7th International Food Operations & Processing Simulation Workshop
18th International Multidisciplinary Modeling & Simulation Multiconference

ISSN 2724-0355 ISBN 978-88-85741-69-0 © 2021 The Authors.
doi: 10.46354/i3m.2021.foodops.002

An economic order interval-based simulation model for perishable products

Roberto Montanari[1], Eleonora Bottani[1,*], Andrea Volpi[1], Federico Solari[1], Giorgia Scozzesi[1]

[1]Department of Engineering and Architecture, University of Parma, viale delle Scienze 181/A, 43124 Parma, Italy

[*]Corresponding author. Email address: eleonora.bottani@unipr.it

Abstract

The aim of this paper is to develop a model for reproducing an Economic Order Interval (EOI)-based inventory control model for perishable products. After a description of the model, a simulation approach is developed and used for determining the optimal parameters of the inventory policy, as well as the relationships between them and the numerical values that can minimize the total inventory management cost, thus making the system as efficient as possible. A numerical example, with realistic data, is proposed for showing the application of the model and its effectiveness for the identification of the optimal inventory policy parameters.

Keywords: economic order interval (EOI); analytic model; simulation; perishable products.

1. Introduction and literature

"Perishable" items are simply defined as items whose characteristics can "decay or go bad very quickly". As such, this definition embraces food, beverages or pharmaceutical products (which can be subject to depletion, decay or spoilage when they reach the expiry date), but also products that can experience a change in their value because of reduced functionality (Amorim et al., 2013).

Managing and controlling the stock level of perishable inventories is important in many units and industrial enterprises (Sharifi et al., 2021). Incorrect management of the stock level of perishable items can generate significant cost in retailing: grocery manufacturers of America (2006) has estimated that the total cost of unsalable products, including items that have reached the expiry date in drugstores and supermarkets accounted for 2.05 billion dollars in 2005. Indeed, meeting a constant demand over time with a perishable product could require markdowns in the price or removal of spoiled product from the retailing channel. Moreover, in a competitive global market, reducing waste is an important factor for maximizing the profits of a system, and is also in line with the sustainable development goals (SDGs) set by the United Nations agenda (https://www.un.org). These goals can be achieved by efficiently managing logistic activities, and in particular, by optimally managing inventories and timely delivering perishable items to the customers (Babagolzadeh et al., 2021). In recent years, this aspect has become even more relevant, because of the increasing consciousness of customers that the fresher the products, the healthier and less harmful they are. Hence, the optimal management of inventories for perishable items is crucial.

Perishable inventory management and control is however more complex and challenging than traditional inventory control of products with unlimited shelf-life

(Sharifi et al., 2021). Most of the traditional inventory models available in literature, such as the economic order quantity (EOQ), economic order interval (EOI) and (S, s) policies, assume an infinite shelf-life of items while they are in storage. This implicitly means that the intrinsic nature of perishable products (e.g. food or pharma items) cannot be captured by these models, which, consequently, turn out to be unsuitable for application when the shelf-life of the items stored is finite.

In the light of this consideration, special purpose models focusing expressly on inventory management for perishable items have been developed. For exhaustive reviews of these models, the reader is referred to Nahmias (1982), Raafat (1991), Sharma (2016) and Chaudhary et al. (2018). As a general rule, papers on perishable inventory models consider either that inventory decays with time or that it is predefined but limited in time. For example, Minner & Transchel (2010) have developed a method to determine dynamic order quantities for perishable products with limited (fixed) shelf-life, non-zero deterministic lead time, First In First Out (FIFO) or Last In First Out (LIFO) issuing policy, non-stationary demand and service level constraints.

Another typical aspect of perishable inventory models is that the demand for the product is price sensitive, and that, accordingly, the vendor may need to backlog demand to avoid costs due to deterioration. In this respect, Ghosh et al. (2011) have proposed a model in which perishable products have a price dependent demand, and partial backordering and sale losses are admitted. The model is solved analytically to obtain the optimal price and size of the replenishment. Similarly, Nagare & Dutta (2012) have presented an inventory model for continuously deteriorating goods with random shelf-life and inventory-dependent demand; the EOQ is determined as a result of the model, for maximizing the system's profit. Yan & Wang (2013) have introduced the seasonality of items and developed an EOQ model for maximizing the expected profit of a retailer selling a seasonal perishable item, over a finite planning time. Another EOQ model has been proposed by Muriana (2016). This author has developed a stochastic model for perishable foods, embodying shortage and outdating costs. The demand is modelled as a stochastic variable with normal distribution, while the lead time is assumed to be deterministic. The amount of expired product and the relating cost is computed on the basis of the probability that the product has been kept in stock for a period longer than its shelf life. The recent work by Patriarca et al. (2020) has introduced an EOQ model for perishables items, that expressly takes into account the market uncertainty generated by the pandemic era. Accordingly, demand is modelled as a stochastic variable that changes over time and depends on the available inventory.

