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Optimization Bread Distribution Scheduling To Minimize Repeated Distribution

Florencia Agatha Damayanti[1,a] | Lusi Mei Cahya Wulandari[2,b*] | Lasman Parulian Purba [3,c]

[1,2,3]Industrial Engineering Study Program, Faculty of Engineering, Darma Cendika Catholic University, Jl. Dr. Ir. H. Soekarno 201, Surabaya 60117, Indonesia
[a]Florencia.agatha@student.ukdc.ac.id, [b]lusi.mei19@gmail*.com, [c]lasman.parulian@ukdc.ac.id
Corresponding author: lusi.mei19@gmail.com

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Abstract:

This The bread industry has seen advancements in distribution, making bread products easier to transport. With the implementation of delivery orders and effective picking processes, the bread industry can streamline the shipping process and make it easier for customers to obtain bread products. To address inefficiencies in distribution, companies can manage data related to bread, orders, and sales. In this context, Toko Roti XYZ, which has three branches (Branch A, Branch B, and Branch C), faces challenges in the distribution process. The unpredictability of bread demand at these branches is a major cause of repetitive distribution. Forecasting bread demand from these branches was performed using fuzzy time series, moving average, and exponential smoothing methods to determine the quantity of products to be distributed. Subsequently, distribution optimization was carried out using the Vehicle Routing Problem (VRP) method to achieve an optimal delivery schedule that affects distribution costs with a minimum result. The forecasting results with the smallest Mean Absolute Percentage Error (MAPE) were obtained using the moving average method, with an error of 23% for large bread and 9% for small bread from Branch A, an error of 17% for large bread and 14% for small bread from Branch B, and an error of 22% for large bread and 14% for small bread from Branch C. In the VRP method, number 1 represents the depot/production place, number 2 represents Branch A, number 3 represents Branch B, and number 4 represents Branch C. The scheduling routes obtained were 1-3-2-1 and 1-4-1, with a maximum of two distributions for the two available vehicles. With these optimizations, Toko Roti XYZ was able to save distribution costs by Rp. 35,492 and reduce distribution time by 116 minutes per day compared to the previous condition. Additionally, the optimization allowed Toko Roti XYZ to reduce total carbon emissions by 5,342 kg CO_2 per year.

Keywords: Forecasting; Distribution; Vehicle Routing Problem; Carbon Emission; Bakery

Introduction:

Bread is a commonly enjoyed accompaniment in Indonesian society and has become quite popular in the market. The development of the bread industry in Indonesia has introduced various flavor variants, such as chocolate-filled bread, jam-filled bread, sweet bread, pizza bread, sponge cake bread, sandwich bread, and other types of bread. Per capita consumption data in Indonesia indicates that bread is considered a staple food equivalent to other staple foods [1](Ministry of Agriculture, 2023). The bread industry has also seen improvements in distribution, making bread products easier to transport. With the advent of delivery orders and effective picking processes, the bread industry can streamline shipping and make it easier for customers to obtain bread products. To address inefficiencies in distribution, companies can manage data related to bread, orders, and sales. This can help companies deliver bread that matches demand, type, location, price, quantity, quality, timing, availability, and consumer needs.

XYZ Bakery, a well-known establishment in Surabaya founded in 1935, offers a wide variety of bread inspired by the Dutch colonial era. Known for its quality and variety, XYZ Bakery sells products such as white bread, filled bread, sweet bread, and sandwich bread across its three branches: Branch A, Branch B, and Branch C. Each day, bread is distributed from the central production site to these branches in one to three rounds of delivery. The first round delivers freshly baked bread, while subsequent rounds respond to customer orders or replenish stock.

While this system ensures customer satisfaction and fast delivery, it also leads to repeated transportation, increasing operational inefficiencies and contributing to higher transportation costs and carbon emissions. By examining the scheduling of deliveries, opportunities arise to not only streamline operations but also reduce the bakery's environmental impact through more efficient logistics planning. This is where forecasting plays a crucial role in balancing customer demand with sustainable practices, helping to mitigate carbon emissions while maintaining service quality.

