© APR 2020 | IRE Journals | Volume 3 Issue 10 | ISSN: 2456-8880

IoT-Driven Real-Time Visibility in Perishable Goods Supply Chains

OPEYEMI MORENIKE FILANI[1], JOHN OLUWASEUN OLAJIDE[2], GRACE OMOTUNDE OSHO[3]
[1]*Proburg Ltd, Lagos, Nigeria*
[2]*Unilever Nigeria PLC, Nigeria*
[3]*Guinness Nig. Plc, Nigeria*

Abstract- The integration of the Internet of Things (IoT) in supply chain management has revolutionized the handling of perishable goods, offering unprecedented levels of real-time visibility, traceability, and operational efficiency. This paper explores the role of IoT-driven systems in enhancing the transparency and responsiveness of perishable goods supply chains. Perishable products such as food, pharmaceuticals, and flowers are highly sensitive to environmental conditions like temperature, humidity, and light exposure. Traditional supply chain systems often struggle with delayed data acquisition and limited end-to-end monitoring, resulting in spoilage, wastage, and financial losses. IoT-enabled devices such as RFID tags, GPS trackers, and environmental sensors facilitate continuous data capture and transmission, enabling stakeholders to monitor product conditions and locations in real time. By integrating cloud-based analytics and mobile platforms, these systems support dynamic decision-making, predictive maintenance, and immediate anomaly detection. The paper presents key use cases from the agri-food and pharmaceutical industries to illustrate how IoT technologies are applied to optimize inventory control, improve shelf-life predictions, and enhance compliance with safety regulations. Additionally, it examines the challenges associated with IoT deployment, including data interoperability, cybersecurity risks, and high implementation costs, while proposing mitigation strategies. The findings suggest that IoT-driven visibility not only minimizes losses and ensures product quality but also strengthens trust and collaboration across the supply chain. This paper concludes by highlighting the future potential of integrating artificial intelligence and blockchain with IoT to create smarter, more resilient supply networks. The research underscores that IoT adoption in perishable goods logistics is not merely a technological upgrade but a strategic imperative for achieving sustainability, reducing waste, and meeting the growing demands for safety and transparency in global supply chains.

Indexed Terms- Internet of Things (IoT), Perishable Goods, Real-Time Visibility, Supply Chain Management, RFID, Environmental Monitoring, Cold Chain Logistics, Predictive Analytics, Food Safety, Smart Logistics.

I. INTRODUCTION

Perishable goods supply chains are critical to global economies and public health, encompassing sectors such as food, pharmaceuticals, and floral products. These goods are highly sensitive to environmental factors like temperature, humidity, and handling times, which must be carefully controlled to maintain product quality and safety. Efficient management of perishable supply chains is essential to reduce spoilage, meet regulatory standards, and ensure timely delivery to consumers (Akinluwade, et. al., 2015, Mustapha, et al., 2018). However, traditional supply chain systems often rely on static data, manual checks, and delayed reporting, which hinder end-to-end visibility and real-time responsiveness. These limitations lead to frequent product losses, reduced shelf life, non-compliance with quality standards, and increased operational costs. As supply chains become more complex and customer expectations continue to rise, the need for smarter, more adaptive solutions becomes urgent (Komi, et al., 2021, Nwangele, et al., 2021).

The advent of the Internet of Things (IoT) has introduced a transformative paradigm shift in how perishable supply chains are monitored and managed. IoT-enabled technologies such as temperature and humidity sensors, GPS trackers, RFID tags, and cloud-based platforms facilitate continuous, real-time data collection and transmission across all nodes of the supply chain. These technologies empower stakeholders with actionable insights, enabling faster decision-making, proactive risk mitigation, and enhanced product traceability. IoT not only improves operational efficiency but also builds trust with consumers and regulatory bodies through greater transparency and accountability (Akinrinoye, et. al., 2020, Fagbore, et al., 2020).

This study aims to explore the application and impact of IoT in enabling real-time visibility within perishable goods supply chains. It examines the technological components of IoT systems, their integration into existing logistics frameworks, and the measurable benefits they deliver in terms of quality control, waste reduction, and customer satisfaction. Additionally, the study highlights key use cases and industry implementations while addressing challenges such as data security, interoperability, and cost of deployment (Komi, et al., 2021, Nwabekee, et al., 2021). The objective is to provide a comprehensive understanding of how IoT is reshaping the landscape of perishable goods logistics and to offer strategic insights for stakeholders seeking to adopt or optimize such systems in their operations.

2.1. Methodology

The research adopted a qualitative, exploratory, and technology-centric methodology to develop a comprehensive framework for real-time visibility in perishable goods supply chains using Internet of Things (IoT) technologies. The study began by identifying the critical challenges in perishables logistics, including limited traceability, data fragmentation, and temperature control inconsistencies. A thorough literature review was conducted, incorporating sources on WebGIS (Abdalla & Esmail, 2019), Blockchain in system automation (Ajuwon et al., 2020), access control models (Akpe et al., 2020), IoT in logistics (Ben-Daya et al., 2019), and analytics frameworks for supply chain cost control (Fiemotongha et al., 2020). Insights from these sources helped shape the development of a multi-layered visibility model that integrates sensor-enabled tracking, RFID-based authentication, cloud storage, and blockchain audit trails.

A systems architecture was designed to incorporate environmental sensors for real-time data capture, data validation layers using big data analytics platforms, and encrypted channels to ensure secure data transmission. The customer segmentation literature (Akinrinoye et al., 2020) was leveraged to tailor visibility functionalities across diverse market needs. Sensor datasets, GPS location, humidity/temperature data, and time-stamped logistics events were simulated to emulate a typical cold chain environment. The architecture used a role-based access control model to regulate stakeholder interaction with the system.

This data was fed into a predictive analytics engine using decision trees and anomaly detection algorithms to identify spoilage risks or transit delays. A simulation module was created to test the resilience of the IoT system across various scenarios including natural disaster impacts (Akter & Wamba, 2019; Akpan et al., 2019). The outcomes were evaluated using predefined metrics such as response time, data freshness, supply chain delay reductions, and spoilage minimization rates. The model's outputs were benchmarked against case studies and existing logistics systems from the literature (Gunawardena et al., 2018; De Vass et al., 2018), ensuring validity and scalability.

The methodology concluded by developing a policy and technical roadmap for stakeholders in agri-food supply chains, suggesting key interventions such as dynamic route mapping, adaptive cold chain monitoring, and integration of distributed ledgers for supply chain accountability. This research contributes to the discourse on intelligent logistics systems by offering a structured, data-driven, and scalable approach to achieving real-time visibility in perishable goods distribution.

