Original Research

Economic Order Quantity Model for Agricultural Products with Harvest Period

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Abstract
This study aims to develop an Economic Order Quantity (EOQ) model for agricultural products with a harvest period. These agricultural products can be stored for a long period, such as coffee and rice. The developed model assumes that the product can only be supplied during the harvest period while the demand is continuously increasing throughout the year. The harvest period only takes place once a year. During harvest, product orders are made to meet demand during harvest and storage to meet demand during non-harvest periods. The storage process will require a warehouse with sufficient capacity to accommodate the same number of products as demand in the non-harvest period. The developed model optimizes the order time interval with a minimum total inventory cost. Based on the optimization results, it can be calculated the frequency of orders, the quantity per one order, the minimum warehouse capacity that must be prepared, and the total cost of ordering per year. Based on sensitivity analysis, changes in harvest and non-harvest periods have a significant effect on total costs.

Keywords - Agricultural products; Economic order quantity (EOQ); inventories

INTRODUCTION

The classic Economic Order Quantity (EOQ) model was first introduced by Harris in 1913[1]. This EOQ model determines the optimal order quantity to minimize the total inventory cost, including ordering and storage costs. Taft, in 1918, developed Harris's model for a production system, where products are gradually being produced at known rates. His efforts led to a new generation of inventory models, namely the Economic Production Quantity (EPQ) model. The classical model assumes ideal conditions. Many researchers have created and proposed new models to design a more realistic inventory system over the years including, for instance, an inventory model intended for perishable products where the damage level variable is considered [2]–[9], supply models for the repairable products such as military products [10],[11], and an inventory model for the reusable products such as bottles [12]. The inventory model is proposed to assume that not all products received have good quality [13]–[19]. The inventory model considers deteriorating products or products with a shelf life [20]–[23]. The nature of a product that grows and gains weight is known as a growth product, whose value and size increase over time [24]–[28]. Over the years, more efforts have been made to develop and optimize inventory models in different systems. All the models proposed in the literature have in common that the product is always available at any time, even though some products can only be ordered at a certain period, for example, agricultural products that can only be ordered during the harvest period.

These agricultural products refer to the products that have a long shelf life to be stored for a long time, such as rice, coffee, corn, and wheat. These products can only be ordered during the harvest period while consumed every day. For this reason, an adequate stock must be made so that during the non-harvest period, the demand can be served. For example, coffee is a commodity. That agricultural product has a harvest period from April to August, while the non-harvest period is from September to March [29]. Meanwhile, the demand for coffee is increasing every day.

Few researchers have carried out certain supplies for agricultural products [30], [31]. The results of this study are a model and algorithm of inventory for farm products. However, the previous research has assumed that the product is available throughout the year or does not consider the harvest period. The study by Mauluddin et al. [29] succeeded in describing inventory in agricultural products that took into account the harvest period. However, that research did not produce a mathematical model, and it only simulated the conditions of the inventory. In this study, the EOQ model was developed based on the inventory conditions.

MODEL FORMULATION

Schematically, we can illustrate the inventory condition of agricultural products for one year in Figure 1. During the harvest period (t_1), Q units of coffee are ordered with a frequency of n times. The orders made during the harvest period must be sufficient to meet the demand during the harvest (D_1) and storage (M) to meet the demand (D_2) during the non-harvest period (t_2).

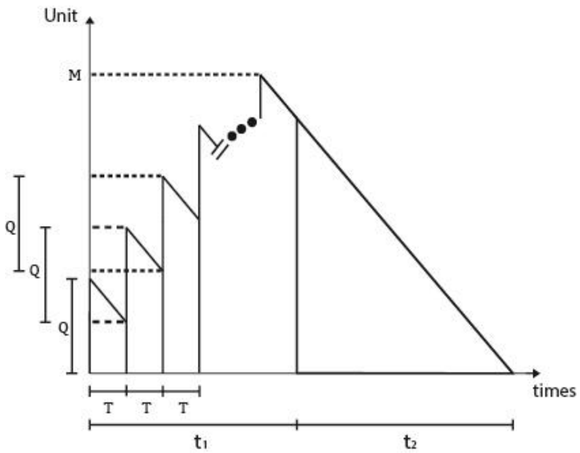

FIGURE 1
INVENTORY CONDITIONS FOR AGRICULTURAL PRODUCTS

ASSUMPTIONS AND NOTATIONS

The assumption of this model is similar to the classic EOQ model assumption. However, there is a loose assumption in this model that the product is unavailable in any period or only available in the harvest period. The notation used in this model are:

