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Product Inventory Optimization with EOQ Approach in the context of Circular Economy

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Abstract

This research discusses product inventory optimization by applying the Economic Order Quantity (EOQ) approach in the context of circular economy. Circular economy is an economic model that aims to minimize waste and maximize the use of resources with the concept of make-use-return, which is based on the reuse of existing products and materials. In this context, EOQ is used as a tool to optimize product order quantities using the circularity index. The objective of this study is to determine the optimal inventory level that not only reduces wastage and waste, but also takes into account the positive environmental and economic impacts. In this study, the decision variables considered are product order quantity and circularity level. Data is taken from Toko Papa Singkong as a case study to test this model. The results of the analysis show that the application of EOQ in the context of a circular economy can result in a more efficient and sustainable inventory strategy. The practical implication of this research is to provide guidance for companies in managing their inventory better, while taking into account the principles of the circular economy. In conclusion, this research provides an important contribution in the development of a sustainable inventory strategy in the era of circular economy.

Keywords

Circular Economy, Circularity Index, EOQ, Inventory Optimization.

1. Introduction

Entering the decade of achieving the Sustainable Development Goals and the target of reducing Green House Gas (GHG) emissions, the Government of Indonesia has further strengthened its commitment and efforts in addressing economic, social, and environmental issues (Huang et al., 2021; Khan et al., 2023). One of the approaches adopted is the circular economy, which is considered as a solution to the current environmental crisis. The circular economy involves replacing the current dominant linear production model with an alternative cyclical model that moves from "extract-produce-use-dump" to "reduce-recycle-recover", thus based on extending the useful life of products, reusing, remanufacturing (repair and reconditioning) and recycling (Hart & Pomponi, 2021; Díaz-García et al., 2020).

Several countries, such as the European Union, China, Japan, the United Kingdom, France, Canada, the Netherlands, Sweden, and Finland, have established policies and promoted circular economy (EU Commission, 2014; Zhu et al., 2018). The circular economy model will also be adopted in Indonesia, as outlined in Indonesia's Vision 2045 as one of the long-term policies that Indonesia will implement in the future (Ali & Shaikh, 2024). As a first step in the implementation of the Circular Economy concept, the Government of Indonesia collaborated with the United Nations Development Program (UNDP) supported by the Government of Denmark to prepare a study analyzing the environmental, economic, and social potential of implementing a circular economy in Indonesia (Rabta, 2020).

In the context of a circular economy, the EOQ model can provide insights that the shift to a circular economy is possible without great risk and can even be profitable for the company. By applying the EOQ model, companies can determine the optimal order quantity by taking into account the level of circularity index. This not only helps companies manage inventory more efficiently but also maximizes product use value and reduces waste (Makhfiroh et al., 2022; Becerra et al., 2022).

Efficient product inventory is a key element in managing an effective supply chain, especially in the food and beverages sector which has perishable characteristics (Wani & Mishra, 2022). The Economic Order Quantity (EOQ) approach offers a solution to determine the optimal order quantity to maximize profits. In the context of a circular economy, the food and beverages industry sector are one of the main focuses in the preparation of the National Action Plan (NAP) and development priorities in the National Medium-Term Development Plan (RPJMN) 2025-2029. This fact emphasizes the importance of a sustainable approach in managing supplies, especially in a sector that is the largest contributor to waste, as recorded in the Sistem Informasi Pengelolaan Sampah Nasional (SIPSN) data with the composition of food waste reaching 40.99% in 2023 and 41.5% in 2022.

The implementation of the EOQ model in the circular economy can help companies in the food and beverages sector to reduce waste and improve efficiency (Karim & Nakade, 2022). By optimizing the products used and controlling inventory, companies can avoid overstock problems that often lead to waste and accumulation of unused products (Ripanti & Tjahjono, 2019; Rocchi et al., 2021). Through the application of an EOQ model that has been adapted to the circular economy approach, companies can determine the optimal level of circularity that provides maximum profit. This not only reduces financial losses but also supports sustainability goals by reducing the amount of food waste. This study aims to examine and test an EOQ model adapted for the circular economy, so that it can help companies in the food and beverages sector obtain optimal profits while supporting environmentally friendly business practices.

