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Harnessing Artificial Intelligence for Reverse Supply Chain Logistics in the FMCG Sector: A Comprehensive Review and Future Outlook through Case Studies

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ABSTRACT
The rapid rise of consumption-driven markets has intensified challenges within reverse supply chain logistics (RSCL), particularly in the Fast-Moving Consumer Goods (FMCG) sector, where product returns, waste management, recycling, and environmental compliance require efficient handling. This paper provides a comprehensive review of how Artificial Intelligence (AI) enhances decision-making across reverse supply chain logistics processes, including return forecasting, defect diagnosis, route optimisation, waste reduction, and circular economy integration. The study synthesises literature from recent industry developments, case studies, and academic findings to identify key AI applications such as machine learning-based demand prediction, automated sorting using computer vision, blockchain-enabled tracking, and real-time optimisation through IoT sensors. The review highlights that AI-driven reverse supply chain logistics not only reduces operational costs but also supports sustainability goals and corporate social responsibility initiatives. However, challenges such as technological integration costs, data privacy, skill gaps, and infrastructure limitations remain. The paper concludes by outlining future research directions, emphasising automation maturity, multi-agent AI systems, and hybrid optimisation models. This paper therefore aims to: (a) map current AI applications in RSCL relevant to FMCG (forecasting, vision-based sorting, routing, traceability, and decision optimization); (b) evaluate national (Indian) and international examples and lessons learned from corporate pilots and programs; and (c) identify remaining technological, organizational, and policy barriers and propose directions for research and practice that enable scalable, equitable, and sustainable AI-enabled reverse logistics
Keywords: Artificial Intelligence, Reverse Logistics, FMCG Sector, Circular Economy, Automation, Supply Chain Return Management.

INTRODUCTION:

The Fast-Moving Consumer Goods (FMCG) sector is characterised by high volumes, short product life-cycles, tight margins, and complex distribution networks; these features make efficient forward and reverse logistics essential for both competitiveness and sustainability. Reverse supply chain logistics (RSCL), the set of processes for handling returns, recalls, expired goods, packaging recovery, refurbishment, and recycling, has moved from a cost-centre afterthought to a strategic capability that supports regulatory compliance, brand reputation, waste reduction, and the circular economy. Global FMCG leaders are therefore investing in digital and intelligent systems to transform RSCL from manual, fragmented operations into data-driven, closed-loop flows that recover value while lowering environmental impact. For example, Unilever has embedded circularity and traceability in its supply-chain strategy and published frameworks for supplier due diligence and material stewardship.

Artificial Intelligence (AI) including machine learning, computer vision, optimisation algorithms, and agent-based decision systems offers capabilities that directly address recurring RSCL problems: demand/return forecasting for perishable, automated sorting and defect detection at returns centres, route and pickup optimisation for collection networks, and real-time traceability for regulatory reporting and anti-fraud measures. Major multinationals such as Procter & Gamble and Nestlé are actively exploring AI and digital pilots to cut waste and improve returns handling; Nestlé has trialled AI tools that significantly reduced edible food waste in factory-level pilots, demonstrating how AI can generate both environmental and cost benefits in reverse flows.

At the national level, leading Indian FMCG firms are also advancing reverse-logistics and circularity initiatives. Hindustan Unilever's Project Circular Bharat aims to scale practical models for plastic circularity in India by coordinating with governments, startups, and waste-management partners, reflecting industry-wide moves to localise collection and recycling infrastructure. Other Indian players across categories, including personal care, food, and packaged goods, are piloting digital solutions (often built on analytics and IoT) to improve traceability and reduce post-consumer waste streams. These national efforts confront particular challenges such as fragmented collection ecosystems, informal waste sectors, and infrastructure variability that demand context-aware AI solutions.

