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Sustainable Vaccine Inventory Model under Carbon Tax policy

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Abstract

In today's era of sustainable expansion, reducing carbon emission is a key factor for financial growth and progress. Along with this, special attention has been paid to the perishable products due to spoilage and deterioration results in a substantial loss of items which obstructs consumer's satisfaction level. The main cause of carbon emission in the inventory system is in consignment, holding of vaccines and spoilage of vaccine because some people took the first dose and did not come back for a second dose. So, keeping this in mind, carbon tax policy is an effective tool to diminish carbon emissions. Hence, the proposed article analyzed the carbon emission in the sustainable COVID-19 vaccine inventory model and a carbon tax is levied to achieve environmental goals. A non-linear formulation is exhibited to calculate the optimum cycle length. A numerical example and sensitivity analysis have been presented to validate the proposed model.

Keywords: Vaccine inventory; Carbon emissions; Carbon tax; Spoilage of vaccine.

1. Introduction

Since, the appearance of the novel human corona virus disease COVID-19 in December-2019 and the consequent global pandemic, people around the word have been pretentious, in the matter of health, and also related to distraction to societal customs and behavior. As a result, people's mobility gets affected, whereas at the government level, the capability and readiness for cooperation has also been wedged. Short term outcomes have improved air quality as it abridged carbon dioxide and other greenhouse gases emissions.

To get this pandemic to an end, a large portion of the world desires to be immune to the virus. The safest way to accomplish this is with vaccine. Vaccines are a technology that mortality has often relied on in the preceding to bring down the death toll of infectious disease. Now, another critical issue to the deduction of the COVID-19 pandemic is the carbon emission due to manufacturing to the end procedure of vaccination. One suggested approach incipient from the pandemic is the concept of glocalization. Glocalization purposes to alleviate the effect of the pandemic while addressing the financial and environmental crises. Rest of the article organized as follow: Literature survey is exhibited in section2. Section 3 provides notations and assumption which are used to construct the model. A mathematical model is formulated in section 4. Numerical validation in presented in section 5. Managerial insight are drawn in section 6. Section 7 concludes the proposed model.

2. Literature Survey

Due to predominance and long gestation without symptoms, the critical breathing syndrome of the NOVEL CORONA virus has infected millions of individuals globally. Moreover, the recent approval of the anti-viral drug known as vaccine becomes one of the reasons for carbon emission. Hence, to prevent environmental degradation, the government can promote investment in carbon reduction policies or carbon tax. Related to this context, Bouchery *et al.* (2012) presented a sustainable order quantity model in which different policies were applied for controlling carbon emission using Pareto optimal solution. After that Chen *et al.* (2013) studied an inventory model for the magnitude of carbon emission and also discussed carbon cap-and-offset and cap-and-price with a carbon tax. Toptal *et al.* (2014) scrutinized inventory replenishment with carbon emission reduction under carbon-cap, tax and cap-and-trade policy. In this article, carbon emission policies based on cost and emissions are provided. Lou *et al.* (2015) analyzed two-stage: optimal investment and pricing decisions for supply chain and derived low carbon products mean a high price. Qin *et al.* (2015) proposed sustainable inventory policies under carbon-cap and trade policy based on trade credit. From this article, the authors conclude that the credit period is not affected by carbon cap under carbon-cap and trade protocols while it is negative affected by carbon trade price and carbon tax. Datta (2017) established a production-inventory model in which production rate is supposed to be a decision variable by taking selling price-dependent demand. Green technology is employed in order to reduce carbon emissions. Wangsa *et al.* (2018) explored an optimization model on the sustainable electrical supply chain system by considering price-sensitive demand. In this article, the transmission and distribution costs are considered to depend on power generation. Mishra *et al.* (2020) investigated a sustainable economic production quantity model for controlling carbon emissions by investing in green technology with and without shortages under partial back-ordering. Taleizadeh *et al.* (2020) proposed a joint pricing and inventory decision in which demand rate associated with purchasing cost without back ordering. Sarkar *et al.* (2021) scrutinized three echelons sustainable supply chain model in which authors tried to reduce imperfect items as well as carbon emissions. Simin *et al.* (2021) proposed an inventory model having a capital-constrained manufacturer and a well-funded supplier by imposing a hard limitation on carbon emissions under Green credit financing and Trade credit financing. Yadav and Khanna (2021) developed a sustainable inventory model for perishable products under price-sensitive demand. The product with maximum lifetime is under consideration and a carbon tax policy is imposed to reduce environmental degradation.

