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Analysis of the Effect of Tolerance Value on EOQ Method for Optimization of Inventory Management Model

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Abstract:
This paper discusses the development of the Economic Ordering Quantity (EOQ) model in the form of a deterministic inventory for single-item by adding a tolerance value for perishable goods. The tolerance value given is called α when an order is placed and β when the item is stored, assuming that $\alpha < \beta$. The model in this paper is able to minimize the damage or shrinkage which is controlled from the start, especially for fish, fruit, vegetables and meat. The EOQ model by adding a tolerance value is able to minimize the total inventory cost by increasing the order cycle and controlling the lifetime for each product.

Keywords: *EOQ; inventory management; perishable goods; tolerance value*

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I. Introduction

An effective inventory management system needs to maintain minimal inventory levels as well as contribute to reducing waste or breakdown levels. Much research has been done focusing on different types of inventory policies aimed at maintaining a balance between optimal inventory levels and the number of defects and overall inventory management costs [7].

In recent decades, the EOQ model for perishable goods has received much attention from researchers. Nahmias [8], discusses the problem of determining the appropriate ordering policy for perishable goods, and experiencing an exponentially decline, taking into account deterministic and stochastic demand, and applying the model to blood bank management.

Padmanabhan and Vrat [10] presented an EOQ model for perishable goods with selling prices depending on inventory. The level of sales is assumed to be a function of the current inventory level and the rate of decline is assumed to be constant. Chen [3] analyzes perishable goods using a dynamic programming model with the Weibull distribution approach.

Raafat [11] does research on products that perish and shrink over time such as fruits, vegetables, dairy products, and bakery products, all of these products are discarded if damaged and expired. Bramorski [1] develops a stochastic model that can be used by store managers to help determine the amount and time of discounting prices to be made for each item. Discount decisions are taken every day before the store opens, taking into account the amount of stock available and taking into account the expiration date.

Hsu [4] compiles an inventory model for goods that decrease in quantity and quality over time so that they reach expiration. These types of goods include fish, fruits, vegetables, meat, bread and other food products, by providing discounted prices to increase sales for goods that are about to expire.

Sukhai et al. [12] develops an application and comparative analysis for forecasting demand for inventory management using the EOQ model on the web-based on points of discount. The application of this EOQ model to minimize costs relates to inventory and analyzes sales data from customers to determine which products should be stored to increase sales. Nahmias [9, pp. 1] considers the inventory model of perishable goods by calculating the product life.

The organization of this paper is as follows: section 1 presents the literature review. Section 2 discusses the necessary assumptions and notations. Section 3 develops the EOQ model by adding a tolerance value α at the time of ordering and the tolerance value β at the time of storage. Section 4 gives the comparative analysis of the general EOQ model and the EOQ model by adding tolerance values. Section 5 gives conclusions.

II. Notations and Assumptions

Assumptions

There are several assumptions that must be considered in the EOQ model by adding a tolerance value, which applies to all research items under normal and stable conditions, meaning that this study is carried out regardless of holidays or religious holidays. The assumptions are as follows:

i. Demand is deterministic and constant.
ii. The shelf life of the item is calculated when it arrives at the store.
iii. Lack of inventory is not allowed.
iv. The lead time for each order is zero.
v. Constant purchase price.
vi. Shipping costs are included in the purchase cost.
vii. All items are checked for the condition of the order and the quantity of the order when it arrives at the store.
viii. There is a tolerance value α when the order arrives.
ix. There is a tolerance value β when the goods are stored.
x. The tolerance value at the time of ordering is less than the tolerance value at the time of storage $(\alpha < \beta)$.
xi. All replenishment orders arrive fresh.
xii. Planning time period of 365 days.

Assumptions for the lifetime m are compared with the time period of each reorder cycle t_o . For each item under study is assumed that

a. $t_o \leq m$, or
b. $t_o > m$.

If $t_o \leq m$, then in each order cycle all units are exhausted before the expiration time. However, if $t_o > m$, then there will be inventory that has not been sold out at the time of expiration, which has expired and must be discarded.