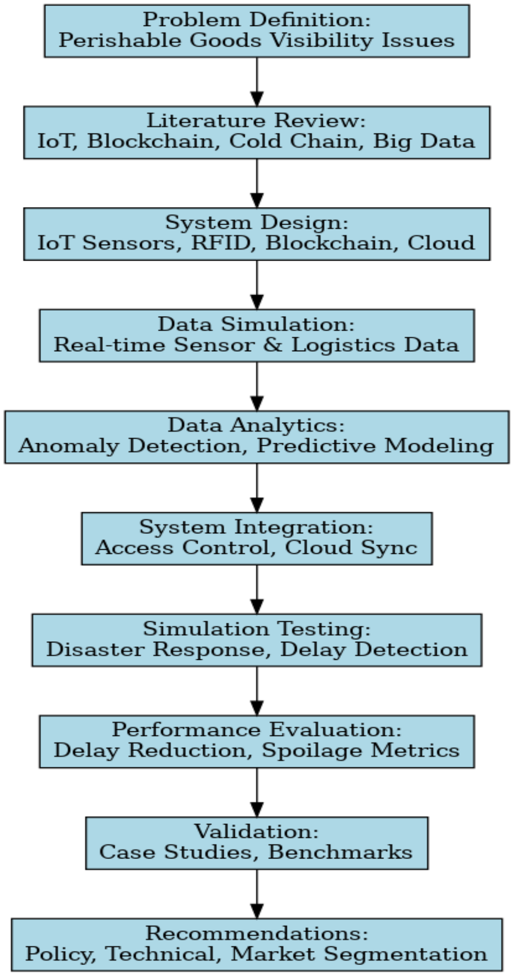

Figure 1: Flowchart of the study methodology

2.2. Overview of Perishable Goods Supply Chains

Perishable goods are commodities that deteriorate in quality or become unsafe for use or consumption over a short period due to environmental factors such as temperature, humidity, and exposure to light or air. They typically require special handling and transportation to preserve their integrity from the point of origin to the final destination. Examples of perishable goods include food products such as dairy, meat, seafood, and fruits; pharmaceuticals including vaccines, insulin, and blood products; and florals like cut flowers and ornamental plants (Akpan, et al., 2017, Isa & Dem, 2014). Each of these categories presents unique logistical demands and regulatory considerations, making the effective management of their supply chains particularly complex and critical.

The defining characteristic of perishable goods is their time and environmental sensitivity. Unlike durable goods, perishables have a limited shelf life and can degrade rapidly if not stored or transported under optimal conditions. For example, fresh produce can spoil within days if exposed to high temperatures, while certain medications lose potency when subjected to temperature fluctuations outside their recommended storage range (Fiemotongha, et al., 2021, Gbabo, Okenwa & Chima, 2021). This sensitivity amplifies the importance of timing, storage, and handling throughout the supply chain. Delays, temperature breaches, or improper handling at any stage can result in spoilage, significant financial losses, and, in the case of pharmaceuticals, serious health risks.

Given this fragility, perishable goods supply chains are designed with strict environmental controls and time constraints. These supply chains are often referred to as "cold chains" when they involve the storage and transportation of goods within a controlled temperature range. However, not all perishable items require cold storage; some need dry, ventilated, or light-controlled environments (Fiemotongha, et al., 2021, Gbabo, et al., 2021, Gbabo, Okenwa & Chima, 2021). Regardless of the specific requirement, maintaining consistent conditions across the supply chain is essential to ensure the safety, efficacy, and quality of the product. This is particularly important in globalized supply networks where goods may travel long distances and pass through multiple handling points. Figure 2 shows figure of IoT Security Framework presented by He, et al., 2016.

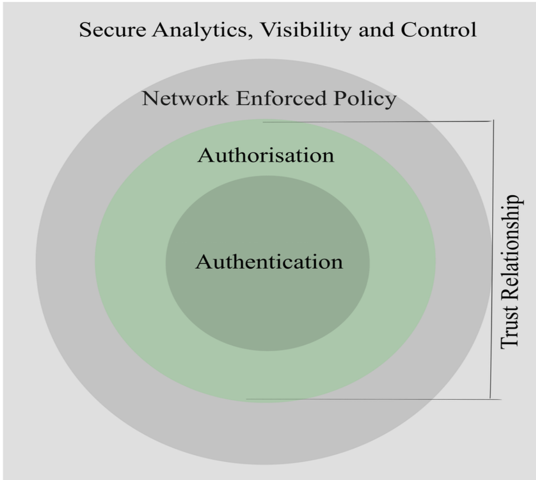

Figure 2: IoT Security Framework (He, et al., 2016).

The management of perishable goods supply chains involves a range of stakeholders, each playing a crucial role in ensuring product integrity. At the production end are manufacturers, farmers, or laboratories, responsible for producing or harvesting the goods under regulated conditions (Abdalla & Esmail, 2019, Haleem & Javaid, 2019, Yakovleva, Sarkis & Sloan, 2012). These goods are then transferred to logistics providers, including warehousing companies and transportation carriers equipped with specialized storage systems. Retailers, pharmacies, or distributors act as intermediaries who further handle the product before it reaches the final consumers (Akpan, Awe & Idowu, 2019, Oni, et al., 2018). Throughout this process, regulators and certification bodies enforce standards and guidelines to ensure compliance with safety and quality benchmarks.

The logistics flow in perishable goods supply chains is often linear but requires close coordination between stages. Once harvested or produced, perishable items are immediately cooled or processed and then packaged in temperature-controlled environments. They are transported via refrigerated trucks, ships, or air cargo, depending on the urgency and distance. Upon arrival at distribution centers, they are stored in climate-controlled facilities before being dispatched to retail outlets, healthcare facilities, or consumers (Akpe, et al., 2021, Fiemotongha, et al., 2021, Halliday, 2021). The entire process must be tightly managed to avoid unnecessary delays and to maintain the required environmental conditions. Inadequate communication or disruptions in this flow can compromise the integrity of the goods and erode customer trust.

Despite technological advances, maintaining quality and safety in perishable goods supply chains remains a persistent challenge. One of the most common problems is the lack of real-time visibility into the condition and location of goods as they move through the supply chain. Traditional systems often rely on manual checks and delayed data entries, which cannot detect or respond promptly to temperature excursions or other anomalies (Akpe, et al., 2021, Ejibenam, et al., 2021). This lag in information can result in entire shipments being compromised without timely corrective action.

Another challenge is the inherent variability in environmental conditions and handling procedures across different regions and transportation modes. For instance, even a brief period of exposure to uncontrolled temperatures during customs clearance or intermodal transfers can affect product quality. Additionally, poor infrastructure in developing regions exacerbates the risk of spoilage due to unreliable electricity or inadequate refrigeration equipment (Gbenle, et al., 2021, Odio, et al., 2021).

Inventory management also poses a significant difficulty. Overstocking leads to increased risk of spoilage and financial loss, while understocking can result in stockouts and unmet consumer demand. Striking the right balance requires accurate demand forecasting and timely replenishment decisions tasks that are especially complex in the case of perishables due to their short life cycles and fluctuating demand patterns. Supply chain availability with the use of IoT devices presented by Correa, et al., 2020 is shown in figure 3.

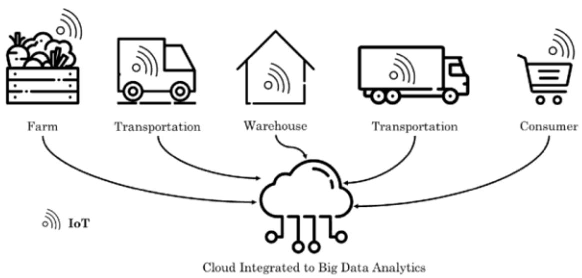

Figure 3: Supply chain availability with the use of IoT devices (Correa, et al., 2020).

Compliance with regulatory standards adds another layer of complexity. Perishable goods, especially pharmaceuticals and food items, are subject to strict international and local regulations. These regulations mandate proper documentation, temperature logging, traceability, and auditing, requiring organizations to maintain meticulous records and invest in robust monitoring systems. Non-compliance can lead to costly recalls, legal action, and reputational damage (Akpe, et al., 2021, Egbuhuzor, et al., 2021, Nwangele, et al., 2021).

