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Research Article

An Improved EOQ Model for Fresh Agricultural Product Considering Fresh-degree Sensitive Demand and Carbon Emission

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Abstract: Due to the serious distribution loss of fresh agriculture products, it attracts more and more attention that how to determine the optimal inventory control strategy, which is one of the research hotspots and difficulties. This study is concerned with an improved Economic Order Quantity (EOQ) model considering fresh-degree sensitive demand and carbon emission, which is proposed to determine the optimum replenishment cycle time and order quantity. In addition, a simulation experiment and sensitivity analysis of parameters (such as carbon emission price, deterioration rate and fresh-degree) are to illustrate the proposed inventory control model, which can provide decision support for the balance of carbon emission cost and inventory cost by adjusting the inventory control strategy. Simulation results show that carbon emission price, deterioration rate and fresh-degree affect the optimal replenishment cycle time and order quantity to some extent. Moreover, suitable carbon emission price can guide fresh retailers to make low-carbon decision through balancing operation cost, carbon emission, deterioration cost and fresh loss cost.

Keywords: Carbon emission, EOQ, fresh agriculture product, fresh-degree, inventory management

INTRODUCTION

As an important branch of supply chain management, inventory management mainly focuses on the determination of the optimal replenishment cycle and order quantity. Due to the advantage of simple implementation, EOQ is one of the most popular models that widely used in the field of inventory management. Since classic EOQ model always assumes that external demand is constant, it can't meet the actual time-varying demand of deteriorating items' inventory control. In view of their shorter freshening time, easier deteriorating characteristics and more strongly temperature-dependence storage environments than traditional deteriorating items, fresh agricultural products have more serious time-varying demand when faced with inventory control, which makes EOQ is even less applicable. It's well known that the fresh-degree of agricultural products (such as shape, smell, color, size and so on.) is essential for consumers, which has a great influence on consumers' purchase decisions. In other words, the complexity of fresh agricultural products' inventory control reflects in the fresh-degree of products. Therefore, the matching problem between the fresh-degree of agriculture products and the fresh-tolerance-degree of consumers is one of the urgent tasks for us, which might cause customers to give up purchasing. The more fresh-degree, the more demand of agriculture products. Since the fresh-degree of products shows a general tendency of declining with the increasing storage time, the demand of fresh agricultural products is also a time-varying variable. Unfortunately, the research on the inventory control for fresh agricultural product considering fresh-degree sensitive demand is not sufficient.

On the other hand, with the growing global warming and increasing extreme environmental issues, energy conservation and reduction of emissions should be logistics enterprises' global responsibilities and obligations. Cold-chain logistics is one of the most important means of maintaining the agriculture products' freshness and quality, which is high energy dependence and heavy carbon emission. Although cold-chain logistics can bring sales revenue to fresh retailer by keeping products' fresh-degree, carbon emission cost is inevitably increasing. At the same time, the trade-off phenomenon that mentioned above is bound to impact on fresh retailer's inventory decision. To balance the economic benefits and carbon emission cost is an urgent task for fresh retailers, which is to maximize the economic, environmental and social benefits.

The objectives of the present study were to propose a novel EOQ model for fresh agricultural product,

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which considers fresh-degree sensitive demand and carbon emission. Furthermore, it evaluates a sensitivity analysis about main parameters by numerically simulation tests.