3. Assumption and Notations

3.1 Notations

This section provides notations, which are used to construct the proposed model.

Inventory parameters

A	Set-up cost ($ /order).
h	Holding cost ($ /vaccine /unit of time).
c	Purchase cost ($ /vaccine).
C_T	Carbon tax ($).
r	Rate of spoiled vaccine.
□	Emissions per damaged vaccine.
F_0	Fixed Freight cost ($/ vaccine)
F_1	Variable Freight cost ($/ vaccine)
h_0	Fixed emission factor for holding vaccines in the inventory system ($ /vaccine /unit of time)
h_1	Variable emission factor for holding vaccines in the inventory system ($ /vaccine /unit of time)
CE_0	Fixed emission factor for transporting vaccines.
CE_1	Variable emission factor for transporting vaccines.
□	Rate of health warriers who did not turn up for vaccination after registration.
a	Scale demand in units.
b	Constant > 0
Q	Order quantity of vaccines (units).
$I(t)$	Inventory level at any time t

$R(t)$ Time dependent demand rate ae^{bt}

Decision variables

T Cycle time

Objective function

$TC(Q)$ Total cost per unit time ($ /unit time).

Problem

Minimize $TC(Q)$

Subject to $Q > 0$

3.2 Assumptions

The proposed inventory model of vaccine is formulated under the following assumptions:

I. Only one type of vaccine is considered.

II. The demand rate for the vaccination is $R(p) = ae^{bt}$, where $a > 0$ scale demand and $0 < b < 1$.

III. The transshipment cost for transporting Q units is $SC = F_1 + F_2Q$.

IV. Carbon emissions during transportation of Q units is $CE_0 + CE_1Q$.

V. Carbon emission in warehouse during carrying the Q units is $h_0 + h_1AI$, where AI the average inventory.

VI. The vaccine loses its effectiveness due to maintenance at the rate □ $(0 □ □ < 1)$.

VII. Shortages are not permissible because of health warriers and family members are directly coming in contact with COVID-19 infectious patients.

4. Problem formulation

Specifically, COVID-19 vaccine-hesitant or resistant persons were distinguished from their vaccine-accepting counterparts by being more self-interested. So the demand for vaccines continuously declines. Hence, the rate of change of inventory level during the interval is governed by the following differential equation. $\frac{dI(t)}{dt} = □ae^{bt}, \quad 0 □ t □ T$ (1)

With the boundary condition $I(T) = 0$.

Using the boundary condition $I(T) = 0$, the inventory level defines by the following equation

$$I(t) = \frac{a}{b}\left[e^{bT} - e^{bt}\right], \quad 0 \le t \le T \tag{2}$$

Subsequently, the order quantity Q is $Q = I(0) = \frac{a}{b}\left(e^{bT} - 1\right)$ (3)

Average inventory in the warehouse is $AI = \frac{a}{b^2}\left[e^{bT}bT - e^{bT} + 1\right]$ (4)

Number of spoiled vaccines are $SV = rQ = r\frac{a}{b}\left(e^{bT} - 1\right), \; 0 < r \le 1$ (5)

The carbon emission in transportation, holding inventory and spoilage is

$$CE = \frac{a}{b^2}\left(e^{bT}bT - e^{bT} + 1\right)h_1 + \frac{aCE_1\left(e^{bT} - 1\right)}{b} + \frac{ra\left(e^{bT} - 1\right)}{b} + CE_0 + h_0 \tag{6}$$

Next, we calculate different cost components related to proposed problem.

