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ICT and digital technologies for last-mile delivery

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Abstract

In agricultural supply chains, the last-mile delivery segment is the last and most important link, having a direct bearing on consumer satisfaction, food security, and farmer incomes. This article explores how the transformative role of digital advances and information and communication technologies (ICT) are revolutionizing agricultural product last-mile delivery systems. This study illustrates how digital solutions are tackling conventional issues like inadequate infrastructure, exorbitant costs, and supply chain inefficiencies through a thorough examination of cutting-edge technologies such as blockchain, artificial intelligence, mobile platforms, and the Internet of Things (IoT). The study provides proof of effective implementations in a range of geographic contexts, emphasizing notable gains in smallholder farmers' market accessibility, cost reduction, and delivery efficiency.

Keywords: Last-mile delivery, ICT, digital agriculture, supply chain management, rural logistics, precision agriculture

Introduction

Last-mile delivery, which accounts for about 28% of overall transportation costs and poses particular difficulties in agricultural contexts, is the last phase of the supply chain where goods are delivered to end users (Mangiaracina et al., 2019). Inefficient last-mile transportation systems cause post-harvest losses that can reach 40% in some areas, which has a direct effect on farmer livelihoods and food security in developing nations where agriculture continues to be a major economic activity.

Unprecedented chances to solve these systemic issues have been made possible by the development of information and communication technologies, or ICT. Digital technologies provide ways to close the divide between metropolitan customers and rural producers while lowering expenses, increasing productivity, and making the supply chain more transparent. For smallholder farmers, who have historically faced obstacles in accessing official markets because of poor infrastructure and scarce resources, this technological revolution is especially important.

A paradigm change from conventional, labor-intensive methods to data-driven, automated solutions is represented by the incorporation of ICT into last-mile delivery systems. The way agricultural products are transported from farm to table has been completely transformed by these technologies, which allow for real-time tracking, predictive analytics, and efficient routing.

Literature review

Oyelami *et al.* (2022) using the panel ARDL technique, examined how ICT infrastructure affects agricultural performance in 39 sub-Saharan African nations. According to their findings, ICT has a long-term positive impact on agricultural output but not a short-term one, suggesting that adoption of new technologies takes time. Internet usage has a negative impact on export performance, indicating underutilization of digital platforms, but mobile subscriptions boost agricultural exports. These findings support the idea that effective agricultural technology adoption requires more than just ICT infrastructure in the absence of farmer education and extension services.

Shah (2022) examines how ICT tools, including as smartphones and online platforms, are revolutionizing Indian agriculture by facilitating better access to weather updates, market data, and professional guidance. These tools decrease information gaps, boost production, and assist farmers in making better decisions. The essay also discusses issues like governmental restrictions, digital literacy hurdles, and poor infrastructure. Notwithstanding these challenges, ICT is seen as a major force behind India's agricultural modernization and rural development, with the ability to advance inclusive growth and food security.

Mulungu, Kassie, and Tschopp (2025) review how ICT-based agricultural extension improves farmer knowledge, adoption of practices, yields, and income. According to the report, videos, SMS, and mobile apps are important resources for providing timely information. Good training, support, and material are essential for success, yet issues like infrastructure and digital gaps

still exist. The analysis highlights potential uses of AI and other technologies in the future to advance agricultural development.

Key ICT Technologies Transforming Last-Mile Delivery

The integration of advanced ICT technologies has significantly enhanced agricultural supply chains revolutionizing last-mile delivery in agriculture by addressing challenges such as fragmentation, lack of transparency, and limited access to information. Key innovations include Artificial intelligence (AI) and machine learning (ML), which optimize routes by analyzing traffic, weather, and delivery locations, forecast demand, predict crop yields, and anticipate supply chain bottlenecks, enabling better planning and reduced costs. It optimizes routes, forecast demand, and manage inventory by analyzing historical data, weather, and market trends, thereby reducing costs, minimizing waste, and improving satisfaction, especially for seasonal crops with fluctuating demand. Internet of Things (IoT) solutions provide real-time tracking of temperature, humidity, and location, support smart warehousing with automated environmental control, and enable GPS/RFID-based asset tracking for enhanced security and product traceability, ensuring cold chain integrity for perishable products like fruits, vegetables, and dairy. GPS tracking provides accurate delivery estimates and proactive delay management, even in rural areas with poor communication infrastructure. Digital platforms and mobile applications empower farmers with direct-to-consumer marketplaces, advisory services, market price updates, and logistics aggregators. Smartphone applications and SMS-based systems, connect farmers directly with consumers, facilitating order management, payments, and communication, ensuring inclusivity for regions with limited internet or smartphone access. Meanwhile, blockchain ensures transparency and trust through immutable ledgers and smart contracts that automate payments upon successful delivery. Together, these technologies are transforming agricultural logistics into a data-driven, integrated system that reduces waste, increases farmer profitability, and strengthens consumer confidence.

Case Studies and Success Stories

Case Study 1: Digital Marketplace Integration in India

One example of effective illustration of ICT integration in agricultural supply chains is the Indian e-NAM (National Agriculture Market) platform. By removing middlemen and guaranteeing fair pricing, this online marketplace links farmers and purchasers directly. The

platform has enabled transactions totaling more than $2 billion since its inception, showcasing the revolutionary potential of digital technologies.