Notations

The following notations are used in developing the model:

OC := Ordering cost per year.
HC := Storage cost per year.
TC := Total inventory cost per year.
q := Number of orders.
D := Needs in one planning period.
K := Costs that must be incurred each time an order is made.
h := Costs that must be incurred to keep each unit of inventory.
T^* := Reorder cycle.
t_0 := Optimum time period for each order cycle.
n := Planning time period.
$TC(q)$:= Total cost of inventory incurred when q is ordered.
m := Lifetime for each item.
α := Tolerance value when the order arrives.
β := Tolerance value at the time of storage.

III. EOQ MODEL

Inventory theory discusses how to determine the optimal level of inventory while still serving demand within one period so that the total cost of expenditure is minimized. Taha [13, pp.427-428] explains that the inventory problem involves placing and receiving orders of a certain size on a regular basis, from this point of view inventory policy answers two basic questions, namely how much to order and when to order.

Cargal [2] explains that the EOQ model can determine the order quantity, which balances ordering costs and holding costs to minimize total costs. The larger the order quantity, the less shopping or placing an order. On the other hand, the larger the order quantity, the greater the storage costs incurred. Kumar [6] mentions the EOQ model is a model used to calculate the optimal quantity that can be purchased to minimize inventory holding costs and purchase order processing. Taha [13, pp. 428] states that the purpose of a simple EOQ model is to determine the amount each time an order is placed, so that the minimum total cost is obtained.

Iwu et al. [5] extends the model of Taha [13, pp. 431] and Winston [14, pp. 849-851] using the general EOQ model which is presented in the following equations:

a. Ordering Cost

$$OC = \frac{D}{q}K\,. \tag{1}$$

b. Storage cost

$$HC = \frac{q}{2}h\,. \tag{2}$$

c. Number of order

$$q = \sqrt{\frac{2KD}{h}}\,. \tag{3}$$

d. Total Cost

$$TC = \frac{DK}{q} + \frac{qh}{2}. \tag{4}$$

e. Reorder cycle

$$T^* = \frac{D}{q} \tag{5}$$

f. Time period for each order cycle

$$t_0 = \frac{n}{T^*}\,. \tag{6}$$

As for the EOQ model by adding a tolerance value, it is a development of the general EOQ model, which is to develop it by adding a tolerance value at the time of ordering and a tolerance value at the time of storage. Based on equation (1) of the ordering cost of the general EOQ model, the ordering cost is multiplied by the tolerance value α when the order arrives and is divided by the order per cycle, so that

$$OC = \frac{KD\alpha}{q} \tag{7}$$

Based on the general EOQ model in equation (2), storage costs are the average inventory times orders per cycle times storage costs and times tolerance values β during storage. Storage costs yield

$$HC = \frac{qh\beta}{2} \tag{8}$$

The total cost of inventor $TC(q)$ is the sum of the ordering cost of equation (7) and the cost of holding of equation (8), then the total inventory cost is obtained as follows:

$$TC = \frac{KD\alpha}{q} + \frac{qh\beta}{2} \tag{9}$$

Based on the first derivative test of one variable to determine the optimal value of q, namely by showing the first derivative test and equating it to 0 to obtain

$$\frac{dTC(q)}{dq} = -\frac{KD\alpha}{q^2} + \frac{h\beta}{2}$$

$$-\frac{KD\alpha}{q^2} + \frac{h\beta}{2} = 0$$

$$h\beta q^2 = 2KD\alpha$$

$$q = \sqrt{\frac{2KD\alpha}{h\beta}} \tag{10}$$

Analysis of General EOQ Model and EOQ Model by Adding Tolerance Value

a. *General EOQ model*

The data obtained are presented in Table 1.

Table 1: Item Data

Item	*D*	*K*	*h*	*m*
Fish	12775	50	38.325	3
Meat	1095	50	38.325	15
Fruit	2190	50	38.325	10
Vegetable	14600	50	38.325	2

Assuming that demand occurs at a constant rate and shortages are not allowed. Order costs incurred for each order are in the thousands, and storage costs are in the tens of millions.

Analysis for the general EOQ model determine the optimal order q using equation (3), the cost of ordering using equation (1), the cost of holding using equation (2), the total cost of inventory using equation (4) issued when q is ordered. The results obtained are presented in Table 2. Cost is presented in Indonesian rupiah (IDR) currency.