2. Literature Review

The EOQ (Economic Order Quantity) model was first introduced by Harris in 1913 and is widely known as the classic EOQ model. This model helps companies determine the optimal quantity of goods to order in order to minimize inventory costs. EOQ is based on three main components: ordering costs, holding costs, and constant demand (John & Mishra, 2023). Assuming stable demand, this model provides a balance between holding and ordering costs, allowing companies to minimize total inventory costs (Vennila & Karthikeyan, 2022). The EOQ model remains relevant today due to its simplicity in implementation and effectiveness in inventory management. Despite the emergence of newer, more complex models, EOQ is still frequently used, especially by companies with relatively stable demand patterns. Researchers like Andriolo et al. (2014) have shown that this model is still widely accepted by many companies due to its ability to support operational efficiency.

The classic EOQ model is a mathematical tool used to determine the optimal order quantity that minimizes total inventory costs, which include both ordering and storage costs (Romagnoli et al., 2023; Correani et al., 2023). This model operates under several key assumptions. It assumes that the demand level over a given period is deterministic and constant, meaning demand does not fluctuate unpredictably. Additionally, it only applies to one type of product, assuming that the goods are homogeneous. The model also does not account for stock-outs, implying that the inventory will never run out. Lastly, it assumes that lead time, the time between placing and receiving an order, is zero, meaning orders are fulfilled instantaneously (Lahcen et al., 2022; Correani et al., 2023). These assumptions, while simplifying real-world complexities, allow the EOQ model to be widely used for inventory management in settings where such conditions are met, helping businesses optimize their inventory decisions.

The parameters and variables used in the classic EOQ model include:

D	= Quantity of goods demanded per ordering cycle
K	= Ordering cost (constant for each ordering cycle)
p	= Selling price of goods (per unit)
h	= Storage cost (per unit per year)
Q	= Quantity of goods ordered (per ordering cycle)
Q^*	= Optimal goods order quantity (per order cycle)
T	= Length of period in one order cycle
$TC(Q)$	= Total inventory cost (per order cycle)

Mathematically, the total inventory cost per order cycle can be calculated using the following formula.

$$TC(Q) = \frac{KD}{Q} + pD + \frac{hQ}{2}$$

To calculate the optimal number of orders for goods that minimize total inventory costs, the formulation used is:

$$Q^* = \sqrt{\frac{2KD}{h}}$$

By applying the classic EOQ model, companies can minimize total inventory costs by striking a balance between ordering and storage expenses. The model helps reduce the frequency of excessive ordering, which can lead to higher administrative and handling costs. At the same time, it prevents companies from holding excessive amounts of inventory, which would otherwise result in elevated storage costs. By

optimizing the order quantity, the EOQ model supports efficiency in inventory management, allowing companies to maintain just enough stock to meet customer demand while avoiding unnecessary expenditures. This method ensures that companies can respond to market demand in a timely manner without overcommitting resources to inventory holding. Overall, the classic EOQ model offers a straightforward yet effective approach to managing inventory, contributing to operational cost savings and improved resource allocation within a company.

3. Methods

In this research, the types of data used are primary data and secondary data. Primary data was obtained through observation and direct interview with the owner of Papa Singkong Store, Mr. Krido Santoso. This method aims to obtain in-depth information about the inventory management practices applied in the store and collect data needed for product optimization calculations using the EOQ model in the context of a circular economy. Secondary data was obtained from various sources such as academic literature, which includes journals and research papers that discuss the theory and application of the EOQ model in the circular economy, as well as other documents related to inventory management. This secondary data provides the theoretical and empirical context that strengthens the analysis and interpretation of the research results, and helps in formulating relevant and practical recommendations for product inventory optimization in the food and beverages sector. The population of this study includes all products at Toko Papa Singkong, while the research sample used is the “gethuk bakar” product because the product is the store's flagship product that has many enthusiasts.

The data collection methods for this study involved three main approaches. First, interviews were conducted directly with the owner of Toko Papa Singkong to gather data on demand levels, gross profit, ordering costs, and storage costs. This data will be used in calculations based on the EOQ model, which has been adapted to a circular economy approach to maximize profitability while supporting environmentally responsible corporate practices. Second, direct observations were made at Toko Papa Singkong to closely examine the inventory management and product storage processes. This provided valuable insights into the operational practices of the business. Lastly, a literature study was conducted to gather information from academic sources, including journals, articles, and reports, related to the theory and application of the EOQ model within the context of a circular economy. These methods ensured a comprehensive understanding of the topic, combining practical business data with theoretical knowledge.