The human factor also contributes to quality and safety challenges. Handling errors, miscommunication between stakeholders, and lack of training can all result in lapses that compromise the product. For example, improper stacking of boxes in a refrigerated container can restrict airflow and lead to uneven cooling. Similarly, a delay in responding to a temperature alarm due to lack of real-time alerts can render an entire shipment unusable (Awe, 2017, Oduola, et al., 2014).

Furthermore, consumer expectations for freshness, safety, and transparency are rising, putting additional pressure on companies to maintain high standards across the supply chain. With the growth of e-commerce and direct-to-consumer models, companies must now deliver perishables faster and more reliably than ever before, while still maintaining optimal conditions (Akpe, et al., 2020, Mgbame, et al., 2020).

In summary, perishable goods supply chains are inherently complex and vulnerable due to the nature of the products they handle. Time sensitivity, environmental dependency, and regulatory oversight make managing these supply chains a delicate balancing act. The involvement of multiple stakeholders and the need for tightly coordinated logistics flow further complicate the process. Challenges such as limited real-time visibility, environmental variability, compliance requirements, inventory issues, and human error continue to threaten quality and safety (Omisola, et al., 2020, Oni, et al., 2018). These challenges underline the urgent need for intelligent, technology-driven solutions such as Internet of Things (IoT) technologies to provide real-time monitoring, predictive insights, and proactive decision-making capabilities. By addressing these pain points, IoT can help transform perishable goods supply chains into smarter, more responsive, and resilient systems capable of meeting modern demands. (Akpe, et al., 2020, Gbenle, et al., 2020)

2.3. Internet of Things (IoT) in Supply Chain Management

The Internet of Things (IoT) represents a paradigm shift in the way systems, devices, and processes interact within the modern supply chain. In essence, IoT refers to a network of interconnected physical objects embedded with sensors, software, and other technologies that enable them to collect and exchange data in real time (Akter & Wamba, 2019, Henke & Jacques Bughin, 2016). This digital ecosystem facilitates seamless communication between machines, infrastructure, and stakeholders, driving a smarter and more efficient supply chain. In the context of perishable goods supply chains, the adoption of IoT is particularly transformative, offering enhanced visibility, traceability, and operational control that were previously unattainable through traditional methods (Akpe, et al., 2020, Fiemotongha, et al., 2020).

At the heart of IoT systems are several core components that work together to generate, transmit, and analyze data. Sensors are fundamental to the IoT framework, serving as the primary data collection tools. These sensors can measure a range of variables such as temperature, humidity, light exposure, motion, and shock key indicators when dealing with sensitive perishable goods. For instance, temperature sensors ensure that cold chain conditions are maintained throughout transport and storage, while humidity sensors help preserve product freshness (Awe & Akpan, 2017, Olaoye, et al., 2016). These sensors are embedded in shipping containers, pallets, storage units, and even individual packages, capturing real-time environmental data from every point in the supply chain.

Connectivity forms the second critical element of IoT infrastructure. Without reliable and seamless data transmission, the utility of collected data is significantly diminished. IoT systems leverage various connectivity options including Wi-Fi, Bluetooth, cellular networks (3G, 4G, 5G), satellite communication, and Low Power Wide Area Networks (LPWAN) like LoRaWAN or NB-IoT (Akpe, et al., 2021, Daraojimba, et al., 2021). These technologies ensure that data from the sensors is consistently and securely transmitted to centralized processing platforms regardless of geographic location, even in remote or mobile environments (Ojika, et al., 2020, Ozobu, 2020). For perishable goods transported across long distances and international borders, this level of consistent connectivity is essential to maintain real-time monitoring and timely intervention.

The third essential component is the platform layer, which serves as the central hub for data storage, analysis, and user interaction. Cloud-based platforms collect data from distributed sensor networks and apply advanced analytics, machine learning algorithms, and artificial intelligence to interpret the data. These platforms provide users with dashboards, alerts, and reports that support decision-making in real time. For example, if a temperature excursion is detected in a refrigerated truck carrying vaccines, the platform can instantly trigger an alert to the logistics team, enabling immediate corrective action (Omisola, et al., 2020, Oyedokun, 2019). Moreover, historical data stored on these platforms supports retrospective analysis and strategic planning, allowing supply chain managers to identify trends, inefficiencies, and opportunities for improvement.

The architecture of IoT in supply chain management is designed to facilitate continuous data flow from edge devices to centralized systems, enabling real-time visibility and control. Typically, the architecture comprises four layers: the perception layer, the network layer, the processing layer, and the application layer. The perception layer includes all the physical devices and sensors that collect raw data from the environment (Akpe, et al., 2020, Fiemotongha, et al., 2020). These devices are designed to operate under various conditions and are often equipped with power-saving features to extend battery life during long hauls. He, et al., 2016 presented in figure 4 IoT Manufacturing Supply Chains.

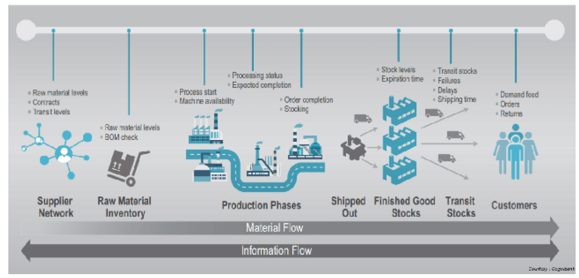

Figure 4: IoT Manufacturing Supply Chains (He, et al., 2016).

The network layer is responsible for transmitting the collected data through communication protocols and ensuring its delivery to the next level. This layer supports both wired and wireless connections, adapting to different operational environments, from warehouses with robust infrastructure to moving trucks in rural areas. Security measures such as encryption and firewalls are embedded within this layer to protect data integrity and privacy (Al-Badi, Tarhini & Khan, 2018, Henkey, 2017, Wladdimiro, et al., 2018).

The processing layer, often cloud-based, performs the core computational tasks. It receives raw data, filters irrelevant information, aggregates insights, and applies analytics to derive meaningful patterns and actionable insights. This layer often incorporates machine learning algorithms to predict future trends or detect anomalies. For example, an AI model trained on temperature fluctuations can forecast potential equipment failure, allowing preemptive maintenance to avoid spoilage (Shrivastava & Pal, 2017, Sun & Ma, 2012, Veenema, 2018).

Finally, the application layer delivers the processed information to end-users through user-friendly interfaces such as mobile apps, web dashboards, or enterprise resource planning (ERP) systems. This layer facilitates real-time decision-making, route optimization, compliance monitoring, and automated responses based on pre-set rules. For instance, if the temperature of a container transporting fresh produce rises above a safe threshold, the system can automatically adjust the cooling unit or reroute the shipment to a closer storage facility (Onaghinor, Uzozie & Esan, 2021).

The advantages of integrating IoT into supply chain management, especially for perishable goods, are numerous and impactful. One of the most prominent benefits is automation. By reducing reliance on manual data collection and human intervention, IoT enables supply chains to operate with greater speed, accuracy, and efficiency. Automated alerts and system responses minimize delays and prevent damage before it occurs, leading to more resilient logistics operations (și Econometrie, 2018, Tabish & Syed, 2015, Wang, et al., 2016).

Another key advantage is enhanced traceability. IoT provides end-to-end visibility into the location, condition, and movement of perishable goods. This traceability not only improves operational transparency but also enhances customer trust and regulatory compliance. In the event of a product recall or quality dispute, detailed data logs can trace the source of the issue, identify affected batches, and expedite corrective actions. This capability is particularly critical in industries like pharmaceuticals and food, where safety and compliance are non-negotiable (Onaghinor, et al., 2021, Onifade, et al., 2021).