A : Ordering cost
h : Holding cost
D_1 : Demand in the harvest
D_2 : Demand on non-harvest period
Q_1 : Quantity order for the harvest period
Q_2 : Quantity order for the non-harvest period
Q : Economic quantity order
t_1 : The number of days of harvest
t_2 : The number of days of the non-harvest period
n : Frequency of ordering
T : Order interval
M : Max Inventory

FORMULATION

Total Cost. (TC)
The costs involved in this model are the ordering cost and holding cost. Total cost is a sum between the ordering cost and holding cost.

$$TC = Total\ Ordering\ Cost\ + Total\ Holding\ Cost \quad (1)$$

Total Ordering Cost.
Ordering cost is ordering cost (A) multiplied by the frequency of ordering (n).

$$Total\ Ordering\ Cost = A.n \quad (2)$$

Ordering frequency (n) is how many times the order was made at the time of the harvest (t_1) with the order interval (T).

$$n = \frac{t_1}{T} \quad (3)$$

Equation 3 is substituted in equation 2.

$$Total\ Ordering\ Cost = \frac{t_1 A}{T} \quad (4)$$

Total Holding Cost
Figure 1 shows the inventory condition of agricultural products. Total holding cost is divided into several regions. The stock cost distribution has been done in previous research [32]–[34]. In this study, the holding is divided into three areas, as in Figure 2.

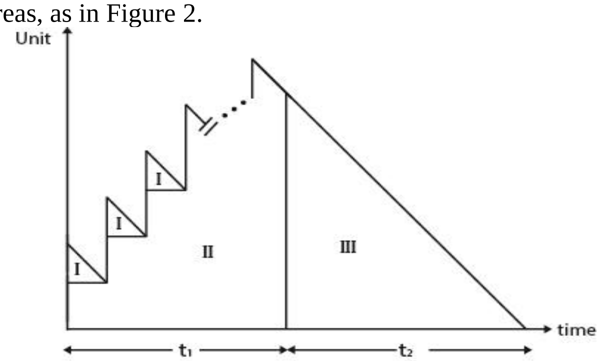

FIGURE 2
HOLDING COST

Holding I is the cost of storing raw materials to be used for the harvest period. If the holding cost I in Figure 2 is pulled down, it will form as in Figure 3.

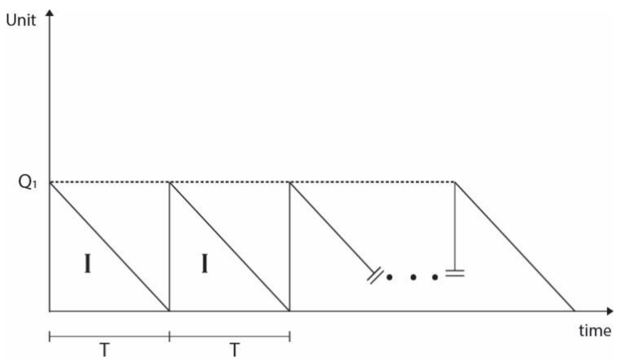

FIGURE 3
HOLDING COST I

These inventory conditions are the same as in classic EOQ so that the holding cost I can be found with the following formulation:

$$Holding\ cost\ I = \frac{Q_1}{2} t_1 h \quad (5)$$

The Harvest period (t_1) can be searched with the following formulation:

$$t_1 = T.n \quad (6)$$

The order frequency (n) can be searched with the following formulation:

$$n = \frac{D_1}{Q_1} \quad (7)$$

Equations (6) and (7) are substituted into equation (5).

$$Holding\ cost\ I = \frac{Q_1 D_1 Th}{2Q_1} = \frac{D_1 Th}{2} \quad (8)$$

Holding cost II is the cost that must be spent to store raw materials used during the non-harvest period. The shaded image in Figure 4 shows the condition of inventory holding costs II. The number of raw materials stored in the cumulative is the order quantity of n orders. This kind of condition has ever been proposed [32]–[34].

