BAREKENG: Journal of Mathematics and Its Applications
March 2023 Volume 17 Issue 1 Page 0021–0028
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol17iss1pp0021-0028

AN EOQ MODEL FOR DETERIORATING AND AMELIORATING ITEMS UNDER CUBIC DEMAND AND PARTIAL BACKLOGGING

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ABSTRACT

Article History:

Received: 16th July 2022
Revised: 6th November 2022
Accepted: 6th January 2023

Keywords:

Amelioration;
Deterioration;
EOQ;
Partial Backlogging;
Shortage.

The inventory model aims to determine policies in inventory control. Therefore, the availability needs to be managed as well as possible to obtain optimal performance. This study aimed to produce EOQ models for deteriorating and ameliorating products with shortage and partial backlogging policies. The traditional Economic Order Quantity (EOQ) inventory model was used to develop the model. The search algorithm of the model solution was made to get a solution from the model. In the end, a case study of the model implementation at Minimarket SATUMART, Sidoarjo, is given.

How to cite this article:

H. N. Laily, S. Abusini and U. Sa'adah, "AN EOQ MODEL FOR DETERIORATING AND AMELIORATING ITEMS UNDER CUBIC DEMAND AND PARTIAL BACKLOGGING," *BAREKENG: J. Math. & App.*, vol. 17, iss. 1, pp. 0021-0028, March, 2023.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*

Research Article • Open Access

1. INTRODUCTION

Inventory control is a prevention that is carried out so that there is no inventory shortage or excess inventory where the level of consumer demand is uncertain [1]. In inventory control, the type of goods or products must also be considered because not all products can last long during storage and be damaged, causing losses to suppliers and buyers. Goods that experienced deterioration included food products, medicines, blood banks, electronics, and food ingredients. Therefore, it is necessary to take care of or maintain the goods. Goods or products that experience an increase during maintenance or maintenance are called ameliorating items or goods that experience amelioration [2][3][4].

Rice is one of the main staple foods for Indonesian people that are easily damaged. An attack by Sitophilus oryzae can cause this damage. Based on the research conducted by Syahrullah et al., it was shown that the relationship between the number of imago Sitophilus oryzae and the percentage of damage to rice had a positive relationship with a correlation of more than 50%. Thus, the higher the number of imago, the greater the damage to the rice. [5].

Inventory control research by considering amelioration and deterioration has also been widely carried out. Aisha et al. developed the basic EOQ model with production-distribution integration for damaged products with Backorder policies [6]. Shanti and Karthikeyan developed an EOQ model for three cases of deterioration items with a Weibull distribution of deterioration rates and a time-dependent cubic function of demand. In the first case, it is assumed that there is a partial backlog and a shortage. The second is a shortage with a full backlog, and the third is no shortage [7]. Chatterji extends the inventory model for defective products with exponential improvement, two Weibull parameters, demand rate patterns, and storage costs [8]. Mallick et al. added the assumption of the backlog level as a variable that depends on the waiting time for the following procurement [9]. Pratibha Yadav has also conducted research with Weibull distributed demand and production rates [10]. Mandal developed a research model by considering the degree of amelioration of the Weibull distribution and allowing a full backlog [11][12]. In 2021, Mandal was also conducting research considering exponential demand rates and allowing partial backlogging [13]. Sahoo and Paul developed an inventory model for deteriorating items with uniform procurement levels and Weibull demand, but no shortages occurred [14]. Vora and Gothi also developed a model developed by Mandal but added with consideration that storage costs are a linear function [15]. Other studies that consider damaged goods have also been carried out by Mishra et al., Krishnaraj, and Venkateswarlu [16][17][18][19].

Research on the EOQ model for products that experience deterioration is still small, and there is not much amelioration, which is prevention so that deterioration does not occur or reduces the loss of goods. In addition, it does not allow shortages with backlogging, which is the economic consequence of unfulfilled orders that will be fulfilled later. Therefore, the author wants to develop an EOQ model for products that experience deterioration and amelioration with partial shortage and backlog policies so that products in inventory become more optimal and produce lower inventory costs.

