2012 LSCM CONFERENCE PROCEEDINGS

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May 11 to 12, 2012

Graduate School of Logistics Management
Takming University of Science and Technology
Neihu, Taipei, Taiwan

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Production Inventory Model for Deteriorating Items with Common Distribution Machine Unavailability

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Abstract

In this work we developed EPQ models for deteriorating items by considering stochastic machine unavailability and price-dependent demand. Moreover, we approach the distribution of the machine unavailability using kernel density estimation. Therefore, the assumption of any distribution models, such as uniformly or exponentially distribution can be neglected and the shape of the distribution will follow the given data. To solve the models, we will employ Genetic Algorithm, since the close form solution cannot be derived. A numerical example and sensitivity analysis will be given to illustrate the models.

Keywords: EPQ, deteriorating items, machine unavailability time, price-dependent demand, kernel density.

Introduction

Many researchers have been investigated the most suitable the production inventory models for solving the real-world inventory problems. One of the problems that had been developed so far is EPQ models for unreliable production facility since it is difficult to set a reliable facility in reality. That unreliable production facility might be caused by material unavailability, machine repair, maintenance or breakdown. Investigation of unreliable production facility has been done previously such as Abboud et al (2000), Lin and Gong (2006), and El-Ferik (2008).

This paper extends the Widyadana and Wee (2010), which developed the production inventory models for deteriorating items with stochastic machine unavailability time and lost sales and price dependent demand. On that work Widyadana and Wee (2010) only considered two distribution cases to represent the probability density function of machine repair time. Those distributions were uniform and exponential. In this work, we assumed the distribution free to model the probability density function of machine repair time.

The organization of this paper will be presented as follows. First, we delivered the motivation and literature review. The mathematical model development for solving the problem will be given next. It follows by the result and discussion, and conclusions and future research are given in the last section.

Methods

Following the Widyadana and Wee (2010), these assumptions are used in the model development: (1) Production is constant. (2) Deterioration rate is constant. (3) There is no repair or replacement for a deteriorated item. (4) Demand rate depends on price. The demand rate equation is $\alpha p^{-\varepsilon}$.

The inventory policy for lost sales case is illustrated in Figure 1.

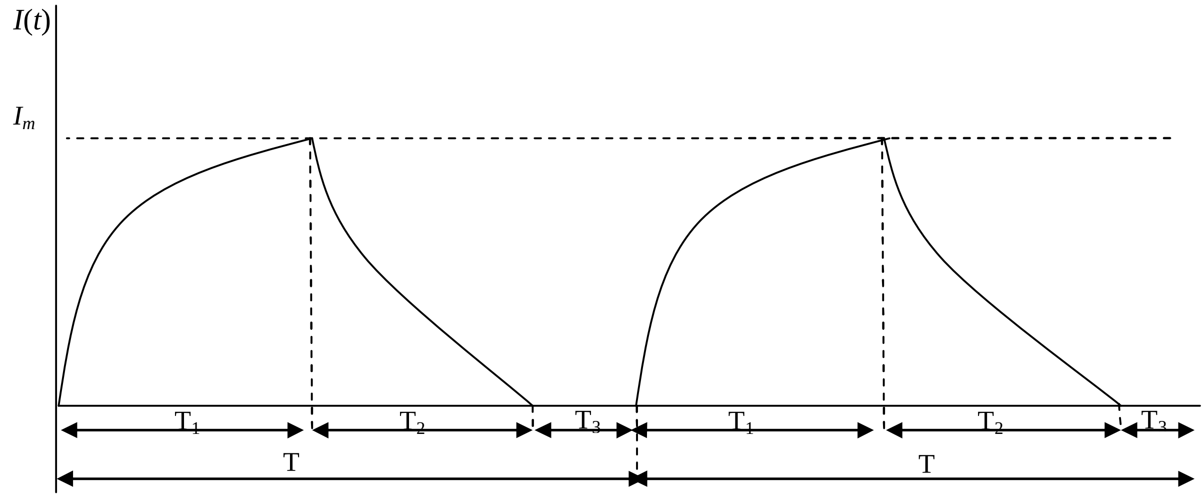

Figure 1. Inventory level of lost sales case (Widyadana and Wee, 2010)

