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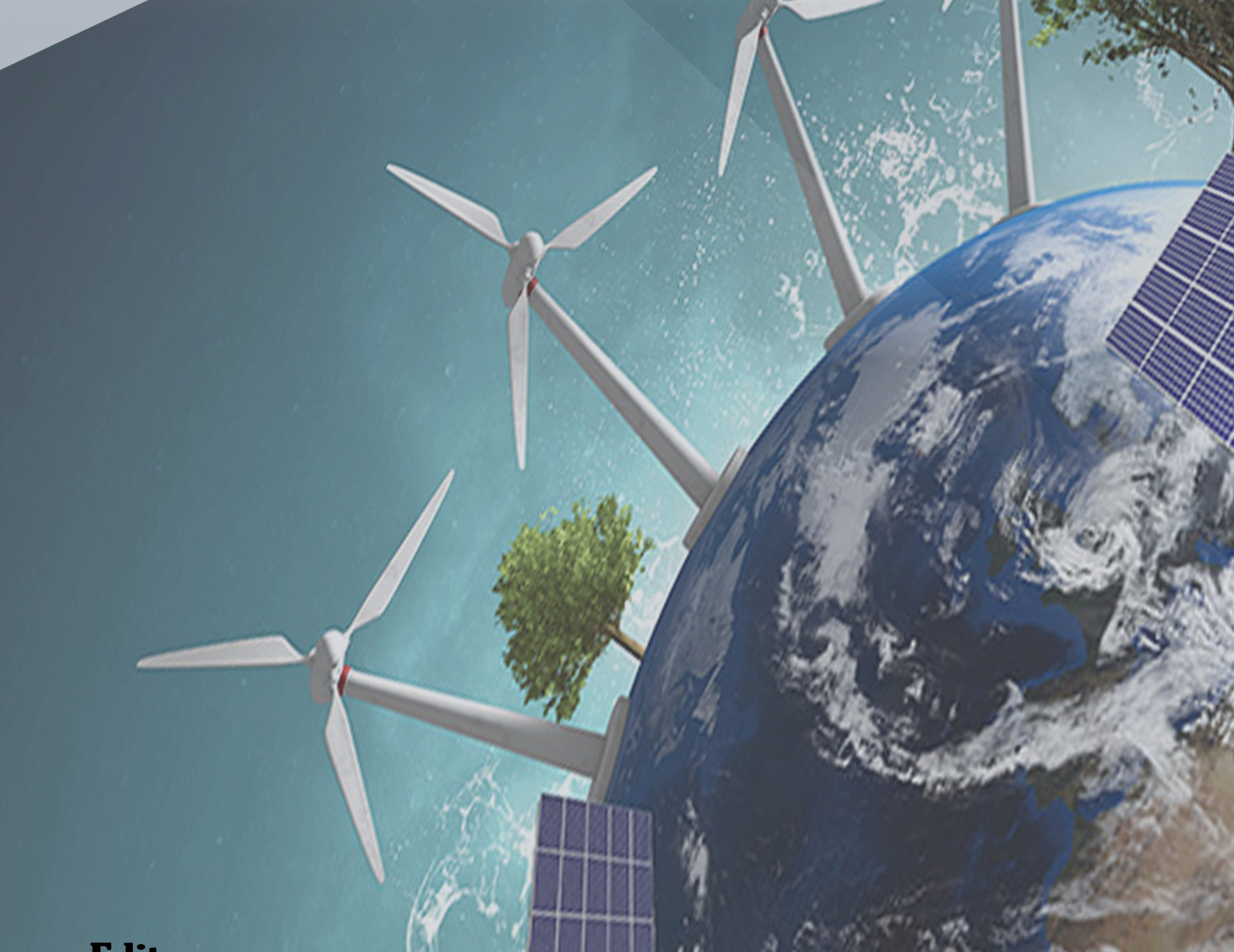

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INVENTORY MANAGEMENT OF RESIDENTIAL SOLAR PANELS

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Abstract-
In this paper, inventory problem of residential solar panels is solved using (s, Q) continuous review inventory system. Nowadays, there has been surge the development of renewable power, that lead to the development of solar panels for residential and commercial deployments. Residential solar panels in particular are in high demand. Optimal order quantity of residential solar panel is determined under order service level and fill rate constraints. The paper further studies effect of partial backordering on order quantity of solar panels.