A static set-up cost occurs at the beginning of each cycle, so the ordering cost per cycle is

Ordering cost $OC = A$ (7)

Cost of the vaccine depends on the order quantity purchased during the cycle, thus the purchase cost is: $PC = cQ = \frac{a}{b}c\left(e^{bT} - 1\right)$ (8)

The vaccines are transported to the vaccination center. As container and the distance may vary so freight cost is fixed as well as variable component. Therefore, the transshipment cost is

$$FC = F_0 + F_1 Q = \frac{a}{b}F_1\left(e^{bT} - 1\right) + F_0 \tag{9}$$

Vaccine storage must be appropriate to avoid spoilage. Thus an organization invest for maintaining vaccines in the inventory system. Henceforth, the holding cost is

$$HC = hAI = h\frac{a}{b^2}\left(e^{bT}bT - e^{bT} + 1\right) \tag{10}$$

Carbon tax is an essential policy which is levied by the government on amount of carbon emission as to check and control it. As a result, carbon emission tax is

$$CET = CE \times C_T = C_T\left[\frac{a\left(e^{bT}bT - e^{bT} + 1\right)h_1}{b^2} + CE_1\frac{a\left(e^{bT} - 1\right)}{b} + r\frac{a\left(e^{bT} - 1\right)}{b} + CE_0 + h_0\right] \tag{11}$$

So, from equations (7) to (11), total cost per unit time is

$$TC = \frac{1}{T}\left(OC + PC + FC + HC + CET\right)$$

$$TC = \frac{1}{T}\left[\begin{array}{l} A + \frac{a}{b}c\left(e^{bT} - 1\right) + \frac{a}{b}F_1\left(e^{bT} - 1\right) + F_0 + h_0\frac{a}{b^2}\left(e^{bT}bT - e^{bT} + 1\right)h \\ + C_T\left(\frac{a\left(e^{bT}bT - e^{bT} + 1\right)h_1}{b^2} + CE_1\frac{a\left(e^{bT} - 1\right)}{b} + r\frac{a\left(e^{bT} - 1\right)}{b} + CE_0 + h_0\right) \end{array}\right] \tag{12}$$

5. Numerical Validation

In this section, numerical example is exhibited to validate the vaccine inventory model. In order to establish an optimality, following steps should be considered.

Step-I: Differentiate the cost function given in equation (12) partially with respect to T

Step-II: Allocate the numeric values to all inventory parameters other than decision variable T.

Step-III: In order to get solution, take $\frac{\partial(TC)}{\partial T} = 0$.

Step-IV: Find the values of all cost functions and decision variables.

The following numeric values are considered.

$a = 150$, $b = 0.8$, $c = \$20$ per vaccine, $h = \$10$ per vaccine, $A = \$100$ per order, $F_0 = \$80$ per vaccine, $F_1 = \$0.3$ per vaccine, $CE_0 = 20$, $CE_1 = 0.1$, $h_0 = \$5$ per vaccine, $h_1 = \$0.1$ per vaccine, $r = 0.02$ per vaccine, [illegible] $= 0.2$, $C_T = 5$

The optimal costs are:

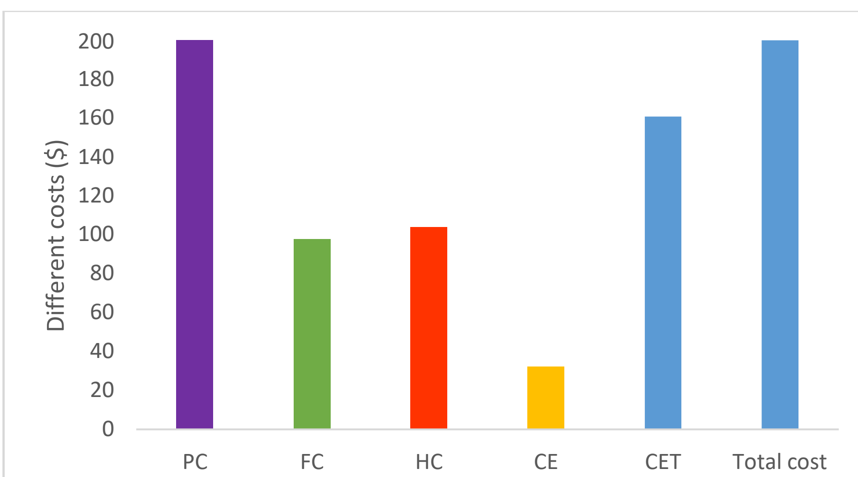
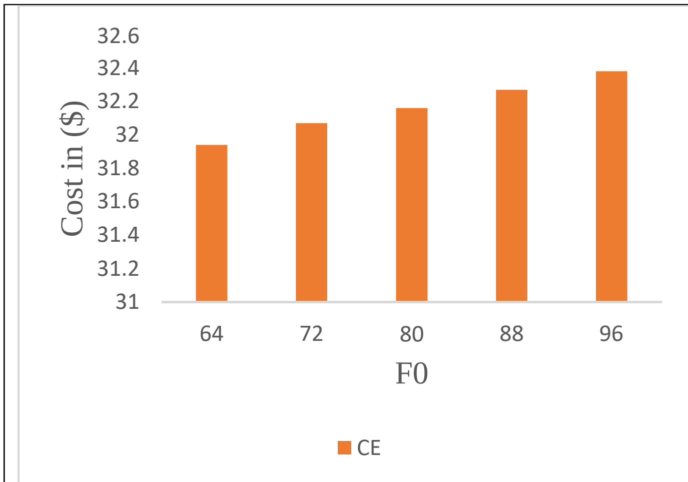


Fig. 1 Feasible solution

As depicted in Fig. 1, the various optimal costs are: purchase cost $1178, transshipment cost $97.66, holding cost $104, carbon emission $32.16, carbon emission tax $160.80 resulting total $4808 to gain 58.90 vaccine units. Each vaccine unit consist of 100 vaccines.

6. Sensitivity Analysis

In this section, we carried out sensitivity analysis of crtical parameters in the carbon emission during transshipment, holding inventory and deterioration.



From the Fig. 2(a), it can be observed that Carbon emission is increased as increases in freight cost. So one can design proper vehicle to transporat the vaccines to the vaccination center.

Fig. 2(a) Carbon emission due to freight cost F_0

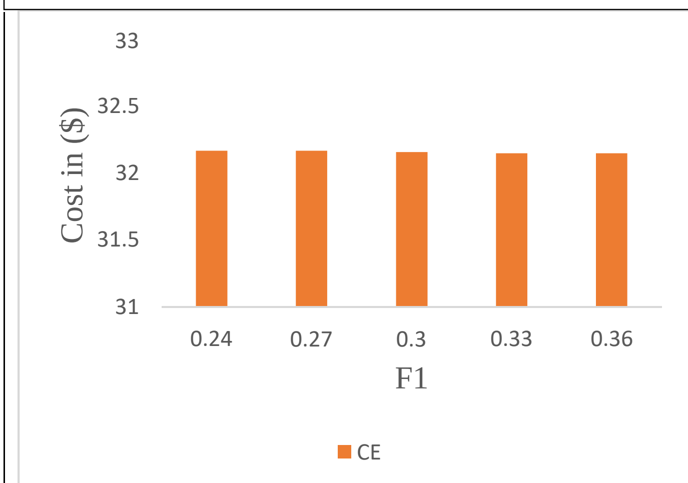


Fig. 2(b) shows that variable freight cost is increased by 24% to 36%, the carbon emission incresed by 32%.

