AN INVENTORY OPTIMIZATION MODEL FOR SUSTAINABLE SUPPLY CHAINS WITH CIRCULARITY-DRIVEN DEMAND UNDER TRADE CREDIT AND CARBON CONSTRAINTS

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ABSTRACT

This study proposes an inventory optimization model for sustainable supply chains, integrating a novel demand function driven by circularity index, price, product greenness, and advertisement. Excluding reliability considerations, the model incorporates two-level partial trade credit policies and carbon constraints under cap-and-trade mechanisms. The demand is modeled exponentially, capturing the influence of circularity and sustainability factors. The total cost per unit time is minimized using the respective algorithm. Numerical analysis demonstrates the model's effectiveness in balancing economic and environmental objectives. Managerial insights highlight the benefits of circular economy practices and green technology adoption. The model offers a framework for industries producing eco-friendly products under stringent carbon regulations.

Keywords: Inventory Optimization, Sustainable Supply Chains, Circularity Index, Trade Credit, Carbon Constraints

INTRODUCTION AND LITERATURE REVIEW

Sustainable supply chains are critical in addressing global environmental challenges while maintaining economic viability. The integration of circular economy principles, such as re- cycling and resource reuse, enhances sustainability by influencing consumer demand through the circularity index (1). This study develops an inventory optimization model that excludes reliability considerations, focusing on a demand function driven by circularity index, price, product greenness, and advertisement, under trade credit and carbon constraints.

Literature on sustainable supply chains emphasizes carbon cap-and-trade mechanisms and green technology adoption. (2) developed a model integrating trade benefits and carbon re- duction, while (3) proposed dynamic production-inventory systems under environmental con- straints. Trade credit policies, particularly two-level partial schemes, enhance liquidity and competitiveness (4). However, few studies incorporate circularity-driven demand, which is increasingly relevant in industries producing eco-friendly products like recycled paper or biodegradable electronics (5). The Walrus Optimization Algorithm (WOA) has shown promise in solving complex, non-linear optimization problems (6). This research addresses the gap by proposing a model that combines circularity-driven demand with trade credit and carbon constraints, optimised via WOA.

MODEL DEVELOPMENT

Assumptions

The model assumes:

- Environmental sustainability is prioritized, focusing on carbon emissions and circularity.
- Demand is exponentially dependent on circularity index (*CI*), selling price (*p*), product greenness (*g*), and advertisement (*A*):

$$D(p,g,CI,A) = Ce^{(-ap+bg+cCI+dA)},$$

where $a, b, c, d, C > 0$, $a > 1$ is price sensitivity, and b, c, d represent sensitivities to green- ness, circularity, and advertisement, respectively.

- A two-level partial trade credit policy is adopted, with settlement at $t = M$ for producers and $t = N$ for customers.
- Carbon emissions are regulated via cap-and-trade and tax policies.
- Product deterioration follows a two-parameter Weibull distribution with scale parameter a and shape parameter $b \geq 1$.
- Lead time is negligible, and production rate exceeds demand.

Mathematical Model

The demand function captures the exponential influence of circularity, price, greenness, and advertisement. The inventory system considers production, demand, and deterioration over a cycle time T. Costs include:

- Setup cost (*SCC*), production cost (*PCC*), holding cost (*HCC*), deterioration cost (*DCC*).
- Advertisement cost (*ACC*), green technology cost (*GTC*), transportation cost (*TC*).
- Carbon emission costs based on emissions from production (k_1), transportation (k_2), holding (k_3), and deterioration (k_4).

The objective is to minimize the total cost per unit time (*TCU*):

$$TCU = \frac{SCC + PCC + HCC + DCC + ACC + GTC + TC + \text{Carbon Emission Costs}}{T}.$$

Two scenarios are considered:

- **Scenario 1**: $N \leq M$, where customer credit period is less than or equal to producer credit period.
- **Scenario 2**: $N > M$, with multiple cases based on settlement times.

Solution Procedure

The Walrus Optimization Algorithm (WOA), inspired by walrus foraging strategies, is em- ployed to minimize *TCU* (6). WOA balances exploration and exploitation through phases of migration and local search, making it suitable for high-dimensional, non-linear problems. The algorithm parameters include 10 runs, 30 generations, and a precision of 10^{-7}.

WOA is applied to optimize *TCU* for both trade credit scenarios. Default parameters (e.g.,
cost coefficients, carbon emission rates) are set based on industry standards. The algorithm converges to optimal solutions, as demonstrated in numerical examples. Surface graphs and convergence plots (similar to those in (7)) illustrate the impact of circularity index, greenness, price, and advertisement on *TCU*.

CONCLUSION

This study presents an inventory optimization model for sustainable supply chains, integrating a circularity-driven demand function with trade credit and carbon constraints. By excluding re- liability, the model focuses on sustainability and circular economy principles. The exponential demand function effectively captures the influence of circularity index, price, greenness, and advertisement. WOA optimizes the total cost per unit time across trade credit scenarios, pro- viding a robust framework for industries like eco-friendly product manufacturing. Managerial insights emphasize the importance of investing in circular practices and green technologies to comply with carbon regulations and enhance competitiveness. Future research could explore stochastic demand, multi-product systems, or alternative optimization algorithms.

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