In time series analysis, several key techniques are used for forecasting data, including fuzzy time series, moving averages, and exponential smoothing. Each of these methods offers a different approach to the challenges of forecasting. Fuzzy Time Series (FTS), for example, is particularly effective at handling uncertainty and ambiguity in data, especially in non-linear and non-stationary contexts, by leveraging fuzzy logic to improve prediction accuracy [2][3]. Moving averages smooth data by averaging past observations, which helps reduce variance but may sometimes overlook recent trends [4]. On the other hand, exponential smoothing applies exponentially decreasing weights to historical data, making it more responsive to recent changes, though it often lacks flexibility in rapidly changing environments [5].

Time Windows in the context of distribution scheduling refers to the time constraints set within the product distribution system. These time constraints are implemented to minimize waiting times, which often occur due to inaccurate arrival times [6]. The time constraint for the object includes a total estimated delivery time of 9 hours, from 07:00 to 16:00 WIB. Thus, Time Windows in the context of distribution scheduling serves as a precise parameter for transporters to measure their adherence to the distribution schedule.

To address the issues mentioned, forecasting can be conducted for the sales volume based on historical data from each branch for March 2024 to determine the demand from each branch. The forecasting methods that can be used in this research include fuzzy time series, single moving average, and single exponential smoothing. In the bread distribution process, the Vehicle Routing Problem (VRP) method is used. VRP is a problem of finding the best way to deliver or transport goods from one or more depots to various locations while minimizing transportation costs [7]. Additionally, the VRP method has the capability to reduce distance and travel time, thereby saving on fuel costs.

Materials and method:

Forecasting Methods. Forecasting is both an art and a science aimed at predicting what will happen in the future. It involves collecting historical data and projecting it into the future using mathematical models [8]. Forecasting is the process of estimating future demand, including the quantity, quality, timing, and location needs required to meet the demand for a product or service. It involves making predictions for future scenarios based on past data. Since predicting accurately is challenging, forecasting is necessary. Uncertainty in attempting to predict an issue impacts the production capacity within a company [9]. In this context, the forecasting methods used include fuzzy time series, moving average, and exponential smoothing.

Fuzzy Times Series. At this stage, forecasting is performed by the author using previously obtained historical data. The following are the steps of the fuzzy time series model according to Chen [10]:

1. Determining the Universal Set

At this stage, the formation of the universal set (U) is carried out using the formula:

U = [Dmin-D1, Dmax+D2] (1)

2. Determining interval

To determine the class intervals, the universal set is divided into several intervals of equal length. This can be done using Sturges' formula to calculate the number of intervals needed:

Number of class intervals = 1 + 3.3 log(n) (2)

3. After calculating the number of class intervals, the next step is to compute the interval length using the following formula:

Interval length = (Dmax - Dmin) / Number of class intervals (3)

4. Defining Fuzzy Membership Functions and Fuzzification of Data

Input and output variables are divided into one or more fuzzy sets so that they can be used to

calculate the truth values of premises for each rule. Input and output variables are also defined in

fuzzy sets [11].

5. Determining FLG and FLRG Relationships

In this method, the determination of fuzzy intervals uses fuzzy logical relationships (FLR),

incorporating all relationships (all relations) and assigning weights based on the order and

repetition of the same FLR [12].

6. Calculating Forecasting or Defuzzification.

Moving Average. The Moving Average method is a forecasting technique used to predict future values based on past values. This method involves calculating the average of values from several past periods to forecast future values. Moving averages calculate the average over a specific time range, such as 5 days, 20 days, 60 days, or 120 days. There are several types of moving averages, including Simple Moving Average, Weighted Moving Average, and Exponential Moving Average. Simple Moving Average is the most basic and widely used type, where all the most recent data points are summed and then divided by the number of data points within a certain period. The Weighted Moving Average assigns different weights to the stock price data, with more recent data receiving a higher weight compared to older data. Exponential Moving Average gives more weight and significance to the most recent data, i.e., the latest stock prices [13].