Fig. 2(b) Carbon emission due to variable freight cost F_1

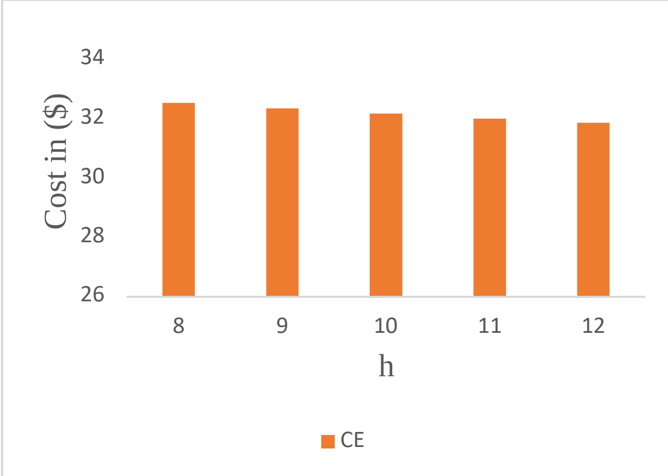
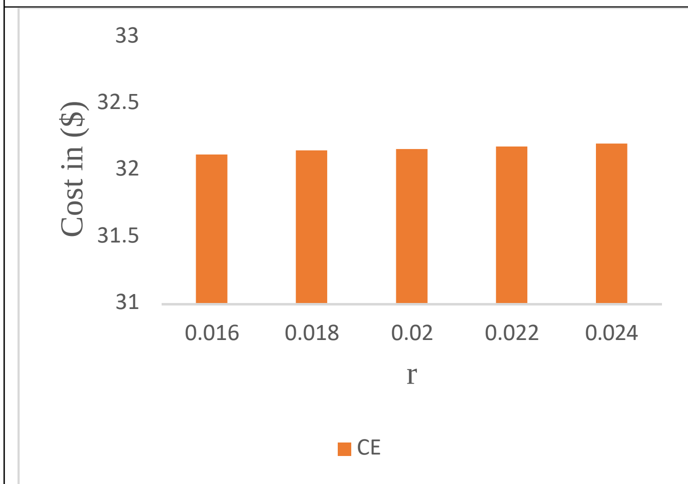
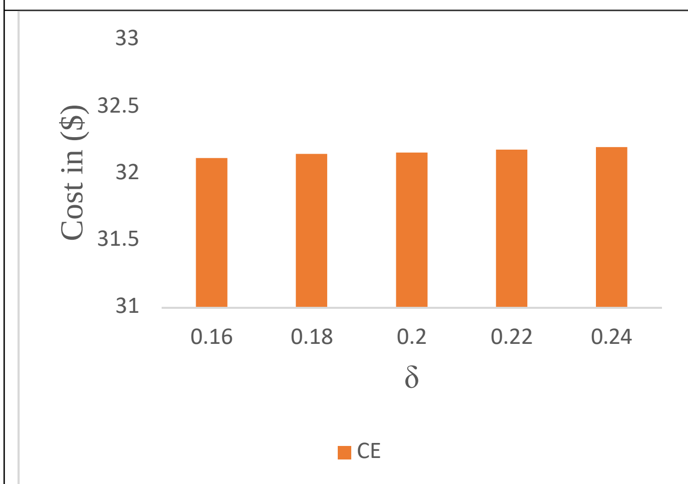
	Fig. 2(c) depicted that -20% to +20% variation holding cost results into managerial carbon emissions.
Fig. 2(c) Carbon emission due to holding cost	
	The effect of spoiled vaccine is exhibited in Fig. 2(d). This is not reasonable so the individuals are inspire for not to skip the any dose of vaccine.
Fig. 2(d) Carbon emission due to spoiled vaccine	
	Carbon emission due to damaged vacines is shown in Fig. 2(e). As it is not good for environment as well it will not available for end user which puts a good fraction of population which is hazard of infection of COVID-19.
Fig. 2(e) Carbon emission due to damaged vaccine	