BRIEF LITERATURE REVIEW

There are some previous studies on the inventory control models for these deteriorating products, which considered a time-varying external demand. Kalpakam and Sapna (1994) analyzed a perishable system with Poisson demands and exponentially distributed lead-times for items with exponential lifetimes. Ning *et al*. (2013) presented inventory models for fresh agriculture products with time-varying deterioration rate. Dye and Hsieh (2012) formulated an inventory model with a time-varying rate of deterioration and partial backlogging. Song and Zipkin (2012) discussed an inventory planning problem with a one-time uncertain demand, in which demand is driven by an underlying Markov process, representing economic conditions, weather, market competition and other environmental factors. Lodree Jr. and Uzochukwu (2008) concerned the inventory control of a deteriorating product with non-negligible procurement lead-time that perishes after a known number of periods, in which the demand during each period is represented as a random variable with known probability distribution. Since studies showed that the fresh-degree of fresh agriculture products can severely impact the purchase decision of consumer (Baron and Mueller, 1995; Ergönül, 2013), researchers began to study the inventory control model considering fresh-degree. Bai and Kendall (2008) proposed a single-period inventory and shelf-space allocation model for fresh produce, in which the demand rate is assumed to be deterministic and dependent on both the displayed inventory and the items' freshness condition. Avinadav and Arponen (2009) put forward an extension of the classical EOQ model for items with a fixed shelf life and a declining demand rate, which reflected consumer preference for fresh items, is a polynomial function of the remaining time until the expiry date of the item. Dan and Ding (2012) studied how demand cannibalization affects retailers' ordering decision and profit under different customer classification, which classified customers into three types: fresh product only, price discount only and those without preference.

Furthermore, as one of the newest research topics in the inventory control field, the issue of carbon emissions during the process of inventory control has attracted attention by international academia. In addition, the addition of carbon emission constraint factors to the classical inventory control model is the major research methods. Hua *et al*. (2011) investigated how firms manage carbon footprints in inventory management under carbon emission trading mechanism. Benjaafar *et al*. (2013) illustrated how carbon emission concerns could be integrated into operational decision-making, which is with regard to procurement, production and inventory management. Zhang and Xu (2013) analyzed the multi-item production planning problem with carbon cap and trade mechanism. Gong and Zhou (2013) develop a dynamic production model, which is to study how emissions trading impact on production planning.

Unfortunately, the relevant study of fresh products' inventory management considering fresh-degree sensitive demand and carbon emission is few reports. In view of the backgrounds and status that mentioned above, this study provides a novel EOQ model considering fresh-degree sensitive demand and carbon emission, which can balance economic performance with environmental and social considerations for fresh agriculture product retailers.

PROBLEM FORMULATION

Problem description: Fresh agriculture product retailer implements several replenishments in a whole sales cycle, in which demand is a fresh-degree sensitive time-varying variable. Assumed that the inventory control costs include such as order cost, purchase cost, inventory cost, deterioration cost and carbon emission cost. In additional, carbon emission cost includes transport carbon emission cost and inventory carbon emission cost. Furthermore, transport carbon emission is constituted of empty vehicle carbon emission and per unit product carbon emission and inventory carbon emission is constituted of per unit of time fixed storage carbon emission and per unit product average carbon emission.

Since customer's demand is dependent on the fresh-degree of agriculture product, a fresh-degree function is introduced in this study, which is to describe the fresh-degree of agriculture product at different moments. In theory, the fresh-degree of agriculture product has different values at different moments. However, due to the sales of fresh agriculture product retailer are generally recorded by day, fresh-degree in this study is measured by day. Meanwhile, we assume that the declining moment of agriculture product's fresh-degree is at the initial stage of each day, which is to ensure products have a uniform fresh-degree value in the same day. At the same time, a deterioration rate is adopted to characterize the loss of agriculture product, which is caused by man-made damage and so on. Also the deterioration rate is measured by day, which is assigned a uniform value in the same day. In this study, for the proposed EOQ model considering fresh-degree sensitive demand and carbon emission, we commonly assumed the following conditions:

- Single species fresh agriculture product

- Regardless of order leads time
- out-of-stock not allowed
- Instantaneous replenishment
- The inventory is 0 at the end of each order cycle
- Identity period replenishment. According to the actual order cycle is measured by day, this study assumes order cycle is an integer day.
- The demand is dependent on the fresh-degree. Given the fresh-degree function is γ^t.
- The demand of customer is $D\gamma^t$ at the moment of t.
- The deterioration rate function is $\theta(t)=\partial$, which represents the average deterioration rate (per day) is constant. Given that the deterioration products fully lose surplus value.
- For each order cycle T, $I(0) = Q$ and $I(T) = 0$.