All the models sketched above refer to the EOQ policy, which is also called "continuous review" because the inventory status needs to be tracked continuously, to ensure that the manager will place an order when the amount of stock reaches the reorder point (Chopra & Meinld, 2010). This policy is typically useful when demand is high but the loss of order quantity is variant. On the contrary, the EOI policy (also called "periodic review") requires the inventory status to be tracked at specified time intervals, which makes the application of the policy easier in practice (Chopra & Meinld, 2010). EOI-based inventory models for perishables have bene proposed in literature, but compared to EOQ-based models, are significantly less in number. Rossi (2013) has presented a model of a periodic-review, single-product, inventory control problem with non-stationary demand. The product modelled is a perishable item, with fixed shelf-life. Bottani et al. (2014) have instead carried out a comparative study in which EOI, EOQ and (S,s) policies are evaluated with respect to their applicability to perishable items.

In the light of the very limited literature targeting periodic review policies for perishables, this paper aims to develop an EOI-based model for perishable items. A framework, completed by a set of analytic formulae, is first proposed in section 2 for computing the total cost of inventory as a function of the typical parameters of the EOI policy. Then, in section 3 a simulation approach is implemented in a realistic scenario to determine the optimal value of these parameters, as well as to identify the combination of these parameters that can minimize the total cost of the inventory policy, thus making the system as efficient as possible. Section 4 completes by summarizing the key findings of the study, highlighting the main implications and outlining future research activities.

2. The EOI model for perishables

2.1. Nomenclature

The following nomenclature is used to describe the proposed EOI model for perishable products:

- i = i-th day ($i = 1, \dots, n$);
- ΔT = EOI period [days];
- d_i = daily demand [kg/day];
- G_{OH_i} = on−hand inventory at day i [kg/day];
- c_{eo} = unitary order issuing cost [€/order];
- C_{eo_i} = order issuing cost at day i [€/day];
- c_{so} = unitary stock-out cost period [€/kg];
- C_{so_i} = stock-out cost at day i [€/day];
- c_{inv} = unitary inventory holding cost [€/kg];
- C_{inv_i} = inventory holding cost at day i [€/day];
- c_{disp} = unitary disposal cost [€/kg];
- C_{disp_i} = disposal cost at day i [€/day];
- OOS_i = amount of out-of-stock products at day i [kg/day];
- SL_i = shelf-life of the products ordered at day i

[days];

- Q_{exp_i} = amount of product expired at day i [kg/day];
- $OUTL$ = order-up-to level [kg];
- O_i = amount of product ordered at day i [kg/order];
- LT = procurement lead time [days].

2.2. Overview and assumptions

Using the nomenclature detailed above, an EOI-based (periodic review) inventory control model was developed. The model targets a distribution center (DC) of perishable products, that serves various retail stores and receives items from suppliers (e.g. manufacturers). The DC handles multiple products, but there are evaluated one at a time in the model, meaning that the solution returned refers to one product with given characteristics. On the basis of the findings from the literature, the model assumes a stochastic demand of finished products, with normal distribution, known mean and standard deviation. The procurement lead time is fixed and once an order has been issued to the supplier, the new lot will be available within the physical stock after LT days. Orders are placed at regular time intervals, according to the EOI policy, to restore a targeted stock level. The cost of order is independent upon the quantity ordered, as it mainly concerns the cost of administrative processes and transport.

The stock of on-hand products is checked daily to find possible products whose shelf-life has expired. Obviously, if some products have not been sold within their shelf-life, they will be disposed of.

Backorder is admitted when the stock on-hand is not sufficient for meeting the whole demand. A rigorous FIFO policy is applied to fulfil the costumer's orders, in line with the perishability of the products. At the same time, however, any quantity of product that is not available for meeting the immediate customer's demand involves a stock-out situation from which the relative costs will arise.

It is also implicitly assumed that following a FIFO policy also involves the application of a FEFO (first expired first out) policy, which means, in turn, that the products received in the same order all have the same shelf-life, and that products received in two subsequent orders have been shipped to the DC on the basis of their residual shelf-life.