MA = (n1+n2+n3+…)/n (4)

where:

MA = Moving Average

n1 = Data for the First Period

n2 = Data for the Second Period

n3 = Data for the Third Period

n = Number of Moving Average Periods.

Exponential Smoothing. Exponential Smoothing is a forecasting method used to predict future values based on past values. This method follows the observed data fluctuations over a period to make forecasts for the future, assigning exponentially decreasing weights to older observations. Exponential smoothing methods include several types, such as Single Exponential Smoothing, Double Exponential Smoothing, and Triple Exponential Smoothing. Single Exponential Smoothing is used for short-term forecasting, typically for 1 month ahead, and assumes that the data fluctuates around a constant mean value or shows a horizontal pattern, without trends, seasonality, or consistent growth patterns [14].

$F_t = F_{t-1} + \alpha (D_{t-1} - F_{t-1})$ (5)

where:

Ft = Current Demand Forecast

Ft-1 = Past Demand Forecast

α = Exponential constant

Dt-1 = Actual Demand.

Vehicle Routing Problem Time Window (VRPTW). The Vehicle Routing Problem (VRP) is a combinatorial optimization problem focused on determining effective routes for delivering goods from a depot to multiple destination points [15]. VRP requires the optimal use of vehicles to visit several customers with varying demands while minimizing operational costs and delivery times. This problem is crucial in supply chain management and logistics, as efficient delivery can enhance customer satisfaction and reduce operational costs.

One development of the VRP model is the VRPTW. In this variation, each location has a time window, or service time, in addition to vehicle capacity constraints. Service can only be performed when the time window is open; otherwise, service cannot be performed if the time window has closed.

One development of the VRP solution model is the VRPTW. In this solution, each location has a time window or service time, in addition to vehicle capacity constraints. Service can be performed when the time window is open; otherwise, service cannot be performed if the time window has closed. To solve the VRPTW, taking into accounts the vehicle capacity used and the service time for each branch point, it can be expressed in the following mathematical formulation:

$$\text{Min} \sum_{i=1}^{1} \sum_{j=1}^{3} \sum_{k=1}^{2} C_{ij} X_{ijk} \quad (6)$$

Constraints:

1. Each route starts and ends at the depot

Starts at the depot: $\sum_{j \in N}^{3} X_{0jk} = 1, \forall k = 1,2$

Ends at the depot: $\sum_{i \in N}^{1} X_{i,n+1}^{k} = 1, \forall k = 1,2$

2. Each branch point is visited exactly once.

$$\sum_{k=1}^{2} \sum_{i=1}^{1} x_{ijk} = 1, \forall j = 1,2,3 \quad (7)$$

3. A vehicle that has visited a branch must leave that branch.

$$\sum_{i=1}^{1} x_{ihk} - \sum_{j=1}^{3} x_{hjk} = 0, \forall h = 1,2,3\ ; \forall k = 1,2 \quad (8)$$

4. The total demand does not exceed the vehicle capacity.

$$\sum_{i=1}^{1} di \sum_{j=1}^{3} x_{ijk} \leq 1000 \quad (9)$$

5. Start time of the vehicle service from i to j.

$$s_{ik} + t_{ij} - M_{ij}(1 - x_{ijk}) \leq S_{jk,}\ \forall i,j = 1,2,3;\ \forall k = 1,2 \quad (10)$$

6. The service time at each branch adheres to the operational hours of the time windows.

$$a_i \leq s_{jk} \leq b_i, \forall i = 1,2,3, \forall k = 1,2 \quad (11)$$

7. The change in x_ijk represents a binary change.

$$x_{ijk} \in \{0,1\}, \forall i,j = 1,2,3\ ; \forall k = 1,2 \quad (12)$$

Carbon Emission

Carbon emissions have a significant impact on distribution activities, especially in terms of environmental, health, and economic factors. In general, greenhouse gas emissions like carbon dioxide (CO_2) are major contributors to global warming and climate change. The effects include extreme weather anomalies, rising global temperatures, melting polar ice, and increasing sea levels, which indirectly heighten the risk of forest fires and heavy rainfall. Climate change also triggers the emergence of diseases related to bacteria, viruses, and parasites, as well as air pollution and extreme weather, affecting human health.