Parameters notation: The following notations are used to describe the proposed EOQ model, which considers:

D : The maximum demand per unit of time.
Q : The order quantity.
$I(t)$: The inventory level at the moment of t.
H : The whole schedule sales period.
n : The order times in H
T : The order cycle time.
T_C_T : The total costs in T
T_C_k : The order cost in T
T_C_h : The inventory cost in T
T_C_p : The purchase cost in T
T_C_r : The deterioration cost in T
T_C_c : The carbon emission cost in T
H_G : The profit in H
H_C : The total cost in H
H_Q : The total order quantity in H
H_C_k : The total order cost in H
H_C_p : The total purchase cost in H
H_C_h : The total inventory cost in H
H_C_r : The total deterioration cost in H
H_CE : The total carbon emission in H
k : The fixed order cost for each order period.
h : Per unit product average inventory cost.
S : Per unit sales price of fresh agriculture product.
P : Per unit purchase price of fresh agriculture product.
c_e : Per unit price of carbon emission.
γ_i^t : The average fresh-degree during the t period.
α : The deterioration rate.
$\theta_i(t)$: The average deterioration rate during the t period.
g_0 : Fixed carbon emission of inventory per unit of time.
g_1 : The average carbon emission of per unit product.
ρ_0 : The transport carbon emission of the empty vehicle.
ρ_1 : The transport carbon emission of per unit product.

EOQ model considering fresh-degree sensitive demand and carbon emission: Since the inventory level of fresh agriculture product is dependent on fresh-degree and carbon emission, the inventory changing of the i order period during the process of H can be described as the differential Eq. (1). Based on the assumptions for the proposed EOQ model, we may certainly infer that the average fresh-degree during the t period is γ_i^t, the demand during the t period is $D\gamma_i^t = D\gamma^i$, the average deterioration rate during the t period is $\theta_i(t)=i\partial$. Therefore, the total order quantity of T can be deduced as Eq. (2). All manners of costs for a whole schedule sales period are inferred as Eq. (3)~(10):

$$\frac{dI(t)}{dt} = -D\gamma_i^t - \theta_i(t)I(t) \qquad 0 \le t \le t_i \tag{1}$$

$$\begin{aligned} Q &= \int_0^T I(t)dt \\ &= \int_{t_0}^{t_1} I(t)dt + \int_{t_1}^{t_2} I(t)dt + \cdots \int_{t_{i-1}}^{t_i} I(t)dt + \cdots \int_{t_{T-1}}^{t_T} I(t)dt \\ &= \int_{t_0}^{t_1} \frac{D\gamma_{t_0}^{t_1}}{1-t_1\partial}dt + \int_{t_1}^{t_2} \frac{D\gamma_{t_1}^{t_2}}{1-t_2\partial}dt + \cdots \int_{t_{i-1}}^{t_i} \frac{D\gamma_{t_{i-1}}^{t_i}}{1-t_i\partial}dt \\ &+ \cdots \int_{t_{T-1}}^{t_T} \frac{D\gamma_{T-1}^{T}}{1-T\partial}dt \\ &= \sum_{i=1}^{T} \frac{D\gamma^i}{1-i\partial} \end{aligned} \tag{2}$$

where, $[t_0, t_T]$ corresponds to $[0, T]$; t_i is a positive integer; $i = 0, 1 \cdots T$:

$$T\_C_k = k \tag{3}$$

$$T\_C_P = p\int_0^T I(t)dt = p\sum_{i=1}^{T} \frac{D\gamma^i}{1-i\partial} \tag{4}$$

$$T\_C_h = h\int_0^T I(t)dt = h\sum_{i=1}^{T} \frac{D\gamma^i}{1-i\partial} \tag{5}$$

