EFFECTS OF INSPECTION ON RETAILER'S ORDERING POLICY FOR A DETERIORATING ITEM WITH WEIBULL DISTRIBUTION DETERIORATION, TIME-DEPENDENT DEMAND UNDER INFLATIONARY CONDITION

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ABSTRACT

For an unstable supply inventory model, the received lots may carry a random proportion of damaged products characterized by a known distribution.Accordingly, inspection of the lot is essential in nearly every case.The Weibull distri- bution with two parameters specifically represents the time to deterioration.Defective units are presumed to be retrieved as a single batch following inspection.For many consumer goods, it is also noted that the price and demand increase linearly with time, especially in inflationary circumstances.Since demand and price change over time, this study looks at how merchants' ordering procedures for deteriorating items are impacted by defective items under inflation. The proposed model aims to maximize the order quantity and the retailer's expected profit. An example is provided to illustrate the outcomes.

Keywords

Inventory, Inspection, Time-dependent demand, Inflation, Weibull distribution.

INTRODUCTION

This research concentrates on designing an EOQ model for deteriorating goods, integrating Weibull deterioration, time- varying demand, and inflation. For the derating items, a number of economic order quantity (EOQ) models have been developed thus far. The following models are:

- Porteus (1986): Optimal Lot Sizing, Process Quality Improvement and Setup Cost Reduction,
- Lee and Rosenblatt (1987): Simultaneous determination of production cycles and inspection schedules in a pro- duction system,
- Salameh and Jaber (2000): Economic Production Quan- tity model for items with imperfect quality,
- Ghosh and Chaudhuri (2004): An order level inventory model for a deteriorating item with Weibull distribution deterioration, time-quadratic demand and shortages,
- Convert and Philip (2007): An EOQ model for items with Weibull distribution deterioration,
- Jaggi, Mittal, and Khanna (2013),
- Mittal, Khanna, and Jaggi (2017): Retailer's ordering policy for deteriorating imperfect quality items when demand and price are time-dependent under inflationary conditions and permissible delay in payments,
- Alshanbari, Rashid (2021): Economic order quantity model with Weibull distributed deterioration under a mixed cash and prepayment scheme,

- Yadav, Chand, and Sarkar (2023): Smart production sys- tem with random imperfect process, partial backordering, and deterioration in an inflationary environment,
- Rajawat, Mittal, and Sarkar (2025, March): Inventory optimization for deteriorating products using exponential demand forecasting and machine learning with carbon emission constraints,
- Rajawat, Mittal, and Rana (2025, January): A compara- tive analysis of 3PL logistics for deteriorating products: a CNN approach to demand and carbon emission predic- tion.

Driven by this consideration, this article discusses the inven- tory model used by retailers for Weibull deteriorating, subpar products in inflationary environments where price and demand are time dependent. Product where demand and price fluctuate linearly over time, such as crops (paddy, wheat, potato, onion, ginger, etc), benefit greatly from this model. The model further considers that customer demand is covered by screened non- defective units, since the screening process operates faster than the demand rate. The model is designed to achieve simultaneous maximization of the retailer's expected profit and optimization of the order quantity. A numerical example is used to examine the effects of deterioration, inflation, and the expected number of poor-quality items on order quantity and overall profit.

NOTATIONS

The symbols applied in constructing the model are listed as follows:

$I(t)$	The quantity of stock present at any point in time $t > 0$.
$B(t)$	Instantaneous demand rate at time $t > 0$.
$F_p(t)$	Pricing per unit at time t.
K	Value of money represented by the discount rate.
l	Rate of inflation per unit of time.
N	Net inflation rate, $N = (K - l)$.
C	Price per unit.
C_1	Inventory storage cost per unit per unit time.
C_3	Order placement cost.
T	Duration of a cycle.
B_0	Demand at the initial time.
F_0	Per-unit selling price at the start.
m	Rate of variation of the unit selling price with respect to t.
n_1	Demand rate gradient with respect to t.
P_s	Salvage value assigned to each defective item, $P_s < C$.
d	Rate of screening of units.
μ_1	Screening period.
δ	Fraction of faulty units.
$f(\delta)$	Probability density function of δ.
$E_p(\cdot)$	Mean value operator.
$E_p(\delta)$	Average defective fraction, $E_p(\delta) = \int_{\lambda_1}^{\lambda_2} \delta f(\delta) d\delta,\ \lambda_1 \leq \delta \leq \lambda_2$.
$I_1(t)$	Inventory level during $0 \leq t \leq \mu_1$.
$I_2(t)$	Stock level during $0 \leq t \leq \mu_2$.
$I_3(t)$	Inventory quantity during $0 \leq t \leq T$.
$I_{eff}(\mu_1)$	Usable inventory at μ_1 after removing defectives.
$\Pi(T)$	Net present value of total profit.
$E_p[\Pi(T)]$	Expected present value of total profit.
$Z(t)$	$\alpha\beta t^{\beta-1}$, instantaneous deterioration rate for Weibull distribution with parameters $\alpha > 0$, $\beta > 0$.

MATHEMATICAL MODEL

For this study, B(t) is modeled as a function of time, staying constant until t = µ1, after which it grows linearly with time. In crops (such as paddy, wheat, potatoes, onions, ginger, etc.), this kind of demand pattern is frequently observed. Since the businesspeople initially stock the commodities in warehouses or cold stores, the market's demand for them stays steady for a certain amount of time (0,µ1). Following that specific time frame (0,µ1), the market's demand naturally rises since all consumers must buy their necessities because of the harvested item's decline. The pricing of these goods has a similar behavior. Fp(t) rises over time because the selling price rises in response to the demand rate. As a result, we define B(t) and Fp(t) as follows:

$$B(t) = B_0 + n_1(t - \mu_2)G(t - \mu_2) \tag{1}$$

$$F_p(t) = F_0 + m(t - \mu_2)G(t - \mu_2) \tag{2}$$

where

$$G(t) = \begin{cases} 1, & t \geq \mu_2 \\ 0, & t < \mu_2 \end{cases} \tag{3}$$

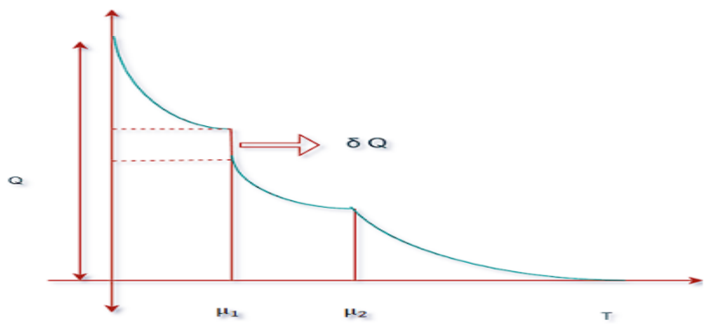

Fig. 1. The predicted total profit function is concave.

ASSUMPTIONS

The model is constructed considering the following assumptions:

- **Deterioration rate depends on time**
- **Demand rate varies with time.**
- **The per-unit selling price changes as time progresses.**
- **There is no lead time.**
- **Stockouts are prohibited.**
- **The analysis accounts for inflation as well as the time value of money.**

Initially, Q goods are purchased. It is assumed that some defective goods may be present in every lot. With the probability density function $f(\delta)$, computable from past data, let δ be the proportion of defective items. From 0 to μ_1, all units are subjected to screening at a per-unit time rate, presumed to exceed the demand rate $B(t)$. Demand arises concurrently with the screening process and is satisfied by the high-quality merchandise.

Upon completion of inspection at time μ_1, all defective units are offered for sale in bulk at a reduced price. At $t = \mu_1$, the effective inventory falls to $I_{\text{eff}}(\mu_1)$. The demand remains constant until μ_2, after which it increases linearly with time. Moreover, Fig. 1 shows that the inventory level diminishes to zero by time T, primarily influenced by demand and partially by deterioration.