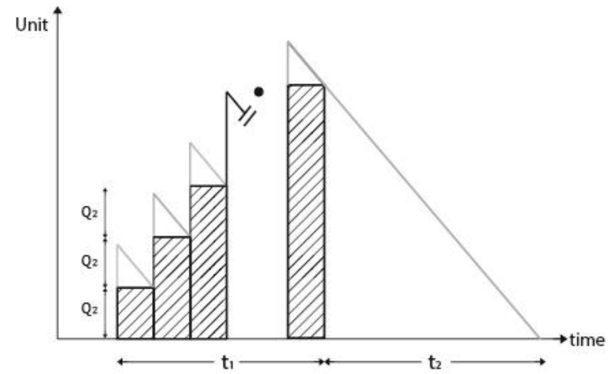

FIGURE 4
HOLDING COST II

It can be seen in Figure 5 that the level of inventory constantly rises by Q_2 and n orders. The total of raw material can be found by:

$$Q_2 + 2Q_2 + 3Q_2 + \cdots + nQ_2 = \frac{n(n+1)Q_2}{2} \quad (9)$$

So that the formulation of holding costs II can be found with the total of raw material multiplied by the saving cost:

$$Holding\ cost\ II = \frac{n(n+1)Q_2}{2} Th \quad (10)$$

Q_2 can be searched by requesting during the non-harvest time (D_2) divided by the frequency of orders (n)

$$Q_2 = \frac{D_2}{n} \quad (11)$$

Equation (11) is substituted in equation (10)

$$Holding\ cost\ II = \frac{n(n+1)\frac{D_2}{n}}{2} Th \quad (12)$$

Equation (3) is substituted in equation (12)

$$Holding\ cost\ II = \frac{\frac{t_1}{T}(\frac{t_1}{T}+1)\frac{D_2}{n}}{2} Th = \frac{D_2(t_1+T)h}{2} \quad (13)$$

Holding cost III is the cost that must be spent to store raw materials used during the non-harvest period. The image shaded in Figure 5 shows the inventory condition of holding costs III.

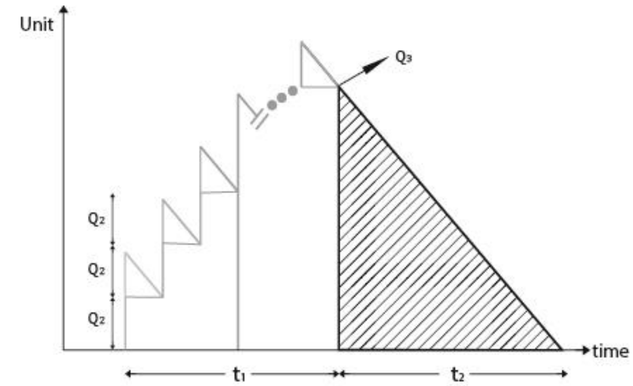

FIGURE 5
HOLDING COST III

The cost of inventory is the cost of saving as much as Q_3. To reach the point Q_3 is by multiplying Q_2 by *n*.

$$Holding\ cost\ III = \frac{Q_2 n}{2} t_2 h \quad (14)$$

Equation (11) is substituted for equation (14)

$$Holding\ cost\ III = \frac{\frac{D_2}{n} n}{2} t_2 h = \frac{D_2 t_2 h}{2} \quad (15)$$

The total of holding cost is the sum of holding cost I, holding cost II, and holding cost III or equation (8), equation (13), and equation (15)

$$Total\ Holding\ cost = \left(\frac{D_1 T}{2} + \frac{D_2(t_1+T)}{2} + \frac{D_2 t_2}{2}\right) h \quad (16)$$

The total cost is the sum of the total ordering cost and holding cost.

$$TC = \frac{t_1 A}{T} + \left(\frac{D_1 T}{2} + \frac{D_2(t_1+T)}{2} + \frac{D_2 t_2}{2}\right) h \quad (17)$$

The optimal solution to the proposed inventory system is determined by finding *T* value, which differentiates *TC* (equation 17) as:

$$\frac{\partial TC}{\partial T} = -\frac{t_1 A}{T^2} + \frac{D_1 h + D_2 h}{2}$$

$$0 = -\frac{t_1 A}{T^2} + \frac{D_1 h + D_2 h}{2}$$

$$T = \sqrt{\frac{2 t_1 A}{D_1 h + D_2 h}} \quad (18)$$

The number of raw materials that must be ordered can be found by formulation:

$$Q = Q_1 + Q_2 \quad (19)$$

The formulation can search for Q_1 and Q_2:

$$Q_1 = \frac{D_1}{n} \quad (20)$$

$$Q_2 = \frac{D_2}{n} \quad (21)$$

Equation (20) and equation (21) are substituted for equation (19)

$$Q = \frac{D_1}{n} + \frac{D_2}{n} \quad (22)$$

Ordering frequency (n) can be searched by formulation:

$$n = \frac{t_1}{T} \quad (23)$$

The number of raw materials that must be ordered can be found by substituting equation (23) with equation (22).