Keywords: **Solar Panel; Inventory; Renewable, Partial Backordering, Fill Rate**

INTRODUCTION

For sustainable energy development, Renewable energy is looked as an essential step to bring down the use of fossil fuels (Elliott, 2000). To mitigate global warming the emissions of greenhouse gases are to be lowered with encouraging the use of solar panels Solar panels reduce global warming and urban heat island (Masson et al., 2014). Solar energy is absorbed by solar panels to produce energy usable in residential households and commercial buildings, as heat or as electricity. Fardi et al. (2021) discussed on relevance and provided an optimum way of photovoltaic solar panels deployment in residential buildings situated in urban areas.

Service levels are preferred to replace stockout costs, when intangible components such as loss of goodwill and possible delays are associated with shortage costs and it becomes hard to find out exact value of stockout cost. Service levels are usually considered of two types – cycle service level and fill rate. Schneider (1978) has discussed on different service levels and their relationship to shortage costs and different inventory control policies. Hadley and Whitin (1963), Silver et al. (1998), Schneider (1978) and Nahmias (2009) have determined cycle service levels as fraction of cycles in which stockout do not occur. Hopp and Spearman (2000) have defined cycle service level as probability of not stocking out during lead time. Axsater (2006) discussed order service level as probability that an order arrives in time. Silver et al. (2009) define fill rate as the fraction of demand satisfied immediately from on hand stock. Sobel (2004) and Zhang and Zhang (2007) estimated fill rate as average fraction of demand fulfilled directly from on hand stock. Guijarro et al. (2012) have computed fill rate for periodic review order up to level system. Srivastav and Agrawal (2012, a) have computed order service level for stochastic inventory system under order crossover. Srivastav and Agrawal (2012, b) have discussed on service levels in presence of stochastic lead time. A lot of work in the past has carried out to determine optimal inventory policy under service constraint. Fill rate constraint inventory models have developed by many researchers as Tijms et al. (1984) , Sobel (2004), Samii et al. (2011). Nahmias (2009) has developed optimal inventory policy under service level constraint for backorder model. In this paper we have developed the optimal inventory policy under both Type-1 and Type -2 service constraint and consider the case of mixture inventory model.

A lot of papers have been written on mixture inventory models. The prominent work on mixture inventory model is of Montgomery et al. (1973), Park (1983), Kim and Park (1985), Padmanabhan and Vrat (1990), Zeng (2001), Yang et al. (2008), Srivastav and Agrawal (2015, 2020a, 2020b). In the past, service order quantity has been computed for backorder inventory systems. Srivastav and Agrawal (2012c) have computed service order quantity under fill rate constraint for partial backordering inventory model. Gruson et al. (2017) studies influence of service level constraints for the capacitated and incapacitated lot sizing problems for complete backorder in discrete and finite time horizon. Unfortunately, no work is found in literature that has computed service order quantity for both order service level and fill rate.

In this paper, an attempt is made to determine service order quantity for Residential Solar Panels under Type-1 (Order Service Level) and Type-2 (Fill Rate) constraints.

The subsequent part of the paper is organized as follows: section 2 shows notations, section 3 discusses on assumptions of the models. Section 4 discusses on mixture inventory system. Section 5 and 6 shows the computation of service order quantity under Type-1 and Type-2 constraint respectively. Numerical problem and results are shown in Section 7. Finally, section 8 concludes the paper.