Now, the screened lot must exceed the demand during μ_1 to prevent shortages during the screening period:

$$(1 - E_p[\delta])Q \geq B_0\mu_1 \quad \Rightarrow \quad E_p(\delta) \leq 1 - \frac{B_0}{d} \tag{4}$$

where δ is a uniformly distributed random variable with values between d_1 and d_2, and its expected value is $E_p(\delta)$. The time spent on screening is

$$\mu_1 = \frac{Q}{d} \tag{5}$$

Let $I_1(t)$ represent the inventory level at any given time t, where $0 \leq t \leq \mu_1$. The differential equation describing the instantaneous behaviour of $I_1(t)$ in the interval $(0, \mu_1)$ is given by

$$\frac{dI_1(t)}{dt} + Z(t)I_1(t) = -B_0, \quad 0 \leq t \leq \mu_1 \tag{6}$$

At $t = 0$, under the boundary condition, $I_1(0) = Q$, where $Z(t) = \alpha\beta t^{\beta-1}$.

This represents a first-order linear differential equation, and its integrating factor is

$$\exp\left[\alpha\beta \int t^{\beta-1} dt\right] = \exp\left[\alpha t^{\beta}\right].$$

Multiplying both sides of (6) by $\exp[\alpha t^{\beta}]$ gives

$$\left(\frac{dI_1(t)}{dt} + \alpha\beta t^{\beta-1} I_1(t)\right)\exp[\alpha t^{\beta}] = -B_0 \exp[\alpha t^{\beta}].$$

Assuming the boundary condition $I_1(0) = Q$, the solution is

$$I_1(t) = -B_0\left[\sum_{n=0}^{\infty} \frac{\alpha^n t^{(n\beta+1)}}{(n\beta+1)n!}\right]\exp[-\alpha t^{\beta}] + Q\exp[-\alpha t^{\beta}] \tag{7}$$

The inventory level at time μ_1, including the defective items, is

$$I_1(\mu_1) = -B_0\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_1^{(n\beta+1)}}{(n\beta+1)n!}\right]\exp[-\alpha\mu_1^{\beta}] + Q\exp[-\alpha\mu_1^{\beta}] \tag{8}$$

After screening, δQ faulty units remain at time μ_1; therefore, the effective inventory level is

$$I_{\text{eff}}(\mu_1) = -B_0\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_1^{(n\beta+1)}}{(n\beta+1)n!}\right]\exp[-\alpha\mu_1^{\beta}] + Q\exp[-\alpha\mu_1^{\beta}] - \delta Q \tag{9}$$

Once more, the inventory level at any given moment (μ_1, μ_2) is provided by

$$\frac{dI_2(t)}{dt} + Z(t)I_2(t) = -B_0, \quad \mu_1 \leq t \leq \mu_2 \tag{10}$$

with the boundary condition $I_2(\mu_1) = I_{\text{eff}}(\mu_1)$. Its solution is

$$I_2(t) = -B_0\left[\sum_{n=0}^{\infty} \frac{\alpha^n t^{(n\beta+1)}}{(n\beta+1)n!}\right]\exp[-\alpha t^{\beta}] + Q\exp[-\alpha t^{\beta}] - \delta Q\exp\left[\alpha(\mu_1^{\beta} - t^{\beta})\right] \tag{11}$$

Additionally, during (μ_2, T), the inventory level is

$$\frac{dI_3(t)}{dt} + Z(t)I_3(t) = -B_0 + n_1(t - \mu_2), \quad \mu_2 \leq t \leq T \tag{12}$$

with boundary condition $I_3(\mu_2) = I_2(\mu_2)$. Its solution is

$$\begin{aligned} I_3(t) = &(B_0 - n_1\mu_2)\left[\sum_{n=0}^{\infty} \frac{\alpha^n t^{(n\beta+1)}}{(n\beta+1)n!}\right]\exp[-\alpha t^{\beta}] \\ &- n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n t^{(n\beta+2)}}{(n\beta+2)n!}\right]\exp[-\alpha t^{\beta}] \\ &+ Q\exp[-\alpha t^{\beta}](1 - \delta\exp[-\alpha\mu_1^{\beta}]) \\ &- n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_2^{(n\beta+2)}}{(n\beta+2)n!}\right]\exp[-\alpha t^{\beta}] \end{aligned} \tag{13}$$