Economically, weather anomalies impact economic activities such as agriculture, tourism, and maritime industries, and can damage infrastructure like roads, bridges, and power lines. Therefore, reducing carbon emissions in distribution activities is crucial. This can be achieved by using sustainable transportation, renewable energy, and energy-efficient equipment. Additionally, planting trees, reducing energy consumption, and adopting more efficient technologies can help lower carbon emissions.

The equation used to calculate the carbon footprint is:

E= Kbb x dll x FE (13)

Where:

E : total emission (kg CO_2 eq)

Kbb: fuel consumption (L)

dll : energy conversion (MJ/L)

FE : emission factor (kg/TJ)

To calculate the fuel consumption:

Kbb = Number of Vehicles x Distance Traveled × Energy Consumption (14)

Results and discussion

In this study, fuzzy time series, moving average, and exponential smoothing are applied to demand data categorized into large bread and small bread for the period of March 2024. This data is sourced directly from the store's database. In this case, the demand data will be used as test data to predict branch demand. The method yielding the lowest error will be used as the constraint function in the VRPTW method. Below is the actual bread demand data for each branch for March 2024.

Table 1. Demand for each brand

Date	Big Bread			Small Bread		
	Branch A	Branch B	Cabang C	Branch A	Branch B	Cabang C
1	17	18	15	448	257	304
2	22	20	12	463	208	292
3	13	20	21	584	483	386
4	20	18	11	424	258	313
5	21	17	14	499	211	304
6	17	13	18	515	260	269
7	29	12	16	570	229	304
8	23	13	21	399	272	386
9	26	20	11	450	295	386
10	21	11	7	503	274	304
11	26	20	8	671	413	287
12	14	18	20	549	264	313
13	23	15	15	503	353	269
14	14	16	9	464	348	287
15	24	9	11	462	290	386
16	22	17	14	598	282	292
17	25	20	17	480	467	304
18	21	23	14	532	284	386
19	21	16	7	483	329	386
20	12	15	21	472	341	386
21	20	21	20	502	318	292
22	25	15	17	515	316	313
23	10	8	20	569	394	287
24	26	13	11	503	381	386

25	17	11	8	435	429	292
26	27	12	8	535	300	292
27	20	15	5	524	213	269
28	15	20	9	749	345	386
29	14	19	14	452	275	287
30	25	8	9	582	377	313
31	26	12	18	562	387	287

A Mean Absolute Percentage Error (MAPE) test was conducted on the three forecasting methods used: fuzzy time series, moving average, and exponential smoothing. The results of the MAPE test are as follows: **Fuzzy Time Series**: Branch A: 33% error for large bread and 30% error for small bread, Branch B: 28% error for large bread and 19% error for small bread, Branch C: 42% error for large bread and 31% error for small bread. **Moving Average**: Branch A: 23% error for large bread and 9% error for small bread, Branch B: 17% error for large bread and 14% error for small bread, Branch C: 22% error for large bread and 14% error for small bread. **Exponential Smoothing**: Branch A: 26% error for large bread and 11% error for small bread, Branch B: 28% error for large bread and 17% error for small bread, Branch C: 41% error for large bread and 18% error for small bread.

