International Journal of Commerce and Management Research
www.managejournal.com
ISSN: 2455-1627
Received: 19-11-2025, Accepted: 18-12-2025, Published: 02-01-2026
Volume 12, Issue 1, 2026, Page No. 5-8

Sustainable Transportation Route Optimization and Its Impact on Logistics Efficiency in Nutri-Cereals Supply Chains

A Anisha[1], Dr. K Chandrasekar[2]
[1] Research Scholar, Alagappa Institute of Management, Alagappa University, Karaikudi, Tamil Nadu, India
[2] Professor, Alagappa Institute of Management, Alagappa University, Karaikudi, Tamil Nadu, India

Abstract
Sustainable transportation has emerged as a critical component of green logistics, particularly in agri-food supply chains where efficiency and environmental responsibility must coexist. The Nutri-cereals supply chain, characterized by dispersed production regions, multiple intermediaries, and cost-sensitive logistics operations, faces significant challenges related to fuel consumption, route inefficiencies, and delivery reliability. This study examines the impact of sustainable transportation route optimization on logistics efficiency within the Nutri-cereals supply chain. Adopting a quantitative, cross-sectional research design, primary data were collected from key supply chain stakeholders, including producers, transport operators, wholesalers, and distributors, using a structured questionnaire. Sustainable route optimization practices such as efficient route planning, reduced travel distance, fuel-efficient routing, and time reliability were analysed in relation to logistics efficiency indicators, including transportation cost efficiency, delivery timeliness, vehicle utilization, and operational performance. The empirical results reveal a strong and positive relationship between sustainable route optimization and logistics efficiency, indicating that optimized routing not only reduces environmental impact but also enhances core operational outcomes. The findings highlight the strategic importance of integrating sustainability-driven routing practices into Nutri-cereals logistics to improve supply chain performance, resilience, and long-term sustainability. The study offers valuable insights for logistics managers and policymakers seeking to balance environmental objectives with efficiency imperatives in agri-food supply chains.

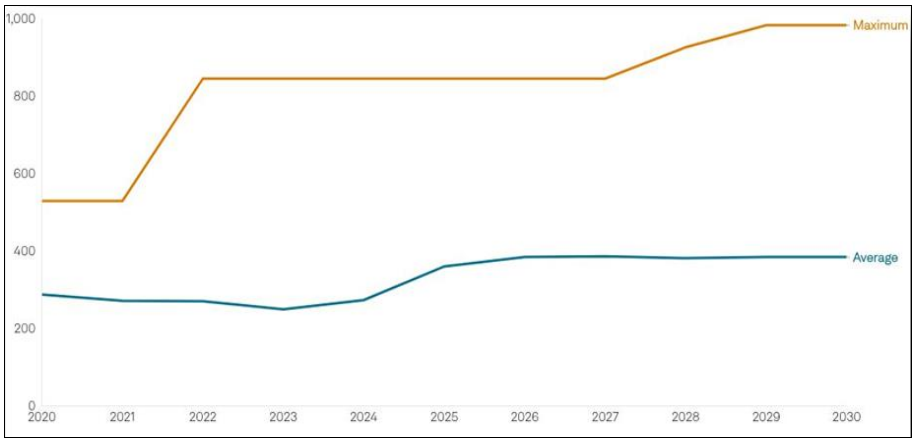
Keywords: Sustainable transportation, route optimization, logistics efficiency, nutri-cereals supply chain, sustainable supply chain management

Introduction

Overview

In the content of the sustained development of the worldwide economy, the fast growth of the logistics industry has brought significant energy consumption and environmental pollution problems. Traditional transportation methods often rely on high energy fuels and inefficient transportation routes, which not only increases operating costs but also has a serious impact on the ecological environment. With the popularization of the concept of sustainable development, green logistics has gradually become an important direction for the development of the industry. Optimizing transportation routes to reduce energy consumption and emissions has become a core issue that needs to be solved urgently. By collecting and analysing a large amount of transportation-related data, including vehicle operation information, cargo characteristics, road conditions and meteorological factors, logistics companies can more accurately predict transportation demand and conduct efficient route planning based on this.

The use of advanced algorithms, can minimize environmental impact while ensuring economic benefits, thereby promoting the logistics industry to develop in a green and sustainable direction. Transportation has a great effect on economic growth and is a foundational infrastructure in any country. Efficient transportation scheduling improves logistics performance and supply chain and increases the competitive advantage of companies (Guo *et al*. 2016).



