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Product Demand Prediction in E-Commerce Systems Using the Monte Carlo Method

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Abstract

The rapid growth of e-commerce has intensified demand uncertainty, creating significant challenges in inventory management due to the risks of overstock and stockout conditions. Fluctuating consumer behavior and dynamic digital market trends require forecasting approaches capable of modeling probabilistic variability rather than relying solely on deterministic estimates. This study aims to analyze and implement the Monte Carlo simulation method to forecast product demand in an e-commerce system and to evaluate its effectiveness in supporting optimal inventory decision-making. The research adopts a quantitative approach using historical monthly sales data of laptop products collected over a ten-month period. The Monte Carlo method was applied by constructing probability distributions, calculating cumulative probabilities, defining random number intervals, and performing repeated simulations to generate demand predictions. The simulation results produced an average predicted demand of 139 units, closely aligned with the historical average of 137 units, with a Mean Absolute Deviation (MAD) of 2 units, indicating a low prediction error. These findings demonstrate that the Monte Carlo approach effectively captures demand variability and provides accurate probabilistic estimates. The study implies that integrating Monte Carlo simulation into e-commerce inventory planning can enhance risk-based decision-making, improve stock control accuracy, and reduce potential financial losses associated with demand uncertainty.

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1. Introduction

The development of digital technology over the past decade has driven significant transformation in various economic sectors, particularly the e-commerce sector in Indonesia. Increased internet penetration, mobile device adoption, and the ease of digital payment systems have changed people's consumption patterns from conventional transactions to fast and practical online transactions. This transformation has not only had an impact on increasing transaction volumes but also on the complexity of business operational management, especially in terms of inventory management. Increasingly dynamic demand variations, rapid trend changes, and consumer responses to digital promotions create demand fluctuations that are difficult to predict deterministically. Sitorus and

Harahap (2023) explain that in modern e-commerce systems, demand uncertainty is a major risk factor that can cause an imbalance between stock and market demand. Overstocking has the potential to increase storage costs and the risk of obsolete goods, while stockouts can reduce customer satisfaction and revenue opportunities. This condition shows that inventory management in e-commerce can no longer rely solely on managerial intuition, but requires a systematic data-driven and quantitative analysis approach. Therefore, accurate demand modeling is a key element in supporting operational sustainability and company competitiveness amid an increasingly competitive and uncertain digital business environment.

In the context of inventory decision-making, e-commerce systems require forecasting methods that can accommodate the variability of historical data and unstable changes in demand patterns. Traditional forecasting methods such as moving average and linear regression are often used because of their ease of implementation, but these approaches tend to assume relatively linear and stable data patterns over time. Kartikasari et al. (2025) emphasize that in conditions of fluctuating demand influenced by external factors such as digital promotions, seasonal discounts, and social media trends, deterministic methods often produce inaccurate estimates. Heizer et al. (2023) also state that in modern operations management, forecasting approaches must be able to capture elements of uncertainty and risk, rather than just producing a single prediction value. In other words, an effective prediction system needs to consider the distribution of possible outcomes, so that managers can understand the range of risks that may occur. This is even more important in e-commerce, where demand changes can occur suddenly due to marketing campaigns or changes in consumer preferences. Therefore, a more flexible and adaptive probabilistic approach is needed to mathematically represent demand uncertainty.

One relevant approach to dealing with this uncertainty is the Monte Carlo simulation method. This method is a numerical simulation technique that uses random numbers to model systems containing probabilistic elements. According to Sitepu et al. (2025), Monte Carlo works by constructing probability distributions based on historical data, then performing repeated simulations to generate various possible future demand values. This approach allows researchers and practitioners to evaluate various possible scenarios, so that decisions are not only based on historical averages, but also take into account variations and risks. Kartikasari et al. (2025) explain that the Monte Carlo process involves forming probability distributions, calculating cumulative probabilities, determining random number intervals, and mapping random numbers to those intervals to obtain simulation results. Heizer et al. (2023) add that probability-based simulations are very effective in risk analysis and inventory planning because they are able to describe uncertainty quantitatively. Thus, Monte Carlo not only functions as a prediction tool, but also as a risk evaluation instrument that supports more comprehensive and data-driven decision making.

Various empirical studies have demonstrated the effectiveness of applying the Monte Carlo method in sales and supply chain management systems. Sitorus and Harahap (2023) found that Monte Carlo simulations are capable of producing demand estimates that are closer to actual values than conventional methods under fluctuating data conditions. Additionally, Kartikasari et al. (2025) reported that integrating Monte Carlo into retail supply chain systems can improve inventory planning efficiency and reduce the risk of losses due to demand uncertainty. Chopra and Meindl (2022) also emphasize that in the context of supply chain management, the use of simulation allows companies to evaluate the impact of various inventory policies before they are implemented in real life, so that decisions can be made with a more measurable level of risk. However, the application of the Monte Carlo method in e-commerce systems in Indonesia is still relatively limited, especially in studies that specifically link probabilistic simulation with inventory decision-making based on historical online transaction data. This limitation opens up opportunities for research to examine in more depth the implementation of Monte Carlo in the context of local e-commerce.