4. Results

The EOQ model for the circular economy is developed by building on the classical EOQ model. The classic EOQ model is commonly used to manage inventory under the assumption that product demand is known and constant, with all costs considered linear. Researchers enhanced this model by introducing the variable of product circularity level (ω) to account for sustainability within the circular economy framework. In this adapted model, product demand is influenced by the level of circularity, while remaining deterministic and constant. Additionally, the product's circularity level directly impacts the gross profit per unit, calculated as the difference between the revenue cost per unit and the selling price. However, ordering and storage costs remain unaffected by the degree of circularity. As with the classic model, stockouts are not permitted. This approach integrates environmental considerations into inventory management while maintaining the efficiency of the EOQ model.

The following are the notations used in the Economic Order Quantity (EOQ) model for products in the context of a circular economy:

- ω : Product circularity index
- Q : Order quantity (unit)
- R : Order cycle duration (days)
- $\lambda(\omega)$: Demand rate (units/day),

Where:

$$\lambda(0) = \lambda_0 \text{ and } \lambda(\omega) > 0$$

K : Ordering cost (IDR/day)

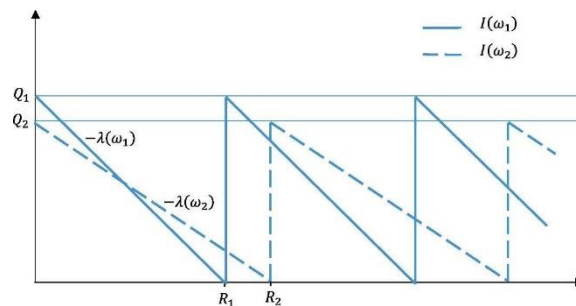
$p(\omega)$: Gross profit per unit (IDR/unit),

Where:

$$p(0) = p_0$$

h : Storage cost (IDR/unit/day)

The product circularity index (ω) has an influence on the inventory level (I), order cycle duration (R), and order quantity (Q) in the EOQ model. For further explanation.



Source: Rabta (2020)

Figure 1. Inventory level I for different circularity indexes

Figure 1 illustrates the variation in inventory level (I) for two different circularity indices, namely ω_1 dan ω_2 . The variation in product circularity index (ω) affects the high level of demand as in $\lambda(\omega_1)$ dan $\lambda(\omega_2)$. The ordering quantity must be able to meet the demand so that when the demand level changes, the company must adjust the ordering quantity (Q) to meet the demand. The difference in circularity index (ω) also affects the inventory level (I) in the warehouse so that the duration of the ordering cycle (R) is also different. Therefore, the storage costs incurred will vary according to changes in the circularity index.

In this EOQ model, level demand and gross profit are functions of the product circularity index (ω). The relationship between product circularity level and unit demand and profit is expressed in the form of a linear equation, where the level of demand is a linear function of ω , that is. $\lambda(\omega) = \lambda_0 + a\omega$, and gross profit per unit is also linearly correlated with ω , with the equation $p(\omega) = p_0 + b\omega$, where a and b are constants. The EOQ model developed in this study has the objective of determining the optimal ordering quantity Q^* and the optimal circularity level ω^* that maximizes profit.

$$\Pi(Q, \omega) = \lambda(\omega)p(\omega) - \frac{\lambda(\omega)K}{Q} - \frac{hQ}{2}$$

The objective of this study is to maximize the average profit of $\Pi(Q, \omega)$ where $0 \leq \omega \leq 1$. This can be written as follows:

$$\begin{cases} \max_{Q, \omega} \Pi(Q, \omega) \\ \text{s. t.} \\ \omega \leq 1 \\ Q, \omega \geq 0 \end{cases}$$

This optimization can be formulated into Lagrangian form:

$$L(Q, \omega, \mu_1, \mu_2) = \lambda(\omega)p(\omega) - \frac{\lambda(\omega)K}{Q} - \frac{hQ}{2} - \mu_1(\omega - 1) + \mu_2\omega$$

To solve the problem, the Lagrangian function must fulfill the necessary conditions using the Karush-Kuhn Tucker (KKT) method. The KKT necessary condition to find the optimal solution is obtained by deriving the function $L(Q, \omega, \mu_1, \mu_2)$ for each variable.

$$\begin{aligned} \frac{\partial L(Q, \omega, \mu_1, \mu_2)}{\partial Q} &= \frac{\lambda(\omega)K}{Q^2} - \frac{h}{2} = 0 \\ \frac{\partial L(Q, \omega, \mu_1, \mu_2)}{\partial \omega} &= \lambda'(\omega)p(\omega) + \lambda(\omega)p'(\omega) - \frac{\lambda'(\omega)K}{Q} - \mu_1 + \mu_2 = 0 \end{aligned}$$

Such that:

$$\begin{aligned} \mu_1(\omega - 1) &= 0 \\ \mu_2\omega &= 0 \\ \mu_1, \mu_2 &\geq 0 \end{aligned}$$

There are three possible cases in this calculation, including:

Case 1: Both the level of demand and gross profit per unit, both increase in proportion to ω (or one increases, while the other is constant).