The inventory cost, stock-out cost, order cost and disposal costs are the relevant cost components of that system, and will be used for determining the total inventory management cost. It is however important to clarify that if the SL is very high (tending to infinitive), the total system's cost will obviously include only three out of these four cost components, as the disposal cost will be null.

2.3. Model structure

The overall model structure is represented in Figure 1.

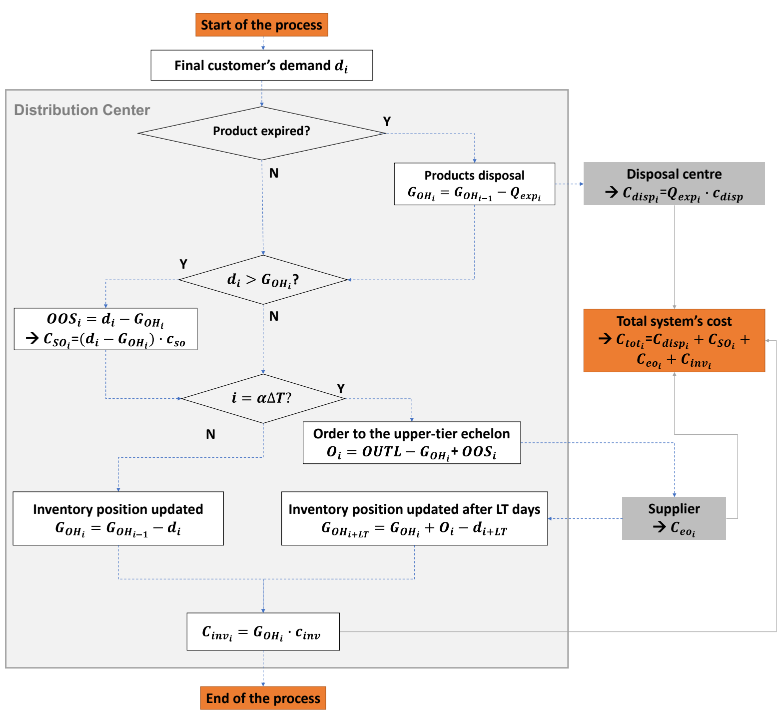

Figure 1. flowchart of the proposed approach.

At the beginning of each period (i), the DC faces the demand for the finished products d_i. This involves a first check on the products in stock, which consists in verifying whether the i-th period coincides with the shelf-life of some of the products ordered in a previous period. If this is the case, a given amount of product will need to be discarded, because of shelf-life expiration. This amount is denoted as Q_{exp_i}. The presence of expired products, which need to be discarded, also involves recalculating the on-hand inventory, whose amount will be updated as follows:

$$G_{OH_i} = G_{OH_{i}-1} - Q_{exp_i} \quad (1)$$

A disposal cost will be computed as:

$$C_{disp_i} = Q_{exp_i} \cdot c_{disp} \quad (2)$$

If there are, instead, no products to be discarded, the DC will check whether the amount of on-hand inventory is sufficient to satisfy the demand faced ($d_i > G_{OH_i}$?). If the demand is found to be higher than the available stock, an out-of-stock is observed for a quantity equal to $d_i - G_{OH_i}$, which will be used to compute the corresponding stock-out cost:

$$C_{so_i} = (d_i - G_{OH_i}) \cdot c_{so} \quad (3)$$

If, instead, $d_i \leq G_{OH_i}$, the demand can be satisfied with the available stock and no out-of-stock situations are observed. The inventory position will be therefore updated by removing the products shipped to the customer. Before updating it, however, the system will check whether an order should be placed on day i, i.e. if $i = \alpha\Delta T$?,with $\alpha \in N$. In case an order should be placed, the amount of product ordered will restore the $OUTL$, as follows:

$$O_i = OUTL - G_{OH_i} + OOS_i \quad (4)$$

Eq.4 takes into account the out-of-stock quantity (when applicable) as backorder is admitted in the proposed model. Issuing an order involves an order cost C_{eo}, and implies that the supplier will have to deliver the O_i quantity in LT days, and then, the physical stock will the updated again:

$$G_{OH_{i+LT}} = G_{OH_i} + O_i - d_{i+LT} \quad (5)$$

If instead no orders are placed, the O_i will obviously score zero, and the available stock will be simply updated as follows:

$$G_{OH_i} = G_{OH_{i-1}} - d_i \quad (6)$$

The inventory cost will then be computed as:

$$C_{inv_i} = G_{OH_i} \cdot c_{inv} \quad (7)$$

The total system's cost is finally computed as the sum of the costs components previously listed, i.e.:

$$C_{tot_i} = C_{inv_i} + C_{so_i} + C_{disp_i} + C_{eo_i} \quad (8)$$

3. Numerical example and results

By means of simulation, the proposed model was used to explore a wide set of solutions. These latter were obtained by varying the typical operating leverages of the EOI policy (i.e. ΔT and $OUTL$), as well as some key characteristics of perishable products, i.e. the shelf-life and disposal cost.

To this end, the set of equations described above was embodied into a Microsoft Excel™ spreadsheet. A perishable product with limited shelf life, such as fresh milk, was taken as a realistic example for testing the proposed approach, in terms of its effectiveness in identifying the best settings of the EOI policy (i.e. ΔT and $OUTL$) for managing the product and, consequently, for minimizing the total associated costs, thus increasing the efficiency and effectiveness of inventory management.

The case study has been carried out setting $n = 90{,}000$ days as the simulation length and shows the trend of the warehouse stock and its associated cost for the targeted product. Results are reported in the following in form of average daily values, which were computed as shown in eq.9 (the formula refers to the total cost, but it can be easily extended to all cost components):

$$C_{tot} = \frac{\sum_{i=1}^{n} C_{tot_i}}{n} \quad (9)$$

A first set of simulations has been made by varying ΔT and $OUTL$ in a suitable range of values; the unitary disposal cost was varied as well and their values were taken from a suitable source (i.e. Legambiente, 2013). The rationale for varying this latter parameter is that the disposal cost is expected to be an important cost component in case of perishable products, and investigating expressively its impact on the total cost could be interesting. A second set of simulations was instead made by keeping the disposal cost fixed and the varying instead the product shelf-life SL (besides ΔT and $OUTL$). The variation in SL could sound strange as we are referring to a real (or realistic) product, whose shelf-life should be known and fixed. However, even when referring to a real product (i.e. fresh milk in our example), slight variations in the shelf-life can actually be observed in practice (e.g. micro-filtered milk could have a longer shelf-life compared with milk that has undergone a different treatment). The second set of simulations therefore aimed at evaluating the impact of the shelf-life on the resulting total cost of inventory management.

In both set of simulations, the ultimate aim is to analyse a wide set of possible scenarios and identify the most effective combination of the inventory policy parameters, corresponding to the combination that returns the minimum total cost of the system.

The simulation parameters have been set as shown in Tables 1 and 3, for the first and second set of simulations respectively.

3.1. First set of simulations

Some preliminary considerations needed to set up the simulation system and understand data are here presented. For a real product, LT and SL are typically known and fixed, while the reordering interval was varied, for simulation purposes, in the range $\Delta T < SL < 2\Delta T$, i.e. $\Delta T = 4, 5, 6$ as the product shelf-life is set at 7. This constraint may be relaxed, although the optimal solution would always be reasonably found for SL values that fall within this range. Under these hypotheses, the warehouse stocks different batches of items of the same product, ordered at different times, and having different shelf-life. This happens because the SL of the product has a longer lifetime than the reorder interval ΔT. Under these circumstances, the FIFO order fulfilment logic is a must, although FEFO would actually be the optimal choice. As far as the $OUTL$, this was instead varied in the range 20,000-50,000 kg, with step 2,000 kg (16 values). By combining these values with those of the ΔT, 48 scenarios were evaluated in total. Moreover, six values of c_{disp} (ranging from 0.00 €/kg and 0.30 €/kg, according to Legambiente, 2013) were taken into account in the simulation campaign.

Table 1. First set of simulations - input data.