NOTATIONS

The notations used in this paper are:

$C(Q, z_0)$= total annual inventory cost

A = fixed set up cost per order

D = annual demand

h = holding cost per unit per unit time

π= backorder cost per unit short

π_0= lost sales penalty over unit backorder cost per unit lost (i.e., $\pi + \pi_0$= lost sales cost per unit lost)

Q^*_{WSC}= order quantity without service constraint

Q^*= service level order quantity

α = Type -1 service constraint (cycle service level)

β = Type -2 service constraint (fill rate)

σ_x = standard deviation of demand during lead time

z_0 = safety stock factor, with z~ N(0,1)

$G(z_0) = \int_{z0}^{\infty}(z - z_0)f(z)dz_0$, $\int_{z0}^{\infty}(\mathrm{z} - \mathrm{z}_0)\mathrm{f(z)dz_0}$expected shortage per replenishment cycle on the standard normal curve

q= fraction of shortages backordered

$(1 - q)$ = fraction of shortages lost sales

$P(z > z_0)$=stockout risk

s= reorder point

EOQ = economic order quantity

ASSUMPTIONS

The assumptions used in this paper are:

i. The system is continuous review.
ii. Demand is stochastic and static.
iii. Demand during lead time follows Normal distribution.
iv. Lead time of placing an order is fixed.

MIXTURE INVENTORY SYSTEM

The model under consideration represents more practical situation since it is reasonable to assume that a fraction (q) of the demand during the stockout period is backordered, as some customers whose needs are not critical at that time can wait for the item to be satisfied. Thus only a fraction (1- q) is lost in real inventory systems (results in cost saving).

Total approximate cost equation for mixture of backorders and lost Sales is formulated by considering fraction of shortages backordered (q) and (1-q) fraction of shortages are lost. The total cost equation is formulated by modifying Montgomery (1973) equation as :

$$C(Q, z_0) = \frac{AD}{Q} + h\left(\frac{Q}{2} + z_0\sigma_x\right) + \left[h(1-q) + \frac{D}{Q}[\pi + \pi_0(1-q)]\right]\sigma_x G(z_0) \quad (1)$$

To find out the optimal value of lot size, differentiae $Eq.(1)$ w.r.t Q, and optimal order quantity without considering service level constraint is obtained as below:

$$Q^*_{WSC} = \mathrm{Q}^* = EOQ\sqrt{\left(1 + \frac{(\pi + \pi_0(1-q))\sigma_x G(z_0)}{A}\right)} \quad (2)$$

where $EOQ = \sqrt{\frac{2AD}{h}}$ is economic order quantity.

Similarly optimal value of tail probability is found by differentiating $Eq.(1)$ by z_0.

$$P(z > z_0) = \frac{h}{(1-q)h + \frac{D}{Q}[\pi + \pi_0(1-q)]} \quad (3)$$

SERVICE ORDER COMPUTATION IN MIXTURE INVENTORY SYSTEM SUBJECT TO TYPE-1 CONSTRAINT

Cycle service level or Type-1 service level is the fraction of cycles in which no stockout occurs. It is usually used when shortages are measured as event based, for example, assembly lines.

Cycle service level is determined as below.

$$\alpha = 1 - P(z > z_0) \quad (4)$$

Shortage cost for mixture inventory system can be expressed as below $(Eq.5)$ from $Eq.(3)$.

$$\pi + \pi_0(1-q) = \frac{hQ}{D}\left(\frac{1 - ((1-q)P(z > z_0))}{P(z > z_0)}\right) \quad (5)$$

Now computing optimal service order quantity, by substituting expression of shortage cost $(Eq.5)$ in order quantity equation, $Eq.(2)$. The below expression $Eq.(6)$ is quadratic equation in terms of Q.

$$Q = EOQ\sqrt{\left(1+\frac{\frac{hQ}{D}\left[\frac{1-((1-q)P(z>z_0))}{P(z>z_0)}\right]\sigma_x G(z_0)}{A}\right)} \quad (6)$$

he positive root of $Eq.(6)$ will results in optimal service level order quantity, as shown in Eq. (7).

$$Q^*_{SOQ} = \frac{[(1-(1-q)P(z>z_0)]\sigma_x G(z_0)}{P(z>z_0)} + \sqrt{\frac{2AD}{h} + [\frac{((1-(1-q)P(z>z_0))\sigma_x G(z_0)}{P(z>z_0)}]^2} \quad (7)$$

By substituting value of tail probability, computed from Eq. (4) in the Eq. (7), results in optimal service order quantity subject to cycle service level constraint.