Thus, $\omega = 0$ and $Q = \sqrt{\frac{2\lambda(1)K}{h}}$, while $\mu_1 = 0$ and

$$\mu_2 = -\left[\lambda'(0)p(0) + \lambda(0)p'(0) - \frac{\lambda'(0)K}{Q}\right].$$

Case 2: Both the level of demand and gross profit per unit decrease in proportion to ω (or one decreases, while the other remains constant).

Thus, $\omega = 1$ and $Q = \sqrt{\frac{2\lambda(0)K}{h}}$, while $\mu_2 = 0$ and

$$\mu_1 = \lambda'(1)p(1) + \lambda(1)p'(1) - \frac{\lambda'(1)K}{Q}.$$

Case 3: One of the demand functions or gross profit per unit increases, while the other decreases.

Thus, $\mu_1 = 0$ dan $\mu_2 = 0$, while $Q = \sqrt{\frac{2\lambda(\omega)K}{h}}$. The value calculation ω can be done using the following equation.

$$\begin{aligned} 2\lambda(\omega)[\lambda'(\omega)p(\omega) + \lambda(\omega)p'(\omega)]^2 \\ = \lambda'(\omega)^2 hK \end{aligned}$$

5. Discussion

This research focuses on product inventory optimization using the EOQ approach in a circular economy context. Data was collected from Papa Singkong, a business that sells “gethuk bakar”, a traditional snack made from cassava. The owner, Mr. Krido Santoso, operates his main store at Jalan Slamet Riyadi No. 54A, Ungaran, Semarang Regency, with two other branches in Randugunting and Sidomukti. Papa Singkong is open every day and sells approximately 1.400 units of “gethuk bakar” per day with a gross profit margin of Rp 8,000 per unit. Every day, product orders are placed with a delivery cost of Rp50,000. Gethuk are stored in freezers to prevent spoilage, with a monthly electricity cost of Rp 3,000,000 for ten freezers that can hold fifty units each.

Based on the interview with Mr. Krido, the following are the parameters for the EOQ model:

Basic demand level (λ_0)	: 1,400 units per day
Base unit gross profit (p_0)	: Rp 8,000 per unit
Ordering cost (K)	: Rp 50,000 per order cycle
Storage cost (h)	: Rp 200 per unit per day

The demand function is a linear function of the product circularity index $\lambda(\omega) = \lambda_0 + a\omega$ where the maximum additional demand factor (a) = 200, while the gross profit function is a function of the product circularity index according to the linear relationship $p(\omega) = p_0 + b\omega$, where the premium factor per unit (b) = -Rp 1,000. In this calculation, the optimal circularity level that can provide maximum profit is sought. There are three possible cases in determining the solution to the problem:

Case 1

Suppose $\omega = 0$ and $\mu_1 = 0$, then

$$\lambda(0) = 1,400$$

$$p(0) = 8,000$$

$$Q \approx 837$$

$$\Pi \approx Rp11,032,668$$

$$\mu_2 = -188,047.7139 < 0$$

This solution is not optimal because $\mu_2 < 0$.

Case 2

Suppose $\omega = 1$ and $\mu_2 = 0$, then

$$\lambda(1) = 1,600$$

$$p(1) = 7,000$$

$$Q \approx 894$$

$$\Pi \approx Rp11,021,114$$

$$\mu_1 = -211,180.33988 < 0$$

This solution is not optimal because $\mu_1 < 0$.

Case 3

Suppose $\mu_1 = 0$ and $\mu_2 = 0$.

