ADV MATH SCI JOURNAL
Advances in Mathematics: Scientific Journal **9** (2020), no.5, 3059–3065
ISSN: 1857-8365 (printed); 1857-8438 (electronic)
https://doi.org/10.37418/amsj.9.5.65

INVENTORY MODEL TO COMBAT E-WASTE MANAGEMENT COSTS

A. SASIREKA[1], A. H. NANDHU KISHORE, J. FEMILA MERCY RANI, AND N. MARTIN

ABSTRACT. Manufacturing sectors are making nations march towards economic growth with the highest contribution to waste generation index. Management of waste is an arduous task of these production sectors and the rigorous legislations concerning environmental sustainable have made it mandatory. Production of quality products suiting to the needs of the consumers are the expected outcomes of a production process and the inevitable outcome is the generation of waste. Pollutants, effluents are the agents of pollution and its interaction with the environment aggravates the pollution of all kinds. One of the emerging types of pollution is E-pollution which is caused by the generation of electronic waste to the environment without treatment. In recent times the advancement of technology has made the machines turn modern in the factories and the electronic transformation of all the mechanical process have lightened the production tasks but burdened the waste management. Environmental costing Environmental costing has become an indispensable activity of every production firm along with associated costs of product production. Profit intensification with costs mitigation is the ultimate goal of every manufacturing concern, in support of it, an inventory model is proposed in this paper with the inclusion of costs estimation of E-waste management. The proposed model will certainly meet the demands of the decision makers in the domain of environmental sustainable and economic development.

[1]*corresponding author*

2010 *Mathematics Subject Classification.* 91B76.

Key words and phrases. Environmental sustainable, inventory model, E-waste, costs minimization .

1. INTRODUCTION

The production sectors are always chained by the conventional constraints of profit maximization and costs minimization, but in recent times the incompetence of these sectors to resist waste generation has cuddled them in the hurdles of waste management. These industrial firms are striving hard to handle the emission of pollutants, discharge of effluents and other disposal crises. In addition to these environmental challenges, the industries are also facing the problems pertinent to E-waste management, which is a blossoming environmental problem of the industrial sectors. The stringent rules governing environmental sustainable in this context also puts them under pressure.

The manufacturing sectors predominantly utilize machinery for product production. In this digitalized world the electronic equipment play a vital role in functioning of these sectors. The development in the technology has opened the gates of advanced devices and machines which naturally make the existing production set up obsolete, and it is the triggering point of E-waste generation. A production machine is an embodiment of many electronic parts which is subjected to replacement after certain period of time, [2]. It is estimated that accumulation rate of E-waste in the industrial sectors is increasing every year and this has to be focused as it is an emerging threat to environmentalism. To battle such environmental cataclysm along with economic barriers, the industries are in need of costing models comprising of the facets of economic and environmental aspects. One of the best solutions to such multi crises is the formulation of inventory models incorporating the costs associated with economic and environment.

Economic order and production quantity inventory models was formulated by Harris and Taft in 1913 and 1918, [5, 9], respectively with the incorporation of set up cost, holding costs and ordering costs. These models were extended with the inclusion of shortage costs, backordering costs price breaks, inflation and other economic pricing strategies. Supply chain inventory models with remanufacturing and disposal costs are framed with the intention of reducing waste generation, [1]. Followed by these conventional inventory models, Maurice Bonney changed the stereotype in the development of inventory models by introducing a paradigm shift towards environmental oriented inventory models comprising of social costs. These eco-friendly inventory models

gained momentum and it laid a new platform for the researchers to explore eco-conscious inventory models. The environmental costing models were integrated with inventory models to compute the carbon tax and other costs associated with environmental sustainable. Profit maximization inventory models focusing on disposal of waste were also developed. Also researchers embraced the environmental costs in the inventory models and this paved way for the advent of Enviro-economic oriented inventory models, [4, 6].

Environmental concerned inventory model focusing on waste mitigation was developed by Martin and Ritha, [7], in which the costs related to handle waste of different types (solid, liquid and gaseous) were discussed. But recently the need of E-waste management has motivated,to extend the enviro-eco conscious inventory model to combat E-waste, [3]. E-waste management inventory model has to be formulated as the generation of E-waste is increasing every year; also the rate of import of such waste is also getting accumulated, [8]. To handle such crisis an inventory model is formulated with the inclusion of all the possible E-waste management costs. The proposed model can be extended to reverse logistic inventory model by discussing the activities related to remanufacturing such as rework, recycle and refurbish.

The paper is structured as follows: section 2 presents the model development with problem description, section 3 validates the proposed model with numerical example and the last section concludes the paper.