Despite clear potential and several high-profile pilots, gaps remain in applying AI to FMCG reverse logistics at scale. Academic and industry literature point to inconsistent data quality across partners, limited integration between forward and reverse information systems, high capital and implementation costs, and workforce skill shortages that constrain adoption. Furthermore, FMCG reverse flows add complexity because of perishability, mixed material packaging, and regulatory heterogeneity across markets, factors that make modelling returns, routing, and recovery substantially different from electronics or durable-goods reverse logistics. These limitations constitute the research problem this review addresses: how can AI be systematically harnessed to make RSCL in FMCG both operationally effective and environmentally sustainable across diverse national and international contexts?

The theoretical basis for the study draws on supply-chain circularity theory and socio-technical systems theory. Circularity theory frames reverse logistics as part of value-retention systems, emphasising design-for-recovery, collection economics, and closed-loop material flows, while socio-technical perspectives emphasise that technological solutions (AI models, sensors, robotics) must co-evolve with organisational practices, policy instruments, and labour arrangements to be effective. Combining these lenses helps explain why AI pilots succeed in controlled factory or pilot settings (where technical variables are managed) but struggle to scale across heterogeneous retail and municipal ecosystems.

2. OBJECTIVES

- To examine key AI applications in reverse supply chain logistics within the FMCG sector.
- To assess the impact of AI on cost reduction, sustainability, and operational efficiency.
- To identify challenges and propose future research directions.

3. LITERATURE

Reverse logistics, the process of returning goods from the point of consumption back to the point of origin for repair, recycling, or disposal, has received increasing attention as companies and researchers seek to improve sustainability, cost control, and circular-economy practices. While the bulk of research on artificial intelligence (AI) in logistics historically focused on forward supply chains, a growing body of work studies how AI can optimise reverse logistics. However, clear gaps remain, especially in relation to the FMCG (Fast-Moving Consumer Goods) sector.

Scholars have analysed the integration of AI across reverse logistics from multiple angles. For instance, Bhowmik, Chowdhury, Ashik, Mahmud, Khan, and Hossain (2024) conducted a bibliometric and network analysis of nearly 2,929 articles over three decades and found that machine learning (ML), deep learning, and neural network methods dominate AI applications in this domain. Their study highlights that AI is increasingly applied to returns management, inspection, classification, and optimisation tasks in reverse supply chains.

Another conceptual work by Wilson, Paschen, and Pitt (2021) explores how different forms of AI (mechanistic, analytical, and intuitive) can support reverse logistics functions within a circular economy framework, from forecasting returns to decision-making on reuse vs. disposal.

Furthermore, in a systematic literature review, Sigahi, Silva, Moris, et al. (2025) mapped how supervised, unsupervised, and reinforcement-learning ML models have been used in reverse logistics. Their review reveals that return and waste-generation forecasting are among the most common applications, while fewer studies address module explainability, real-time decision-making, or environmental/social performance metrics.

Integration of AI into various stages of the reverse logistics process has been documented in the literature. A study in 2024 systematically reviews how AI supports planning, execution, and control phases of reverse logistics: strategic decisions (network design), operational choices (collection routes), and return disposition (reuse, recycling, disposal) are all being enhanced via predictive analytics, optimisation algorithms, and decision-support systems.

In a more general technology-framework approach, researchers developing digital-technology frameworks for reverse logistics have found that combining AI with IoT (Internet of Things) and blockchain improves visibility, traceability, and decision quality. For example, a systematic review framework presented by a recent MDPI study shows that AI enables better forecasting of return flows, while IoT provides real-time tracking, and blockchain ensures secure data sharing and provenance.

4. RESEARCH METHODOLOGY

This study adopts a qualitative systematic review methodology aimed at synthesising existing scholarly and industry-based evidence on the role of Artificial Intelligence in reverse supply chain logistics within the Fast-Moving Consumer Goods (FMCG) sector. A qualitative design is appropriate because the research intends to interpret trends, evaluate technological applications, identify thematic patterns, and highlight conceptual and empirical gaps rather than test hypotheses using primary quantitative data. The study is structured as a **descriptive and analytical literature review**. The descriptive component offers a structured summary of existing knowledge on AI-enabled reverse logistics, while the analytical component critically evaluates the relevance, contributions, and limitations of past research. This dual approach helps integrate theoretical insights, real-world industrial practices, and comparative perspectives across national and international FMCG ecosystems. The review draws from a population consisting of academic publications, industry white papers, corporate sustainability reports, case studies, and conference proceedings related to supply chain management, artificial intelligence, circular economy, and FMCG operations. A purposive sampling strategy was employed to select studies relevant to the research topic.

