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EFFICIENCY ANALYSIS OF PALM OIL INVENTORY CONTROL AT PTPN IV USING MONTE CARLO SIMULATION

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ABSTRACT

Uncontrolled palm oil inventory can increase operational costs and disrupt production flow. This study aims to validate the effectiveness of the Monte Carlo simulation method in predicting the total palm oil inventory costs at PT. Perkebunan Nusantara IV. Unlike conventional approaches that ignore uncertainty, this study uses Monte Carlo simulation to model cost variability based on historical data from January to December 2024. The simulation process is performed by generating random numbers using the Linear Congruential Generator (LCG) method and determining the probability distribution from historical data. The simulation is run once using the probability distribution obtained from 12 months of historical data. The simulation results show a predicted total inventory cost of Rp 918.117.054.635.00, lower than the actual cost of Rp 919.958.281.123.00, resulting in a potential savings of Rp 1.841.226.488.00. To measure the reliability of the Monte Carlo simulation results, a MAPE calculation was performed by comparing the simulation results with actual data. The calculation results show that the MAPE value is 0.2%. These findings prove that Monte Carlo simulation not only improves forecasting accuracy but also empirically supports more optimal decision-making in inventory management and efficient stock level determination.

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1. INTRODUCTION

Operational costs, particularly those related to inventory management, are a crucial factor determining profitability and competitiveness in the palm oil industry [1] [2]. This sector is inherently vulnerable to seasonal supply

fluctuations and weather factors, which demand a highly precise inventory control system. This challenge is not unique to PT. Perkebunan Nusantara IV, a state-owned enterprise, but extends across the entire palm oil sector, both nationally and globally. Inaccurate inventory planning triggers significant operational inefficiencies; overstocking can lead to substantial storage costs and tied up capital, while understocking can cause costly production disruptions and lost revenue potential [3] [4] [5] [6].

In the era of data-driven supply chain management, relying on conventional methods that fail to account for inherent uncertainty is no longer sufficient. There is a gap in prevailing industry practices, where most inventory planning approaches fail to effectively model the variability and risks involved. To overcome this shortcoming, a more sophisticated quantitative approach is needed. Monte Carlo simulation is one such relevant method, utilizing random numbers and probability distributions from historical data to more accurately predict future events [7] [8]. Monte Carlo simulation is a probabilistic method that relies on random processes to solve problems. This random process utilizes probability distributions from previously obtained data as well as theoretical probability distributions. This simulation is applied to model and analyze systems that involve risk and uncertainty. The Monte Carlo method uses random values for each variable according to its probability distribution to simulate the system multiple times, depending on the system being analyzed [9]. Monte Carlo simulations are starting to be widely used in agribusiness, for example to forecast crop yields, manage commodity price risks, and analyze agricultural supply chain performance.

Therefore, this study aims to analyze and predict palm oil inventory costs at PT. Perkebunan Nusantara IV using Monte Carlo simulations. Compared to other stochastic approaches, Monte Carlo can handle complex uncertainties without relying on specific distributional assumptions [10]. Monte Carlo generates not just a single optimal value, but also a distribution of possible outcomes that provides a more realistic picture of risk. By comparing these cost predictions with conventional methods, this research seeks to measure the potential cost efficiencies that can be achieved and, ultimately, fill a gap in the literature by demonstrating how data-driven decision-making can lead to more resilient and efficient inventory management across the palm oil sector [11] [12].

2. RESEARCH METHOD

This research is a quantitative study using a simulation approach. Simulation is an activity that involves creating a mathematical model of a real world system to conduct trials and predict its behavior [13]. It serves as a powerful decision-making tool for designing and testing system performance [14]. The method employed is Monte Carlo Simulation, a computational technique that utilizes repeated random sampling to model and analyze systems with inherent uncertainty. In this study, the Monte Carlo method is used to estimate future inventory costs for palm oil at PT. Perkebunan Nusantara IV by simulating the probabilistic nature of the cost data.

The data used in this study are secondary data, specifically the total monthly inventory costs from January to December 2024, with $N = 12$ months, obtained from internal company reports. This figure is considered representative because it covers the full seasonal cycle of palm oil production. The Monte Carlo flowchart is as follows:

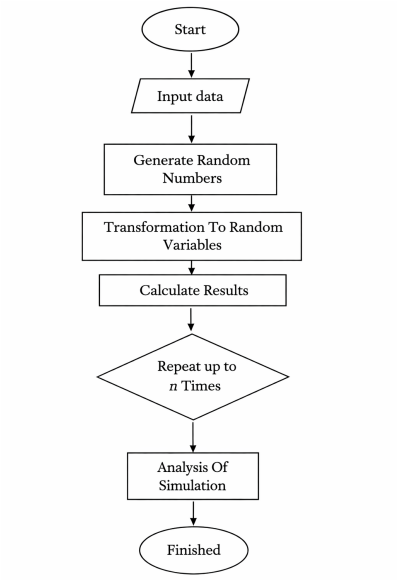

Figure 1: Flowchart of the Monte Carlo

The simulation stages are as follows:

a Determining the Probability Distribution: The probability distribution is determined by analyzing the historical frequency of monthly inventory costs from the provided data. This process involves grouping the cost data into specific ranges and calculating the frequency of each range's occurrence. These frequencies are then converted into probabilities, with the underlying assumption that historical cost patterns are representative of future cost behavior.