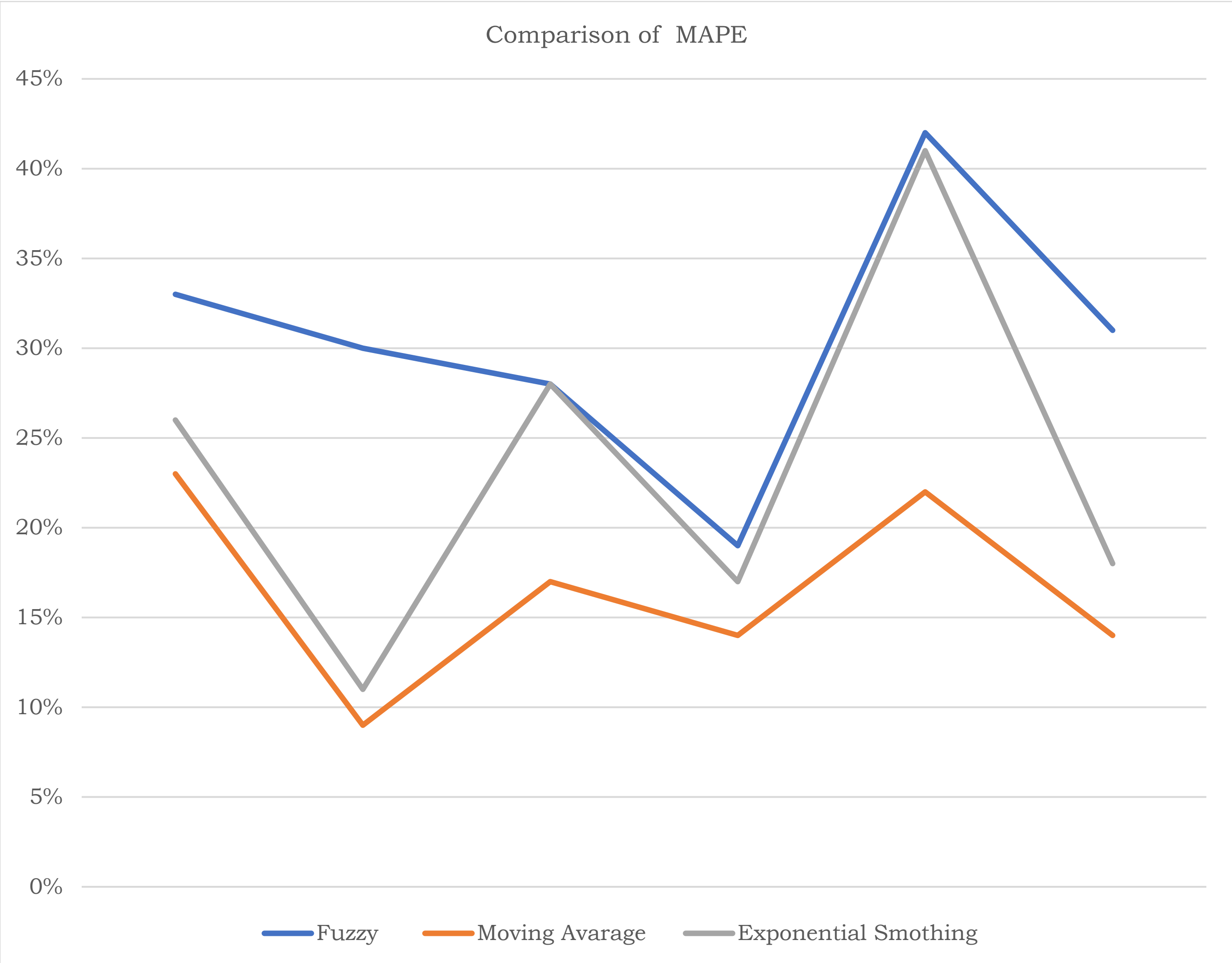

Figure 1. Comparison of MAPE

Based on the smallest error, the selected forecasting method is Moving Average with average Branch A: 16% Branch B: 15%, Branch C: 13%."