The research questions that will be answered in this study are: 1) How to develop a basic EOQ model for products that experience deterioration (a decrease in value after a specific time) and amelioration (increase in goods after maintenance) with shortage and partial backlogging policies? How is the implementation and sensitivity analysis of the resulting model?

2. RESEARCH METHODS

2.1 Initial Identification

The initial identification stage includes the stage of literature study, problem identification, problem formulation, determination of research objectives as a basic framework for further research directions, and literature review.

2.2 Model Development

At this stage, data collection and processing were used to develop the model to obtain the optimal value of the decision variable. Model development begins with system characteristics, model formulas, and finding the optimal solution for the model.

2.3 Application of Model Development

The results of the model development in this study were applied to the inventory data of the SATUMART Minimarket, Sidoarjo.

2.4 Numerical Simulation

This stage is a numerical simulation stage of the EOQ supply model for amelioration and deterioration of products with cubic demand and shortage using the parameters obtained.

2.5 Sensitivity Analysis

At this stage, a sensitivity analysis was carried out on the effect of changes in parameter values A_0, p_c, h_c, d_c, a_c, c_s, o_c, θ, and δ to the objective function based on the model that has been developed. This analysis was done by making some parameter changes. The purpose of conducting this sensitivity analysis is to see the level of sensitivity of the model to one or more factors involved in the model.

The notations used in the formulation of this mathematical model are as follows:

A_0	=	The cost of ordering each unit during the cycle (Rp)
a	=	The first demand level
b	=	The second demand level
c	=	The third demand level
d	=	The fourth demand level
θ	=	The deterioration level of goods (decrease in the quality of goods) where $0 \leq \theta < 1$
p_c	=	Purchase cost per unit (Rp /unit)
h_c	=	Storage cost per unit (Rp /unit)
d_c	=	Deterioration cost per unit (Rp /unit)
a_c	=	Amelioration cost per unit (Rp /unit)
c_s	=	Shortage cost per unit (Rp/unit)
T	=	The length of one inventory cycle
α	=	Shape parameters on the Weibull distribution
β	=	Scale parameters in the Weibull distribution
$I(t)$	=	Total inventory at time t
$A(t)$	=	The amelioration level at time t
$R(t)$	=	The demand level at time t
TC	=	the average total cost of each item

The assumptions used in this study were as follows:

1. The waiting time is zero.
2. Finite increment size.
3. Time horizon is limited.
4. There is no repair of damaged items during the current cycle.
5. Amelioration and deterioration occur when the item is in stock.
   $A(t)$ is the amelioration rate with the Weibull distribution
   $$A(t) = \alpha\beta t^{\beta-1}, \qquad 0 \leq \alpha < 1, \qquad \beta \geq 1$$
   where α is the parameter of shape and scale.
6. The demand rate is a cubic function (x^3) that depends on time
   $$R(t) = a + bt + ct^2 + dt^3, a \geq 0, b \geq 0, c \geq 0, d \geq 0$$
   where a is the first demand level, b is the second demand level, c is the third demand, level and d is the fourth demand level.
7. Shortage is allowed, and the notation is used. The unfulfilled demand enters the backlog, and a small shortage is ordered back is $e^{\delta t}$. δ is a positive constant and t is the waiting time for the next addition (item). It can be assumed that $te^{-\delta t}$ is a nested function (*increasing*).[20]
8. Storage costs are a linear function of time [15]
   $$\boldsymbol{h_c = h + rt, h > 0,\ r > 0}$$

3. RESULTS AND DISCUSSION

3.1. Writing Mathematical Equations

In this study, the EOQ model used starts with no shortage of goods. Therefore, the procurement of goods is carried out when $t = 0$ and the inventory level reaches the maximum. At $t = 0$ to $t = t_1$, the stock will decrease due to amelioration, deterioration, and demand levels, causing goods to return to zero at $t = t_1$. Shortage occurs during $[t_1, T]$ with the policy that only some goods are reprocured. The model is described by the differential equation as follows.

$$\frac{dI(t)}{dt} + \left(\theta - \alpha\beta^{\beta-1}\right)I(t) = -(\alpha + bt + ct^2 + dt^3), 0 \leq t \leq t_1 \tag{1}$$

$$\frac{dI(t)}{dt} = -(\alpha + bt + ct^2 + dt^3)e^{-\delta(T-t)}, t_1 \leq t \leq T \tag{2}$$

with initial conditions $I(0) = Q$ and $I(t_1) = 0$.