The T_1 is the production time period, after the inventory reach maximum at level I_m,, the production stops and the inventory decreases due to demand and deterioration. At time ($T_1 + T_2$) the inventory level reaches zero units and the machine should start again to produce the item. However, the machine can be unavailable that cause the production may be impossible to start immediately and lost sales occur during T_3 time period. The production system is then run after T_3 time period. This unavailability can be assumed to be randomly distributed with a probability density function $f(t)$.

Widyadana, and Wee (2010) modeled the total profit consists of total revenue minus setup cost, production cost, holding cost, deteriorating cost and lost sales cost as follow:

$$TP(T_1, T_2, p) = \alpha p^{1-\varepsilon}(T_1 + T_2) - \left(K + C_p P T_1 + \left(\frac{hP}{\alpha p^{-\varepsilon}} + \pi\theta\right)\frac{PT_1^2}{2}\left(1 - \frac{\alpha p^{-\varepsilon}}{P}\right) + S\alpha p^{-\varepsilon}\int_{t=T_2}^{\infty}(t - T_2)f(t)\,dt\right) \quad (1)$$

where

T_1 : production period
T_2 : non-production period
T_3 : lost sales period
P : production rate (unit/time)
θ : deterioration rate
α : constant price dependent parameter
ε : increased price rate
p : product price ($)
K : setup cost ($/setup)

h	: holding cost ($/unit/time)
S	: lost sales cost ($/unit)
π	: deterioration cost ($/unit/time)
C_p	: production cost ($)
TP	: total profit

Kernel Density Estimate (KDE)

In this section we will give a brief description of kernel density estimate, for detail explanation we refers to Wand and Jones (1995).

Let $(x_1, \ldots, x_n)$ be an iid sample drawn from some distribution with an unknown density f. We are interested in estimating the shape of this function f. Its kernel density estimator is

$$\hat{f}_H(x) = \frac{1}{n}\sum_{i=1}^{n} KD_H(x - x_i) = \frac{1}{nH}\sum_{i=1}^{n} KD\left(\frac{x - x_i}{H}\right) \quad (2)$$

where $KD(.)$ is a kernel function and H is the bandwidth.

Some properties of KDE

1. To ensuring KD should be symmetric and have a unique maximum at 0 and also $\int KD(u)du = 1$ is to take KD as probability density function (pdf).
2. To ensure that a kernel estimator has attractive mean squared error properties, it turns out to be important to choose KD so that
   - $\int uKD(u)du = 0$, $\int KD^2(u)du < \infty$,
   - $\int u^2 KD(u)du < \infty$
3. $KD_H(.)$ denotes $H^{-1}KD(./h)$ for a kernel KD.

Some Kernel functions

$KD_R(u) = \frac{1}{2} I_{(-1,1)}(u)$	Rectangular Kernel
$KD_G(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$	Gaussian Kernel
$KD_E(x) = 0.75(1 - x^2)$, $\lvert x\rvert \leq 1$	Epanechnikov Kernel

It is well known that the choice of kernel functions will not change the estimation significantly. However, the choice of bandwidth matter on the density estimation. Since, if the bandwidth is too small then the bias of a kernel estimator becomes smaller in magnitude, but its variance will increase, and vice versa. Moreover, smaller bandwidth makes the kernel estimate becomes too wiggle, and it becomes over smooth when the bandwidth is large. Therefore the principal goal in kernel estimation is the "optimal" bandwidth.