$$Q = \frac{D_1}{\frac{t_1}{T}} + \frac{D_2}{\frac{t_1}{T}} = \frac{(D_1+D_2)T}{t_1} \quad (23)$$

Max Inventory

A lot of raw materials will be ordered for the maximum inventory or minimum warehouse capacity that must be prepared. Based on Figure 6, the company should provide warehouse capacity to accommodate as many as *M* units.

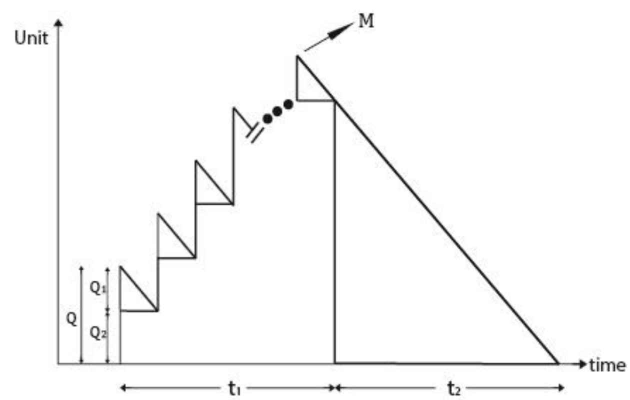

FIGURE 6
MAXIMUM INVENTORY

The mathematical formulation to obtain *M* point is:

$$M = nQ_2 + Q_1 \quad (24)$$

The formulation to find Q_2 is by equation (3) substituted into the equation (10), obtained:

$$Q_2 = \frac{D_2 T}{t_1} \quad (25)$$

While the formulation to find Q_1 is:

$$Q_1 = Q - Q_2 \quad (26)$$

Equations (25) are substituted to equations (26)

$$Q_1 = Q - \frac{D_2 . T}{t_1} \quad (27)$$

Equations (27), (3), and (23) are substituted to the equation (24)

$$M = \frac{D_2 T t_1}{t_1 T} + \left(Q - \frac{D_2 T}{t_1}\right) = D_2 + \left(Q - \frac{D_2 T}{t_1}\right) \quad (28)$$

NUMERICAL EXAMPLE

A coffee company produces coffee for 30 kg/day. The coffee harvest period occurs in April - August (153 days) and not in September - March (212 days). The ordering cost is IDR 620,000 / order. The holding cost is IDR 500/kg/day. Determining the interval, quantity, and frequency of orders, you will know the total cost and warehouse capacity that must be prepared.

Answer: Known:

D_1 = 30 kg/day × 153 = 4590 kg

D_2 = 30 kg/day × 212 = 6360 kg

t_1 = 153 day

t_2 = 212 day

A = IDR 620,000

h = IDR 500

Asked, *T, Q, n, M, and TC*

Solutions

1) Determine the order interval

$$T = \sqrt{\frac{2 t_1 A}{D_1 h + D_2 h}} = \sqrt{\frac{2 \times 153 \times 620000}{4590 \times 500 + 6360 \times 500}} = 5{,}89 \text{ day}$$

2) Determine the number of orders

$$Q = \frac{(D_1 + D_2) T}{t_1} = \frac{(4590 + 6360) \times 5{,}89}{153} = 421{,}30 \text{ kg}$$

3) Determine the frequency of ordering

$$n = \frac{t_1}{T} = \frac{153}{5{,}89} = 25{,}98 \text{ times ordering}$$

4) Determine maximum inventory

$$M = 6360 + \left(421{,}30 - \frac{6360 \times 5{,}89}{153}\right) = 6536{,}46 \text{ kg}$$

5) Total cost

$$TC = \frac{t_1 A}{T} + \left(\frac{D_1 T}{2} + \frac{D_2 (t_1 + T)}{2} + \frac{D_2 t_2}{2}\right) h$$

$$TC = IDR\ 612{,}579{,}132$$

The inventory conditions of that Coffee Company can be seen in Figure 7.