5. Key AI-Driven Applications in FMCG-RSCL

From the literature and corporate case studies, the following major AI application areas in reverse logistics for FMCG emerge:

1. **Return Forecasting**
2. **Automated Sorting & Recognition**
3. **Route Optimisation for Collection**
4. **Sustainability & Traceability**

Below is a summary (Table 1) of specific use cases and corporate examples.

AI Application	Function in Reverse Logistics	Corporate / Industry Examples	Impact / Benefit	Challenges
Return Forecasting	Predict volume of returns, anticipate peak return windows.	From AI in the Chain: predictive returns forecasting using ML (e.g., XGBoost + Prophet).	Better capacity planning for returns handling, reduce overstaffing or under-utilisation.	Requires historical return data, consumer-behaviour modelling, and data privacy.
Automated Sorting & Recognition	Classify returned or recyclable items, and detect material type.	Unilever + Alibaba pilot: AI-enabled recycling machines identify and sort plastic by grade.	Increased recycling quality, better segregation of plastics, higher loop-back rate of recycled material.	High setup cost, need for accurate computer vision models, and maintenance of hardware.
Route Optimisation / Collection Network	Optimise pick-up of returned goods, plan collection routes.	While specific FMCG reverse logistics routing case studies are limited, general AI reverse-logistics models propose automated routing for reuse or recycling.	Reduced transport cost, more efficient collection cycles, lower carbon footprint.	Infrastructure variability, unpredictability of return points, and limited data from informal waste collectors.
Sustainability & Traceability	Track material through its lifecycle, scoring environmental impact	Unilever's recycling machines contribute to its circular economy goals.; AI-in-reverse-logistics frameworks emphasise the sustainability loop.	Better traceability, meeting sustainability KPIs, and regulatory compliance	Data integration across systems, transparency with third-party recyclers, cost of blockchain / IoT if used

6. Case Studies: National & International Organisation

Here are some detailed company-level illustrations of how AI is being used in reverse logistics (or adjacent 'circular' operations) within FMCG, based on available literature and industry reports.

- ***Unilever (International)***

- **AI-Enabled Sorting Machines for Plastic Recycling:**
  Unilever, in collaboration with Alibaba, piloted AI-powered recycling machines in China that can automatically identify different types of plastic bottles, sort them by grade, and store them for collection.
  - **Impact:** By pre-sorting plastics intelligently, these machines improve the quality of recyclables, reduce contamination, and make it economically viable to re-feed plastic back into production.
  - **Sustainability Contribution:** This effort helps Unilever meet its circular economy goals (e.g., reducing virgin plastic usage and increasing recycled content) for 2025.
  - **User Engagement:** Consumers deposit bottles via machines after scanning a QR code (Alipay), and are incentivised via "green energy points" on Alipay's Ant Forest platform.
- **AI for End-to-End Supply Chain Forecasting & Planning:**
  As per Unilever's report, they developed an AI-powered model for **collaborative planning, forecasting, and replenishment** with key retail customers.
  - **How it works:** The model integrates point-of-sale data, forecast data, and actual sales to synchronise supply chain decisions in real time.
  - **Benefits:** The pilot with Walmart Mexico delivered on-shelf availability of **98%**, reducing inefficiencies and inventory waste.
  - **Scalability:** The model is being expanded to 30 major customers globally.

These initiatives show that Unilever is not only applying AI for forward logistics but also embedding intelligence in its reverse flows (especially packaging recycling).

- ***Nestle (International)***

- **AI to Reduce Food Waste:**
  A recent pilot involving Nestlé (UK) used an AI tool developed by Zest to monitor edible food waste in real time at one of its factories.
  - **Outcomes:** In just two weeks, the AI system reportedly led to an **87% reduction** in edible food waste.