Based on this background, this study aims to analyze and implement the Monte Carlo method in product demand forecasting in e-commerce systems to support optimal inventory decision-making. Theoretically, this study is expected to enrich the literature on the application of probabilistic

simulation in digital inventory management, particularly in business environments with high levels of uncertainty. Practically, the results of this study are expected to provide more adaptive stock policy recommendations for e-commerce players, thereby minimizing the risks of overstocking and stockouts simultaneously. By integrating a probability distribution approach and repeated simulations, this study seeks to present a prediction model that not only produces demand value estimates but also presents a range of possible outcomes and their risk levels. This approach is expected to support more rational, measurable, and quantitatively-based decision-making in the face of demand dynamics in the digital economy era.

2. Research Methodolgy

2.1 Research Types and Approaches

This research uses a quantitative approach with numerical simulation methods. A quantitative approach was chosen because the research focuses on processing historical sales data in numerical form, which is analyzed mathematically to produce demand estimates for future periods. According to Creswell (2018), the quantitative approach aims to test and model phenomena through statistical data analysis so that the results obtained are objective, measurable, and replicable. In the context of this study, the phenomenon modeled is the fluctuation in product demand in an e-commerce system that has probabilistic characteristics.

The method used is Monte Carlo Simulation, which is a probability-based modeling technique that utilizes random numbers to represent various possible future demand values. Monte Carlo Simulation is carried out by forming a probability distribution from historical data, calculating cumulative probabilities, determining random number intervals, and generating random numbers to obtain simulation prediction results. This approach was chosen because it is capable of quantitatively describing demand uncertainty and producing a range of possible prediction values, rather than just one deterministic value. Thus, this method is relevant to support inventory decision-making in a dynamic and volatile e-commerce environment.

2.2 Research Object and Subject

The object of this study is the demand or sales data of products on the e-commerce system owned by Toko Maju Jaya Komputer. The data represents the number of product units sold in a certain period and is used as the basis for forming a probability distribution in the simulation.

The subject of the study focuses on electronic products that have a regular and stable sales history, so that there is sufficient historical data for analysis. To maintain modeling consistency and reduce the complexity of the analysis, this study specifically focuses on one type of product, namely laptops. The selection of one type of product aims to increase accuracy in forming probability distributions and simplify the process of interpreting simulation results. In addition, laptops were chosen because they are a category of products with relatively fluctuating demand levels, making them suitable for analysis using a Monte Carlo-based probabilistic approach.

2.3 Type and Source of Data

The data used in this study is quantitative data in the form of monthly product sales. This data is secondary data obtained from the company's e-commerce system and monthly sales transaction reports for 2025. This historical data is used as the basis for forming the probability distribution of demand. Table 3.1 below presents historical data on the number of laptop product requests over ten months in 2025.

Table 1 Historical Data on Laptop Product Demand in 2025

Month	Number of Requests (Units)
1	100
2	120
3	150
4	100
5	180

6	150
7	120
8	150
9	180
10	120

The data in Table 3.1 is used to calculate the frequency of occurrence of each demand level, then transformed into probability distributions and cumulative probabilities as the basis for forming random number intervals in Monte Carlo simulations.

2.4 Data Collection Techniques

Data collection techniques in this study were carried out through two main methods, namely system observation and documentation.

a. System Observation

Observation was carried out by directly observing the e-commerce system used by the company, particularly in the transaction recording and sales report modules. The purpose of the observation was to understand the data recording flow, database structure, and consistency of product sales recording.

b. Documentation

The documentation technique was carried out by collecting and copying historical sales data from monthly transaction reports available in the system. The data obtained was then verified to ensure its completeness and accuracy before being used in the analysis and simulation process.

2.5 Research Variables

This study used one main variable, namely: Variable X (Product Demand): The number of laptop units sold in a period (month). This variable is analyzed to form a probability distribution of demand. The output generated from this research is a prediction of the number of product demands in the next period based on the results of Monte Carlo simulations. These predictions are presented in the form of estimated demand values along with a distribution of possible outcomes, so that they can be used as a basis for more measured and risk-based inventory decisions.

3. Results and Discussion

3.1 Probability Distribution Calculation

The initial stage in applying Monte Carlo simulation is to form a probability distribution based on historical data on laptop demand over a period of 10 months. The probability distribution is calculated using the following formula:

$$P(x) = \frac{f}{n}$$

where f is the frequency of occurrence of a demand level and n is the total number of observations (10 months).

