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A Sustainable Supply Chain Model with the Consideration of Logistics, Yard Management Systems, and Green Investments

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Abstract

Objectives: To analyze and justify the significance of yard management and green technology investments for both production and distribution processes in the supply chain along with effects of carbon taxes. **Methods:** A non-linear sustainable supply chain model considering carbon emissions during manufacturing, distribution, storage of inventory, idling during a delivery, idling and unnecessary wandering at a facility is formulated with an incorporation of yard management systems investments along with the effects of carbon taxes. Green technology investment is also incorporated to optimize total cost of systems. Lagrangian method is used to obtain the optimal solution of the problem. **Findings:** The proposed model has been solved with the prescribed method and it gives the total integrated supply chain model cost with yard management systems investment is $108,220.650 and the total integrated supply chain model cost without yard management systems investment is $112,520.340. This shows that the model with yard management systems performs better than the other one. **Novelty:** Yard management systems and green technology investment has been incorporated in a supply chain simultaneously, along with carbon taxes whereas earlier research has predominantly emphasized solely on green technology investments.
2020 Mathematics Subject Classification: 90B05, 90B06.

Keywords: Logistics; Yard Management System; Carbon emission; Carbon taxes; Green Technology

1 Introduction

In an ever-growing competitive world, organizations must pioneer their supply chain strategy to remain successful in the marketplace. The environmental impact of a company always intertwined with its supply chain. A supply chain is a process that converts the raw materials into finished goods in numerous steps. All these processes emit a significant amount of carbon emissions, which can lead to serious health issues. Several researchers focused solely the carbon emissions factoring during traditional process such as manufacturing, distribution, storage of inventory. But carbon emissions while idling during a delivery and emissions while idling and unnecessary wandering at a facility also significantly influences profitability of supply chain. NH Shah formulated a non-linear inventory model and investigated the relation between impacts of carbon emissions and utility of a covid-19 vaccine.[(1)] Emissions are found to be highest while purchasing followed by delivery and storage of the vaccine. AHM Mashud Proposed a non-linear inventory model considering two warehouse inventory systems with an incorporation of green investments during the transportation.[(2)]

Many companies have not even taken the first step towards a sustainable future. So, the government should place a high priority on achieving sustainability. Carbon Taxation is the efficient way in lowering carbon footprint in supply chain. A Paul examined the effects of carbon taxation and importance of green operations investments by the retailers.[(3)] Global maximum solution is obtained by using Mathematica software and found that net profit is inversely proportional to deterioration rate. I Konstantaras developed a mixed integer nonlinear programming problem under carbon tax mechanism and concluded that taxation has serious influence on total profitability of the system.[(4)] WA Jauhari examined the carbon tax regulations and investment in green technologies in production systems on the integrated inventory model.[(5)] However, there are several other carbon policies aimed at reducing emissions in inventory systems, but the carbon tax remains the most effective. This policy directly incentivizes companies to lower emissions by imposing a financial cost, assisting more sustainable practices throughout the supply chain. YS Huang examined different carbon policies on a integrated inventory model and concluded that the taxation has significant influence in profitability of the supply chain.[(6)] Chi-Jie Lu established an inventory model under different policies for decaying products and substantiated the significance of carbon taxation.[(7)] Moreover, carbon taxes incentivize the transition to cleaner energy alternatives, compelling companies to adopt more sustainable practices and contribute to environmental preservation efforts. Currently, there are 27 countries have implemented a carbon taxation mechanism. According to visual capitalist, "France and Canada are the leading countries that earns from carbon taxes in the year 2022". Fan Li investigated the Simulation and optimization of cold chain logistics system towards lower carbon emission.[(8)] Xiaoyi Zhang examined the green vendor-managed inventory problems in a three-tier supply chain network and found that the investment in green technology can help to improve the performance of the supply chain.[(9)]

In recent years, researchers have placed significant emphasis on sustainability, especially within the context of supply chain management. Incorporating green technologies into a supply chain, utilizing renewable energy, and adopting biofuels and electric vehicles are effective strategies for reducing emissions. M Ikram prioritized the green technology indicators to achieve a sustainable development in the supply chain.[(10)] S Gawusu highlighted the importance of renewable energy green supply chain management.[(11)] M Saeedi formulated a two-stage stochastic programming model for electric vehicle battery supply chain systems on the effect of carbon emissions.[(12)] In this order, yard management has the power to optimize move management enhance yard visibility maximize space utilization and ensure safe equipment. Traditional operations meant unnecessary moves across the facility consuming fuel and increasing emissions. With Yard Management Systems (YMS) transportation sector can avoid unnecessary travel distances and improve space utilization. YMS provides real time visibility outside of the yard revolutionizing the way facilities manage their logistics, and it shows where your facilities are located on a real time map and track the location of the driver using Global Positioning System (GPS) technology. Logistics Network provides the exact location of the drivers and expected time of arrival eliminating the need for constant driver calls. Facilities faced a common challenge prolonged wait times at dock doors and errors caused by inefficient manual dock door scheduling. With YMS, scheduling processes can be done using an automated dock door scheduler based on customer defined rule, reduce weight time and errors. Manual temperature checks led to excessive labor hours and the risk of spoiled products led to the reputation of logistics companies. YMS temperature guard has the visibility to maintain temperature eliminating the risk of spoiled products. A Muller prioritized the critical sub process of yard systems using an Analytical Hierarchy Process methodology.[(13)]