Since $I_3(T) = 0$, the order quantity Q is obtained as

$$\begin{aligned} Q = &(1 - \delta\exp[\alpha\mu_2^{\beta}])\Bigg\{(B_0 - n_1\mu_2)\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+1)}}{(n\beta+1)n!}\right] \\ &+ n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+2)}}{(n\beta+2)n!}\right] + n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_2^{(n\beta+2)}}{(n\beta+2)n!}\right]\Bigg\} \end{aligned} \tag{14}$$

Since $Q = d\mu_1$, we obtain

$$\begin{aligned} \mu_1(1 - \delta\exp[\alpha\mu_2^{\beta}]) = \frac{1}{d}\Bigg\{&(B_0 - n_1\mu_2)\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+1)}}{(n\beta+1)n!}\right] \\ &+ n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+2)}}{(n\beta+2)n!}\right] \\ &+ n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_2^{(n\beta+2)}}{(n\beta+2)n!}\right]\Bigg\} \end{aligned} \tag{15}$$

Neglecting second and higher order terms of $\alpha\mu_2^{\beta}$ (assuming $\alpha\mu_2^{\beta} < 1$), the Taylor expansion yields

$$\begin{aligned} \mu_1[1 - \delta - \delta\alpha\mu_2^{\beta}] = \frac{1}{d}\Bigg\{&(B_0 - n_1\mu_2)\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+1)}}{(n\beta+1)n!}\right] \\ &+ n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+2)}}{(n\beta+2)n!}\right] \\ &+ n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_2^{(n\beta+2)}}{(n\beta+2)n!}\right]\Bigg\} \end{aligned} \tag{16}$$

Since $\delta \in [0, 0.1]$, the term $\alpha\mu_2^{\beta}$ is negligible. Thus,

$$\begin{aligned} \mu_1 = \frac{1}{d(1-\delta)}\Bigg\{&(B_0 - n_1\mu_2)\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+1)}}{(n\beta+1)n!}\right] \\ &+ n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n T^{(n\beta+2)}}{(n\beta+2)n!}\right] + n_1\left[\sum_{n=0}^{\infty} \frac{\alpha^n \mu_2^{(n\beta+2)}}{(n\beta+2)n!}\right]\Bigg\} \end{aligned} \tag{17}$$

For one cycle, the retailer's profit is given by

$$\pi(T) = \text{Sales Revenue} - \text{Ordering Cost} - \text{Purchasing Cost} - \text{Screening Cost} - \text{Holding Cost} \tag{18}$$

Moreover, under inflationary conditions, the present value of sales revenue is given by

$$\text{Revenue} = P_s \delta Q e^{-N\mu_1} + \int_0^{\mu_2} F_0 B_0 e^{-Nt}\, dt + \int_{\mu_2}^{T} \{B_0 + n_1(t-\mu_2)\}\{F_0 + m(t-\mu_2)\} e^{-Nt}\, dt \tag{19}$$

Evaluating the above integrals, we obtain

$$\begin{aligned}\text{Revenue} =& P_s \delta Q e^{-N\mu_1} + F_0 B_0 \left(\frac{1-e^{-NT}}{N}\right) \\ &+ (B_0 m + F_0 n_1)\frac{e^{-N\mu_2} - e^{-NT}}{N^2} \\ &- (T-\mu_2)\frac{e^{-NT}}{N} + mn_1 \frac{(T-\mu_2)^2 e^{-NT}}{N^2} \\ &+ \frac{2e^{-NT} - 2e^{-N\mu_2}}{N^3}\end{aligned} \tag{20}$$

The current ordering cost is simply

$$\text{Ordering Cost} = C_3 \tag{21}$$

(The ordering cost is unaffected by inflation because the order is placed at $t = 0$.)