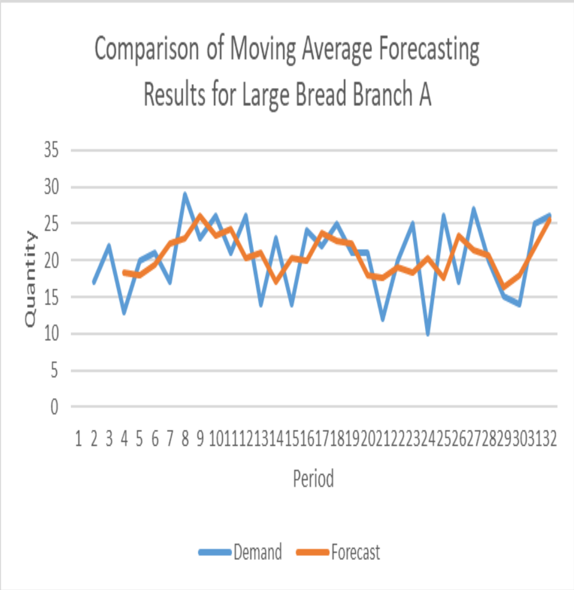

Figure 2.a MA Large Bread Branch A

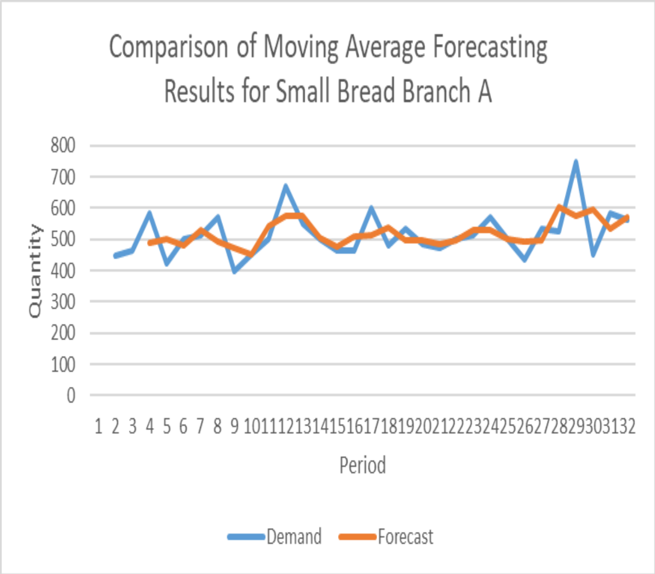

Figure 2.b MA Small Bread Branch A

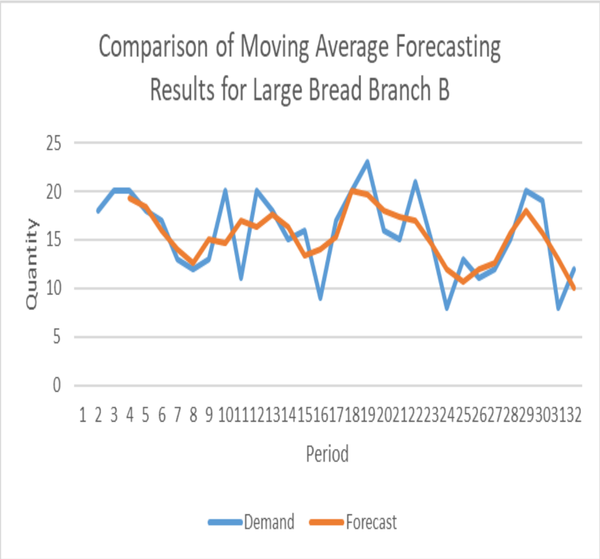

Figure 3.a MA Large Bread Branch B

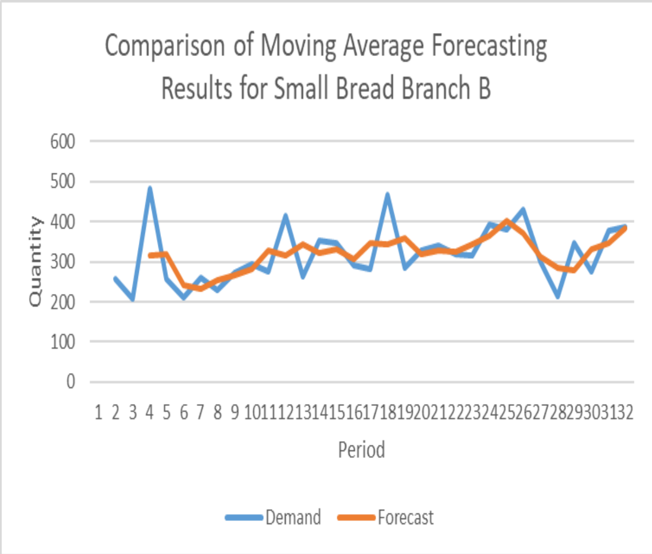

Figure 3.b MA Small Bread Branch B

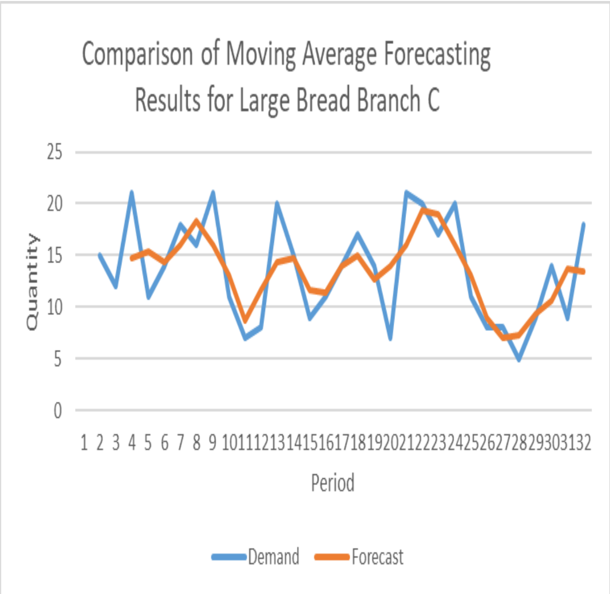

Figure 4.a MA Large Bread Branch C

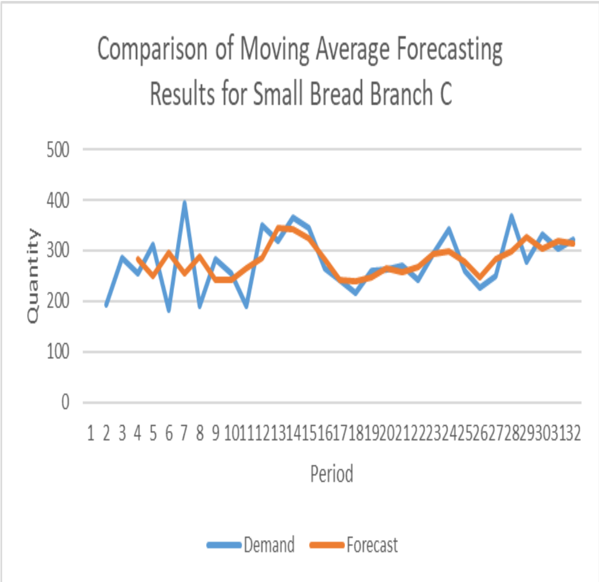

Figure 4.b MA Small Bread Branch C

Optimal Route Results. The values of the decision variables XijkX_{ijk}Xijk can be used to determine the optimal route. In the bread distribution process, a value of 1 for XijkX_{ijk}Xijk indicates that the route is selected. Below is a summary of the decision variables XijkX_{ijk}Xijk with a value of 1.

Table 2. Result

Decision Variable	Value
X (1, 3, 1)	1.000000
X (2, 1, 1)	1.000000
X (3, 2, 1)	1.000000
X (1, 4, 2)	1.000000
X (4, 1, 2)	1.000000

The Solution to the VRPTW with two vehicles (k), three branch points (j), and one depot point (i) is provided below. Using LINGO 19.0 software, the routes for each vehicle can be ordered based on the value of XijkX_{ijk}Xijk for consistency. For the branch points, each can be viewed from the values of iii and jjj, resulting in continuous routes. The routes start from the production site (i), indicated by value 1, to the branch points (j), indicated by value 4.