$$\begin{aligned} T\_C_r &= p\int_0^T \theta(t)I(t)dt \\ &= p\begin{pmatrix} \int_{t_0}^{t_1}\theta(t)I(t)dt + \int_{t_1}^{t_2}\theta(t)I(t)dt \\ +\cdots\int_{t_{i-1}}^{t_i}\theta(t)I(t)dt + \cdots\int_{t_{T-1}}^{t_T}\theta(t)I(t)dt \end{pmatrix} \\ &= p\begin{pmatrix} \int_{t_0}^{t_1}\theta_{t_1}(t)\dfrac{D\gamma_{t_0}^{t_1}}{1-t_1\partial}dt + \int_{t_1}^{t_2}\theta_{t_2}\dfrac{D\gamma_{t_1}^{t_2}}{1-t_2\partial}dt \\ +\cdots\int_{t_{i-1}}^{t_i}\theta_{t_i}\dfrac{D\gamma_{t_{1-1}}^{t_i}}{1-t_i\partial}dt + \cdots\int_{t_{T-1}}^{t_T}\theta_{t_T}\dfrac{D\gamma_{T-1}^{T}}{1-T\partial}dt \end{pmatrix} \\ &= p\sum_{i=1}^{T}\frac{i\partial D\gamma^i}{1-i\partial} \end{aligned} \tag{6}$$

$$\begin{aligned} T\_C_c &= c_e\Big((\rho_0+\rho_1\int_0^T I(t)dt) + (g_0T + g_1\int_0^T I(t)dt)\Big) \\ &= c_e\Big((\rho_0+g_0T)+(\rho_1+g_1)\sum_{i=1}^{T}\frac{D\gamma^i}{1-i\partial}\Big) \end{aligned} \tag{7}$$

$$T\_C_T = T\_C_k + T\_C_p + T\_C_h + T\_C_r + T\_C_c \tag{8}$$

$$H\_C = \sum_{j=1}^{n} T\_C_T \tag{9}$$

$$H\_G = ns\sum_{i=1}^{T} D\gamma^i - H\_C \tag{10}$$

SIMULATIONS AND DISCUSSION

Simulation parameters: In this section, simulation experiments are adopted to study the proposed EOQ model, which considers fresh-degree sensitive demand and carbon emission. Then the sensitivity analysis about the main parameters (per unit price of carbon emission, deterioration rate and fresh-degree.) are discussed. In order to solve out the optimal solution, a recursive algorithm is adopted in this study, which have been carried out on MATLAB R2014a. The initial parameters are setting as follows. D = 1000; k = 200; h = 0.3; p = 6; S = 30; C_e = 50; g_0 = 4; ∂ = 0.005; H = 60; ρ_0 = 5; g_1 = 0.005; ρ_1 = 0.001; γ = 0.997.

SIMULATION RESULTS AND DISCUSSION

The results of economic order quantity at different replenishment cycle time are illustrated in Table 1, which are simulated with the initial simulation parameters. Moreover, this study makes sensitivity analysis about the influence of main parameters (carbon emission price c_e, deterioration rate α and fresh-degree γ, which changes only one parameter based on the initial parameters.) on the optimal inventory control decision. The sensitivity analysis results are depicted in Table 2 to 4.

In Table 1, we can infer that:

- For the same c_e, α and γ, the total profit H_G shows a rising trend firstly and a decreasing trend at later period, which is changing with the increasing of T. And H_G is to be optimized when T = 3 and Q = 3012.
- With the prolonging of order time T, order quantity Q and total order quantity H_Q will increase. Also the increasing of H_C_k and H_C_p is inevitable. In general, H_C_h and H_C_r are also increasing, due to the extending storage time that caused by the prolonging of order cycle time T.
- During the process of simulation tests, carbon emission H_CE gradually decreases when T is given from 1 to 20. And the carbon emission H_CE gradually increases when T is given from 20 to 60. For the reasons, on the one hand there is a positive correlation between the fixed carbon emissions (transport and inventory) and order times and on the other hand there is a negative correlation between the dynamic carbon emissions (transport and inventory) and order times. With the increasing of T, the changing trend of carbon emission is dependent on whether the declining of fixed carbon emission is greater than the increasing of dynamic carbon emission. It is noted that the minimum carbon emission occurs when T = 20 and T = 30.