- **Sustainability & Cost Impact:** This translates to potential savings of up to **700 tonnes of food**, equivalent to 1.5 million meals, and an estimated **1,400 tonnes of CO_2** emission avoidance.
- **Broader Implications:** The system can help firms not only minimise returns or "waste-forward," but also improve reverse-flow sustainability by redesigning processes around AI-based insights.

Indian FMCG Context

- **ITC Infotech / FMCG Company – Digital Twin + AI for Risk & Supply Chain Forecasting:**
  A case study by AnyLogistix demonstrates how an Indian FMCG firm used a digital twin built with AI to simulate and forecast logistics performance, risk, and root causes for under-performance.
  - **Features:** The digital twin uses ERP data, supply chain event data, and machine learning-driven demand sensing to predict metrics like stock-outs, fill rates, and logistics cost up to 15 days ahead.
  - **Benefit:** AI-driven root cause analysis identifies where problems may occur and proposes counter-measures, supporting proactive decision-making.
  - **Vision:** The next phase of the project is to enable the system to **suggest and automatically trigger corrective actions** via ERP.
- **Dabur / Marico / Other Indian FMCG Firms:**
  According to government-AI reports from India, companies such as **Dabur** already use AI, machine learning, robots, and automation for multiple functions, including supply chain, operations, and forecasting.
  - While these primarily deal with forward logistics, the same AI infrastructure can be adapted for reverse flows (e.g., forecasting returns, monitoring expiry, planning collection of waste packaging).
  - The report indicates that firms are using data-driven analytics to improve resource allocation, decision support, and operational agility.
- **Recycling Ecosystem & Technology Firms:**
  Recykal, an Indian digital-tech company, is building a marketplace connecting waste collectors (kabadiwalas), recyclers, and FMCG companies.
  - Though not purely AI-focused in all their operations (public information is limited), firms like Recykal can serve as infrastructure partners where AI-enabled sorting or forecasting tools could plug in to manage reverse stream logistics for FMCG firms.
  - As reverse logistics matures in India, such platforms may become crucial nodes for AI-enabled collection planning, traceability, and quality assessment.

7. Thematic Insights & Trends

From the case studies and literature, several broader **trends** emerge:

1. **AI is moving from forward to reverse logistics**: While many FMCG firms historically used AI for demand forecasting and replenishment (Unilever being a prime example), recent pilots show that AI is being extended to reverse flows (returns and recycling).
2. **Circular economy is a strong motivator**: AI is not just about cost savings, but also environmental sustainability. Unilever's plastic-sorting machines and Nestle's food-waste monitoring illustrate that reverse logistics investments must support corporate ESG goals.
3. **Hybrid systems and data integration**: AI-driven reverse logistics depends on integration with IoT, digital twins, and ERP systems to deliver visibility, prediction, and automation. The ITC Infotech digital twin case is a good example.
4. **Scalability remains a challenge**: While pilots are promising, the real large-scale implementation of AI in reverse logistics in the FMCG sector is still limited. Challenges include infrastructure cost (e.g., recycling machines), data quality, and coordinating with third-party waste collection and recycling partners.
5. **Role of local tech partners is expanding**: In emerging markets like India, local platforms (e.g., Recykal) could enable FMCG firms to deploy AI-enabled reverse logistics by facilitating structured collection, data exchange, and traceability.

8. Challenges revealed by the results

Although AI applications are promising, the review of real-world cases also surfaces several **key challenges:**

- **Cost of Hardware & Infrastructure**: Installing AI-enabled sorting machines (as Unilever did) involves significant capital investment.
- **Data Gaps**: Reverse flows often involve third-party players (waste collectors, recyclers) who may not have digitised operations, leading to fragmented data.

- **Regulatory & Policy Variability**: Regulations for recycling, extended producer responsibility (EPR), and waste management differ across geographies, affecting the feasibility of AI-based reverse logistics.
- **Skill & Change Management**: Implementing AI in reverse logistics requires skilled data scientists, AI engineers, and domain experts in recycling – a rare combination.
- **Sustainability Trade-Offs**: Even though AI can optimise returns or recycling, the energy and resource footprint of AI hardware and data centres must be justified in ESG terms.