2. Model Development

2.1. **Problem Description.** Consider a manufacturing firm, which produces at a constant rate to fulfil the deterministic type of its demand. The production process is continuous and the demands of the customers are satisfied. The objective of the firm is to minimize the costs and maximize the profit. One of the challenging tasks is handling of waste generation. To combat the waste, the firm segregates the waste to degradable and non-degradable to which the E-waste comes under the latter category. Fixed and variable costs are imposed to handle the wastes of both kinds. A deterministic inventory model addressing these issues and solutions is proposed as follows.

2.2. **Notations.** The following notations will be used throughout the paper when developing the mathematical model.

D demand per unit of time
P production per unit of time
x $\frac{D}{P}$
$1-x$ the fraction of time the production process spends actually idling
A fixed ordering cost/ set up cost per production run
h holding cost per unit per unit of time.
M Purchasing costs of machinery and electrical equipments
Ws Waste segregation costs
Ei Infrastructure costs for E-waste managing set up.
Di Infrastructure costs for Degradable waste managing set up.
Dp Processing costs of Degradable waste
Ddp Degradable waste disposal costs
Df Fixed Degradable waste management costs
Dv Variable Degradable waste management costs
Ef Fixed E-waste management costs
Ev Variable E-waste management costs
Ewc E-waste collecting costs
Es E-waste sorting costs
Ed E- waste dismantling costs
Esh E-waste Shredding costs
Esp E-waste secondary processing costs
Edp E-waste disposal costs

The EPQ cost per unit of time

$$C(Q) = A\frac{D}{Q} + \frac{hQ(1-x)}{2}\,.$$

The purchasing costs of machinery per cycle

$$CP(Q) = M\,.$$

The waste segregation cost per cycle

$$CW(Q) = Ws\,.$$

The establishment costs of waste managing set up

$$CI(Q) = Ei + Di\,.$$

The associated degradable waste management costs per cycle

$$CDW(Q) = Df + Dv + Dp + Ddp\,.$$

The associated E-waste management costs per cycle

$$CEW(Q) = Ef + Ev + Ewc + Es + Ed + Esh + Esp + Edp\,.$$

Total cost per unit of time

$$\Psi(Q) = C(Q) + \frac{C_p\,(Q) + C_W(Q) + C_I(Q) + C_{DW}(Q) + \mathrm{CE}_W(Q)}{T}\,,$$

where

$$\begin{aligned} T &= \frac{Q}{D} = A\frac{D}{Q} + \frac{hQ(1-x)}{2} + \frac{D}{Q}(M + Ws + Ei + Di + Df + Dv + Dp \\ &\quad + Ddp + Ef + Ev + Ewc + Es + Ed + Esh + Esp + Edp) \\ \frac{\partial\Psi(Q)}{\partial Q} &= \frac{\partial}{\partial Q}\Bigg(A\frac{D}{Q} + \frac{h(1-x)Q}{2} + \frac{D}{Q}\Big(M + Ws + Ei + Di + Df \\ &\quad + Dv + Dp + Ddp + Ef + Ev + Ewc + Es + Ed + Esh + Esp + Edp\Big)\Bigg)\,. \end{aligned}$$

The objective is to determine the optimal quantity. The necessary condition is

$$\frac{\partial\Psi(Q)}{\partial Q} = 0.$$

The optimal solution is

$$\begin{aligned} Q = \Big[2D\Big(A + M + Ws + Ei + Di + Df + Dv + Dp + Ddp + Ef + Ev + Ewc \\ + Es + Ed + Esh + Esp + Edp\Big)/\Big(h(1-x)\Big)\Big]^{1/2}\,. \end{aligned}$$

3. Numerical Example

Consider an inventory system with following data. $A = \$100/cycle$, $h = \$5/unit/cycle$, $D = 50,000 units/year$, $P = 75,000 units/year$, $M = \$1000$, $Ws = \$25$, $Ei = \$15$, $Di = \$30$, $Df = \$40$, $Dv = \$20$, $Dp = \$10$, $Ddp = \$20$, $Ef = \$40$, $Ev = \$30$, $Ewc = \$50$, $Es = \$35$, $Ed = \$15$, $Esh = \$40$, $Esp = \$20$, $Edp = \$30$. The optimal order quantity is 9455 units.

4. Conclusion

The production quantity inventory model with the incorporation of E-waste management costs is proposed in this research work. This model comprises of costs associated with handling E-wastes. This developed model can be extended to a probabilistic, stochastic and fuzzy production inventory model reflecting the various economic and environmental scenarios. Inventory model reflecting the fluctuations in the deterministic nature of the demand and production can also be framed. The formulation of such models will certainly assist the decision makers at managerial level.

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DEPARTMENT OF MATHEMATICS
PSNACET, DINDIGUL

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
PSNACET, DINDIGUL

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
PSNACET, DINDIGUL

DEPARTMENT OF MATHEMATICS
ARUL ANANDAR COLLEGE (AUTONOMOUS)
KARUMATHUR