law of Probability in Business Decision Making***

Opportunity is a number or quantity used to express how likely something is to happen. Opportunity can be expressed as a fraction or decimal or percentage. Opportunity has a conceptual relationship between possibility and events. When we have a small chance, the possibility of what will happen is also small, but when we have a large chance, the possibility of what will happen will also be large. Probability theory is a mathematical science that follows the principles of combinatorics used for statistics (Toruan, 2022).

In the business world, probability theory plays an important role in supporting data-based decision making by considering various possible scenarios. Through approaches such as Expected Monetary Value (EMV) and Decision Tree Analysis, companies can measure and manage risk more systematically. For example, in investment analysis, companies can determine the chances of success or failure of a project by calculating the probability of each possible outcome and the estimated profit or loss that accompanies it. With the EMV calculation, the alternative with the highest expected value can be selected to maximize profits. Meanwhile, Decision Tree Analysis facilitates the visualization of various scenarios that can occur, helping decision makers choose the most profitable strategy based on the available probabilistic information.

As an example of the application of EMV in business decision making, assume a company must choose between two investment projects, A and B. By considering the probabilities of gains and losses from each project, the company can calculate the expected monetary value to determine the most profitable choice.

**Table 1. Probability of Profit and Loss from Projects A and B**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Proyek** | **Keuntungan (Rp)** | **Probabilitas Keuntungan** | **Kerugian (Rp)** | **Probabilitas Kerugian** |
| A | 500 juta | 0,7 | 100 juta | 0,3 |
| B | 400 juta | 0,8 | 150 juta | 0,2 |

EMV for each project:

EMV A = (500 million × 0.7) + (-100 million × 0.3)

EMV A= 350 million – 30 million = 320 million

EMV B = (400 million × 0.8) + (-150 million × 0.2)

EMV B= 320 million – 30 million = 290 million

Because Project A generates a higher EMV (320 million) than Project B (290 million), Project A is more recommended to be selected.

***Monte Carlo Simulation Method***

Monte Carlo simulation is a statistical sampling technique used to estimate the solution to a quantitative problem through a randomization process. This method works by generating random samples from a probability distribution to estimate the expected value or measure risk (Hasugian, Muhyi, & Firlidany, 2022). In the business context, Monte Carlo simulation is widely applied in financial planning, risk management, and optimization of production processes because of its ability to handle uncertainty with a probabilistic approach.

For example, a company wants to predict cash flow for the next year assuming that its monthly income follows a normal distribution with an average of IDR 1 billion and a standard deviation of IDR 200 million. To conduct this simulation, the steps that can be applied include: 1) Determining the probability distribution: A normal distribution with an average (μ) of IDR 1 billion and a standard deviation (σ) of IDR 200 million; 2) Generating random samples: Using computer simulations by performing 10,000 repetitions; 3) Calculating total cash flow: Adding up the results of each month from each simulation; and, 4) Analyzing the results: Calculating the average, standard deviation, and the possibility of cash flow below a certain value (for example, IDR 800 million).

With this approach, companies can obtain a more accurate estimate of the potential for future cash flow, so they can design a more optimal business strategy.

***Bayes' Theorem in Business Decision Making***

Bayes' Theorem is a statistical method used to update the probability of an event based on new information. This method utilizes the Bayes formula to adjust the initial odds with the additional data available (Putri, Emalia, & Iskandar, 2024). This concept is known as Bayesian Probability and can be applied in various business fields such as market research, consumer analysis, and predictive analytics to support more accurate decision making.

For example, a company that wants to launch a new product can use Bayes' Theorem to update its marketing success estimate based on the latest survey data. Initially, the company estimated the product's chance of success at 0.6. However, after conducting a survey of 1,000 respondents, it was found that 700 people liked the product. So, it can be calculated using the Bayes' Theorem formula as follows:

$$P\left(B\right)=\frac{P(B|A)P(A)}{P(B|A)P\left(A\right)+P(B|A^{c})P(A^{c})}$$

Explanation:

* $P\left(A\right)=0,6$ (Initial chance of product being accepted)
* $P\left(A\right)=\frac{700}{1.000}=0.7$ (Chances are the survey results will show positive acceptance if the product is accepted)
* $P\left(A^{c}\right)=0.4$ (The assumption is that if the product is rejected, the probability of showing positive acceptance remains at 0.4)
* $P\left(A^{c}\right)=1-0,6=0,4$