Source: S &P global mobility

The expansion of technologies such as vehicle-to-grid integration and Indian EV charging infrastructure will also make sustainable transportation in India more accessible and resilient. However, understanding real-world range in plug-in EVs requires careful consideration of technological progress, environmental factors and shifting consumer expectations. These evolving capabilities will empower original equipment manufacturers to design vehicles that meet diverse user demands while being less reliant on frequent charging, easing the load on India's EV charging ecosystem.

Review of literature

1. Sustainable transportation and route optimization

Sustainable transportation has emerged as a critical dimension of supply chain management, driven by rising fuel costs, environmental regulations, and the need for operational efficiency. Route optimization has been widely acknowledged as a strategic tool to enhance logistics performance by minimizing travel distance, fuel consumption, delivery time, and greenhouse gas emissions. Recent studies emphasize that sustainable route planning integrates economic and environmental objectives through multi-objective optimization models, enabling firms to achieve cost efficiency while reducing ecological impact (Chen, 2022; Jahagirdar *et al*., 2023). The Vehicle Routing Problem (VRP) serves as the theoretical foundation for most transportation optimization studies. Recent advancements extend classical VRP into Green VRP (GVRP), Time-Dependent VRP, and Stochastic VRP models to reflect real-world logistics conditions. Systematic reviews conducted between 2021 and 2024 indicate a growing focus on integrating carbon emission metrics, energy efficiency, and service reliability into routing models (Nielsen *et al*., 2023). Metaheuristic and hybrid algorithms such as genetic algorithms, particle swarm optimization, and ant colony optimization are frequently applied to handle large-scale logistics networks efficiently. These models demonstrate strong potential for application in agri-food supply chains, where routing decisions significantly affect both cost and sustainability outcomes.

2. Logistics Efficiency

Multiple empirical investigations confirm that sustainable route optimization positively influences logistics efficiency indicators such as transportation cost, delivery time, fuel consumption, and vehicle utilization. Studies report measurable reductions in total logistics cost and emissions when optimized routing models are implemented, compared to conventional practices (Li *et al*., 2022). Furthermore, integrated routing and distribution planning improves coordination across supply chain actors, leading to smoother material flows and enhanced operational performance. These efficiency gains are particularly relevant for Nutri-cereals supply chains, where margins are sensitive to transportation inefficiencies. Agri-food supply chains, including Nutri-cereals, pose unique transportation challenges due to dispersed production locations, seasonality, bulk handling, and sensitivity to delays. Recent studies on sustainable transportation in food supply chains emphasize the importance of route optimization in reducing post-harvest losses, maintaining product quality, and lowering transportation costs (Wang *et al*., 2023) [8]. Although Nutri-cereals are relatively less perishable than fresh produce, timely and efficient transportation remains essential to preserve nutritional value, ensure market availability, and prevent storage losses. Literature suggests that adopting sustainable routing practices in cereal logistics can substantially improve supply chain responsiveness and cost efficiency, especially in developing-country contexts.

Research Gap

Although there is an increasing literature on sustainable transportation and optimal route planning, there are still definite research gaps that still exist, especially when dealing with the Nutri-cereals supply chain. Prior studies have extensively examined route optimization using advanced algorithms, GIS, and data-driven models to reduce fuel consumption, carbon emissions, and delivery time, largely focusing on general logistics, e-commerce, or industrial supply chains (Dijkstra *et al*., 2020; Demir *et al*., 2021) [1, 2]. However, these studies predominantly emphasize environmental performance and cost minimization, while giving limited empirical attention to how sustainable route optimization directly enhances logistics efficiency dimensions such as delivery reliability, transit time consistency, inventory responsiveness, and distribution flexibility (Mangiaracina *et al*., 2022) [6]. Furthermore, existing research on agri-food and cereal supply chains tends to concentrate on post-harvest losses, storage infrastructure, and cold-chain efficiency, with transportation treated as a supporting function rather than a strategic sustainability driver (Aday & Aday, 2020; Kamble *et al*., 2021) [5]. Specifically, Nutri-cereals, which are characterized by dispersed production regions, smallholder farmers, and semi-urban markets, remain underrepresented in route optimization studies, despite their logistical complexity and sustainability relevance (FAO, 2021) [3]. Moreover, limited research integrates sustainability indicators with operational efficiency metrics within a single analytical framework, particularly in emerging economies where infrastructure and data availability constraints significantly influence routing decisions (Rehman *et al*., 2022) [7]. Therefore, there exists a clear research gap in empirically examining how sustainable transportation route optimization practices impact logistics efficiency within the Nutri-cereals supply chain, especially in developing-country contexts. Addressing this gap can provide actionable insights for policymakers and logistics managers seeking to balance sustainability goals with operational performance in agri-food supply networks.