Table.2: Analysis of EOQ General Model

Item	q	OC	HC	$TC(q)$
Fish	183	3498.577836	3498.577836	6997.155672
Meat	53	1024.278710	1024.278710	2048.557419
Fruit	76	1448.548843	1448.548843	2897.097686
Vegetable	195	3740.137030	3740.137030	7480.274059

Based on Table 2, it can be seen that for the optimal order of fish as much as 183kg with a total inventory cost of IDR6997 millions, for optimal ordering of meat it is carried out as much as 54kg with a total inventory cost of IDR2048 millions. Then for the optimal order of fruit as much as 76kg and the total cost of inventory issued in a year is IDR2897 millions. The optimal order of vegetables is 195kg with a total inventory cost of IDR7480 millions. Then based on the second derivative test, if the second derivative test is greater than 0, then $TC(q)$ is the minimum value of q. The value of q accordingly is proven to minimize the total cost.

b. ***EOQ model by adding tolerance value***

Furthermore, using the same data based on Table 1, an analysis is carried out for the EOQ model by adding a tolerance value. The analysis uses equation (7) to determine the cost of ordering per year, equation (8) to determine the cost of holding per year, equation (9) to determine the optimal number of orders q, equation (10) to determine the total cost of inventory issued when q is ordered. The tolerance value at the time of ordering is less than the tolerance value during storage $\alpha < \beta$. For order tolerance value α = 0.01 and tolerance value at the time of storage β = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1. The results of the analysis are presented in Table 3.

Table 3: Analysis of the EOQ Model by Adding Tolerance Value $\alpha = 0.01$ at the Time of Ordering for Fish Case

β	q	OC	HC	$TC(q)$
0.02	129	49.47736225	49.47736225	98.9547245
0.03	105	60.59714566	60.59714566	121.1942913
0.04	91	69.97155672	69.97155672	139.9431134
0.05	82	78.23057866	78.23057866	156.4611573
0.06	75	85.69730524	85.69730524	171.3946105
0.07	69	92.56366897	92.56366897	185.1273379
0.08	65	98.95472450	98.95472450	197.9094490
0.09	61	104.9573351	104.9573351	209.9146702
0.1	58	110.6347453	110.6347453	221.2694907

The results obtained are based on Table 3. It shows that the EOQ model by adding a tolerance value at the time of ordering is $\alpha = 0.01$ and the tolerance value at the time of storage is $\beta =$ 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1. The optimal order of fish q decreases as the tolerance value β increases during storage and the total inventory cost increases as the number of orders decreases. So the greater the tolerance value when storage is carried out, the less the number of orders made in each order and the total inventory cost is increasing. While ordering costs and holding costs are the same for each change in the tolerance value β at the time of storage.

Tabel 4: Analysis of the EOQ Model by Adding Tolerance Value $\alpha = 0.01$ at the Time of Ordering for Meat Case

β	q	OC	HC	$TC(q)$
0.02	38	14.48548843	14.48548843	28.97097686
0.03	31	17.74102766	17.74102766	35.48205532
0.04	27	20.48557419	20.48557419	40.97114839
0.05	24	22.90356823	22.90356823	45.80713645
0.06	22	25.08960193	25.08960193	50.17920386
0.07	20	27.09986739	27.09986739	54.19973478
0.08	19	28.97097686	28.97097686	57.94195371
0.09	18	30.72836129	30.72836129	61.45672258
0.1	17	32.39053681	32.39053681	64.78107362

Table 4 presents the results of the calculation of the EOQ model by adding a tolerance value at the time of ordering of α and at the time of storage of β for the meat case. The tolerance value at the time of ordering is $\alpha = 0.01$ and the tolerance value at the time of storage is β = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1. Table 4 shows that the optimal order quantity q of meat decreases as the tolerance value β increases during storage and the total inventory cost increases along with the decrease in the number of orders. So the greater the tolerance value when storage is carried out, the less the number of orders made in each order and the total inventory cost is increasing. While ordering costs and holding costs are the same for each change in the tolerance value β at the time of storage.