The solution of the differential equation using the initial conditions for any time t is as follows.

$$I(t) = Q\left(1 - \theta + \alpha t^{\beta}\right) - \left\{\alpha t + \left(\frac{b}{2} - \frac{a\theta}{2}\right)t^2 + \left(\frac{c}{3} + \frac{b\theta}{6}\right)t^3 + \left(\frac{d}{4} - \frac{c\theta}{12}\right)t^4 - \frac{d\theta}{20}t^5 + \frac{a\alpha\beta}{\beta+1}t^{\beta+1} + \frac{b\alpha\beta}{2(\beta+2)}t^{\beta+2} + \frac{c\alpha\beta}{3(\beta+3)}t^{\beta+3} + \frac{d\alpha\beta}{4(\beta+4)}t^{\beta+4}\right\}, \text{for } 0 \leq t \leq t_1 \tag{3}$$

and

$$I(t) = \left[\frac{(\alpha + bt + ct^2 + dt^3)}{\delta} - \frac{(3dt^2 + 2ct + b)}{\delta^2} + \frac{(6dt + 2c)}{\delta^3} + \frac{6d}{\delta^4}\right]e^{-\delta(T-t)} \tag{4}$$

Based on the initial conditions $I(t_1) = 0$, the inventory equation obtained from **Equation (3)** is as follows.

$$Q = at_1 + \left(\frac{b}{2} + \frac{a\theta}{2}\right)t_1^2 + \left(\frac{c}{3} + \frac{b\theta}{3}\right)t_1^3 + \left(\frac{d}{4} + \frac{c\theta}{4}\right)t_1^4 + \frac{d\theta}{5}t_1^5 - \frac{a\alpha}{\beta+1}t_1^{\beta+1} - \frac{b\alpha}{\beta+2}t_1^{\beta+2} - \frac{c\alpha}{\beta+3}t_1^{\beta+3} - \frac{d\alpha}{\beta+4}t_1^{\beta+4} \tag{5}$$

3.2. Cost Component

Components of inventory costs during the period $[0, T]$ consist of storage costs, ordering costs, purchasing costs, deterioration costs, amelioration costs, and shortage costs which are explained as follows:

a. Ordering costs (OC) $= A_0$

b. Purchase cost (PC) $= p_c I(O) = p_c Q = p_c\left[at_1 + \left(\frac{b}{2} + \frac{a\theta}{2}\right)t_1^2 + \left(\frac{c}{3} + \frac{b\theta}{3}\right)t_1^3 + \left(\frac{d}{4} + \frac{c\theta}{4}\right)t_1^4 + \frac{d\theta}{5}t_1^5 - \frac{a\alpha}{\beta+1}t_1^{\beta+1} - \frac{b\alpha}{\beta+2}t_1^{\beta+2} - \frac{c\alpha}{\beta+3}t_1^{\beta+3} - \frac{d\alpha}{\beta+4}t_1^{\beta+4}\right]$

c. Storage cost (HC) $= h_c I_t = h_c\left[\frac{a}{2}{t_1}^2 + \left(\frac{b}{3} + \frac{a\theta}{6}\right){t_1}^3 + \left(\frac{c}{4} + \frac{b\theta}{8}\right){t_1}^4 + \left(\frac{d}{5} + \frac{c\theta}{10}\right){t_1}^5 + \frac{d\theta}{12}{t_1}^6 - \frac{a\alpha\beta}{(\beta+1)(\beta+2)}{t_1}^{\beta+2} - \frac{b\alpha\beta}{(\beta+1)(\beta+3)}{t_1}^{\beta+3} - \frac{c\alpha\beta}{(\beta+1)(\beta+4)}{t_1}^{\beta+4} - \frac{d\alpha\beta}{(\beta+1)(\beta+5)}{t_1}^{\beta+5}\right]$