Parameter	Value	Measurement unit
n	90,000	days
SL	7	days
LT	1	days
μ_d (average demand)	5,000	kg/day
σ_d (demand standard deviation)	141.42	kg/day
c_{inv}	0.022	€/kg/day
c_{so}	0.44	€/kg/day
C_{eo}	2,000	€/order
c_{disp}	**0 – 0.30**	**€/kg**

The results obtained from the first set of simulations (Table 2) shows that, in case of highly perishable product, the optimal values of the EOI policy are ΔT=5 days and $OUTL$=30,000 kg/order. These values remain constant although the disposal cost varies. More in detail, as the disposal cost increases, the total cost of inventory remains almost constant with a very limited deviation. Given the quite high stock-out costs, the optimal combination of the inventory policy seeks to minimise the shortage condition; on the other hand, it must be noticed that the expired product can also generate stock-out, as the expired product cannot be used to satisfy the customer's demand. Hence, the stock level must be precisely determined in order to limit product expiration. Consequently, the best condition involves a very low cost of stock-out and expired product. These considerations justify the behaviour of the model outputs ($OUTL$ and ΔT), which are actually not significantly affected by changes in c_{disp}; in fact, the effect on C_{tot} of the increasing c_{disp} is very limited, as the quantity of expired product is small.

Table 2. First set of simulations - output results. **OUTL = 30,000 kg/order and ΔT = 5 days**.

Cost components	Numerical value [€/day]					
C_{disp} [€/kg]	**0.00**	**0.06**	**0.12**	**0.18**	**0.24**	**0.30**
C_{inv} [€/day]	220.01	219.98	220.04	220.05	220.00	220.05
C_{so} [€/day]	12.59	13.25	12.31	12.31	12.86	12.31
C_{eo} [€/day]	399.97	399.97	399.97	399.97	399.97	399.97
C_{disp} [€/day]	0.00	1.76	3.44	5.13	6.98	8.52
C_{tot} [€/day]	**632.58**	**634.97**	**635.77**	**637.47**	**639.81**	**640.86**

3.2. Second set of simulations

A second simulation campaign was carried out by varying the SL of the product keeping constant the disposal cost c_{disp}, set at the intermediate value of 0.12 €/kg. This setting is expected to allow investigating the impact of the product's perishability on the warehouse management costs. In particular, SL was varied between 6 and 12 days (see Table 3). As in the previous case, $OUTL$ was varied in the range 20,000-50,000 kg, with step 2,000 kg (16 values), while the ΔT was varied as a function of the SL, following the logic mentioned above (i.e. $\Delta T < SL < 2\Delta T$). The optimal combination of $OUTL$ and ΔT is shown in Table 4 for the different values of SL investigated.

Table 3. Second set of simulations - input data.

Parameter	Value	Measurement unit
n	90,000	days
SL	**6 - 12**	**days**
LT	1	days
μ_d (average demand)	5,000	kg/day
σ_d (standard deviation)	141.42	kg/day
c_{inv}	0.022	€/kg/day
c_{so}	0.44	€/kg/day
c_{eo}	2,000	€/order
c_{disp}	0.12	€/kg

Table 4. Second set of simulations - output results.

SL [days]	6	7	8	9
C_{inv} [€/day]	181.48	219.98	220.67	296.94
C_{so} [€/day]	1.16	14.29	12.31	2.03
C_{eo} [€/day]	499.97	399.97	399.97	333.31
C_{disp} [€/day]	30.01	3.59	0.00	0.19
C_{tot} [€/day]	**712.62**	**637.82**	**632.96**	**632.47**
OUTL [kg/order]	26,000	30,000	30,000	36,000

ΔT [days]	4	5	5	6

SL [days]	**10**	**11**	**12**
C_{inv} [€/day]	330.59	330.59	330.66
C_{so} [€/day]	10.40	10.89	9.95
C_{eo} [€/day]	285.58	285.58	285.58
C_{disp} [€/day]	0.08	0.12	0.00
C_{tot} [€/day]	**626.65**	**627.19**	**626.19**
OUTL [kg/order]	40,000	40,000	40,000
ΔT [days]	7	7	7

Results in Table 4 show that overall, increasing the SL of the product generates a decrease in C_{tot}. Several effects can be identified. First of all, with longer SL, the optimal values of $OUTL$ and ΔT increase, probably because there is less need for placing frequent orders as the product does not reach the expiry date so quickly. Hence, orders become less frequent, which leads to a decrease in the cost of order issuing, that is assumed to be constant regardless of the quantity ordered; more in detail, two truckloads are considered for product transportation. Increasing the SL also has a positive effect on the disposal cost, whose impact on the total system's cost is however, quite limited.

4. Conclusions

This study has proposed an EOI-based model for managing inventories of perishable items, such as food products in particular. The model grounds on a set of analytic formulae that describe the inventory management process and return, as output, the optimal settings of the EOI policy (in terms of $OUTL$ and ΔT), as well as the total cost of managing inventories. Disposal cost is included in the analysis, to take into account the peculiarities of perishable items.