Tabel 5: Analysis of the EOQ Model by Adding Tolerance Value $\alpha = 0.01$ at the Time of Ordering for Fruit Case

β	q	OC	HC	$TC(q)$
0.02	53	20.48557419	20.48557419	40.97114839
0.03	44	25.08960193	25.08960193	50.17920386
0.04	38	28.97097686	28.97097686	57.94195371
0.05	34	32.39053681	32.39053681	64.78107362
0.06	31	35.48205532	35.48205532	70.96411065
0.07	29	38.32500000	38.32500000	76.65000000
0.08	27	40.97114839	40.97114839	81.94229677
0.09	25	43.45646528	43.45646528	86.91293057
0.1	24	45.80713645	45.80713645	91.61427291

The results obtained are based on Table 5. It shows the EOQ model by adding a tolerance value at the time of ordering is $\alpha = 0.01$ and the tolerance value at the time of storage is β = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1. The optimal order of fruit decreases as the tolerance value β increases during storage and the total inventory cost increases as the number of orders decreases. So the greater the tolerance value when storage is carried out, the less the number of orders made in each order and the total inventory cost is increasing. While ordering costs and holding costs are the same for each change in the tolerance value β at the time of storage.

Tabel 6: Analysis of the EOQ Model by Adding Tolerance Value $\alpha = 0.01$ at the Time of Ordering for Vegetable Case

β	q	OC	HC	$TC(q)$
0.02	138	52.89352512	52.89352512	105.7870502
0.03	113	64.78107362	64.78107362	129.5621472
0.04	98	74.80274059	74.80274059	149.6054812
0.05	87	83.63200643	83.63200643	167.2640129
0.06	80	91.61427291	91.61427291	183.2285458
0.07	74	98.95472450	98.95472450	197.9094490
0.08	69	105.7870502	105.7870502	211.5741005
0.09	65	112.2041109	112.2041109	224.4082218
0.1	62	118.2735177	118.2735177	236.5470355

The same thing is also shown from the results obtained based on Table 6, that is the EOQ model by adding a tolerance value at the time of ordering is $\alpha = 0.01$ and the tolerance value at the time of storage is β = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.1. Optimal vegetable orders decrease as the tolerance value β increases during storage and the total inventory cost increases as the number of orders placed decreases. So the greater the tolerance value when storage is carried out, the less the number of orders made in each order and the total inventory cost is increasing. While ordering costs and holding costs are the same for each change in the tolerance value β at the time of storage.

Based on the EOQ model by adding a tolerance value α at the time of ordering and the tolerance value β at the time of storage shows that ordering costs per year, holding costs per year and total inventory costs per year are less than the general EOQ model. Then based on the second derivative test, if the second derivative test is greater than 0, then $TC(q)$ is the minimum value for q. It can be shown that the value of q is proven to minimize the total cost.

c. *Lifetime of General EOQ Model and EOQ Model with Added Tolerance Value*

This section discusses the lifetime of the product studied in this study. Equation (6) is to determine the time period for each reorder cycle. Equation (5) is a reorder cycle and to determine the service life based on the information provided by the store with a planning time period for all items in 365 days meaning that in 1 year there are 365 days. Equation (3) is to determine the number of orders. All shipments are assumed to be new goods only. Using the general EOQ model gives Table 7.

Table 7: General Model Analysis of EOQ

Item	q	$TC(q)$	T^*	t_0	m
Fish	183	6997.155672	70	5	3
Meat	53	2048.557419	20	18	15
Fruit	76	2897.097686	29	13	10
Vegetable	195	7480.274059	75	5	2

The analysis of the general EOQ model presented in Table 7. It also shows that ordering 183kg of fish requires a total inventory cost of IDR6997 millions with an order cycle time of 70 times per year, and the time period for ordering occurs in 5 days. Furthermore, for each order of 53kg of meat, the total inventory cost incurred is IDR2048 millions with a cycle time of ordering 20 times per year, and the ordering period is 18 days. Meanwhile, for each order of fruit is 76kg with an optimal total inventory cost of IDR2897 millions and the order cycle in one year is 29 times per year with an ordering period of 13 days. Then for every 195kg vegetable order, the total inventory cost is IDR7480 millions and the order cycle time occurs 75 times per year with the order time period occurring in 5 days.