Service Order Computation in Mixture Inventory System subject to Type-2 constraint

Fill rate or Type-2 service level is the proportion of units that are satisfied from the available stock. It is usually used when shortages are measured on basis of magnitude, for example, retail stores.

Fill rate is determined as below.

$$\beta = 1 - \frac{\sigma_x G(z_0)}{Q} \quad (8)$$

Expected shortage per replenishment cycle on the standard normal curve as shown in $Eq.(9)$.

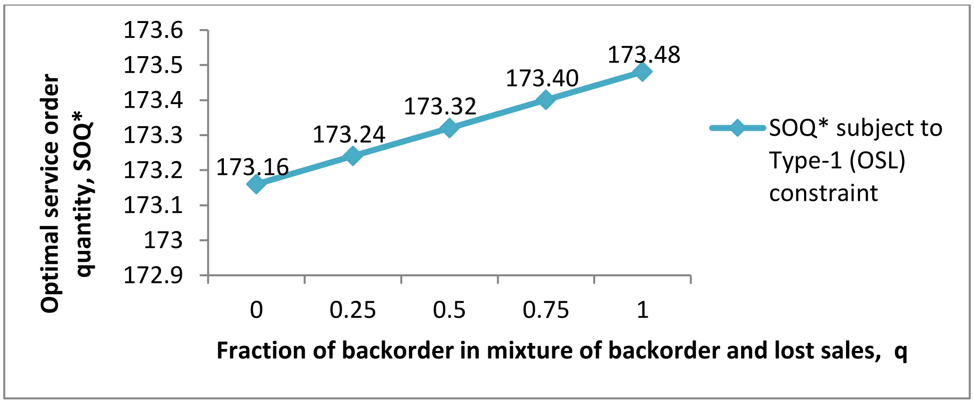
$$G(z_0) = \frac{(1-\beta)Q}{\sigma_x} \quad (9)$$

Now solving Eqs. (7) and (9), simultaneously results in optimal order quantity and safety stock factor subject to fill rate constraint.

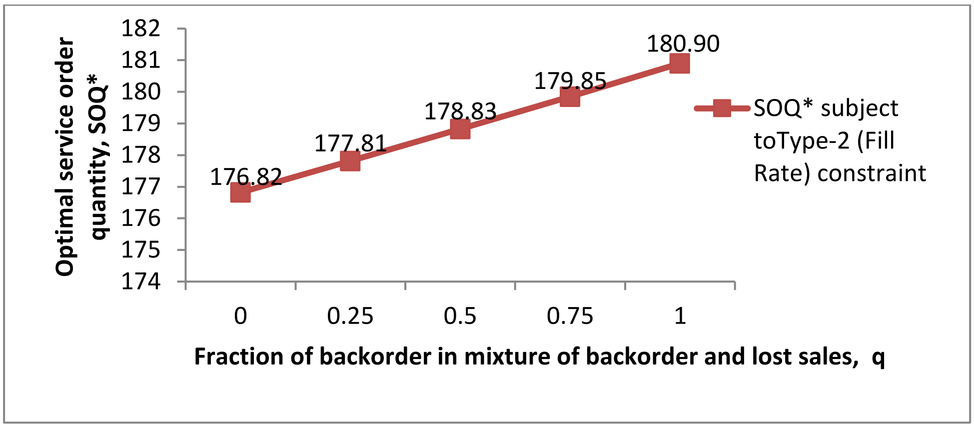
Numerical Problem and Results Analysis

A residential solar panel dealer incurs, *A* \$ 50, *h*= \$. 2, 75% of shortages are backordered and rest are lost sales. A penalty of 125% is charged over backorder cost for the calculation of lost sales. During six months replenishment lead time, the average demand for six month period is 250. Standard deviation of demand during each six months period is 40. Demand during lead time follows Normal distribution. Determine the optimum service order quantity and reorder point for fulfilling 98% cycle service level objective and 98% fill rate.