In Table 2, we can infer that:

- With the decreasing of γ, both the optimal order times n and order quantity Q are declined, which results in decreasing the purchase cost H_C_p and inventory cost H_C_h. Also this replenishment type (often and in small quantities) can decline the total deterioration cost H_C_r. But the total profit would decrease, due to sales income declining caused by lower demand at lower γ.
- It is very interesting to note that the optimal order cycle time T has no change when γ is declined from 0.991 to 0.98, in which carbon emission has a decreasing trend change. Because the dynamic carbon emission would decline with the decreasing of demand and the fixed carbon emission keeps no change. With the decreasing of γ (from 0.991 to 0.98), the total profit is decreasing, due to sales income declining caused by lower demand at lower γ.

In Table 3, we can infer that:

- Regardless of the carbon emission cost (c_e = 0), the maximum profit $H\_G = 1396070$ when carbon emission is to be maximum value $H\_CE = 701$. It is obvious that fresh agriculture product retailers have the intention of pursuing a high profit at the expense of a high carbon emission.

Table 1: Inventory control simulation results using the initial parameters

T	Q	H_Q	H_C_k	H_C_p	H_C_h	H_C_r	H_CE	H_G
1	1002	60121	30000	360724	18036	1804	901	1339000
2	2006	60182	15000	361091	18055	2709	751	1357499
3	3012	60244	10000	361461	18073	3617	701	1360997
4	4020	60306	7500	361836	18092	4528	677	1360744
5	5031	60369	6000	362214	18111	5441	662	1358989
6	6043	60433	5000	362595	18130	6356	653	1356483
10	10116	60693	3000	364160	18208	10047	634	1343444
12	12166	60828	2500	364965	18248	11908	630	1336163
15	15258	61034	2000	366203	18310	14724	626	1324852
20	20464	61392	1500	368350	18418	19478	623	1305450
30	31082	62163	1000	372980	18649	29245	623	1265654
60	65023	65023	500	390140	19507	61219	635	1141486

Table 2: The influence of γ on the optimal inventory control

γ	T	Q	H_Q	H_C_k	H_C_p	H_C_h	H_C_r	H_CE	H_G
1.000	5	5076	60917	6000	365501	18275	5501	666	1371448
0.997	3	3012	60244	10000	361461	18073	3617	701	1360997
0.994	3	2994	59881	10000	359289	17964	3592	699	1352677
0.991	2	1988	59639	15000	357837	17892	2682	748	1344971
0.988	2	1979	59369	15000	356214	17811	2668	746	1338725
0.985	2	1970	59099	15000	354596	17730	2655	745	1332492
0.980	2	1955	58651	15000	351905	17595	2633	742	1322132
0.950	1	955	57286	30000	343719	17186	1719	884	1273191
0.900	1	905	54271	30000	325628	16281	1628	866	1203181
0.850	1	854	51256	30000	307538	15377	1538	848	1133171
0.800	1	804	48241	30000	289447	14472	1447	829	1063161

Table 3: The influence of c_e on the optimal inventory control

c_e	T	Q	H_Q	H_C_k	H_C_p	H_C_h	H_C_r	H_CE	H_G
0	3	3012	60244	10000	361461	18073	3617	701	1396070
5	3	3012	60244	10000	361461	18073	3617	701	1392563
10	3	3012	60244	10000	361461	18073	3617	701	1389055
20	3	3012	60244	10000	361461	18073	3617	701	1382041
30	3	3012	60244	10000	361461	18073	3617	701	1375026
40	3	3012	60244	10000	361461	18073	3617	701	1368012
50	3	3012	60244	10000	361461	18073	3617	701	1360997
60	3	3012	60244	10000	361461	18073	3617	701	1353982
70	4	4020	60306	7500	361836	18092	4528	677	1347207
80	4	4020	60306	7500	361836	18092	4528	677	1340439
100	4	4020	60306	7500	361836	18092	4528	677	1326902
150	4	4020	60306	7500	361836	18092	4528	677	1293060
200	5	5031	60369	6000	362214	18111	5441	662	1259657
300	5	5031	60369	6000	362214	18111	5441	662	1193436
400	6	6043	60433	5000	362595	18130	6356	653	1128075