Calculation

$$P\left(B\right)=\frac{P\left(A\right)P(A)}{P\left(A\right)P\left(A\right)+P\left(A^{c}\right)P(A^{c})}$$

$$P\left(B\right)=\frac{0.7×0.6}{\left(0.7×0.6\right)+\left(0.4×0.4\right)}$$

$$P\left(B\right)=\frac{0.42}{0.42+0.16}$$

$$P\left(B\right)=\frac{0.42}{0.58}$$

$$P(A|B)=0.724$$

With this calculation result, the chance of the product being accepted by the market increases to 0.724 or 72.4%. By applying Bayes' Theorem, companies can update their estimates of the probability of product success in the market and formulate more effective marketing strategies.

***Use of Probability Distributions in Business***

A probability distribution is a mathematical representation of how probabilities are distributed on random variables, both discrete and continuous. This distribution shows the likelihood of various outcomes occurring in a random experiment and is used to understand data patterns and make predictions. Some common probability distributions used in business include the normal, binomial, and Poisson distributions.

The normal distribution is often used in product demand analysis or sales forecasting, where the data collected is symmetrically distributed around the mean. The binomial distribution is suitable for use when businesses want to calculate the probability of success or failure from a fixed number of experiments, such as the success rate of a marketing campaign.

Meanwhile, the Poisson distribution is a discrete probability distribution that describes the number of events that occur in a given time or space interval, assuming these events occur independently and at a constant rate (Aji, Sutrisno, & Rijal, 2024). Therefore, the Poisson distribution is widely applied in business analysis, such as calculating the number of customers coming to a store in an hour or the number of calls received to a customer service center in a certain period. For example, in sales forecasting, if a product has an average sale of 1,000 units per month with a standard deviation of 100 units, the company can calculate the probability of sales exceeding 1,100 units using the normal distribution. The z value can be calculated using the formula:

***Discussion***

The importance of discussions

The discussion section is often considered the most critical part of the research paper because this is where: 1) most effectively demonstrates researcher to think critically about an issue, to develop creative solutions to problems based upon a logical synthesis of the findings, and to formulate a deeper, more profound understanding of the research problem under investigation; 2) present the underlying meaning of the research, note possible implications in other areas of study, and explore possible improvements that can be made in order to further develop the concerns of your research; 3) highlight the importance of the study and how it may be able to contribute to and/or help fill existing gaps in the field. If appropriate, the discussion section is also where to state how the findings from the study revealed new differences in the literature that had not been previously exposed or adequately described; and, 4) engage the reader in thinking critically about issues based upon an evidence-based interpretation of findings; it is not governed strictly by objective reporting of information.

The content of the discussion section of the paper most often includes 1) Explanation of results: comment on whether or not the results were expected for each set of results; go into greater depth when explaining findings that were unexpected or especially profound. If appropriate, note any unusual or unanticipated patterns or trends that emerged from the current results and explain their meaning in relation to the research problem. 2) References to previous research: either compare the present results with the findings from other studies or use the reviews to support a claim. This can include re-visiting key sources already cited in the introduction, or, save them from quoting later in the discussion section if they are more relevant to compare with the current results instead of being a part of the general literature review of research used to provide context and background information. 3) Deduction: a claim for how the results can be applied more generally. For example, describing lessons learned, proposing recommendations that can help improve a situation, or highlighting best practices.

$$z=\frac{x-μ}{σ}$$

Explanation:

* $x=1,100$ (the number of units to be predicted)
* $μ=1,000$ (average sales)
* $σ=100$ (standard deviation)

Calculation**:**

$$z=\frac{x-μ}{σ}$$

$$z=\frac{1,100-1,000}{100}=\frac{100}{100}=1$$

Based on the normal distribution table, the probability of z≤1 is approximately 0.8413. Therefore, the probability of selling more than 1,100 units is as follows:

$$P\left(X>1.100\right)=1-P\left(Z\leq 1\right)$$

$$P\left(X>1.100\right)=1-0,8413$$

$$P\left(X>1.100\right)=0,1587$$

This means that there is a 15.87% chance that sales will exceed 1,100 units in one month. With this information, companies can make more informed decisions regarding marketing and production strategies to anticipate market demand.