Optimal Bandwidth
To get the optimal bandwidth we have to compromise between the bias and variance of the KDE. Fortunately, this comprise can be achieved via optimizing the mean square error (MSE) of the estimator, since by definition:

$$\begin{aligned} MSE_x &= \mathbb{E}\left[\left(\hat{f}(x) - f(x)\right)^2\right] \\ &= \mathbb{E}\left[\left(\hat{f}(x) - \mathbb{E}[\hat{f}(x)] + \mathbb{E}[\hat{f}(x)] - f(x)\right)^2\right] \\ &= \left(\mathbb{E}[\hat{f}(x)] - f(x)\right)^2 + \mathbb{V}[\hat{f}(x)] \\ &= Bias[\hat{f}(x)]^2 + Variance[\hat{f}(x)] \end{aligned} \quad (3)$$

Take the integration of (3) then we get,

$$MISE_x = \mathbb{E}\left[\int \left(\hat{f}(x) - f(x)\right)^2 dx\right] = \int \mathbb{E}\left[\left(\hat{f}(x) - f(x)\right)^2\right] dx \quad (4)$$

The bias and variance of (3) can be written consecutively as:

$$Bias\left(\hat{f}(x)\right) = \frac{1}{2}H^2 f''(x) k_2 + O(h^4) \quad (5)$$

$$\mathbb{V}[\hat{f}(x)] = \frac{f(x)R(KD)}{nH} - \frac{f(x)^2}{n} + O\left({}^{H}/_{n}\right) \quad (6)$$

$$k_2 = \int t^2 KD(t)dt \neq 0;\ R(KD) = \int KD(t)^2 dt$$

Put equations (5) and (6) into (4) and let $n \to \infty$ then we get the Asymptotic MISE, i.e.

$$AMISE(H) = \frac{1}{nH} R(KD) + h^4 R(f'') k_2{}^2 \quad (7)$$

Finally, we take derivative of (7) with respect to H and solve for the derivative equal to zero, then we get the optimal global bandwidth, i.e., the bandwidth will be the same for the whole function of estimate.

$$H_{AMISE} = \left[\frac{R(KD)}{nR(f'')k_2^2}\right]^{1/5} \sim n^{-1/5} \quad (8)$$

Now, we can model (1) as a free distribution case by substituting the $f(t)$ in (1) by equation (2).

Result and Discussion

In this section we give a numerical example. Since the model is a hard optimization problem, so the Genetic Algorithm (GA) method is used to solve the two parameters: production uptime (T_1) and product price (p). The GA method use 20 population in each generation and it is stopped at 200th generation. Initial population is generated randomly. We use roulette wheel method as parent selection. As the genetic operators, we use elitism, two point crossover with probability 80%and uniform mutation with probability 3%.

The following values are considered for the numerical example and the values are set as: K= \$ 50 per production cycle, P = 1000 unit/time, α = 100000, ε = 1.1, h = \$ 1 per unit per unit time, C_p = \$ 25 per unit, S = \$ 5 per unit, $\theta = 0.05$, unavailability time is generated as absolute value of mixture normal distribution, and π = \$ 1 per unit per unit time. The minimum value of the product price is set as equal to the product cost and the maximum value of the product price is 152. The minimum and maximum production uptime is set to 0 and 2 respectively. In each computation, the GA is run five times and the best solution is chosen. The optimal solution is derived when production uptime (T_1) = 0.654 and the product price (p) = 152. We use increase price rate parameter to analyze behavior of the model. The result is shown in Table 1.

Table 1. Sensitivity analysis with different value of price rate

ε	T_1	**Price**	**Profit**
0.95	2.008	152	101853.7
1.00	1.906	152	82881.0
1.05	1.031	152	64519.0
1.10	0.654	152	50213.6
1.15	0.504	152	39043.4
1.20	0.504	150	30308.7
1.25	0.378	125	23700.1

Table 1 shows that the production up time, the price and the optimal profit tend to decrease as the price rate increase. It means when demand is more sensitive to the price, manufacture will has less profit. Then she tries to increase her profit by reduce product price to increase demand. When demand decrease, manufacture only need less production up time to fulfill the demand.

Conclusions

In this paper, a production economic quantity for deteriorating items with price dependent demand and common distribution machine unavailability time is developed. It complements some previous research that only use specific distribution as the case study and can be used widely in practice. A sensitivity analysis has been conducted to analyze the effect of price rate to profit and the decision variables. This research can be developed by implementing the model in real manufacture system.

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