Table 4: The influence of ∂ on the optimal inventory control

∂	T	Q	H_Q	H_C_k	H_C_p	H_C_h	H_C_r	H_CE	H_G
0.000	5	4955	59462	6000	356773	17839	0	657	1370414
0.005	3	3012	60244	10000	361461	18073	3617	701	1360997
0.010	3	3043	60861	10000	365165	18258	7321	705	1353219
0.015	2	2037	61108	15000	366648	18332	8267	757	1345829
0.020	2	2053	61583	15000	369499	18475	11118	759	1339842
0.025	2	2069	62067	15000	372400	18620	14018	762	1333750
0.030	2	2085	62559	15000	375352	18768	16971	765	1327550
0.040	2	2119	63570	15000	381418	19071	23036	771	1314813
0.045	2	2136	64089	15000	384533	19227	26152	775	1308270
0.050	1	1049	62968	30000	377811	18891	18891	918	1303118
0.060	1	1061	63638	30000	381830	19091	22910	922	1294677
0.070	1	1072	64323	30000	385935	19297	27015	926	1286055
0.080	1	1084	65022	30000	390130	19507	31210	930	1277246
0.090	1	1096	65736	30000	394418	19721	35498	934	1268243
0.100	1	1108	66467	30000	398800	19940	39880	939	1259040
0.200	1	1246	74775	30000	448650	22433	89730	989	1154355

- With the increasing of carbon emission cost c_e, the total profit H_G and H_CE would decrease. It shows that carbon emission of inventory control system can be decreased by implementing an appropriate carbon emission price.

In Table 4, we can infer that:

- Regardless of the deterioration cost ($\partial = 0$), the maximum profit $H\_G = 1370414$ when $T = 5$ and $Q = 4955$.
- With the increasing of ∂, both the optimal order times n and the total order quantity H_Q are declined. Meanwhile, all manners of cost are generally increased, which results in declining total profit.
- It is interesting to note that the optimal T keeps no change ($T = 2$) when ∂ is given from 0.015 to 0.045, which causes the increasing of H_Q, H_C_p and H_C_h. Actually, with the increasing H_Q and ∂, the total deterioration cost H_C_r is inevitably increasing, which decreases the total profit of fresh agriculture retailer to some extent.

CONCLUSION

In this study, we proposed a novel EOQ model for fresh agriculture product, which is synthetically considering fresh-degree sensitive demand and carbon emission. Through simulation experiments, we make sensitivity analysis about the influence of main parameters (carbon emission price, deterioration rate and fresh-degree) on the optimum inventory control. From the simulation results that reported in this study, we can draw some conclusions as follows:

- With the decreasing of γ (c_e and α keep unchanged), the optimal T, Q, H_CE and H_G are declined.
- With the increasing of c_e (γ and α keep unchanged), the optimal T and Q are increasing, on the other hand H_CE and H_G are declined.
- With the increasing of α (γ and c_e keep unchanged), the optimal T, Q and H_G are declined, on the other hand H_CE is increasing.

Therefore, the perishable fresh agriculture retailers face difficulties in obtaining a relative high profit, which drives them to implement a high emissions replenishment type (often and in small quantities). In view of climate warming dangerous, they should pay more attention to the influence of the higher carbon emission that caused by this replenishment type. To balance the economic benefits, environmental and social benefits is an urgent task for fresh retailers. For the nonperishable agriculture products such as potato, sweet potato and so on, the retailer can gain more profit by means of prolonging the replenishment cycle and increasing the order quantity. Since the retailers have the intention of make high profits at the expense of high carbon emission, it is essential for us to make appropriate carbon emission laws and policies to guide enterprises to make low-carbon inventory decision through balancing operation costs, carbon emission, deterioration costs and fresh loss costs.

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