Farmers can upload product details from their fields, such as available quantity and quality requirements, using the platform's mobile application. The technology automatically optimizes delivery routes based on geographic proximity and transportation availability, allowing buyers to access this information in real-time and place orders. Better transaction transparency and more equitable pricing are made possible by this relationship.

Case Study 2: IoT-Enabled Cold Chain Management in Kenya

Using Internet of Things (IoT) technologies to monitor and regulate temperature-sensitive supply chain operations is known to be IoT-enabled cold chain management in Kenya. These IoT-enabled systems are particularly helpful for rural cold storage and transportation in Kenya, where infrastructure and power limitations are prevalent. Farmers can safely keep produce in mobile cold storage units with Internet of Things (IoT) sensors, lowering post-harvest loss and increasing the supply of high-quality products.

IoT sensors were used in a trial project in Kenya to monitor temperature conditions from agricultural collecting points to urban distribution centers along the dairy supply chain. The technology increased delivery dependability while reducing milk spoiling by 18%. Real-time warnings made it possible to react quickly to temperature changes, avoiding product losses and upholding quality standards. Over 10,000 smallholder dairy farmers benefited from the project's extension throughout several counties as a result of its success. Farmers were able to access upscale markets in cities thanks to the increased supply chain dependability, which resulted in a 25% increase in their average pay.

Case Study 3: Drone Delivery Networks in Rwanda

The drone delivery network in Rwanda, which has been in place since 2016 and was started by Zipline, is a groundbreaking example of how cutting-edge technology can solve problems with timely delivery of agricultural inputs, vaccines, and products. Delivering necessary agricultural supplies is severely hampered by Rwanda's steep topography and poor road system, particularly in rural areas. High-value, low-weight agricultural products, such seeds and small-scale fresh food, are currently being tested for delivery to remote locations via drone networks.

This technology is especially beneficial in areas with difficult terrain or inadequate road systems. According to preliminary tests, drone delivery could cut the time it takes to transfer

emergency agricultural supplies by 75%, allowing for a quicker reaction to disease or pest outbreaks. Current research is assessing the technology's potential for scaling to regular agricultural supplies. In conclusion, Rwanda's drone delivery network case study serves as an example of how low-resource environments can be scaled by utilizing autonomous drone technology in a supportive regulatory context.

Challenges and Barriers to Implementation

ICT technologies have a lot of potential, but a number of obstacles prevent their broad use in last-mile delivery systems for agriculture. In remote locations, infrastructure constraints especially unstable internet, cost barriers, digital literacy, localized needs and electrical connectivity present major obstacles. The substantial upfront expenses associated with implementing technology may be unaffordable for small-scale logistics providers and smallholder farmers. For investors and implementers, regulatory frameworks can lag behind technical advancements, causing uncertainty. Interoperability and system integration are restricted by the lack of platform-specific standardization of data formats and communication protocols. Equitable technology adoption requires addressing digital literacy through thorough training and user-friendly design, which will enable farmers to access better market information, boost yields, and promote economic participation. The possibility of acceptance and long-term adoption rises dramatically when these pilots are supported by continuing assistance, peer endorsements, and local advocates who attest to the technology's worth.

Future Opportunities and Recommendations

In agricultural last-mile delivery, integrated, ecosystem-wide solutions that incorporate several technologies for optimal impact are the way of the future. Real-time decision-making and autonomous delivery systems will be made possible by the confluence of 5G networks, edge computing, and artificial intelligence. To ensure that the adoption of technology is sustainable and inclusive, capacity building initiatives should concentrate on fostering digital literacy among farmers and rural communities. To be as effective as possible, these programs should be presented in the local languages and be culturally relevant. It is necessary to update policy frameworks to take into account new technology while maintaining consumer protection and food safety. Before implementing creative ideas on a large scale, regulatory sandboxes might offer secure settings for testing.

Economic Impact and Sustainability

Beyond the obvious cost savings, there are additional systemic advantages to ICT integration in last-mile delivery. Farmers may obtain fair pricing for their goods thanks to improved market access, which lowers rural poverty and fosters economic growth. Decreased post-harvest losses minimize waste's negative environmental effects while also promoting food security. The ability of digital solutions to function commercially while providing social and environmental advantages is what determines their sustainability. Long-term success is more likely for business strategies that fairly divide costs and rewards among stakeholders.

Conclusion

In agricultural last-mile delivery, ICT and digital technologies are a game-changer, providing answers to enduring problems and opening up fresh avenues for economic growth. Evidence from successful implementations shows that smallholder farmers' efficiency, cost-effectiveness, and market access have significantly improved. However, in order to fully utilize these technologies, concerted efforts are needed to increase digital capacity, address infrastructure constraints, and establish favorable regulatory frameworks. Inclusive techniques that guarantee benefits reach all stakeholders, especially smallholder farmers who are the backbone of agricultural output in many developing economies, are essential to the future viability of digital agricultural supply chains. In the end, more resilient, effective, and sustainable food systems that benefit producers, consumers, and society at large will be created as these technologies develop further and are more intricately integrated into agricultural supply chains.

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