The current purchase cost is

$$\text{Purchase Cost} = CQ \tag{22}$$

The current screening cost is

$$\text{Screening Cost} = hQe^{-N\mu_1} \tag{23}$$

The holding cost associated with the present replenishment cycle is

$$\text{Holding Cost} = C_1 \left[\int_0^{\mu_1} I_1(t) e^{-Nt}\, dt + \int_{\mu_1}^{\mu_2} I_2(t) e^{-Nt}\, dt + \int_{\mu_2}^{T} I_3(t) e^{-Nt}\, dt\right] \tag{24}$$

Substituting (19)–(23) into (18) gives the present value of the total profit $\Pi(T)$:

$$\begin{aligned}\Pi(T) =& F_0 B_0 \left(\frac{1-e^{-NT}}{N}\right) \\ &+ (B_0 m + F_0 n_1)\frac{e^{-N\mu_2} - e^{-NT}}{N^2} \\ &- (T-\mu_2)\frac{e^{-NT}}{N} + mn_1 \frac{(T-\mu_2)^2 e^{-NT}}{N^2} \\ &+ \frac{2e^{-NT} - 2e^{-N\mu_2}}{N^3} + P_s \delta Q e^{-N\mu_1} \\ &- C_3 - CQ - hQe^{-N\mu_1} \\ &- C_1 \left[\int_0^{\mu_1} I_1(t) e^{-Nt}\, dt + \int_{\mu_1}^{\mu_2} I_2(t) e^{-Nt}\, dt \right. \\ &\left. + \int_{\mu_2}^{T} I_3(t) e^{-Nt}\, dt\right]\end{aligned} \tag{25}$$

Since δ follows the probability density function $f(\delta)$, the expected present value of profit is

$$\begin{aligned}E_p[\Pi(T)] =& F_0 B_0 \left(\frac{1-e^{-NT}}{N}\right) \\ &+ (B_0 m + F_0 n_1)\frac{e^{-N\mu_2} - e^{-NT}}{N^2} \\ &- (T-\mu_2)\frac{e^{-NT}}{N} + mn_1 \frac{(T-\mu_2)^2 e^{-NT}}{N^2} \\ &+ \frac{2e^{-NT} - 2e^{-N\mu_2}}{N^3} \\ &+ P_s E_p[\delta] Q e^{-N\mu_1} \\ &- C_3 - CQ - hQe^{-N\mu_1} \\ &- C_1 \int_0^{\mu_1} I_1(t) e^{-Nt}\, dt - C_1 \int_{\mu_1}^{\mu_2} I_2(t) e^{-Nt}\, dt \\ &- C_1 \int_{\mu_2}^{T} I_3(t) e^{-Nt}\, dt\end{aligned} \tag{26}$$

where

$$N = k - l$$

V. Solution Procedure

To achieve the maximum of the expected total profit $E_p[\Pi(T)]$, the optimal cycle time $T = T^*$ must be identified, and the following conditions must be met:

$$\frac{d}{dT}E_p[\Pi(T)] = 0 \tag{27}$$

$$\frac{d^2}{dT^2}E_p[\Pi(T)] < 0 \tag{28}$$

We have,

$$\begin{aligned}\frac{d}{dT}E_p[\Pi(T)] = F_0B_0\left(\frac{1-e^{-NT}}{N}\right)& \\ +(B_0m+F_0n_1)\frac{e^{-N\mu_2}-e^{-NT}}{N^2}& \\ -(T-\mu_2)\frac{e^{-NT}}{N}+mn_1\frac{(T-\mu_2)^2e^{-NT}}{N^2}& \\ +\frac{2e^{-NT}-2e^{-N\mu_2}}{N^3}+P_sE_p[\delta]Qe^{-N\mu_1}& \\ -C_3-CQ-hQe^{-N\mu_1}& \\ -C_1\left[\int_0^{\mu_1}I_1(t)e^{-Nt}\,dt+\int_{\mu_1}^{\mu_2}I_2(t)e^{-Nt}\,dt\right.& \\ \left.+\int_{\mu_2}^{T}I_3(t)e^{-Nt}\,dt\right]=0&\end{aligned} \tag{29}$$

Through the solution of (26), the optimal value T^* can be determined.