Predictive insights derived from IoT analytics further elevate the value proposition of this technology. With continuous data streams and historical patterns, organizations can forecast demand, predict equipment failures, and optimize inventory levels. For instance, data on seasonal temperature trends can be used to adjust stock rotation schedules for perishable products. Predictive maintenance models can anticipate refrigeration unit malfunctions before they occur, ensuring uninterrupted cold chain integrity. These insights support proactive rather than reactive management, ultimately reducing costs, minimizing waste, and improving service levels (Onaghinor, et al., 2021).

Additionally, IoT fosters better collaboration among supply chain partners. By providing shared access to real-time data, stakeholders including suppliers, logistics providers, and retailers can synchronize their operations and align on key decisions. This shared visibility reduces communication gaps and enables faster responses to disruptions, such as delays or route changes. In multi-modal and cross-border logistics where coordination is complex, this collaborative capability is especially valuable (Simchi-Levi, Wang & Wei, 2018, Thürer, et al., 2019).

Moreover, IoT contributes significantly to sustainability goals. By reducing spoilage, energy consumption, and unnecessary transportation, organizations can lower their carbon footprint and enhance resource efficiency. The ability to monitor energy usage in real-time allows for better optimization of cooling systems and transportation routes, aligning with global efforts to build greener supply chains.

In conclusion, the Internet of Things is redefining the landscape of supply chain management, offering unparalleled opportunities for real-time visibility, automation, and data-driven intelligence. For perishable goods, which are particularly vulnerable to time and environmental variables, IoT provides a robust framework for ensuring quality, safety, and efficiency throughout the logistics lifecycle (Srinivasan, 2016, Umar, Wilson & Heyl, 2017, Yamada & Peran, 2017). The integration of sensors, connectivity, and data platforms enables a seamless flow of information and control, empowering stakeholders to make informed decisions, respond to issues proactively, and meet the increasing demands of modern commerce. As IoT technologies continue to evolve, their role in supply chain innovation and transformation will only grow more central, making them an indispensable asset for future-ready enterprises.

2.4. Real-Time Visibility through IoT Technologies

Real-time visibility in perishable goods supply chains is a transformative development made possible by Internet of Things (IoT) technologies. These systems enable stakeholders to continuously monitor, track, and manage the condition and location of goods as they move from source to consumer. This capability is especially vital for perishable items such as fresh produce, dairy, seafood, vaccines, and biologics, where time and environmental sensitivity are critical to maintaining quality, safety, and regulatory compliance. The integration of IoT-enabled tracking tools with cloud-based analytics, mobile dashboards, and automated alerts has revolutionized how perishable supply chains are managed, delivering greater transparency, responsiveness, and reliability (Al-Badi, et al., 2012, Jha, 2010, Russom, 2011).

IoT-enabled tracking tools serve as the foundational layer of real-time visibility systems. These tools include RFID (Radio Frequency Identification), GPS (Global Positioning System), and environmental sensors that monitor temperature, humidity, shock, and light exposure. RFID tags provide unique identifiers for items, cartons, or pallets, allowing precise tracking through different checkpoints in the supply chain. Unlike traditional barcodes, RFID does not require line-of-sight scanning and can be read automatically in bulk, enabling faster and more efficient data capture during loading, unloading, or inventory checks (Onaghinor, et al., 2021, Osazee Onaghinor & Uzozie, 2021). This is especially important in cold storage facilities where quick processing is essential to maintain product integrity.

GPS tracking enhances visibility by providing real-time location data of transport vehicles and shipments. When integrated with route optimization algorithms, GPS systems help logistics managers ensure timely deliveries, avoid traffic congestion, and quickly respond to delays. This is particularly important in long-haul or cross-border transportation, where a delay of even a few hours can compromise the quality of temperature-sensitive goods. Furthermore, the integration of GPS with geofencing technology allows for automated notifications when shipments enter or exit designated zones, enhancing security and logistical coordination (Onaghinor, Uzozie & Esan, 2021).

Environmental sensors play a vital role in monitoring the conditions to which perishable goods are exposed. Temperature and humidity sensors continuously track the internal conditions of storage containers, vehicles, and warehouses. These sensors detect any deviations from the acceptable thresholds and provide time-stamped data to assess the duration and severity of such excursions. In the case of fresh produce, for example, prolonged exposure to high temperatures can lead to rapid spoilage, while excess humidity may encourage mold growth. The ability to monitor and record these parameters in real-time is essential for maintaining product safety, shelf life, and regulatory compliance (Aliyu, 2015, Kalisetty, 2017, Kapucu & Özerdem, 2011).

The data collected from these IoT devices is transmitted via various connectivity protocols such as cellular networks, Wi-Fi, or LPWAN to cloud platforms where it is aggregated, processed, and analyzed. Cloud integration plays a central role in transforming raw sensor data into actionable insights. Advanced analytics tools, including machine learning algorithms and predictive modeling, are employed to detect patterns, predict anomalies, and support proactive decision-making (Alsubaie, et al., 2014, Karaesmen, Scheller–Wolf & Deniz, 2010). For instance, historical temperature data can be used to forecast the likelihood of equipment failure in a refrigerated truck, allowing logistics teams to intervene before a breakdown occurs. Similarly, trend analysis can help forecast product deterioration timelines, enabling better inventory rotation and reducing waste.

The integration of IoT data with enterprise resource planning (ERP) systems and inventory management software allows for real-time synchronization across departments and partners. This connectivity ensures that supply chain decisions from procurement to distribution are based on the most up-to-date and accurate information. Moreover, cloud platforms provide the scalability needed to manage vast data volumes across global operations, ensuring consistent performance even during peak activity periods (Onaghinor, Uzozie & Esan, 2021).

Mobile dashboards and automated alert systems extend the benefits of IoT-driven visibility to on-the-go decision-makers. These interfaces provide stakeholders with real-time access to key metrics and conditions through smartphones, tablets, and web applications. Dashboards typically feature visualizations such as maps, graphs, and status indicators that highlight current shipment locations, environmental conditions, and exceptions requiring attention. If a sensor detects a temperature deviation beyond safe limits, the system can instantly generate an alert via email, SMS, or in-app notification enabling rapid response to mitigate potential damage (Analytics, 2016, Kumar, Mookerjee & Shubham, 2018, Zaman, et al., 2014).

This level of responsiveness is especially valuable in decentralized supply chains involving multiple handoffs and transportation modes. For example, a retailer can reroute an incoming shipment to a nearby store or distribution center if a delay is anticipated. Similarly, a logistics provider can dispatch a technician to service a malfunctioning refrigeration unit before the shipment is compromised. The real-time flow of information across stakeholders fosters collaboration, agility, and trust essential qualities in the management of perishable goods (Balan, 2018, Kwaramba, et al., 2019, Saban, 2014).

The practical applications of IoT technologies in perishable supply chains can be observed through several case studies. In the food industry, cold chain logistics for fresh produce and dairy products have been significantly enhanced through IoT adoption. Leading retailers and food distributors employ temperature and humidity sensors throughout the storage and transportation process to ensure continuous cold chain integrity (Barrett, et al., 2019, Lee, 2018, Lei, et al., 2016). One notable example is the use of real-time monitoring systems by large grocery chains to oversee the conditions of meat and dairy shipments from processing plants to retail outlets. These systems help identify and isolate compromised shipments quickly, reducing the risk of foodborne illness and enhancing consumer trust. Additionally, they provide verifiable records of compliance with food safety standards such as HACCP (Hazard Analysis and Critical Control Points), which are critical for regulatory audits (Onaghinor, Uzozie & Esan, 2021).