To the best of our knowledge, majority of the existing literature has predominantly emphasized on carbon footprint factoring on traditional process of inventory. Specifically, vast research has concentrated on green investment in lowering emissions in supply system. There exists a research gap which does not considers the carbon emissions other than the traditional process of the supply chain. Carbon emissions while idling during a delivery and emissions while idling and unnecessary wandering at a facility also significantly influences profitability of supply chain. So, research on supply chain model considering all the carbon emission factors to achieve sustainability is necessarily required. Most studies have examined solely on the green technology investment in the production inventory models. But investments in the yard management systems has also significantly reduces the emissions. Consequently, this leads to the existence of a research gap that does not investigates all the carbon emission factors and the investments in yard management systems and green technology simultaneously. The research gap has been filled by considering the different factors of the supply chain. So, in this study, a non-linear supply chain model considering carbon emissions during production, transportation, storage, idling during a delivery idling and unnecessary wandering at a facility is scrutinized in context of taxation on carbon mechanism. Investment in the yard management systems and green technology investment are incorporated simultaneously to lower total cost of systems and address the sustainable issue parameter.

The remainder of this research is classified below. In Section 2, Notations and Assumptions are described. The suggested model is formulated, and methodology has been described in Section 3. In Section 4, Numerical illustrations are performed. Finally, conclusion has been stated in Section 5.

2 Methodology

A non-linear sustainable supply chain model considering carbon emissions during manufacturing, distribution, storage of inventory, idling during a delivery, idling and unnecessary wandering at a facility is formulated and solved analytically. Lagrangian method is used to obtain the optimal solution of the problem. Notations and Assumptions which are used to formulate the proposed model are given in 2.1 and 2.2.

2.1 Notation

D Demand rate

P Production rate where$R > M$

Q Transportation lot size

A_v Supplier's cost for setup

A_B Retailer's order processing cost

h_v Supplier's cost for storage

h_B Retailer's cost for storage

n Number of consignments per production cycle

F Cost for transportation (per unit)

d Distance

E_h CO_2 emissions from storage

E_T CO_2 emissions from product delivery

E_P CO_2 emissions from product production

E_S CO_2 emissions from setup

G Investment for green technology

α Carbon reduction effectiveness factor

β Carbon offset reduction factor

C_1 Tax on carbon (per unit)

e_1 Idling emission of a truck while delivering

e_2 Idling emission of a truck waits at a facility

e_3 Unnecessary wandering emission at a facility

ρ Carbon reduction efficiency factor with respect to yard management

M Amount for yard management system

2.2 Assumptions

1. A single manufacturer-retailer is considered, and the demand is constant.
2. Rate of production is fixed and exceeds retailer's demand rate. Shortages are not allowed.
3. Both parties can handle storage and transportation capacities, and extreme scenarios are assumed to be unlikely.
4. Average method is used to estimate carbon emissions based on different truck types and shipment weights.
5. Emissions while idling during a delivery and emissions while idling and unnecessary wandering at a facility is also scrutinized.
6. According to government environmental restrictions, manufacturers should pay a carbon emissions tax for the manufacturing and shipping of commodities.
7. The manufacturer intends to invest in modern technology, machinery that conserves energy, in order to transition to a more environmentally friendly manufacturing system. There is a cap on the total amount of money that can be invested. The manufacturer might make improvements to his production methods to make them more environmentally friendly. This investment function is consistent in various industries and has widely been used in literature to formulate various investing options.
8. The manufacturer also intends to invest in Yard Management Systems such as vehicle advanced tracking systems for trucks, automated dock scheduler, temperature guard in order to move toward a more environmentally friendly logistics network.

2.3 Supply chain model with green technology investment

In the scenario of taxation on carbon, the carbon tax is C_1 for unit carbon emissions, which would linearly rise along with the amount of emissions that are generated. Both the supplier and retailer can adopt green technologies to lower carbon emissions, and thus reduce the expense of paying the tax. The costs of the integrated inventory model comprises of supplier's manufacturing setup cost, the retailer's order fulfillment cost, product shipping expenses, supplier's and retailer's holding costs, overall cost of paying the tax, and the green investment. By summing up the amount of carbon emissions from various activities associated with both parties and then subtracting the carbon emissions reduction effectiveness from the green cost, the total amount of carbon emissions can be obtained.