Research objectives

1. To examine the existing transportation and routing practices adopted in Nutri-cereals supply chains.
2. To evaluate the relationship between route optimization and environmental performance in the Nutri-cereals logistics network.
3. To identify operational and infrastructural challenges in implementing sustainable route optimization within Nutri-cereals supply chains.

Research methodology

This study adopts a quantitative, cross-sectional research design to examine the impact of sustainable transportation route optimization on logistics efficiency within the Nutri-cereals supply chain. Primary data were collected through a structured questionnaire administered to key supply chain stakeholders, including Nutri-cereals producers, transport

operators, wholesalers, and distributors operating across major production and distribution regions. A stratified random sampling technique was employed to ensure adequate representation of upstream and downstream logistics actors, thereby enhancing the generalizability of the findings. The measurement instrument comprised validated scales capturing sustainable transportation route optimization practices such as efficient route planning, fuel optimization, reduced travel distance, time reliability, and emissions-conscious routing and logistics efficiency indicators, including delivery timeliness, transportation cost efficiency, vehicle utilization, inventory responsiveness, and overall operational performance. Responses were measured using a five-point Likert scale. Prior to full-scale data collection, a pilot study was conducted to assess clarity, reliability, and content validity of the questionnaire. The methodological approach ensures analytical rigor and provides empirical insights into how sustainable transportation practices contribute to enhanced logistics performance in Nutri-cereals supply chains.

Demographic Profile

Table 1: Demographic Profile of Respondents (N = 126)

Demographic Variables	Category	No. of Respondents	Percentage (%)
Gender	Male	238	57.2
	Female	178	42.8
Age Group	Below 25 Years	83	20.0
	25–35 Years	121	29.1
	36–45 Years	97	23.3
	Above 45 Years	115	27.6
Role in Supply Chain	Producers	116	28.0
	Transport Operators	108	26.0
	Distributors	100	24.0
	Wholesalers	92	22.0
Years of Experience	Less than 5 Years	129	31.0
	5–10 Years	141	34.0
	11–15 Years	87	21.0
	Above 15 Years	59	14.0
Operational Region	Local	104	25.0
	Regional	125	30.0
	State	116	28.0
	National	71	

Discussion

The empirical findings of the study reveal a strong and positive influence of sustainable transportation route optimization on logistics efficiency within the Nutri-cereals supply chain. The results indicate that a majority of respondents perceive optimized routing practices such as efficient route planning, reduced travel distance, fuel-efficient routing, and technology-enabled navigation as critical drivers of improved logistics performance.

The high level of agreement among stakeholders suggests that route optimization contributes substantially to timely deliveries, lower transportation costs, enhanced vehicle utilization, and reduced operational delays. These outcomes are particularly significant for Nutri-cereals, which require time-sensitive and cost-efficient logistics to preserve product quality and ensure market competitiveness. The moderate impact observed among a segment of respondents reflects varying levels of technology adoption and infrastructural constraints across logistics operators.

Meanwhile, the relatively low proportion reporting minimal impact highlights the need for broader diffusion of digital routing tools and sustainability-oriented logistics strategies. Overall, the findings reinforce the argument that integrating sustainability into transportation planning not only supports environmental objectives but also strengthens core logistics efficiency outcomes in agri-food supply chains.

Conclusion

The study concludes that sustainable transportation route optimization plays a decisive role in enhancing logistics efficiency in the Nutri-cereals supply chain. By minimizing fuel consumption, reducing delivery lead times, improving vehicle productivity, and supporting environmentally responsible operations, optimized routing emerges as a strategic enabler of efficient logistics performance. The dominance of high-impact responses demonstrates that sustainability-driven transportation decisions are no longer optional but essential for resilient and competitive Nutri-cereals supply chains.

The findings provide practical implications for supply chain managers and policymakers, emphasizing the need to invest in route optimization technologies and data-driven transportation planning. From a broader perspective, the study affirms that sustainability initiatives, when operationalized through efficient routing practices, generate tangible performance benefits while contributing to long-term supply chain sustainability.

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