9. DISCUSSION

The findings of this review demonstrate that Artificial Intelligence has significant potential to transform reverse supply chain logistics (RSCL) in the Fast-Moving Consumer Goods (FMCG) sector by shifting traditional manual, fragmented return processes toward autonomous, data-driven systems. While prior research on AI interventions in supply chain management has largely emphasised forward logistics, routing efficiency, and demand forecasting, this study identifies the need for AI solutions tailored to the distinct characteristics of reverse flows in FMCG namely, short product life cycles, rapid turnover rates, perishability, and high-volume packaging waste. These characteristics make reverse processes more complex compared to industries such as electronics, where return cycles are longer and more structured.

The results align with existing literature advocating the role of predictive analytics, IoT, and machine learning in enhancing sustainability and supporting circular economy initiatives. However, this review extends scholarly discourse by highlighting barriers that are underrepresented in previous studies, particularly infrastructure limitations in emerging economies, fragmented digital ecosystems, a lack of standardised data formats, and algorithmic bias arising from low-quality datasets. These structural challenges hinder the adoption of automated waste sorting, blockchain-enabled traceability, and autonomous material recovery systems across large-scale FMCG operations. In addition, the review reveals disparities in implementation maturity across global regions. International corporations such as Unilever, Nestlé, and Coca-Cola exhibit more advanced deployment of AI-enabled return kiosks, blockchain-based packaging traceability, and robotics-driven recycling plants. In contrast, Indian FMCG firms typically operate hybrid models where digital tracking coexists with manual waste segregation due to socio-economic conditions, logistical diversity, and infrastructural constraints. These differences underscore the need for scalable AI frameworks adaptable to varying levels of technological readiness.

Furthermore, the review identifies emerging innovation pathways that can reshape reverse logistics in the future. Autonomous multi-agent systems, reinforcement learning-based routing models, and real-time sustainability scoring frameworks could enable fully closed-loop supply chains, where products are digitally tracked from production to disposal, and materials continuously circulate with minimal human intervention. Such advancements would not only improve operational efficiency but also support environmental compliance, extended producer responsibility (EPR), and global sustainability targets.

However, to realise these benefits, collaboration between FMCG firms, technology providers, policymakers, and waste management stakeholders is essential. Cross-industry partnerships can facilitate data-sharing ecosystems, regulatory harmonisation, and investment in circular infrastructure—ensuring that AI-driven reverse logistics evolves from isolated pilot initiatives to widespread industry standards.

Overall, the discussion reinforces that while AI offers transformative potential for RSCL in FMCG, its impact will be maximised only when technological innovation is aligned with institutional support, ecological goals, and socio-economic feasibility. The future of reverse logistics lies not merely in automation, but in the strategic integration of intelligent systems that enable a sustainable, closed-loop economy.

10. CONCLUSION

This study examined the role of Artificial Intelligence in enhancing reverse supply chain logistics (RSCL) within the Fast-Moving Consumer Goods (FMCG) sector through a qualitative systematic review of scholarly and industry-based literature published between 2015 and 2025. The findings indicate that AI has the potential to significantly advance RSCL by improving automation, accuracy, traceability, sustainability outcomes, and operational responsiveness. Technologies such as machine learning, computer vision, blockchain, and IoT sensors can optimise key processes, including return forecasting, waste sorting, packaging recovery, product recall management, and circular material flows. The review highlights that while global FMCG companies have initiated AI-enabled circular systems, emerging markets such as India display hybrid adoption due to infrastructural, financial, and technological constraints. A critical insight from the analysis is that reverse logistics in FMCG present distinct challenges compared to other sectors, driven by high consumption rates, short shelf life, product perishability, and large-scale packaging waste. These factors necessitate tailored AI frameworks rather than general supply chain solutions.