d. Deterioration cost (CD) $= d_c D_T = d_c\theta\left\{\frac{a}{2}t_1^2 + \left(\frac{b}{3} + \frac{a\theta}{6}\right)t_1^3 + \left(\frac{c}{4} + \frac{b\theta}{8}\right)t_1^4 + \left(\frac{d}{5} + \frac{c\theta}{10}\right)t_1^5 + \frac{d\theta}{12}t_1^6 - \frac{a\alpha\beta}{(\beta+1)(\beta+2)}t_1^{\beta+2} - \frac{b\alpha\beta}{(\beta+1)(\beta+3)}t_1^{\beta+3} - \frac{c\alpha\beta}{(\beta+1)(\beta+4)}t_1^{\beta+4} - \frac{d\alpha\beta}{(\beta+1)(\beta+5)}t_1^{\beta+5}\right\}$

e. Amelioration cost (AMC) $= a_c A_T = a_c\left[\frac{a\alpha}{\beta+1}t_1^{\beta+1} + \frac{b\alpha}{\beta+2}t_1^{\beta+2} + \frac{c\alpha}{\beta+3}t_1^{\beta+3} + \frac{d\alpha}{\beta+4}t_1^{\beta+4}\right]$

f. Shortage cost (CS)$= c_s S_T = c_s\left[-e^{-\delta(T-t_1)}\left[\frac{(\alpha+b(T-t_1)+c(T-t_1)^2+d(T-t_1)^3)}{\delta^2} - \frac{(2b+4c(T-t_1)+6d(T-t_1)^2)}{\delta^3} + \frac{(18d(T-t_1)+6c)}{\delta^4} - \frac{24d}{\delta^5}\right]\right]$

3.3. Model Solutions

Based on the previous cost components, the total cost of inventory in the period [0,T] is:

$$TC(t_1) = \frac{1}{T}[OC + PC + HC + CD + AMC + CS] \\ = \frac{1}{T}[A_0 + p_c Q + h_c I_t + d_c D_T + a_c A_T + c_S S_T] \tag{6}$$

The conditions required for the total inventory cost to be minimum are: $\frac{dTC(t_1)}{dt_1} = 0$, therefore

$$\frac{dTC(t_1)}{dt_1} = 0$$

$$p_c\left[a + (b + a\theta)t_1 + (c + b\theta){t_1}^2 + (d + c\theta){t_1}^3 + d\theta {t_1}^4 - a\alpha {t_1}^{\beta} - b\alpha {t_1}^{\beta+1} - c\alpha {t_1}^{\beta+2} - d\alpha {t_1}^{\beta+3}\right] + (h_c + \theta d_c)\left[a t_1 + \left(b + \frac{a\theta}{2}\right){t_1}^2 + \left(c + \frac{b\theta}{2}\right){t_1}^3 + \left(d + \frac{c\theta}{2}\right){t_1}^4 + \frac{d\theta}{2}{t_1}^5 - \frac{a\alpha\beta}{(\beta+1)}{t_1}^{\beta+1} - \frac{b\alpha\beta}{(\beta+1)}{t_1}^{\beta+2} - \frac{c\alpha\beta}{(\beta+1)}{t_1}^{\beta+3} - \frac{d\alpha\beta}{(\beta+1)}{t_1}^{\beta+4}\right] + a_c\alpha\left[a{t_1}^{\beta} + b{t_1}^{\beta+1} + c{t_1}^{\beta+2} + d{t_1}^{\beta+3}\right] - c_s e^{-\delta(T-t_1)+1}\left[\frac{18d(T-t_1)+6c}{\delta^4} + \frac{4c(T-t_1)+6d(T-t_1)^2+2b}{\delta^3} + \frac{b(T-t_1)+d(T-t_1)^3+c(T-t_1)^2+a}{\delta^2} - \frac{24d}{\delta^5}\right]\left[\frac{-b-2c(T-t_1)-3d(T-t_1)^2}{\delta^2} + \frac{-4c-12d(T-t_1)}{\delta^3} - \frac{18d}{\delta^4}\right] = 0 \tag{7}$$

The minimum conditions that are met are with condition $\frac{d^2TC(t_1)}{d{t_1}^2} > 0$. After the two conditions above are fulfilled, then, for example $t_1 = t_1^*$ is the optimal value of t_1. Therefore, the optimal value of the amount of inventory that must be ordered during the cycle (Q^* from Q) and the optimal value of the total inventory cost (TC^* from TC) is obtained by substituting the value of $t_1 = t_1^*$ from **Equation (5)** and **Equation (6)**.