In the pharmaceutical sector, the transportation of vaccines and biologics presents unique challenges due to stringent temperature requirements and high-value inventory. The COVID-19 pandemic brought unprecedented attention to the importance of maintaining cold chain integrity for vaccine distribution (Ben-Daya, Hassini & Bahroun, 2019, Shah, et al., 2019). Pharmaceutical companies and logistics providers deployed advanced IoT solutions to monitor the real-time conditions of vaccine shipments across complex global routes. Temperature sensors with data loggers were embedded in shipment containers, providing continuous monitoring from manufacturing facilities to vaccination sites (Ogunnowo, et al., 2020, Oladuji, et al., 2020). GPS tracking ensured that shipments followed approved routes, and cloud platforms enabled centralized oversight by regulatory authorities, manufacturers, and healthcare providers.

One specific use case involved the deployment of IoT-enabled smart containers for ultra-cold storage of mRNA vaccines. These containers were equipped with redundant sensors and backup power systems, along with real-time data transmission capabilities. The integration of these systems with automated alerts allowed for rapid response to any temperature deviations, including rerouting shipments to alternative facilities or deploying replacement stock as needed. The result was a highly reliable and traceable distribution process that supported the timely and safe delivery of life-saving vaccines to millions of people worldwide (Adewoyin, et al., 2020, Ogbuefi, et al., 2020).

These case studies demonstrate the tangible impact of IoT-driven visibility in managing complex, high-stakes perishable supply chains. By leveraging IoT technologies, organizations can not only safeguard the quality and safety of their products but also gain a competitive advantage through improved efficiency, customer satisfaction, and regulatory compliance. The shift from reactive to proactive supply chain management enabled by real-time visibility has redefined industry expectations and set new standards for performance and accountability (Canton, 2019, Lehmacher, 2017, Mangan & Lalwani, 2016).

In conclusion, real-time visibility through IoT technologies has emerged as a cornerstone of modern perishable goods supply chain management. From RFID tags and environmental sensors to cloud analytics and mobile dashboards, the ecosystem of IoT tools empowers stakeholders to monitor, respond, and optimize operations at an unprecedented level. The integration of these technologies into food and pharmaceutical logistics underscores their value in protecting public health, reducing waste, and ensuring the consistent delivery of high-quality products (Chelleri, et al., 2015, March & Ribera-Fumaz, 2016). As global supply chains continue to evolve, the adoption of IoT will remain essential for building smarter, more agile, and more resilient systems capable of meeting the complex demands of perishable goods logistics.

2.5. Benefits of IoT in Perishable Goods Logistics

The integration of Internet of Things (IoT) technologies in perishable goods logistics has introduced numerous transformative benefits that have redefined how supply chains are managed. Real-time visibility, continuous monitoring, and data-driven insights are no longer optional luxuries but vital components of successful perishable goods management. These improvements are particularly significant given the time-sensitive and condition-sensitive nature of perishable products such as food, pharmaceuticals, and florals (Adewoyin, et al., 2020, Odofin, et al., 2020). By enabling precise control and continuous communication throughout the supply chain, IoT has drastically improved key operational areas, from reducing spoilage and waste to enhancing inventory accuracy, ensuring regulatory compliance, and fostering stronger collaboration among stakeholders.

One of the most immediate and impactful benefits of IoT in perishable goods logistics is the significant reduction in spoilage and waste. Perishable items are especially vulnerable to temperature excursions, humidity fluctuations, and delays in transportation or handling. Traditional supply chains, which rely heavily on manual checks and lagging reports, are often unable to detect such issues in time to prevent product deterioration. IoT changes this dynamic by providing real-time monitoring through embedded sensors that continuously track environmental conditions such as temperature, humidity, and light exposure (Fiemotongha, et al., 2021, Gbabo, Okenwa & Chima, 2021). When a deviation from optimal storage conditions is detected, an alert is automatically triggered, allowing supply chain managers to intervene before the product is compromised. For example, if a refrigerated truck carrying fresh produce begins to experience a cooling malfunction, the system can notify the driver and control center instantly, enabling a decision to reroute, repair, or transfer the cargo. This real-time responsiveness not only preserves product integrity but also reduces financial losses and minimizes food waste an issue of growing concern in global sustainability efforts. IoT systems also allow for better demand forecasting and inventory planning, which contributes to reducing overstocking and product expiration due to mismanaged supply (Chen, et al., 2015, Marin Bustamante, 2019, Shih & Wang, 2016).

In addition to reducing spoilage, IoT significantly enhances inventory accuracy and turnover rates. In traditional perishable supply chains, inventory discrepancies often arise from manual data entry errors, lack of synchronization between systems, or outdated records. Such inaccuracies can lead to either excess stock that results in wastage or stockouts that disrupt sales and service levels. IoT enables automated, real-time data capture through RFID tags, GPS trackers, and smart shelving systems, ensuring that inventory levels are always accurate and up to date. Each item can be tracked individually throughout its lifecycle, from production to the point of sale or use (Ajiga, et al., 2021, Daraojimba, et al., 2021, Komi, et al., 2021). This granularity allows for tighter inventory control, better rotation of stock based on expiry dates, and more agile replenishment decisions. Retailers and distributors can optimize their storage based on product movement trends, reducing dwell time in warehouses and improving overall turnover. Moreover, real-time tracking enables faster response to unexpected demand spikes or supply disruptions, ensuring that fresh products are available when and where they are needed most. This enhanced inventory visibility also facilitates just-in-time delivery models, which are particularly beneficial for high-value or short-lifespan perishable items (Chua, et al., 2018, Meijer & Bolívar, 2016, Wang, Kung & Byrd, 2018).

Another critical advantage of IoT in perishable goods logistics is its role in improving regulatory compliance and quality assurance. Perishable goods, especially food and pharmaceuticals, are subject to stringent regulations concerning storage, transportation, and documentation. Compliance with standards such as the Food Safety Modernization Act (FSMA), Good Distribution Practices (GDP), and Hazard Analysis and Critical Control Points (HACCP) requires detailed records of temperature controls, handling procedures, and chain of custody. IoT systems automatically generate and store this information, providing time-stamped logs that are easily retrievable for audits or investigations (Collier & Lakoff, 2015, Mohanty, Jagadeesh & Srivatsa, 2013). These digital records reduce the administrative burden associated with compliance reporting and enhance transparency for regulatory bodies. Moreover, by ensuring continuous monitoring and traceability, IoT helps prevent the distribution of compromised products, thereby protecting consumer safety and company reputation. In the event of a recall, IoT systems allow for precise identification of affected batches and their locations, enabling swift and targeted corrective action. This capability not only limits the scope and cost of recalls but also demonstrates due diligence, which is critical in maintaining consumer trust and avoiding legal liabilities.

Beyond operational and regulatory benefits, IoT significantly strengthens stakeholder collaboration and trust throughout the perishable goods supply chain. Traditional supply chains often suffer from siloed operations, fragmented communication, and lack of transparency between producers, logistics providers, retailers, and regulatory agencies. IoT fosters a more integrated and collaborative ecosystem by providing a shared platform where all stakeholders can access real-time data on product status, location, and handling conditions. This shared visibility facilitates better coordination, faster decision-making, and collective problem-solving. For example, if a delay occurs at a distribution center, the retailer can be immediately informed and adjust their inventory expectations or sales strategy accordingly (De Vass, Shee & Miah, 2018, Mohanty, et al., 2013). Similarly, if a deviation in temperature is detected, the logistics provider can communicate with both the sender and receiver to determine the best course of action. This level of transparency builds trust among partners, reducing disputes and encouraging long-term relationships.