Table 2. Sensitivity Analysis

		T	*Q*	*PC*	*FC*	*HC*	*CE*	*CET*	*TC*
Inventory parameters	a	⇓	⇑	⇑	⇑	↗	⇑	⇑	⇑
	b	⇒	⇒	↙	⇒	⇒	↙	⇒	⇒
	c	⇓	⇓	⇑	↙	⇓	↙	⇑	⇑
	h	⇓	⇓	↙	↙	⇑	↙	⇓	↗
	A	⇑	⇑	⇑	⇑	⇑	↗	⇑	⇑
	F_0	⇑	⇑	⇑	⇑	⇑	↗	⇑	↗
	F_1	↙	→	↙	⇑	→	→	→	→
	CE_0	⇑	⇑	↗	↗	↗	⇑	⇑	↗
	CE_1	→	→	⇓	→	↙	↗	⇑	⇑
	h_0	↗	↗	⇑	↗	⇑	↗	⇑	↗
	h_1	↙	→	⇓	↙	↙	↗	↗	⇑
	r	↙	→	⇓	↙	→	↗	↗	⇓
	[illegible]	↙	→	⇓	↙	→	↗	↗	⇓
	C_T	⇑	⇑	⇑	⇑	⇑	↗	⇑	⇑

From the sensitive analysis Table. 2, it can be seen that cycle time is positively affected by set-up cost, fixed freight cost, carbon emission for transporting vaccine and carbon tax, whereas it is negatively affected by scale demand, purchase cost and holding cost. Purchase cost gets increased with increases in scale demand, purchase cost, set-up cost, fixed freight cost, the fixed emission factor for holding inventory and carbon tax while it decreases with increases in the rate of spoilage vaccine, damaged vaccines, the variable emission factor for transporting vaccine and variable emission factor for holding vaccines in the inventory. The transshipment cost gives rise to scale demand, set-up cost, fixed freight cost, variable freight cost and carbon tax and it will decrease with purchase cost, holding cost, the variable emission factor for holding vaccines in the inventory, spoilage of vaccines and damaged vaccines. Holding cost is most sensible with respect to set-up cost, fixed freight cost, the fixed emission factor for holding inventory and carbon tax. Purchase cost and constant have a reversible effect on holding cost. Scale demand, fixed freight cost, carbon emission for transporting vaccines have a positive impact but managerial on holding cost. Variable freight cost, rate of spoilage of vaccine and damaged vaccines have a negligible effect on holding cost. Carbon emission tax is positively affected by scale demand, set-up cost, fixed freight cost, the fixed emission factor for transporting vaccines, the variable emission factor for transporting vaccines, the variable emission factor for holding vaccines in the inventory and carbon tax however, it is negatively affected by purchase cost and holding cost. Total cost increases with increases in scale demand, purchase cost, constant, set-up cost, the variable emission factor for transporting vaccines and carbon tax while it decreases with spoilage vaccine and damaged vaccine.

7. Conclusion

In a tough corona pandemic, people become more cognizant and conscious about their health and environment. Moreover, the utility of vaccines declines over time, so organizations face many challenges while managing vaccines. Vaccines have special storage conditions such as maintaining their durability and the voltage fluctuation results in the spoilage of vaccines. Hence, the proposed article is investigated carbon emission in the whole procedure of vaccination. Carbon tax policy and some strict regulations by the government can be prompted to mitigate carbon emissions during transshipment, holding inventory in the system and spoilage of inventories. So, in order to accomplish environmental and financial advantages, an organization always tries to reduce carbon emissions. This research can further be extended by expiration date and proper preservation technology. Green investment technology should be employed for reducing carbon emissions and one can include carbon policies like carbon-cap-and-trade, carbon offset, etc.

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