Based on historical data, four demand levels were obtained, namely 100 units (occurred twice), 120 units (three times), 150 units (three times), and 180 units (twice). Thus, the probability of each demand is as follows:

- $P(100) = \frac{2}{10} = 0{,}20$
- $P(120) = \frac{3}{10} = 0{,}30$
- $P(150) = \frac{3}{10} = 0{,}30$
- $P(180) = \frac{2}{10} = 0{,}20$

The results show that demand for 120 units and 150 units has the highest probability (0.30), while demand for 100 units and 180 units has a probability of 0.20. This distribution forms the basis for determining cumulative probability and random number intervals.

3.2 Cumulative Probability and Random Number Intervals

Cumulative probability is calculated by summing the probabilities sequentially using the formula:

$$PK = P_1 + P_2 + \cdots + P_n$$

The cumulative probability calculations are presented in Table 4.2 below..

Table 2 Cumulative Probability

Demand (Units)	Probability	Cumulative
100	0,20	0,20
120	0,30	0,50
150	0,30	0,80
180	0,20	1,00

Based on the cumulative probability, random number intervals are formed in the range of 00–99 as shown in Table 4.3.

Table 3. Random Number Intervals

Demand (Units)	Random Number Interval
100	00–19
120	20–49
150	50–79
180	80–99

This interval is used to map random numbers generated in the Monte Carlo simulation process to determine the predicted demand value for the next period.

3.3 Simulation Results and Accuracy Analysis

Based on 12 simulations conducted using random numbers, a total demand prediction of 1,670 units was obtained, so that the average simulation result was:

$$\bar{X}_{sim} = \frac{1670}{12} = 139{,}17 \approx 139 \text{ units}$$

For comparison, the historical average is calculated using the following frequency distribution:

$$\bar{X}_{hist} = \frac{(100 \times 2) + (120 \times 3) + (150 \times 3) + (180 \times 2)}{10}$$

$$\bar{X}_{hist} = \frac{1370}{10} = 137 \text{ units}$$

The difference between the simulation average and the historical average is:

$$139 - 137 = 2 \text{ units}$$

To measure the prediction error rate, Mean Absolute Deviation (MAD) is used:

$$MAD = \frac{\sum | X_{sim} - X_{hist} |}{n}$$

$$MAD = |139 - 137| = 2$$

Since the average difference is 2 units, the MAD value is 2. This relatively small error value indicates that the Monte Carlo simulation results closely match historical demand patterns..

Discussion

The results show that the application of the Monte Carlo method in predicting laptop demand produces an average estimate of 139 units, which is very close to the historical average of 137 units, with a difference of only 2 units and a MAD value of 2. These findings indicate that the simulation model is able to represent historical demand distribution patterns consistently and realistically. The closeness between the simulation and historical values shows that the frequency distribution-based probabilistic approach is effective in describing the characteristics of demand fluctuations. Conceptually, Monte Carlo does not only produce a single prediction value, but models possible events based on probability distributions, making it more adaptive to uncertainty than simple deterministic methods. In the context of e-commerce inventory management, these results have significant practical implications because stock decisions can be based on estimates that take demand variation into account. The low error rate shows that the model has good predictive validity for use as a decision-making tool. Thus, Monte Carlo simulation can be recommended as a fairly accurate and relevant method to support inventory planning, especially in conditions where demand is volatile and cannot be fully predicted linearly.

4. Conclusion

This study demonstrates that the application of the Monte Carlo simulation method provides a reliable probabilistic approach for forecasting product demand in an e-commerce environment. Based on historical sales data of laptop products, the simulation produced an average predicted demand of 139 units, which is very close to the historical mean of 137 units, with a minimal deviation of 2 units and a Mean Absolute Deviation (MAD) value of 2. These findings indicate that the Monte Carlo model is capable of accurately representing historical demand patterns and capturing inherent demand variability. Unlike deterministic forecasting techniques that rely on single-point estimates, the probabilistic framework applied in this research allows demand to be modeled as a distribution of possible outcomes, thereby reflecting uncertainty more realistically. Consequently, the results confirm that Monte Carlo simulation is an effective analytical tool for supporting inventory decision-making in dynamic and volatile e-commerce systems. The integration of probability distributions and repeated simulations enhances the robustness of demand estimation and provides a more comprehensive basis for risk-aware inventory planning. Although the results indicate high predictive consistency, this study is limited to a single product category and a relatively short historical observation period. Future research is therefore recommended to extend the model by incorporating longer time-series data, multiple product categories, and seasonal or promotional variables to improve generalizability and model sensitivity. Additionally, integrating Monte Carlo simulation with other forecasting techniques—such as time-series models or machine learning algorithms—may further enhance predictive performance and allow comparative validation. From a managerial perspective, e-commerce practitioners are encouraged to implement probabilistic simulation tools within their decision-support systems to evaluate various inventory scenarios before policy implementation. By adopting a risk-based forecasting framework, companies can minimize the likelihood of overstock and stockout conditions while maintaining operational efficiency and customer satisfaction in increasingly uncertain digital markets.

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