The study contributes to existing knowledge by identifying emerging innovations—such as autonomous sorting systems, hybrid optimisation algorithms, and sustainability scoring models that could support the long-term development of closed-loop supply chains. At the same time, barriers including fragmented data ecosystems, a lack of standardisation, limited digital infrastructure, and potential algorithmic bias must be addressed through policy support and cross-industry collaboration. Despite offering valuable theoretical insights, the study is limited by its reliance on secondary data and the scarcity of empirical evidence specific to FMCG-focused AI applications. Future research should adopt primary data approaches, conduct industry-level case studies, develop quantitative performance models, and evaluate region-specific implementation frameworks to validate AI's long-term impact on reverse logistics.

Overall, the study concludes that AI represents a transformative enabler for sustainable and circular RSCL systems in the FMCG sector, but its full potential can be realised only through integrated technological innovation, regulatory alignment, and collaborative stakeholder engagement.

11. Future of Reverse Supply Chain Management in FMGC Organisations

The future of AI-enabled reverse supply chain logistics for FMCG will be shaped by converging forces cheaper sensors and connectivity, stronger sustainability regulation, growing e-commerce return volumes, and advances in AI for vision, optimisation, and privacy. but the trajectory and speed will differ markedly between India and international markets. In India, the near- to mid-term future will be driven by pragmatic, cost-sensitive deployments: lightweight ML models for returns forecasting that integrate POS, marketplace and promotional data; smartphone/edge-vision triage tools that let small hubs and MSME distributors automatically grade returned packaging and detect salvageable items; rule-based + ML routing heuristics that produce high utility with limited compute; and federated or privacy-preserving approaches that enable brand–retailer collaboration without heavy data sharing. Indian adoption will be accelerated by large e-commerce players and organised retail pilots, but constrained by fragmented logistics networks, intermittent cold-chain coverage for perishables, and limited analytics talent in smaller firms. Policy levers such as extended producer responsibility (EPR) and state-level incentives for packaging recovery will catalyse more formal reverse collection networks and create demand for AI systems that can quantify and optimise circularity outcomes (recovery rates, avoided emissions, cost per kg recovered). Practically, expect hybrid human-AI workflows to dominate early deployments, AI flags and scores items while operators make final disposition decisions, plus many low-cost pilots focused on urban last-mile consolidation and reverse hubs near metro centres.

Internationally, particularly in developed markets, the future will emphasise end-to-end, data-rich automation and multi-stakeholder platforms. Advanced computer vision and multimodal models will run on high-throughput sorting lines to classify product condition at scale; reinforcement-learning-based routing will dynamically consolidate reverse flows across retailers and 3PLs while optimizing for cost and emissions; lifecycle-aware decision engines will automatically recommend reuse, refurbishment, or material-level recycling based on real-time market prices and LCA inputs; and blockchain or verifiable provenance systems combined with AI will substantially reduce fraud and improve traceability. Stricter regulations on packaging waste, carbon reporting, and producer responsibility will push firms to adopt sophisticated KPI dashboards that tie reverse logistics performance to Scope 3 emissions and circularity metrics. Because data is less siloed and infrastructure is stronger, federated learning will be used mainly for privacy regulation compliance rather than necessity, and explainable AI will be a legal and operational requirement to satisfy auditors and consumers. Industry consortia will produce standardised benchmark datasets and open APIs for routing, triage and valuation services, enabling faster innovation cycles.

Across both contexts the shared future themes are clear: (1) movement from pilots to scale will require rigorous ROI evidence, standardized datasets and KPIs (cost per return, salvage value recovered, turnaround time, emissions avoided); (2) human-in-the-loop systems and explainability will be essential for trust and regulatory compliance; (3) cold-chain perishables and packaging recovery will be priority domains where AI can materially reduce waste; and (4) MSME-friendly, low-compute solutions and public–private collaboration will determine success in emerging markets like India. To realise these futures, researchers and practitioners should focus on interoperable architectures, realistic benchmarking, policy engagement (EPR design, incentives for returns consolidation), and deployment studies that measure both operational and environmental outcomes. Only then will AI move from promising pilots to ubiquitous, sustainable reverse-logistics capability in FMCG globally.

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