b Calculating the Cumulative Probability Distribution: The cumulative probability is calculated by summing the individual probabilities, which helps in assigning a range of random numbers to each cost outcome.

c Defining Random Number Intervals: Random number intervals are defined based on the cumulative probabilities. Each cost outcome is assigned a specific interval, ensuring that the size of the interval corresponds to the probability of that outcome [15] [16].

d Generating Random Numbers: Random numbers are generated using the Linear Congruential Generator (LCG)[17] [18] method with the following parameters:

   a) Initial number (Z0) = 15
   b) Multiplicative constant (a) = 17
   c) Displacement constant (c) = 27
   d) Modulus (m) = 100 The selection of these parameters is crucial for ensuring the unpredictability and statistical quality of the generated random numbers [19]. A poor choice of parameters can lead to a short cycle length, causing the random sequence to repeat prematurely and thus compromising the accuracy of the simulation results.

e Running the Simulation: The simulation is run by matching the generated random numbers to the predetermined intervals to estimate the total inventory cost.

3. RESULT AND ANALYSIS

The data analyzed in this study consists of the total monthly palm oil inventory costs from January to December 2024, which were sourced from internal reports of PT. Perkebunan Nusantara IV Regional I Medan. These monthly costs are an aggregate of several key components, including storage costs, handling costs and financing costs. Each figure presented in the following tables and figures provides a comprehensive overview of the company's monthly inventory expenditure, measured from the combination of these specific cost elements.

Table 1: . Total Inventory Cost

Year 2021	**Cost**
January	Rp. 71,101,451,015.20
February	Rp. 78,032,092,587.54
March	Rp. 64,265,687,092.00
April	Rp. 85,236,345,990.00
May	Rp. 77,816,965,871.72
June	Rp. 87,266,128,321.68
July	Rp. 77,817,657,897.92
August	Rp. 73,739,188,480.00
September	Rp. 77,037,904,493.04
October	Rp. 75,411,804,721.00
November	Rp. 77,046,691,494.00
December	Rp. 75,186,363,159.00

After obtaining the total inventory cost of the company data, calculations will then be carried out using the Monte Carlo Simulation method using inventory cost variables.

Table 2: . Total Inventory Cost

Year 2021	Cost	Probability Distribution
January	Rp. 71,101,451,015.20	0.08
February	Rp. 78,032,092,587.54	0.08
March	Rp. 64,265,687,092.00	0.07
April	Rp. 85,236,345,990.00	0.09
May	Rp. 77,816,965,871.72	0.08
June	Rp. 87,266,128,321.68	0.09
July	Rp. 77,817,657,897.92	0.08
August	Rp. 73,739,188,480.00	0.08
September	Rp. 77,037,904,493.04	0.08
October	Rp. 75,411,804,721.00	0.08
November	Rp. 77,046,691,494.00	0.08
December	Rp. 75,186,363,159.00	0.08
TOTAL	**Rp. 919,958,281,123.10**	**1.00**

Based on Table 2, the probability distribution values are obtained, which will then be used to calculate the cumulative probability distribution based on the probability distribution data. The cumulative probability distribution is obtained by adding the possible numbers with the sum of the previous numbers.

Table 3: Cumulative Probability Distribution

Year 2021	Cost	Probability Distribution	Cumulative Probability Distribution
January	Rp. 71,101,451,015.20	0.08	0.08
February	Rp. 78,032,092,587.54	0.08	0.16
March	Rp. 64,265,687,092.00	0.07	0.23
April	Rp. 85,236,345,990.00	0.09	0.32
May	Rp. 77,816,965,871.72	0.08	0.41
June	Rp. 87,266,128,321.68	0.09	0.50
July	Rp. 77,817,657,897.92	0.08	0.59
August	Rp. 73,739,188,480.00	0.08	0.67
September	Rp. 77,037,904,493.04	0.08	0.75
October	Rp. 75,411,804,721.00	0.08	0.83
November	Rp. 77,046,691,494.00	0.08	0.92
December	Rp. 75,186,363,159.00	0.08	1.00
TOTAL	**Rp. 919,958,281,123.10**	**1.00**	

Table 3. shows the cumulative probability distribution value. The next step is to determine the random number interval for each variable. The random number interval is adjusted according to the probability distribution value and the cumulative probability distribution value.