3.4. Model Implementation

As an implementation of the model, data taken from SATUMART Minimarket, Sidoarjo, was used, in which calculations were carried out with the assistance of Matlab software with $\alpha = 0{,}001$, $\beta = 2$, and $\delta = 0{,}5$ as follows.

Table 1. Parameter Values

Components	Value
Ordering costs (A_0)	Rp249.425/ order
1st demand level (a)	300 unit
2nd demand level (b)	200 unit
3rd demand level (c)	100 unit
4th demand level (d)	30 unit
deterioration rate (θ)	0,8
purchase costs (p_c)	Rp72.493,25/unit
storage costs (h_c)	Rp173.983,8/unit
deterioration costs (d_c)	Rp57.994,6/unit
amelioration costs (a_c)	Rp101.490,55/unit
shortage costs (c_s)	Rp217.479,75/unit
The length of one inventory cycle (T)	1 year

***Data source**: SATUMART Minimarket, Sidoarjo*

The calculation results in Table 1 for $\theta = 0{,}8$ are obtained:

a. Order time (t_1^*) = 0,35 year
b. Number of orders (Q^*) = 136 unit
c. Total cost of inventory (TIC^*) = Rp15.279.102,88

3.5. Sensitivity Analysis

Sensitivity analysis is performed by changing the parameter values in the model. The parameter changes are 25% and 50% of the parameter values in the model implementation. The parameters to be observed in this study are $A_0, p_c, h_c, d_c, a_c, c_s, \theta, and\ \delta$ shown in **Table 2** as follows.

Table 2. The Effects of Changing Parameters on the Model

Parameter	%	% Change	
		Q^*	TIC^*
A_0	−50%	No effect	0,008
	−25%		0,004
	+25%		-0,004
	+50%		-0,008
p_c	−50%	No effect	0,16
	−25%		0,32
	+25%		−0,16
	+50%		−0,32
h_c	−50%	No effect	0,13
	−25%		0,07
	+25%		-0,07
	+50%		-0,13
d_c	−50%	No effect	0,04
	−25%		0,02
	+25%		-0,02
	+50%		-0,04
a_c	−50%	No effect	0,00002
	−25%		0,00001
	+25%		-0,00001
	+50%		-0,00002
c_s	−50%	No effect	-0,000003
	−25%		-0,000001
	+25%		0,000001
	+50%		0,000001
θ	−50%	0,06	0,09
	−25%	0,03	0,05
	+25%	-0,03	-0,05
	+50%	-0,06	-0,09
δ	−50%	2,02	-0,29
	−25%	1,60	1,16
	+25%	-2,19	-3,54
	+50%	-4,76	-9,99

4. CONCLUSIONS

Based on the discussion that has been described above, the following conclusions are obtained:

1. The results of numerical simulations on the EOQ inventory model developed in this study are $\alpha = 0{,}001$, $\beta = 2$, and $\delta = 0{,}5$ optimal ordering time (t_1^*) is $0{,}35$. The optimal order quantity for the model (Q^*) is 136 units. The total inventory cost (TIC^*) is $Rp15.279.102{,}88$.
2. In the sensitivity analysis, changes in the ordering cost of each message during the cycle (A_0), purchase costs per unit (p_c), storage costs per unit (h_c), deterioration costs (d_c), amelioration costs (a_c), and shortage costs (c_s) have no effect on the optimal order quantity. Meanwhile, the deterioration level (θ) and positive constant (δ) have an effect on the optimal number of orders. Positive constant (δ) has a significant effect compared to other parameters on the optimal order quantity and total inventory cost.

ACKNOWLEDGMENT

The authors would like to thank to all participants involved in this research.

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