Therefore, overall cost for model considering carbon tax is

$$\begin{aligned} &TC_1(n,Q,G) \\ &= \\ &\frac{D(A_v+nA_B+C_1E_S)}{nQ}+\frac{D}{Q}d(C_1E_T+F) \\ &+\frac{Q}{2}\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_v+h_B+\left(2+n\left(1-\frac{D}{P}\right)\right)C_1E_h\right) \\ &+C_1DE_P-C_1(\alpha G-\beta G^2)+G+\frac{D}{Q}C_1e_1+\frac{D}{Q}C_1e_2+\frac{D}{Q}C_1e_3 \end{aligned} \tag{2.1}$$

2.3.1. Lemma

The overall cost of integrated inventory model, for the scenario of taxation on carbon is convex with a minimum value, and the optimal transportation batch size is given by

$$Q_1=\sqrt{\frac{2D(n(d(C_1E_T+F)+A_B)+A_v)+C_1E_S+C_1e_1+C_1e_2+C_1e_3}{\left(\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_v+h_B+\left(2+n\left(1-\frac{D}{P}\right)\right)C_1E_h\right)\right)}} \tag{2.2}$$

Proof

Consider that the total cost, factoring in the carbon tax, is influenced by the transportation batch size (Q), and the number of shipments (n) which is a continuous variable, with the first-order derivatives with respect to Q, and n are given by

$\frac{\partial TC_1(n,Q,G)}{\partial n}$ and $\frac{\partial TC_1(n,Q,G)}{\partial Q} = 0$

$$\frac{\partial \left(\begin{array}{l} \frac{D(A_v+nA_B+C_1E_S)}{nQ} + \frac{D}{Q}d\left(C_1E_T+F\right) + \frac{Q}{2}\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_v + h_B + \left(2+n\left(1-\frac{D}{P}\right)\right)C_1E_h\right) \\ +C_1DE_P - C_1\left(\alpha G - \beta G^2\right) + G + \frac{D}{Q}C_1e_1 + \frac{D}{Q}C_1e_2 + \frac{D}{Q}C_1e_3 \end{array} \right)}{\partial Q} = 0$$

Therefore, optimal transportation batch size is given by

$$Q_1 = \sqrt{\frac{2D(n(d(C_1E_T+F)+A_B)+A_v)+C_1E_S+C_1e_1+C_1e_2+C_1e_3}{\left(\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_v + h_B + \left(2+n\left(1-\left(\frac{D}{P}\right)\right)C_1E_h\right)\right)\right)}}$$

And the investment in green technologies (G) is continuous and differentiable, with the first-order derivatives with respect to G is given by

$$\frac{\partial TC_1(n,Q,G)}{\partial G} = 0$$

Therefore, optimal green investment amount is

$$G_1 = \frac{\alpha C_1 - 1}{2\beta C_1} \tag{2.3}$$

2.4 Supply chain model with Carbon Emissions Considering Carbon Tax Incorporating a Yard Management System and green technology investment

A non-linear sustainable supply chain model that rigorously evaluates carbon emissions across various stages of the supply chain production, transportation, storage, idling during delivery, idling and unnecessary movement within a facility was scrutinized. These factors are analyzed under the framework of a carbon tax mechanism, which directly impacts profitability and sustainability. The model integrates strategic investments in advanced yard management systems and green technologies, exploring their simultaneous role in reducing both operational costs and the environmental footprint. By employing the Lagrangian optimization method, the model identifies the optimal order quantity, yard management system investment, and green technology expenditure, striking a balance between cost efficiency and sustainability.

Therefore, overall cost of the supply chain model is given by

$$\begin{aligned} & TC_1(n,Q,G,M) \\ & = \\ & \frac{D(A_v+nA_B+C_1E_S)}{nQ} + \frac{D}{Q}d\left(C_1E_T+F\right) \\ & +\frac{Q}{2}\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_v + h_B + \left(2+n\left(1-\frac{D}{P}\right)\right)C_1E_h\right) \\ & +C_1DE_P - C_1\left(\alpha G - \beta G^2\right) + G + \frac{D}{Q}C_1e_1 + \frac{D}{Q}C_1e_2 \\ & +\frac{D}{Q}C_1e_3 - C_1\rho_1M - C_1\rho_2M - C_1\rho_3M + M + C_1\pi M^2 \end{aligned} \tag{2.4}$$

2.4.1. Lemma

The overall cost of integrated inventory model, for the scenario of taxation on carbon is convex with a minimum value, and the optimal yard management system investment is given by

$$M = \frac{C_1\left(\rho_1+\rho_2+\rho_3\right)-1}{2C_1\pi}$$

Proof:

Consider that the total cost, factoring in the carbon tax, and the investment in yard management system (M) is continuous and differentiable, with the first-order derivatives with respect to M is given by

$$\frac{\partial TC_1(n,Q,G,M)}{\partial M}=0$$

$$\frac{\partial\left(\begin{array}{c}\frac{D(A_v+nA_B+C_1E_S)}{nQ}+\frac{D}{Q}d(C_1E_T+F)+\frac{Q}{2}\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_v+h_B+\left(2+n\left(1-\frac{D}{P}\right)\right)C_1E_h\right)+C_1DE_P\\-C_1\left(\alpha G-\beta G^2\right)+G+\frac{D}{Q}C_1e_1+C_1e_2+\frac{D}{Q}C_3e_3-C_1\rho_1M-C_1\rho_2M-C_1\rho_3M+M+C_1\pi M^2\end{array}\right)}{\partial M}=0$$

Therefore, the Optimal yard management system investment is given by

$$M=\frac{C_1\left(\rho_1+\rho_2+\rho_3\right)-1}{2C_1\pi} \tag{2.5}$$

3 Result and discussion

This study provides a numerical example to examine how various carbon emissions policies impact the overall inventory cost in the supply chain and the viability of investing in environmentally friendly technologies. Previous research has explored the impact of carbon footprints on traditional inventory processes, with much of the focus on green investments aimed at reducing emissions in supply chains. There exists a research gap which does not considers the carbon emissions other than the traditional process of the supply chain. However, carbon emissions from idle periods during deliveries, as well as from idling and unnecessary movement within facilities, also have a significant effect on supply chain profitability. The novelty of this work is that carbon emissions has been considered on different aspects of the supply chain along with the yard management and green technology investments. This study analyzes a non-linear supply chain model that accounts for carbon emissions during production, transportation, storage, idle time during delivery, and unnecessary movement within facilities, all within the framework of a carbon taxation mechanism.

3.1 Example

The numerical problem was taken from [6] and solved using the methodology described in the section 2.3 precisely using the **equation (2.1)**, The values of different parameters are:

$$D=8000, P=10000, A_v=\$1200, A_B=\$100, h_v=\$50, h_B=\$60, F=\$10,$$

$$d=200, E_h=4, E_T=5, E_P=2, E_S=10, \alpha=15, \beta=0.01, C_1=\$1.2$$

Therefore, the total integrated supply chain model cost without yard management systems investment is \$112,520.340

3.2 Example

In this example, the parameters related to idling emissions and efficiency factor with respect to yard management are considered and the numerical example was solved using the methodology described in the section 2.4 precisely using the **equation (2.4)**.

The values of different parameters are:

$$D=8000, P=10,000, A_v=\$1200, A_B=\$100, h_v=\$50, h_B=\$60, F=\$10, d=200, E_h=4,$$

$$E_T=5, E_P=2, E_S=10, \alpha=15, \beta=0.01, C_1=\$1.2, e_1=200gms, e_2=200gms, e_3=300gms, \rho=50\%$$

Therefore, the total integrated supply chain model cost with yard management systems investment is \$108,220.650

The effectiveness of the yard management systems in lowering the total integrated system is shown in the table below.

Table 1 shows the efficiency of the suggested paradigm.

Table 1. Comparison of the supply chain with and without yard management systems investment

Total integrated supply chain model cost	With Yard Management Systems Investment	Without Yard Management Systems Investment
	$108,220.650	$112,520.340

4 Conclusion

In the growing environment, Sustainability has become a significant factor in the inventory and the supply chain management. Most studies have examined solely on carbon emissions during production, transportation, storage, while carbon releases idling during delivery, idling and unnecessary wandering at a facility has also significantly affects net profitability of supply chain systems. In particular, numerous studies have focused on green technology investments within production-inventory models. But investments in the yard management systems has also significantly reduces the emissions, The novelty of this work is that carbon emissions has been considered on different aspects of the supply chain along with the yard management and green technology investments. So, this study, seeks to fill the gap by considering both the parameters simultaneously and thus it aims to maximizes the profit of the supply chain. A non- linear sustainable supply chain model considering carbon emissions during production, transportation, storage, idling during a delivery, idling and unnecessary wandering at a facility is scrutinized under the carbon tax mechanism. Investment in the yard management systems and green technology investment are incorporated simultaneously in lowering total cost of systems and addressing the sustainable issue parameter. Lagrangian method is used to obtain the optimal order quantity, yard management system amount and green investment amount. Numerical illustration is carried out to show effectiveness of suggested model. Results show the total integrated supply chain model cost with investment in the yard management systems and green technology is ($108,220.650) better than the other one ($112,520.340). This work can be extended by considering the variable demand. Further studies can also be broadening by considering multiple retailers and addressing other sustainable issue parameters.

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