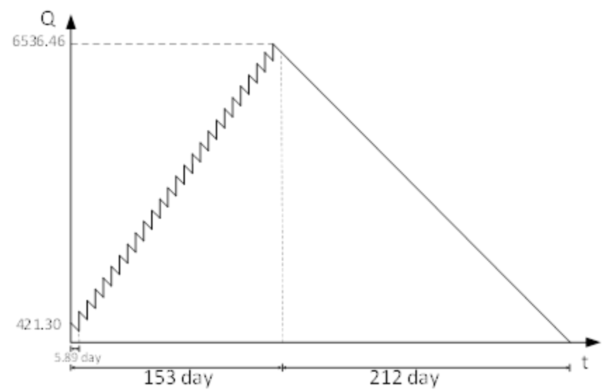

FIGURE 7
INVENTORY CONDITION IN A COFFEE COMPANY

ANALYSIS SENSITIVITIES

Sensitivity analysis is carried out to figure out the influence of the parameter changes on other parameters. This model assumes that the demand, the ordering cost, and the holding cost are known for certainty and unchanged. However, in reality, one of the parameters may change. For example, when the demand of the parameter becomes more substantial, it may affect the total cost. In this case, the case study used to analyze the sensitivity of this model is the numerical example.

TABLE I

SENSITIVITY ANALYSIS: CHANGE IN DEMAND

Change in Demand (D) (%)	*T (day)*	*Q (Unit)*	*TC (IDR)*
-50%	8.32	297.90	RP. 614,534,157.51
-40%	7.60	326.33	RP. 613,636,105.21
-30%	7.04	352.48	RP. 613,093,004.32
-20%	6.58	376.82	RP. 612,779,939.29
-10%	6.21	399.68	RP. 612,623,864.43
0%	5.89	421.30	RP. 612,579,132.78
10%	5.61	441.86	RP. 612,615,736.01
20%	5.37	461.51	RP. 612,713,142.23
30%	5.16	480.35	RP. 612,856,842.27
40%	4.98	498.48	RP. 613,036,306.44
50%	4.81	515.98	RP. 613,243,720.91

Table 1 illustrates the changes in demand (*D*). The demand changes are set up and down every 10% and their effect on the order time interval (*T*), order size *(Q*), and the total cost of supplies (*TC*). It can be seen that the reduction in demand increases the order time of interval and reduces the order size. But the total cost of decreasing and increasing demand is growing.

TABLE 2
SENSITIVITY ANALYSIS: CHANGE IN ORDERING COST

Change in Ordering Cost (A) (%)	T (day)	Q (unit)	TC (IDR)
-50%	4.16	297.90	RP614,534,157.51
-40%	4.56	326.33	RP613,636,105.21
-30%	4.93	352.48	RP613,093,004.32
-20%	5.27	376.82	RP612,779,939.29
-10%	5.58	399.68	RP612,623,864.43
0%	5.89	421.30	RP612,579,132.78
10%	6.17	441.86	RP612,615,736.01
20%	6.45	461.51	RP612,713,142.23
30%	6.71	480.35	RP612,856,842.27
40%	6.97	498.48	RP613,036,306.44
50%	7.21	515.98	RP613,243,720.91

Table 2 illustrates changes in ordering cost (A) and their effect on the order time interval (T), order size (Q), and the total cost of supplies (TC). The change in ordering costs is directly proportional to the time interval and size of the order, but the total cost of reducing and increasing ordering costs is increasing.

TABLE 3
SENSITIVITY ANALYSIS: CHANGE IN HOLDING COST

Change in Holding Cost (h) (%)	*T (day)*	*Q (unit)*	*TC (IDR)*
-50%	8.32	595.80	RP614,534,157.51
-40%	7.60	543.89	RP613,636,105.21
-30%	7.04	503.54	RP613,093,004.32
-20%	6.58	471.02	RP612,779,939.29
-10%	6.21	444.08	RP612,623,864.43
0%	5.89	421.30	RP612,579,132.78
10%	5.61	401.69	RP612,615,736.01
20%	5.37	384.59	RP612,713,142.23
30%	5.16	369.50	RP612,856,842.27
40%	4.98	356.06	RP613,036,306.44
50%	4.81	343.99	RP613,243,720.91

Table 3 illustrates the changes in holding cost (h) and their effect on the order time interval (T), order size (Q), and the total cost of supplies (TC). The changes in saving costs are inversely proportional to the time interval and size of the order, but the total cost of reducing and increasing of ordering cost is increasing.