Based on the table above, the routes formed to service the 3 bakery branches with their respective demands at various locations, considering the store's operating hours, are route 1-3-2-1 for Vehicle 1 and route 1-4-1 for Vehicle 2. Vehicle 1 has a different route compared to the previous condition, which was 1-2-3-1. Both Vehicle 1 and Vehicle 2 distribute three times per day throughout a month. The total distance traveled by Vehicle 1 for three distributions is 43.8 km, and Vehicle 2 covers a total distance of 84 km. The total distribution costs are Rp. 36,485.00 for Vehicle 1 and Rp. 69,972.00 for Vehicle 2. Vehicle 1 travels for 38 minutes, while Vehicle 2 takes 78 minutes or 1 hour and 18 minutes. To maximize vehicle capacity, Vehicle 1 can transport 36 large breads and 723 small breads, and Vehicle 2 can transport 21 large breads and 529 small breads to meet the branch demands.

Given the high distribution costs for both vehicles and the relatively long distribution time for Vehicle 2, it is feasible to optimize by reducing to two distributions. The first distribution would handle the delivery of fresh bread produced the same day, while the second would meet the branch demand. With two distributions, Vehicle 1 travels 29.2 km, and Vehicle 2 travels 56 km. With this approach, XYZ Bakery can reduce costs to Rp. 24,323.00 for Vehicle 1 and Rp. 46,648.00 for Vehicle 2, saving Rp. 35,492 per day and reducing total distribution time by 116 minutes or 1 hour and 56 minutes.

Carbon Emission Total. The total carbon emissions of XYZ Bakery for the year 2024 with 2 vehicles are shown as follows:

	Before Optimization	After Optimization
Fuel Consumption per Year (Liters)	3897,9	2598,6
Energy Conversion (MJ/Liter)	0,1286307	0,0857538
Emision Factor (Kg Co2/TJ)	62,9	62,9
Total Carbon Emision (kg CO_2 eq)	16,025	10,683

The estimated total emissions from gasoline vehicles with RON 90 over one year is 16,025 kg CO2/year for three distributions, while it is 10,683 kg CO2/year for two distributions. In this case, XYZ bakery can reduce total carbon emissions by 5,342 kg CO2/year.

Discussion:

The results of this study show just how powerful it can be to combine Moving Average forecasting with the Vehicle Routing Problem with Time Windows (VRPTW) method to improve distribution processes. By streamlining the number of daily deliveries, XYZ Bakery not only lowers distribution costs but also reduces the environmental impact of its operations. This is achieved by cutting down fuel consumption and carbon emissions, resulting in a significant reduction of 5,342 kg of CO_2 per year. This marks a meaningful shift toward adopting more sustainable practices.

Moreover, this study emphasizes how crucial it is to integrate accurate demand forecasting with logistical planning. The Moving Average method, which achieved the lowest Mean Absolute Percentage Error (MAPE) across most branches, proved essential in predicting demand accurately and ensuring efficient resource allocation. This combination of demand forecasting and VRPTW showcases how XYZ Bakery can benefit from data-driven approaches, ultimately enhancing both productivity and environmental responsibility.

In summary, this research doesn't just improve operational efficiency; it also aligns with the global movement to reduce carbon emissions in supply chain logistics. Future research could explore integrating real-time data with predictive models, allowing for even greater flexibility and responsiveness in an ever-changing market environment. This would enable businesses to not only adapt to demand shifts but also further minimize their environmental impact.

Conclusion:

The Mean Absolute Percentage Error (MAPE) values for each branch were obtained. For each category of large and small bread at each branch, the smallest MAPE values using the 3-day moving average method were as follows:

Branch A: Error rate of 23% for large bread and 9% for small bread.

Branch B: Error rate of 17% for large bread and 14% for small bread.

Branch C: Error rate of 22% for large bread and 14% for small bread.

Using the Vehicle Routing Problem with Time Windows method, the optimal distribution routes are Depot-branch B- Branch A- Depot for Vehicle 1 and Depot-Branch C-Depot for Vehicle 2. With just two distribution rounds, Vehicle 1 can transport 36 large breads and 723 small breads, while Vehicle 2 can transport 21 large breads and 329 small breads. XYZ Bakery can save distribution costs amounting to Rp. 35,492 and reduce distribution time by 116 minutes, or 1 hour and 56 minutes, compared to the previous conditions. With this optimization, XYZ Bakery can also reduce total carbon emissions by 5.342 kg CO2 per year.

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