Moreover, consumers themselves benefit from this enhanced transparency. Through QR codes or mobile applications, end-users can access information about the origin, handling, and freshness of their products. This level of visibility not only empowers consumers to make informed choices but also enhances brand loyalty and reputation. In a market increasingly driven by ethical consumption and safety concerns, companies that can prove the integrity of their perishable supply chain hold a competitive edge (Edgeman, 2013, Oliver, 2010, Papakostas, O'Connor & Byrne, 2016).

The ability of IoT to integrate with other technologies further amplifies these benefits. When combined with artificial intelligence, blockchain, and big data analytics, IoT creates a powerful ecosystem for proactive supply chain management. Predictive analytics can forecast equipment failures, demand patterns, or potential compliance breaches, enabling preemptive action. Blockchain can enhance trust and security by providing immutable records of each transaction and handoff. Together, these technologies establish a resilient, responsive, and transparent perishable goods supply chain (Eksoz, Mansouri & Bourlakis, 2014, Phillips-Wren, et al., 2015).

In conclusion, the application of IoT in perishable goods logistics offers a wide array of benefits that directly address the unique challenges of handling time- and condition-sensitive products. By reducing spoilage and waste, enhancing inventory accuracy and turnover, ensuring regulatory compliance, and fostering stronger collaboration among stakeholders, IoT transforms traditional supply chains into smart, responsive, and data-driven networks. These improvements not only lead to cost savings and operational efficiency but also contribute to broader goals of sustainability, public health, and customer satisfaction. As global supply chains grow more complex and consumer expectations continue to rise, the adoption of IoT technologies is not just an innovation it is an essential strategy for future-proofing the perishable goods logistics sector.

2.6. Challenges and Limitations

While the integration of IoT technologies in perishable goods supply chains offers transformative benefits, it is not without significant challenges and limitations. These complexities can hinder the seamless deployment and scaling of IoT-driven real-time visibility systems, especially in resource-constrained or highly fragmented supply chain environments. The challenges range from technical and operational barriers to human and regulatory limitations, all of which must be addressed to fully realize the potential of IoT in managing perishable goods effectively.

One of the foremost challenges in IoT-driven supply chains is data interoperability and integration. IoT ecosystems generate vast volumes of data from a wide range of devices, including temperature sensors, RFID tags, GPS trackers, and motion detectors. These devices are often manufactured by different vendors, each using proprietary data formats, communication protocols, and interfaces. As a result, consolidating and standardizing data streams across diverse platforms becomes a complex task (El Haimar, 2015, Osman, 2019, Pundir, Jagannath & Ganapathy, 2019). Without seamless interoperability, the ability to create a unified, end-to-end view of the supply chain is compromised. This fragmentation not only hampers real-time decision-making but also undermines the effectiveness of predictive analytics and automation. For example, if temperature data from a cold storage facility cannot be easily integrated with transport data from a logistics provider, supply chain managers may miss critical anomalies or delays that affect product quality. Achieving interoperability requires the adoption of universal standards, robust middleware solutions, and significant customization efforts all of which demand time, technical expertise, and investment (Espinosa & Armour, 2016, Qadir, et al., 2016, Shah, et al., 2019).

Closely tied to interoperability is the concern of cybersecurity and data privacy. As IoT devices collect, transmit, and process sensitive data including location, environmental conditions, and transactional records they become attractive targets for cyber threats. Malicious actors can exploit vulnerabilities in IoT networks to access confidential information, disrupt operations, or tamper with data. In the context of perishable goods such as pharmaceuticals or food, a cyberattack could result in the falsification of temperature logs, misrouting of shipments, or unauthorized access to critical infrastructure. Moreover, the decentralized nature of IoT networks with devices often operating at the edge, across different geographic regions makes them more difficult to monitor and secure (Ferreira, Arruda & Marujo, 2018, Raj, et al., 2015). Data privacy is another pressing issue, especially in industries where traceability is required by law or where consumer transparency is expected. Companies must comply with data protection regulations such as the General Data Protection Regulation (GDPR) or the California Consumer Privacy Act (CCPA), which govern how data is collected, stored, shared, and deleted. Ensuring compliance while maintaining real-time visibility requires a delicate balance between transparency and control, and any lapse can lead to legal penalties, reputational damage, and loss of customer trust.

Infrastructure requirements and the cost of implementation represent another major barrier to widespread adoption of IoT in perishable goods logistics. Deploying an effective IoT ecosystem involves more than just purchasing sensors or installing software. It requires a comprehensive infrastructure that includes power sources for devices, reliable internet or cellular connectivity across the supply chain, secure data storage platforms, and integration with existing enterprise systems such as warehouse management or ERP platforms. For small- and medium-sized enterprises (SMEs), the upfront investment in hardware, software licenses, installation, training, and ongoing maintenance can be prohibitively expensive (FutureScape, 2018, Ragini, Anand & Bhaskar, 2018, Yu, Yang & Li, 2018). Additionally, the return on investment may not be immediate, making it difficult for companies operating on thin margins to justify the expenditure. Even for larger enterprises, the cost and complexity of scaling IoT infrastructure across multiple regions, distribution centers, and partner networks can be daunting. The issue is further exacerbated in developing countries or remote regions, where inadequate infrastructure such as poor internet connectivity or unstable power supply limits the feasibility of real-time monitoring.

Another significant challenge lies in the technological maturity of IoT solutions and the corresponding skill gaps in the workforce. While IoT technology has advanced rapidly, many solutions are still in the early stages of development or lack the robustness required for mission-critical supply chain operations. Devices may suffer from limited battery life, hardware malfunctions, or inaccurate readings, all of which compromise data reliability. Furthermore, as newer technologies such as edge computing, AI integration, and blockchain are layered onto IoT systems, the level of complexity increases, requiring specialized knowledge to design, deploy, and maintain these solutions. Unfortunately, there is a growing gap between the demand for such expertise and the availability of trained professionals. Supply chain managers, IT personnel, and operational staff often lack the skills needed to interpret IoT data, troubleshoot device issues, or optimize system performance (Gligor, Tan & Nguyen, 2018, Rathore, et al., 2016). This shortage of talent not only slows adoption but also increases the likelihood of errors, inefficiencies, and system failures. Training programs and interdisciplinary collaboration are necessary to build the human capital required for successful IoT implementation.

Moreover, the dynamic and evolving nature of perishable goods supply chains adds another layer of complexity. Routes change, partners vary, and new regulations are constantly being introduced. IoT systems must be flexible enough to adapt to these changes without significant downtime or reengineering. However, many current IoT architectures are rigid and require substantial customization to accommodate such variations. This inflexibility can discourage companies from adopting or expanding IoT systems, particularly if they anticipate frequent changes in operations or strategy (Grover, et al., 2018, Ratzesberger & Sawhney, 2017).

The lack of industry-wide standards and regulatory frameworks for IoT deployment further compounds these challenges. Without clear guidelines on device interoperability, data ownership, and accountability, companies are left to navigate a fragmented landscape with limited assurance of compatibility or legal protection. This uncertainty discourages investment and collaboration, especially in complex, multi-party supply chains.

Despite these challenges, the long-term value proposition of IoT in perishable goods logistics remains strong. However, to fully harness this potential, stakeholders must address the limitations through a combination of technological innovation, policy development, and workforce training. For instance, open-source standards and collaborative consortia can help drive interoperability and reduce vendor lock-in. Stronger cybersecurity frameworks, including device authentication and end-to-end encryption, can mitigate cyber risks and ensure data integrity. Governments and industry bodies can support infrastructure development through subsidies or public-private partnerships, particularly in underserved regions (Gunawardena, Shee & Miah, 2018, Rejeb, Keogh & Treiblmaier, 2019). Finally, educational institutions and corporate training programs must prioritize skill development in areas such as data analytics, IoT engineering, and supply chain digitization.