On solving the numerical problem, the optimal service order quantity are obtained for different combinations of backorder and lost sales cases as below (Fig. 1).



(a)



(b)

Fig. 1: Behavior of service order quantity with change in q for (a) Type 1 and (b) Type 2 cases

Table 1 shows that EOQ overestimates the order quantity by 82.37% and 75.83% for Type-1 and Type-2 cases respectively.

Table 1: Optimal order quantity for Type 1 and Type 2 cases (for q=0.75)

Order quantity (q=0.75)	**Mixture Inventory System subject to Type-1(OSL) constraint**	**Mixture Inventory System subject to Type-2 (Fill Rate) constraint**
EOQ	316.23	316.23
SOQ	173.40	179.85
Error %	82.37%	75.83%

Table 2 shows the reorder point for Type-1 and Type-2 cases.

Table 2: Optimal reorder point for Type 1 and Type 2 cases (for q=0.75)

Reorder point (q=0.75)	**Mixture Inventory System subject to Type-1 (OSL) constraint**	**Mixture Inventory System subject to Type-2 (Fill Rate) constraint**
S	332.15	288.37

Table 3 shows the imputed shortage cost for Type-1 and Type-2 cases.

Table 3: Imputed shortage cost for Type 1 and Type 2 cases (for q=0.75)

Imputed shortage cost (in $), (q=0.75)	**Mixture Inventory System subject to Type-1 (OSL) constraint**	**Mixture Inventory System subject to Type-2 (Fill Rate) constraint**
Backorder cost per unit backorder (in $.)	25.34	3.11
Lost sales penalty over backorder (in $)	31.67	3.89

Lost sales cost per unit lost (in $)	57.01	7.00

Table 4 shows that EOQ approach overestimate the total cost by 12.74% and 12.91% for Type-1 and Type-2 cases respectively.

Table 4: Total cost for Type 1 and Type 2 cases (for q=0.75)

Total Cost (in $), (q=0.75)	**Mixture Inventory System subject to Type-1(OSL) constraint**	**Mixture Inventory System subject to Type-2 (Fill Rate) constraint**
EOQ	575.18	494.85
SOQ	510.19	438.26
Error %	12.74%	12.91%

CONCLUSIONS

In this paper optimal inventory policy order level lot size (s, Q) subject to Order Service Level and Fill Rate constraint is designed for Residential Solar Panel inventory problem. Managers often come across this complicated situation to determine the exact cost of stockout cost and this leads to incorrect assumption of stockout cost. The paper overcomes the problem of correct determination of stockout cost, by substituting service level constraint on behalf of stockout cost. The optimal service quantity and cost under both cycle service level and fill rate constraint are computed. A noteworthy reduction in total cost (12.74% and 12.91%) on using service order quantity (Type-1 service level) and service order quantity (Type-2 service level) is found in comparison to economic order quantity. The results show that use of service order quantity is essential in inventory management of Residential Solar Panels in the correct estimation of inventory cost in both situations.

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Renewable energy and sustainable development are the key technologies to offer solutions to the ever-increasing environmental pollutions and depleting conventional fuel reserves. With an aim to discuss the state of art technologies pertaining to the renewable energy domain, RTU (ATU) TEQIP III Sponsored 3rd International Conference on New and Renewable Energy Resources for Sustainable Future (ICONRER-2021) was organized by the Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur in collaboration with Rajasthan Technical University and Department of Mechanical Engineering, Assiut University, Assiut (Egypt) from February 11 to 13, 2021. ICONRER is a series of the conference started in 2017 and it was 3rd event of that series.

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