Implementation Issues in Supply Chain for Lean Technology and Circular Economy in Operations Management Encompassing ZED

Abstract:

This thesis, titled "**Implementation Issues in Supply Chain for Lean Technology and Circular Economy in Operations Management Encompassing ZED**," investigates the integration of Lean, Green Technology, and Circular Economy (CE) within India's **Zero Effect Zero Defect (ZED)** framework. As global industries face pressure to reduce environmental impact, this research aligns industrial practices with **Sustainable Development Goals (SDGs)**, particularly SDG 12 (Responsible Consumption and Production), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action).

1. Problem Statement and Motivation

Traditional manufacturing follows a linear "**take-make-dispose**" model, leading to resource depletion and environmental degradation. While Lean (waste reduction), Green (pollution control), and CE (resource circularity) are conceptually synergistic, their practical integration—especially in Indian **Micro, Small, and Medium Enterprises (MSMEs)**—is hindered by fragmented supply chains, lack of standardized metrics, and limited technical capacity. This study addresses the absence of a comprehensive decision-support framework that combines these paradigms under the national ZED initiative to enhance industrial competitiveness and sustainability.

The study is motivated by five critical needs:

1. Addressing global climate change and environmental pollution.
2. Aligning industrial practices with the national ZED initiative.
3. Improving waste management efficiency, especially in the **MSME** sector.
4. Enhancing product quality through sustainable strategies.
5. Meeting global **ESG (Environmental, Social, and Governance)** standards.

2. Research Objectives

The work is structured around four primary objectives:

- **RO-1:** Develop a comprehensive ZED adoption framework by integrating waste management and CE principles, validated through Lean- and Quality-driven models.
- **RO-2:** Implement an SME-specific CE assessment model using indicators such as eco-design, environmental footprints, and resource efficiency.

- **RO-3:** Quantify Material and Carbon Footprints as CE indicators, utilizing the **Material Circularity Index (MCI)** to evaluate and optimize performance.
- **RO-4:** Design a **Scope 3 emission reduction strategy** using Environmental Value Stream Mapping (EVSM) to identify and mitigate carbon-intensive stages across supply chains.

3. Research Methodology

The study employs a mixed-method approach, combining industrial field investigations with quantitative analytical tools.

- **Field Investigation:** Investigations were conducted across **seven MSMEs** (including sectors like ductile iron pipes, cylinders, and aircraft components) and **two large steel plants**.
- **Analytical Tools:** The researcher utilized multi-criteria decision-making (MCDM) tools such as **AHP, TOPSIS, PROMETHEE, and the CRITIC method**.
- **Statistical and AI Techniques:** Multivariate analysis (PCA and Clustering), Six Sigma tools, and Python-based optimization (Genetic Algorithms and Linear Programming) were applied for performance evaluation and modeling.
- **Strategic Modeling: Game Theory** (Cooperative and Non-Cooperative) was integrated to model stakeholder collaboration for Scope 3 emission reduction.

4. Key Findings and Results

The integration of Lean, Green, and Quality tools (TQM, Six Sigma) with Circular Economy principles was found to significantly improve industrial sustainability.

A. Operational Improvements (RO-1 & RO-2)

- **Performance Predictors:** Indicators such as **Eco-design, Energy Resource Management, and Waste Management** were strong predictors of overall environmental performance in SMEs.
- **Sigma Benchmarking:** The study applied Sigma ratings to compare clusters of industries, providing action plans to improve quality and reduce rejection rates.

B. Optimization in the Steel Sector (RO-3)

- **Technology-Fuel Choice:** Using TOPSIS, the **Electric Arc Furnace (EAF)** combined with electricity was identified as the most optimal technology for balancing production costs and emissions.
- **Scrap Quality:** Improving the **Scrap Quality Index (SQI)** led to a **10–14% reduction in emissions** and a **10–12% reduction in costs**.

- **Material Circularity:** The MCI reached approximately **0.35** under current conditions, with the potential for significant increases through higher recycling rates and better waste management.

C. Scope 3 Carbon Mitigation (RO-4)

- **Carbon Hotspots:** EVSM identified that over **70% of emissions** in the steel industry are Scope 3 (indirect value-chain emissions), which are often overlooked.
- **Collaboration Benefits:** Game-theoretic analysis showed that full coalition between suppliers, manufacturers, and distributors yields the highest net benefits and most effective emission reductions.
- **Renewable Energy:** Adopting **solar energy** was highlighted as a critical strategy to mitigate upstream Scope 3 emissions.

5. General Conclusions and Policy Implications

The thesis concludes that a holistic, integrated framework is vital for transitioning Indian industries toward a low-carbon, resource-efficient future.

Key Recommendations for Policy and Industry:

- **Government Intervention:** Stronger regulatory frameworks for CE and mandatory **Scope 1-3 reporting** are necessary.
- **Incentive Schemes:** Incentive-based programs should be introduced to help MSMEs overcome technical and financial barriers to circularity.

Future Research and Scope:

The researcher identifies **digitalization** as the next frontier for sustainable manufacturing:

- **Real-time Monitoring:** Future work should explore the use of **IoT sensors**, **Digital Twins**, and **Machine Learning** for continuous tracking of resource use and waste streams.
- **AI-Driven Analytics:** Developing **AI-driven CE dashboards** and predictive analytics can help industries optimize circularity and maintain competitiveness in a low-carbon economy.
- **Global Scaling:** The framework's scalability makes it suitable for broader implementation in other emerging economies and high-impact sectors like defense and Public Sector Units (PSUs).

This work serves as a practical roadmap for achieving **SDG 12 (Responsible Consumption)** and **SDG 13 (Climate Action)**, aligning with India’s goal of reaching **net-zero emissions by 2070**.