Based on Table 7 it can be seen that for the case of fish, the time for ordering is done within 5 days, while the shelf life or shelf life of fish is only 3 days. So for the fish $t_0 > m$ or 5 > 3, it means that there are fish that are not sold out when their useful life is up or in other words there are fish that are experiencing decay. The same thing happens to meat when ordering is longer than the shelf life $t_0 > m$ or 18 > 15, meaning that there is meat that has not been sold at the end of its useful life or there is meat that is spoiled and must be discarded. Fruits and vegetables also experience the same thing, meaning that there are fruits and vegetables that experience decay and must be disposed of due to the longer ordering time compared to the product life. So it can be concluded that, using the general EOQ model of all products in this study $t_0 > m$ means that all products have not been sold when their useful life has expired. This indicates that there is a product that has decayed and must be discarded.

Furthermore, for the EOQ model by adding a tolerance value $\alpha = 0.01$ at the time of ordering and the tolerance value β at the time of storage uses equation (6) to determine the time period for each reorder cycle, equation (5) to determine the reorder cycle and to determine the service life based on the information provided by the store with a planning time period for all items in 365 days. For the number of orders, equation (9) is applied to get Table 8.

Table 8: EOQ Model Analysis by Adding Tolerance Value $\alpha = 0.01$ at Time of Order

Item	β	q	$TC(q)$	T^*	t_0	m
Meat	0.03	105	121.19430	121	3	3
Fruit	0.02	38	28.97098	28	13	15
Vegetable	0.02	53	40.97115	41	9	10
Fish	0.05	87	167.26400	167	2	2

Table 8 shows the analysis of the EOQ model by adding the tolerance value $\alpha = 0.01$ at the time of ordering and the tolerance value $\beta = 0.03$ at the time of storage for the case of fish, the optimal number of orders is 105kg with a total inventory cost of IDR121 millions, the order cycle per year is 121 times with the order time period occurring once in 3 days. If the fish lifetime is 3 days, then the fish order time period occurs right when the fish runs out. This means that all fish are sold out before their useful life or before the fish undergoes spoilage. The total cost of inventory and the order quantity of the EOQ model by adding the tolerance value issued is lower and less than the general EOQ model. The EOQ model by adding a tolerance value is also able to increase the order cycle per year which results in a decreased ordering time period. This is very suitable for handling cases of goods that are easily damaged, because the time period for ordering and the life of the goods can be controlled from the start. So that the tolerance value given at the time of storage can control the amount of orders that will be made in each order, this results in the accumulation of goods can be controlled and does not occur.

The same thing also happens for the case of meat and fruit. Table 8 presents the EOQ model by adding a tolerance value $\alpha = 0.01$ at the time of ordering and the tolerance value $\beta = 0.02$ at the time of storage resulting in the optimal order quantity of meat as much as q = 38kg and fruit as much as 53kg with a total inventory cost for each order of q meat of IDR28 millions and the total cost of inventory for each ordering of fruit as much as IDR40 millions, the cycle of ordering meat per year occurs as much as 28 times and cycle time of ordering fruit occurs 41 times per year, with a time period of ordering meat occurs once in 13 days and the time period for ordering fruit occurs in 9 days. If the shelf life of meat is 15 days and the fruit life is 10 days, then $t_0 \leq m$ the time period for ordering meat and fruit occurs before their useful life expires. This means that all meat and fruit are sold out before their useful life or in other words before the meat and fruit undergo spoilage.

Table 3 shows the analysis of the EOQ model of vegetables by adding a tolerance value $\alpha = 0.01$ at the time of ordering and a storage tolerance value β = 0.05. The optimal order quantity is 87kg of vegetables with a total inventory cost of IDR167 millions, the order cycle per year is 167 times with the ordering time period occurring once in 2 days. If the shelf life of vegetables is 2 days, then the time period for ordering vegetables occurs right when the vegetables run out. This means that all vegetables are sold out before their useful life or before the vegetables are spoiled. The total cost of inventory and the order quantity of the EOQ model by adding the tolerance value issued is lower and less than the general EOQ model.