***Risk Analysis with Probability Theory***

Probability theory is used to identify and measure risk in various fields. One method that is often applied is Value-at-Risk (VaR), which is an estimate of the maximum loss that will be incurred during a certain time period under normal market conditions with a certain level of confidence (confidence interval) (Yuliah & Triana, 2021).

In addition, in project management, reliability analysis utilizes probability theory to measure the risk of a component failure. With this approach, companies can develop more effective risk mitigation strategies, such as anticipating losses due to market uncertainty and designing more appropriate preventive measures.

In investment risk analysis, Value-at-Risk (VaR) can be used to measure the potential maximum loss under normal market conditions. For example, an investment has an average return of 5% with a standard deviation of 10%. With a 95% confidence level, the VaR value can be calculated using the standard normal distribution.

For a 95% confidence level, the critical value (Z-score) of the standard normal distribution is -1.645. Therefore, the maximum possible loss can be calculated as follows:

$VaR=$ (Average return) $+$ ( $Z×$ Standard deviation)

$VaR=5\%+(-1,645×10\%)$

$VaR=5\%-16,45\%$

$VaR=-11,45\%$

This means that with a 95% confidence level, the investment is at risk of losing up to 11.45% in a certain period. This information helps investors make more informed risk mitigation decisions, such as diversifying their portfolio or adjusting their investment strategy.

***Statistical Approaches to Business Decision Making***

Statistical approaches to business decision making include the use of descriptive and inferential statistics. Some relevant methods include Hypothesis Testing, Regression Analysis, and Confidence Intervals. These methods allow businesses to analyze data more systematically and make more measurable decisions.

One approach that is often used in analyzing sales trends is linear regression. The linear regression model allows data processing to identify relationships between variables that affect product demand, such as price, promotion, season, and other external factors. By using this method, companies can predict how changes in one factor can affect future sales, so that marketing strategies can be formulated more effectively (Marcelina et al; 2025).

In addition, in inferential statistics, hypothesis testing and confidence intervals play an important role in business decision making. Hypothesis testing is used to test claims or assumptions about population parameters based on collected sample data, by comparing the null hypothesis (H0) and the alternative hypothesis (H1) to determine whether there is a significant difference. Meanwhile, the confidence interval provides a range of values ​​that allow the population parameter to be within it with a certain level of confidence (Ningsih et al; 2024). With this approach, business decisions can be made based on stronger statistical evidence, not just intuition.

For example, a company wants to know if their new marketing strategy increases the average sales of a product. Previously, the average sales of the product were 500 units per month. After implementing the new strategy, the 40-month sample showed an average sale of 520 units with a standard deviation of 50 units. With a significance level of 5%, did this strategy really increase sales?

We will use a hypothesis test for the population mean with a large sample (n≥30) using a one-tailed test because we want to test whether the marketing strategy increases sales.

Determining hypothesis

Null hypothesis (H0): There is no increase in sales, or the average remains at 500 units.

H0∶ μ=500

H1∶ μ>500

Calculating Test Value (Z-Score)

The formula used for the z-test is:

$$Z=\frac{\bar{X}-μ}{\frac{σ}{\sqrt{n}}}$$

Explanation:

* $\bar{X}=$ 520 (Sample average)
* $μ=$ 500 (Population average)
* $σ=$ 50 (Standard deviation)
* $n=$ 40 (Number of sample)

Calculation:

$$Z=\frac{\bar{X}-μ}{\frac{σ}{\sqrt{n}}}$$

$$Z=\frac{520-500}{\frac{50}{\sqrt{40}}}=\frac{20}{7,91}=2,53$$

Determining Critical Value

With a significance level of α=0.05 and degrees of freedom df=n-1=39, we find the t-critical value from the t-distribution table for the one-way test (right-tailed test). Based on the t-distribution table, the value of t\_0.05.39 is approximately 1.685.

Comparing t-statistics with t-critical

The calculated t-statistic is 2.53. The t-critical from the t-distribution table is 1.685. Since 2.53>1.685, we reject the null hypothesis (H0). This means that there is sufficient statistical evidence to conclude that the new marketing strategy significantly increases average sales.