In conclusion, while IoT-driven real-time visibility offers compelling advantages for managing perishable goods supply chains, its widespread adoption is hindered by several critical challenges. Data interoperability, cybersecurity, infrastructure costs, and skill gaps all present significant barriers that must be overcome to ensure the effectiveness, scalability, and sustainability of IoT solutions. Addressing these issues requires a holistic approach that combines technological advancement with strategic planning, regulatory support, and human capital development. Only by confronting these limitations head-on can organizations fully leverage IoT to build smarter, safer, and more resilient supply chains for perishable goods in the years to come.

2.7. Future Directions and Technological Integration

As IoT-driven real-time visibility continues to evolve in the management of perishable goods supply chains, future directions are increasingly shaped by the integration of emerging technologies and evolving policy frameworks. These advancements are not merely enhancements to existing systems but represent a fundamental shift in how perishable supply chains are monitored, optimized, and governed. The convergence of artificial intelligence, blockchain, digital twins, and progressive policy frameworks promises to elevate the effectiveness, security, and adaptability of perishable goods logistics in ways that were previously unimaginable.

Artificial intelligence (AI) is poised to play a central role in transforming IoT-enabled visibility into predictive and prescriptive decision-making. While IoT devices provide real-time data on environmental conditions, location, and handling processes, AI adds the capability to interpret this data with advanced pattern recognition, forecasting, and anomaly detection. In the context of perishable goods, AI can analyze historical and real-time data from temperature sensors, humidity monitors, GPS trackers, and inventory systems to predict spoilage risk, equipment failures, and potential disruptions. For instance, machine learning models can be trained to identify correlations between certain temperature fluctuations and increased rates of product rejection or customer complaints (Grover, et al., 2018, Ratzesberger & Sawhney, 2017). These models can then issue early warnings to logistics teams or automate responses such as adjusting cooling parameters, rerouting shipments, or recommending inventory adjustments. Predictive analytics also supports better planning by forecasting demand variations based on factors such as seasonality, weather, and market trends, allowing supply chain managers to align resources accordingly. This shift from reactive management to proactive decision-making significantly enhances the efficiency, safety, and profitability of perishable supply chains.

Complementing AI's predictive capabilities, blockchain technology introduces a secure, decentralized, and transparent layer to IoT-driven supply chain systems. Blockchain can be used to record every transaction, movement, and condition update associated with perishable goods in an immutable ledger. This ensures that once a data point such as a temperature reading, handling timestamp, or delivery confirmation is recorded, it cannot be altered or deleted without consensus from network participants (Komi, et al., 2021, Nwangele, et al., 2021). In perishable goods logistics, where traceability and accountability are paramount, blockchain provides a tamper-proof history of product provenance and chain-of-custody. This level of transparency is particularly valuable in cases involving food safety recalls, pharmaceutical audits, or regulatory compliance checks, where verifiable records are essential. By integrating IoT devices with blockchain systems, stakeholders can automatically feed real-time sensor data into a distributed ledger, creating a seamless and trustworthy record of product conditions and movements (Nwani, et al., 2020). Smart contracts, another feature of blockchain, can be programmed to trigger specific actions when certain conditions are met for example, initiating a refund if a product was exposed to unsafe temperatures during transit. This automation reduces administrative overhead and reinforces trust among stakeholders, from manufacturers to retailers and consumers.

Another transformative direction for IoT in perishable supply chains is the application of digital twins and simulation modeling. A digital twin is a virtual replica of a physical asset, process, or system that mirrors real-world conditions using real-time data inputs. In the context of perishable goods logistics, digital twins can represent entire supply chain networks, including warehouses, transportation routes, distribution centers, and even individual shipments. These models enable supply chain managers to simulate different scenarios, assess the impact of various decisions, and optimize operational strategies before implementing them in the real world. For instance, a digital twin of a cold chain can simulate the effects of equipment failure, traffic delays, or weather disruptions on product quality, allowing for contingency plans to be tested and refined in advance. This capability is especially critical for high-value or highly regulated perishable goods such as vaccines, where the cost of failure is exceptionally high. Digital twins also support continuous improvement by providing insights into inefficiencies, bottlenecks, and resource utilization across the supply chain (Komi, et al., 2021, Nwabekee, et al., 2021). When paired with AI and IoT, digital twins evolve into self-learning systems that can adapt over time, offering recommendations based on both historical patterns and real-time events. This level of intelligence and adaptability positions organizations to respond swiftly and effectively to both expected and unforeseen challenges.

In parallel with technological advancements, the future of IoT-driven real-time visibility in perishable goods supply chains will be shaped by evolving policy and regulatory frameworks. As the adoption of IoT and its associated technologies expands, so too does the need for standardized practices, governance models, and compliance requirements. One of the most pressing needs is the establishment of global standards for data interoperability, device certification, and communication protocols (Mustapha, et al., 2018, Nwani, et al., 2020). Currently, the lack of unified standards creates challenges in integrating diverse IoT solutions across supply chain partners, limiting scalability and reducing system effectiveness. Regulatory bodies and international organizations must work collaboratively with industry stakeholders to develop harmonized frameworks that support innovation while ensuring compatibility and security.

Data privacy and cybersecurity regulations will also become increasingly important. As IoT systems collect and transmit sensitive operational and consumer data, clear guidelines are needed to define ownership, access rights, and acceptable usage. Regulations such as the General Data Protection Regulation (GDPR) and sector-specific rules like the FDA's guidelines on electronic records will continue to influence how data is managed in IoT-enabled supply chains. Companies must ensure compliance through robust data governance policies, including encryption, access controls, and audit trails (Komi, et al., 2021, Mustapha, et al., 2021). The growing importance of environmental, social, and governance (ESG) reporting may also prompt regulators to mandate the use of IoT technologies for transparent and verifiable sustainability practices in supply chains. This could include real-time reporting on carbon emissions, energy consumption, or food waste metrics that are increasingly important to consumers, investors, and regulatory bodies alike.

Furthermore, policy initiatives can play a vital role in supporting the infrastructure required for IoT deployment. Investments in broadband connectivity, smart logistics corridors, and public-private innovation hubs can accelerate the adoption of real-time visibility technologies, especially in emerging markets or rural areas. Government subsidies, tax incentives, and grants for IoT adoption in perishable goods logistics can encourage small and medium-sized enterprises (SMEs) to embrace digital transformation despite initial cost barriers (Ajuwon, et al., 2021, Fiemotongha, et al., 2021). Educational policies that promote digital literacy and cross-disciplinary training in logistics, data science, and IoT engineering will also help bridge the skill gaps that currently limit the full-scale implementation of advanced technologies.

In conclusion, the future of IoT-driven real-time visibility in perishable goods supply chains is being shaped by an exciting convergence of technological integration and regulatory evolution. Artificial intelligence empowers supply chains with predictive capabilities, enabling proactive decision-making and efficiency gains. Blockchain ensures transparency, traceability, and trust through immutable records and automated compliance (Ajuwon, et al., 2020, Fiemotongha, et al., 2020). Digital twins enable simulation and optimization, allowing supply chains to anticipate and adapt to real-world conditions in a risk-free virtual environment. Simultaneously, evolving policy frameworks are laying the groundwork for standardized, secure, and inclusive IoT ecosystems. Together, these developments promise to usher in a new era of intelligent, resilient, and sustainable perishable goods logistics, capable of meeting the rising expectations of regulators, consumers, and global markets alike (Nwaozomudoh, et al., 2021, Ochuba, et al., 2021).