The EOQ model by adding a tolerance value is also able to increase the order cycle per year which results in a decreased ordering time period. To handle cases of perishable goods, the EOQ model by adding a tolerance value is able to minimize damage or shrinkage caused by service life. The time period for ordering and the shelf life of goods can be controlled from the start. So that the tolerance value given at the time of storage can control the amount of orders that will be made in each order, so that the accumulation of goods does not occur.

Figure 1 shows the optimal order with a tolerance value $\alpha = 0.01$ when ordering and a storage tolerance value β = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1. The optimal order quantity continues to decrease every time an order is placed, along with changes in the tolerance value β when storage is in progress.

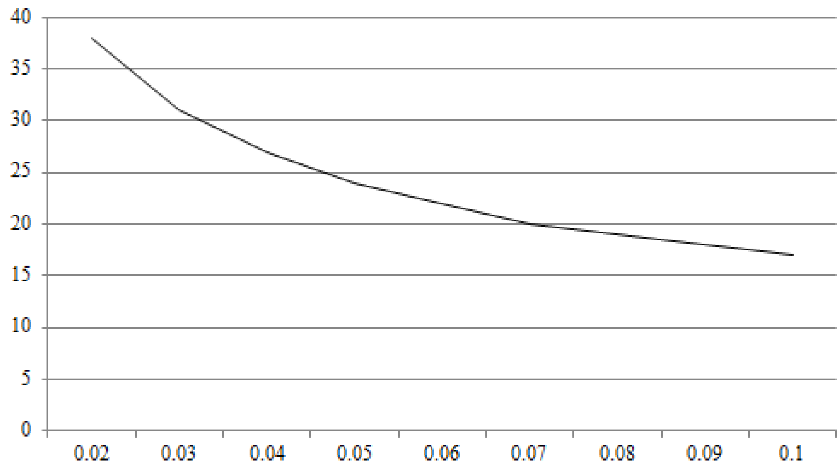

Figure 1: Optimal Order

Figure 2 shows the order cycle per year with a tolerance value $\alpha = 0.01$ when ordering and a storage tolerance value β = 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1. The order cycle is increasing every year in every change in the value of the storage tolerance β that is made.

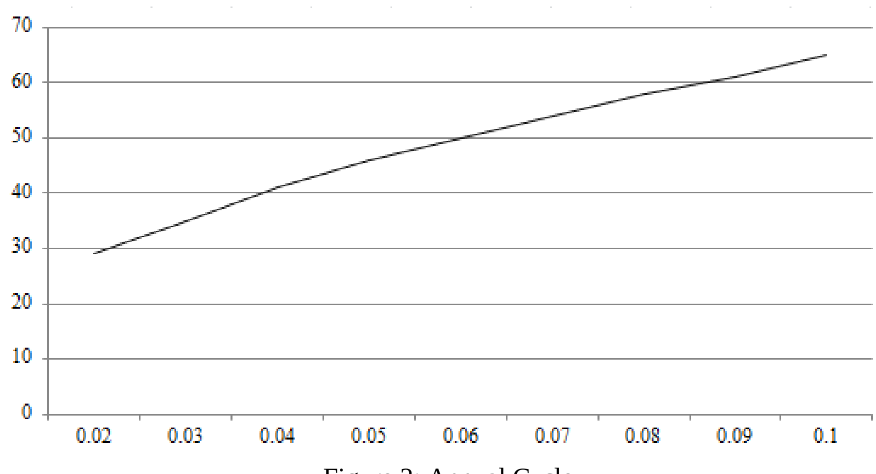

Figure 2: Annual Cycle

Based on Figure 1 and Figure 2, it can be concluded that the ordering cycle increases with every change in the given β storage tolerance value and the optimal order quantity decreases with changes in the given β storage tolerance value. The decrease in the order quantity q is able to minimize the total cost of inventory issued each year.

IV. Conclusion

Based on the analysis and discussion presented in section 4, it can be concluded that the EOQ model by adding a tolerance value is better than the general EOQ model. The results of the analysis of the EOQ model are tolerable values with the assumption that the errors at the time of ordering are smaller than the errors that occur during storage, so it appears that the value of $\alpha < \beta$ is able to minimize the total cost of inventory. The tolerance value for the EOQ model of perishable items can be an alternative, this is because it is able to minimize the level of damage and expiration, with a small amount of orders made with more frequent ordering cycles.

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