Concavity of the expected total profit function is ensured only if the following condition is fulfilled:

$$\frac{d^2}{dT^2}E_p[\Pi(T)] < 0 \tag{30}$$

The mathematical proof of concavity for $E_p[\Pi(T)]$ is difficult due to the complexity of its second derivative. Therefore, a graphical representation of the concavity of $E_p[\Pi(T)]$ is used (see Fig. 2).

VI. Numerical Example

The data listed below has been used to validate the model:

$$C_3 = 230\text{ /cycle},\quad B_0 = 4000\text{ units/year},\quad F_0 = \$35,\quad C = \$15,$$
$$m = 0.22,\quad n_1 = 3.5,\quad k = 0.12,\quad l = 0.06,\quad N = 0.08,\quad C_1 = \$10$$
$$P_s = \$12,\quad \mu_2 = 1.2,\quad \lambda_1 = 0,\quad \lambda_2 = 0.8,\quad E[\delta] = 0.04,$$
$$h = 0.35\text{ /unit},\quad d = 12{,}000\text{ units/year},\quad \alpha = 0.002,\quad \beta = 1.5.$$

To make sure there are no shortages during the screening process, we first verify the condition provided by Equation (4) for the given data:

$$E[\delta] \le 0.983$$

Because Equation (27), which yields $T^* = 1.4$ years, may be solved to determine the ideal value of T.

When we substitute T^* into Equations (18), (15), and (26), we obtain:

$$\text{Sales Revenue} = \$186{,}094.33$$
$$\text{Holding Cost} = \$17{,}417.02$$
$$\text{Purchase Cost} = \$84{,}959.44$$
$$\text{Screening Cost} = \$1{,}975.26$$
$$\mu_1^* = 0.4721\text{ years},\quad Q^* = 5663.96\text{ units}$$
$$E_p[\Pi(T^*)] = \$81{,}512.61$$

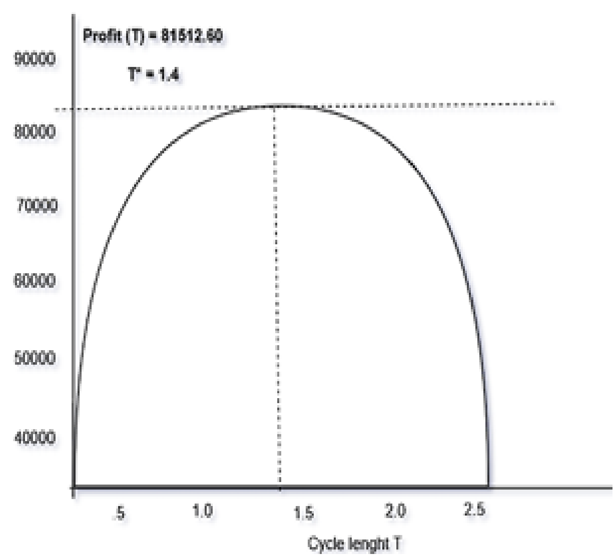

Fig. 2. The predicted total profit function is concave.

CONCLUSION

This article develops inventory models for imperfect-quality items with time-dependent selling price and demand, con- sidering the push-and-pull effects of inflation and Weibull deterioration. All units are inspected, and it is expected that the screening rate exceeds the demand rate. Its significance increases when objects are naturally degrading. Additionally, it has been noted that, particularly in inflationary environments, the price and demand for some consumer goods—such as wheat, paddy, etc.—increase linearly with time. When devel- oping an inventory replenishment strategy for these products, it is vital to consider both inflation and the time value of money. Consumable items and other products that are likely to have these qualities can benefit greatly from the suggested model in the retail sector.

The results have ultimately been verified through a nu- merical case study. The results unmistakably provide retailers with crucial managerial insights for choosing the best ordering strategy in a variety of scenarios, including: (a) The presence of more defective units in the ordered lot should encourage the retailer to exercise greater caution when ordering. (b) Placing more frequent orders for items that are deteriorating rapidly; and (c) Placing large orders in an extremely inflationary market to boost profits.\

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