Two set of simulations were then carried out to evaluate the impact of the disposal cost and product shelf-life on the EOI policy settings and total cost of the system.

On the basis of the outcomes of the simulations, a general conclusion is that the proposed model is effective in determining the optimal setting of the EOI policy parameters and in minimizing the total cost of the system. Looking at the specific results, it is easy to deduce that the disposal cost does not affect the total cost of the system to an appreciable extent (at least within the range of numerical values tested) and consequently, does not involve changes in the optimal settings of the EOI policy. On the contrary, the stock-out cost plays a more significant role for the determination of the optimal EOI policy parameters. There is, at the same time, a possible relationship between the stock-out cost and the disposal cost: indeed, expired products generate (for sure) disposal costs, as they should be discarded, but have also the potential to generate out-of-stock situations, as they cannot be used for satisfying the customer's demand; hence, stock-out cost can also arise from expired products. These aspects are correctly captured by the proposed model.

As far as the impact of shelf-life on the total cost, it was found that the system's cost decreases if the shelf-life of the product becomes longer. This was expected, as a longer shelf-life involves less risk of product's expiration and consequently, lower disposal cost.

Starting from this study, future research activities can be undertaken for evaluating, e.g., products with different shelf-life characteristics, to gain further insights. Similarly, a comparison of the proposed approach with the EOQ or (S,s) policies could be an interesting future research activity.

5. References

Amorim, P., Meyr, H., Almeder, C., Almada-Lobo, B. (2013). Managing perishability in production-distribution planning: A discussion and review. Flexible Services and Manufacturing Journal, 25 (3), 389–413

Babagolzadeh, M., Pirayesh, M., & Shrestha, A. (2021). Optimal delivery and replenishment policies for perishable products considering lost sale cost: An efficient hybrid algorithm. International Journal of Industrial and Systems Engineering, 37(3), 306-333

Bottani, E., Ferretti, G., Montanari, R., & Rinaldi, M. (2014). Analysis and optimisation of inventory management policies for perishable food products: A simulation study. International Journal of Simulation and Process Modelling, 9(1-2), 16-32.

Chaudhary, V., Kulshrestha, R., & Routroy, S. (2018). State-of-the-art literature review on inventory models for perishable products. Journal of Advances in Management Research, 15(3), 306-346.

Chopra, S., Meindl, P. 2010. Supply Chain Management - Strategy, Planning and Operation 4th Ed, Pearson.

Ghosh, S.K., Khanra, S., Chaudhuri, K.S., 2011. Optimal price and lot size determination for a perishable product under conditions of finite production, partial backordering and lost sale. Applied Mathematics and Computation, 217(13), 6047-6053.

Grocery manufacturers of America. 2006 Unsaleables benchmark report. 2006.

Legambiente. 2013. Ridurre e riciclare prima di tutto. Accessed November 28, 2015. http://www.legambiente.it/sites/default/files/docs/riduure_riciclare_primaditutto_dossier2013.pdf.

Muriana, C. (2016). An EOQ model for perishable products with fixed shelf life under stochastic demand conditions. European Journal of Operational Research, 255(2), 388-396.

Nagare, M., Dutta, P., 2012. Continuous review model for perishable products with inventory dependent demand. Lecture Notes in Engineering and Computer Science, 2196, 1513-1517.

Nahmias, S., 1982. Perishable inventory theory: A review. Operations Research 30 (4), 680–708.

Patriarca, R., Di Gravio, G., Costantino, F., & Tronci, M. (2020). EOQ inventory model for perishable products under uncertainty. Production Engineering, 14(5-6), 601-612.

Raafat, F., 1991. Survey of literature on continuously deteriorating inventory models. Journal of the Operational Research Society 42(1), 27–37.

Rossi, R. (2013). Periodic review for a perishable item under non stationary stochastic demand. Paper presented at the IFAC-PapersOnline, 46(9) 2021-2026.

Sharifi, E., Hasanpour, J., & Taleizadeh, A. A. (2021). A lot sizing model for imperfect and deteriorating product with destructive testing and inspection errors. International Journal of Systems Science: Operations and Logistics, 8(1), 87-98.

Sharma, K.P., 2016. Perishable inventory systems: A literature review since 2006. International Journal of Applied Research 2(9), 150-155.

Yan, X., Wang, Y. (2013). An EOQ model for perishable items with supply uncertainty. Mathematical Problems in Engineering, 2013 doi:10.1155/2013/739425.