Confidence Interval

In addition, we can construct a 95% confidence interval for average sales after the new strategy is implemented. The confidence interval is calculated using the formula:

$$CI=\bar{X}\pm Z\_{α/2}×\frac{σ}{\sqrt{n}}$$

Explanation:

* $\bar{X}=$ 520 (Sample average)
* $σ=$ 50 (Standard deviation)
* $n=$ 40 (Number of sample)
* $α=$ 0,05 $\rightarrow Z\_{α/2}=1,96$ (because the 95% confidence interval

Calculation:

$$CI=\bar{X}\pm Z\_{α/2}×\frac{σ}{\sqrt{n}}$$

$$CI=520\pm 1,96×\frac{50}{\sqrt{40}}$$

$$CI=520\pm 1,96×\frac{50}{6,32}$$

$$CI=520\pm 1,96×7,91$$

$$ CI=520\pm 15,51$$

* Upper limit $ =520+15,51=535,51$
* Lower limit $ =520-15,51=504,49$

This means that with a 95% confidence level, the average product sales are in the range of 504.49 to 535.51 units. Since the lower limit of the confidence interval (504.49) is still greater than the previous average (500 units), there is sufficient evidence that the new strategy can indeed increase sales significantly.

1. **Conclusions**

Based on the results of the analysis in this study, it can be concluded that the application of probability theory in business decision making has a significant role in managing risk and uncertainty. Uncertainty in the business world can have an impact on various operational and strategic aspects, so that the probabilistic approach is an effective solution in measuring and controlling risk. Monte Carlo simulation, Bayes' Theorem, and probability distribution analysis are methods that allow companies to make more accurate predictions of possible future events, so that decisions taken can be more measurable and data-based. Thus, the use of probability theory not only helps in risk mitigation, but also in optimizing business strategies to increase the company's competitiveness. In addition, the results of the study show that the probabilistic approach is able to provide a clearer picture of the various scenarios that can occur in business. By using statistical methods and probability distribution, companies can identify patterns of risk and opportunity that may arise, so that resource management can be carried out more efficiently. The implementation of probability theory in decision making has also been shown to increase effectiveness in marketing strategies, investment management, and company operational planning. Therefore, a deep understanding of the concept of opportunity is essential for decision makers to be able to face the ever-evolving market dynamics more adaptively and proactively. With the existence of various opportunity-based methods, companies can reduce uncertainty and improve the quality of decisions taken. However, there are still challenges in its implementation, especially in terms of understanding the concept of probability and the availability of accurate data. Therefore, a stronger integration between opportunity theory and analytical technology is needed so that risk management strategies can be carried out more optimally. With the right approach, opportunity theory can be a very useful tool in supporting sustainable and highly competitive business growth in this era of uncertainty.

To improve the effectiveness of the application of probability theory in business decision making, several strategic steps are needed that can be taken by companies and academics. Some suggestions that can be given based on the results of this study are as follows. First, improving understanding of probability theory. Companies and decision makers need to improve literacy about the concept of probability, probability distribution, and statistical-based analysis methods in order to be able to implement them optimally in business risk management.

Second, integrating technology in risk analysis. Utilizing technology such as artificial intelligence (AI) and big data analytics can help in managing and analyzing probabilistic data more accurately and efficiently, so that probability-based decision making becomes more precise.

Third, implementing simulations and probabilistic models consistently. Companies are advised to routinely implement Monte Carlo simulations, Bayes' Theorem, and probability distribution analysis in their business strategies to minimize risk and increase competitiveness in the market.

Fourth, increasing the availability of accurate data. Data quality greatly influences the application of probability theory. Therefore, companies need to ensure that the data used in the analysis has high validity and reliability to produce more accurate decisions.

Lastly, collaboration with academics and practitioners. Companies can collaborate with academics or experts in statistics and data analysis to develop probabilistic methods that are more in line with industry needs and increase the effectiveness of risk management strategies. By implementing these steps, it is hoped that the application of probability theory in business decision making can be increasingly optimal, so that companies are able to face various challenges and uncertainties with more measurable and data-based strategies.

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