Table 4 illustrates the changes in harvest period (t_1) and their effect on the order time interval (T), order size (Q), and the total cost of supplies (TC). The changes are directly proportional to the order time interval and total cost but inversely proportional to order size.

Table 5 illustrates the changes in the non-harvest period (t_2). That period changes are set up and down every 10% and their effect on the order time interval (T), order size (Q), and the total cost of supplies (TC). The changes are inversely proportional to the order time interval and total cost but directly proportional to order size.

TABLE 4
SENSITIVITY ANALYSIS: CHANGE IN HARVEST PERIOD

Change in Harvest Periode (t1) (%)	T (day)	Q (unit)	TC (IDR)
-50%	4.16	595.80	RP603,139,438.34
-40%	4.56	543.89	RP605,314,578.91
-30%	4.93	503.54	RP607,314,827.09
-20%	5.27	471.02	RP609,176,612.70
-10%	5.58	444.08	RP610,925,239.98
0%	5.89	421.30	RP612,579,132.78
10%	6.17	401.69	RP614,152,199.63
20%	6.45	384.59	RP615,655,246.07
30%	6.71	369.50	RP617,096,865.17
40%	6.97	356.06	RP618,484,024.18
50%	7.21	343.99	RP619,822,465.09

TABLE 5
SENSITIVITY ANALYSIS: CHANGE IN NON-HARVEST PERIOD

Change in Non-harvest Period (t2) (%)	T (day)	Q (unit)	TC (IDR)
-50%	7.66	323.80	RP622,282,696.07
-40%	7.34	337.93	RP620,529,897.96
-30%	7.00	354.08	RP618,697,065.08
-20%	6.65	372.80	RP616,772,116.91
-10%	6.28	394.83	RP614,739,588.54
0%	5.89	421.30	RP612,579,132.78
10%	5.46	453.92	RP610,263,043.98
20%	5.00	495.51	RP607,751,886.80
30%	4.50	551.14	RP604,986,083.29
40%	3.93	631.02	RP601,867,662.51
50%	3.26	760.12	RP598,212,894.50

The interval of the order time (T) based on the sensitivity analysis is directly proportional to the changes in the ordering cost and the harvest period. In contrast, for demand, holding costs and not the harvest period are inversely proportional. In other words, for the case in the numerical example, if the ordering cost and the harvest period increase, the order time interval will be longer, on the other hand, if the demand, the holding cost, and the non-harvest period increase, the order time interval will be shorter.

Order size (Q) based on the sensitivity analysis is directly proportional to changes in the demand, the holding cost, and the non-harvest period. For ordering cost and the harvest, the period is inversely proportional. In other words, for the case in the numerical example, the demand, holding cost, and not the harvest period increases, the order size will be bigger. On the other hand, if the ordering cost and the harvest period increase, the order size will be fewer.

Total Cost (TC), based on the sensitivity analysis, changes in demands, ordering costs, and storage costs remain at their optimal point. Changes occur in the harvest period, which is directly proportional and inversely proportional to the non-harvest period.

CONCLUSION AND FUTURE RESEARCH

The development of the EOQ model of agricultural products with the harvest period was successfully modeled. The model developed optimizes the order time interval so that the period, frequency, quantity, total order cost, and warehouse capacity that must be prepared can be calculated. The numerical example uses the commodity coffee, which has a harvest period from April to September. The results obtained are the same as the modeled inventory conditions, with the value of the period, frequency, and quantity of orders generated. Sensitivity analysis is conducted to determine the impact of parameter changes in demand, order cost, holding cost, harvest period, and non-harvest period on changes in total costs. Changes in the harvest period and the non-harvest period have a significant effect on the total cost.

The resulting model only applies to agricultural products that have a harvest period of once a year. Future development will be modeled for agricultural products that have a harvest period of more than that. The model is a deterministic model which assumes that the parameters of demand, order costs, holding costs, the number of days of the harvest period, and the non-harvest period, are known with certainty and do not change over time. It needs more advanced development, namely, bringing it into the realm of probability.

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