Table 4: Random Number Intervals

Year 2021	Cost	Probability Distribution	Cumulative Probability Distribution
January	Rp. 71,101,451,015.20	0.08	0.08
February	Rp. 78,032,092,587.54	0.08	0.16
March	Rp. 64,265,687,092.00	0.07	0.23
April	Rp. 85,236,345,990.00	0.09	0.32
May	Rp. 77,816,965,871.72	0.08	0.41
June	Rp. 87,266,128,321.68	0.09	0.50
July	Rp. 77,817,657,897.92	0.08	0.59

Year 2021	Cost	Probability Distribution	Cumulative Probability Distribution
August	Rp. 73,739,188,480.00	0.08	0.67
September	Rp. 77,037,904,493.04	0.08	0.75
October	Rp. 75,411,804,721.00	0.08	0.83
November	Rp. 77,046,691,494.00	0.08	0.92
December	Rp. 75,186,363,159.00	0.08	1.00
TOTAL	**Rp. 919,958,281,123.10**	**1.00**	

Table 4 presents the random number intervals, which are created based on the cumulative probability distribution calculated in the previous step. In the context of the Monte Carlo simulation, these intervals act as a bridge between the generated random numbers and the historical cost data. Each interval represents a potential monthly cost outcome. When a random number is generated, it is matched to the corresponding interval to 'select' the cost value that will be used in the simulation. This process allows the model to stochastically, yet probabilistically, simulate future inventory cost possibilities[16]. These random numbers are generated using the Linear Congruential Generator (LCG) method with the formula:

$$Zi + 1 = (aZi + c)\, mod\ m \tag{1}$$

In this study, these parameters are filled with values $Zi = 15; a = 17; c = 27;$ dan $m = 100$ [5]. Then random number generation is carried out with the following calculation

$$Zi = (17 \times 15 + 27) \bmod 100 = 82$$

$$Zi = (17 \times 82 + 27) \bmod 100 = 21$$

$$Zi = (17 \times 21 + 27) \bmod 100 = 84$$

The calculation is carried out until completion so that the following results can be obtained.

Table 5: Monte Carlo simulation results for inventory cost estimation

Year 2021	Random Numbers	Simulations
January	82	Rp. 75,411,804,721.00
February	21	Rp. 64,265,687,092.00
March	84	Rp. 77,046,691,494.00
April	55	Rp. 77,817,657,897.92
May	62	Rp. 73,739,188,480.00
June	81	Rp. 75,411,804,721.00
July	4	Rp. 71,101,451,015.20
August	95	Rp. 75,186,363,159.00
September	42	Rp. 87,266,128,321.68
October	41	Rp. 77,816,965,871.72
November	24	Rp. 85,236,345,990.00
December	35	Rp. 77,816,965,871.72
TOTAL		**Rp. 918,117,054,635.24**

The simulation results show that the predicted total cost of palm oil inventory for the following year is Rp. 918,117,054,635.24, lower than the actual cost of Rp. 919,958,281,123.10. The simulation was conducted with 12 iterations representing the months of January to December, and each generated random number was successfully mapped to the relevant probability distribution interval.

The savings of Rp 1,841,226,487.86 indicate that this simulation method can provide more efficient estimates than the company's conventional approach. This reinforces the findings of, which states that Monte Carlo simulation can be an effective tool in logistics planning and inventory control.

From a managerial perspective, these results can serve as a basis for developing procurement and storage strategies that are more responsive to supply uncertainty. The advantage of this method is its ability to project a range of possible outcomes, taking into account historical variations, significantly reducing the risk of overstocking or understocking.

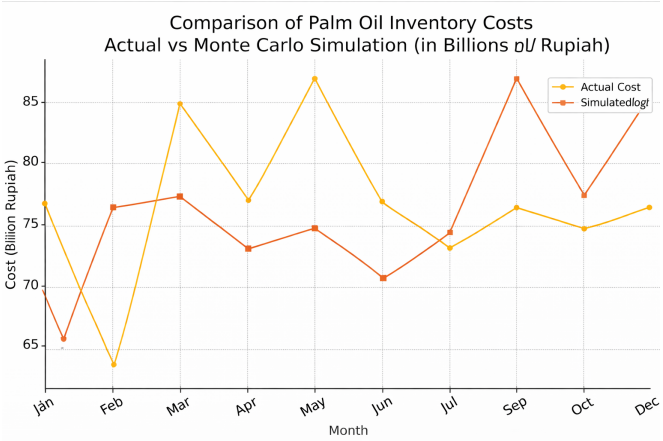

Figure 2: Comparison chart between actual inventory costs and Monte Carlo simulation results

The figure above is a comparison graph between actual inventory costs and Monte Carlo simulation results for 2024. It can be seen that most of the simulation results produce costs that are lower or closer to actual costs, demonstrating the effectiveness of this method in inventory cost planning.

4. CONCLUSION

This study shows that Monte Carlo simulation can accurately predict PTPN IV's inventory costs, resulting in potential savings of Rp 1,841,226,487.86. These findings validate the simulation method as a reliable tool for efficient decision-making amidst uncertainty. However, this study only covers one year of data, a simple probability distribution, and does not consider other external factors. Based on these results, it is recommended that PTPN IV integrate this simulation into its inventory planning to establish optimal stock levels and proactively manage budgets. For future research, Monte Carlo simulation can be applied with machine learning by exploring alternative probability distributions and testing their validity with a wider range of data, resulting in increasingly accurate predictions.

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