The value ω calculation can be done using the following equation.

$$2(\lambda_0 + a\omega)(ap + b\lambda_0 + 2ab\omega)^2 = a^2hK$$

$$640\omega^3 + 3840\omega^2 - 4320\omega + 1116 = 0$$

With the Newton-Raphson method obtained:

$$\omega_1 = 0.47107 \approx 0.47$$

$$\omega_2 = 0.52881 \approx 0.53$$

$$\omega_3 = -6.99988 \approx -7 \text{ (not feasible)}$$

For $\omega = 0.47$, obtained

$$\lambda(\omega) = 1,494, p(\omega) = 7,530$$

$$Q \approx 864$$

$$\Pi \approx Rp11,076,092$$

For $\omega^* = 0.53$, obtained

$$\lambda(\omega^*) = 1,506$$

$$p(\omega^*) = 7,470$$

$$Q^* \approx 868$$

$$\Pi^* \approx Rp11,076,269$$

From the results of the numerical simulation of this linear model, it is obtained that ordering will be optimal if the Papa Singkong store places an order (Q^*) of 868 product units with a circularity level (ω^*) of 0.53. From this order, an optimal profit of Rp11,076,269 will be obtained. To make it easier to observe the effect of circularity index (ω) on profit, the following table presents the comparison results of circularity index (ω) using the linear EOQ model for products with a circular economy approach.

Table 1. Comparison Table of Circularity Index (ω) in Linear Model

Circularity Level (ω)	Order Quantity (Q)	Profit (Π)
0	837 unit	Rp11,032,668
0.47	864 unit	Rp11,076,092
0.53	868 unit	Rp11,076,269
1	894 unit	Rp11,021,115

In Table 1, there is only a slight difference between the optimal profit and the profit corresponding to the trivial solution, which is only 0.4% at $\omega = 0$ and 0.5% at $\omega = 1$. However, it shows that the change to a more circular product can be made without significant loss of profit under certain circumstances, given that the additional cost is compensated by the increase in demand.

The application of the EOQ model has significant implications for Toko Papa Singkong, namely inventory optimization of Gethuk Bakar products. By using EOQ, Toko Papa Singkong can manage their inventory of Gethuk Bakar products more optimally. They can determine the optimal number of orders to get maximum profit. Table 1 shows that circularity levels of 0.47 and 0.53 result in larger earnings than circularity levels of 0 or 1. If the circularity level is 0.47, the Papa Singkong store will order 864 units of items for an optimal profit of Rp11,076,092. Meanwhile, if the circularity level is 0.53, the Papa Cassava store will order 868 units of merchandise for an optimal profit of Rp 11,076,269. To maximize the ordering of "gethuk bakar" products at Papa Singkong Store, utilize a circularity level of 0.47 or 0.53.

In layman's words, ordering approximately 860 units per time to meet a daily requirement of 1,400 units may appear inefficient. However, when viewed logically, this model does not always match the order quantity with the daily need, as ordering more frequently in smaller quantities increases the ordering cost, whilst ordering in big quantities increases the storage cost. With an order volume of approximately 860 units and a demand rate of 1,400 units per day, Papa Singkong will place an order more than once each day. Based on the EOQ calculations:

$$R = \frac{Q}{\lambda(\omega)} = \frac{864}{1,400} \approx 0.6 \text{ Days}$$

This means Toko Papa Singkong will order every 0.6 working days, or about every 7-8 hours. Ordering 860s units each time based on EOQ is a theoretical result that aims to maximize profits.

6. Conclusion

This study introduces an Economic Order Quantity (EOQ) model adapted for the context of the circular economy, with a focus on the food and beverage sector at Toko Papa Singkong. The results show that the level of product circularity, as measured by an index, has an impact on the optimal profit and affects the optimization of the order quantity in the EOQ model. The EOQ model in this study analyzes the optimal order quantity Q^* and the optimal circularity level ω^* that can maximize profits. This model was developed using a linear relationship between the demand function and the gross profit function. The calculation results of the linear relationship model show that ordering will be optimal, if Toko Papa Singkong orders about 860s units of products with a circularity level (ω) of 0.47 and 0.53. When Toko Papa Singkong uses a circularity level of 0.47, then the product order is 864 units with an optimal profit of Rp 11,076,092. Meanwhile, if the Papa Singkong store uses a circularity level of 0.53, then the store orders 868 units of products with an optimal profit of Rp 11,076,269. The results of this calculation reveal that the additional costs incurred in producing products with a higher level of circularity can be offset by increased demand.

The results of this study confirm the importance of circularity levels in EOQ models to optimize ordering and reduce waste, thus supporting sustainability and resource efficiency within the sector. Making products circular is not only economically feasible, but can also support substantial financial returns, as well as provide significant environmental and social benefits. In its implementation to the company, it can shift to circular products without experiencing a significant drop in profits. Thus, the proposed EOQ model uncovers real opportunities in the circular economy, provides strong incentives for companies to adopt sustainable business practices, and accelerates the transition to a more environment-friendly economy.

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