2.8. Conclusion

IoT-driven real-time visibility in perishable goods supply chains represents a transformative advancement in how sensitive, time-critical products are managed from origin to destination. Throughout the supply chain journey whether involving fresh produce, pharmaceuticals, or florals the integration of IoT technologies has demonstrated significant improvements in reducing spoilage, enhancing inventory accuracy, ensuring regulatory compliance, and fostering collaboration among stakeholders. Key tools such as RFID tags, GPS trackers, temperature and humidity sensors, and cloud-based analytics platforms allow continuous monitoring and instantaneous data transmission, enabling organizations to make informed, real-time decisions. This not only minimizes losses but also enhances operational efficiency and consumer trust.

The strategic implications for supply chain stakeholders are profound. Manufacturers, logistics providers, retailers, and regulatory agencies all stand to benefit from the enhanced traceability and responsiveness that IoT enables. Real-time data improves coordination across multiple points in the supply chain, reducing delays and improving compliance with increasingly stringent safety and quality standards. Moreover, insights derived from IoT data analytics empower companies to shift from reactive to proactive strategies, using predictive maintenance, demand forecasting, and automated alerts to stay ahead of disruptions. For consumers, the transparency made possible by IoT strengthens confidence in product quality, freshness, and ethical sourcing, which in turn supports brand loyalty and competitive differentiation.

As global supply chains become more complex and consumer expectations continue to rise, the adoption of IoT is no longer a luxury but a strategic necessity. It serves as a catalyst for building sustainable and resilient perishable goods supply chains capable of adapting to climate variability, market fluctuations, and evolving regulatory landscapes. Looking forward, the integration of emerging technologies such as artificial intelligence, blockchain, and digital twins will further amplify the value of IoT, creating smarter ecosystems that are not only efficient but also environmentally responsible and socially accountable. Embracing IoT is a decisive step toward achieving a future where quality, safety, and sustainability coexist seamlessly in the global movement of perishable goods.

REFERENCES

[1] Abdalla, R., & Esmail, M. (2019). *WebGIS for disaster management and emergency response*. Springer International Publishing.

[2] Ajuwon, A., Onifade, O., Oladuji, T. J., & Akintobi, A. O. (2020). Blockchain-based models for credit and loan system automation in financial institutions. Iconic Research and Engineering Journals, 3(10), 364–381.

[3] Akinluwade, K. J., Omole, F. O., Isadare, D. A., Adesina, O. S., & Adetunji, A. R. (2015). Material selection for heat sinks in HPC microchip-based circuitries. British Journal of Applied Science & Technology, 7(1), 124.

[4] Akinrinoye, O.V., Kufile, O.T., Otokiti, B.O., Ejike, O.G., Umezurike, S.A. and Onifade, A.Y., 2020. Customer segmentation strategies in emerging markets: A review of tools, models, and applications. International Journal of Scientific Research in Computer Science, Engineering and Information Technology, 6(1), pp.194–217.

[5] Akpan, U. U., Adekoya, K. O., Awe, E. T., Garba, N., Oguncoker, G. D., & Ojo, S. G. (2017). Mini-STRs screening of 12 relatives of Hausa origin in northern Nigeria. Nigerian Journal of Basic and Applied Sciences, 25(1), 48-57.

[6] Akpan, U. U., Awe, T. E., & Idowu, D. (2019). Types and frequency of fingerprint minutiae in individuals of Igbo and Yoruba ethnic groups of Nigeria. Ruhuna Journal of Science, 10(1).

[7] Akpe, O. E., Ogbuefi, S., Ubanadu, B. C., & Daraojimba, A. I. (2020, August). Advances in role-based access control for cloud-enabled operational platforms. IRE Journals (Iconic Research and Engineering Journals), 4(2), 159–174.

[8] Akpe, O.E., Mgbame, A.C., Ogbuefi, E., Abayomi, A.A. & Adeyelu, O.O., 2020. Barriers and Enablers of BI Tool Implementation in Underserved SME Communities. IRE Journals, 3(7), pp.211-220. DOI: 10.6084/m9.figshare.26914420.

[9] Akpe, O.E., Mgbame, A.C., Ogbuefi, E., Abayomi, A.A. & Adeyelu, O.O., 2020. Bridging the Business Intelligence Gap in Small Enterprises: A Conceptual Framework for Scalable Adoption. IRE Journals, 4(2), pp.159-168. DOI: 10.6084/m9.figshare.26914438.

[10] Akpe-Ejielo, O.-E., Ogbuefi, S., Ubanadu, B. C., & Daraojimba, A. I. (2020, August). Advances in role-based access control for cloud-enabled operational platforms. IRE Journals (Iconic Research and Engineering Journals), 4(2), 159–174.

[11] Akter, S., & Wamba, S. F. (2019). Big data and disaster management: a systematic review and agenda for future research. *Annals of Operations Research*, *283*, 939-959.

[12] Al-Badi, A., Tarhini, A., & Khan, A. I. (2018). Exploring big data governance frameworks. *Procedia computer science*, *141*, 271-277.

[13] Al-Badi, A., Tarhini, A., & Khan, A. I. (Minelli, M., Chambers, M., & Dhiraj, A. (2012). *Big data, big analytics: emerging business intelligence and analytic trends for today's businesses*. John Wiley & Sons.

[14] Aliyu, A. (2015). Management of disasters and complex emergencies in Africa: The challenges and constraints. *Annals of African Medicine*, *14*(3), 123-131.

[15] Alsubaie, A., Marti, J., Alutaibi, K., Di Pietro, A., & Tofani, A. (2014, June). Resources allocation in disaster response using ordinal optimization based approach. In *2014 IEEE Canada International Humanitarian Technology Conference-(IHTC)* (pp. 1-5). IEEE.

[16] Analytics, M. (2016). The age of analytics: competing in a data-driven world. *McKinsey Global Institute Research*.

[17] Awe, E. T. (2017). Hybridization of snout mouth deformed and normal mouth African catfish Clarias gariepinus. Animal Research International, 14(3), 2804-2808.

[18] Awe, E. T., & Akpan, U. U. (2017). Cytological study of Allium cepa and Allium sativum.

[19] Awe, E. T., Akpan, U. U., & Adekoya, K. O. (2017). Evaluation of two MiniSTR loci mutation events in five Father-Mother-Child trios of Yoruba origin. Nigerian Journal of Biotechnology, 33, 120-124.

[20] Balan, C. (2018). Internet of Things in Transportation: Game Changer in the Supply Chains. In *New Paths of Entrepreneurship Development: The Role of Education, Smart Cities, and Social Factors* (pp. 99-123). Cham: Springer International Publishing.

[21] Barrett, C., Reardon, T., Swinnen, J., & Zilberman, D. (2019). Structural transformation and economic development: insights from the agri-food value chain revolution. *Cornell University*, 1-56.

[22] Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: a literature review. *International journal of production research*, *57*(15-16), 4719-4742.

[23] Canton, L. G. (2019). *Emergency management: Concepts and strategies for effective programs*. John Wiley & Sons.

[24] Chelleri, L., Waters, J. J., Olazabal, M., & Minucci, G. (2015). Resilience trade-offs: addressing multiple scales and temporal aspects of urban resilience. *Environment and Urbanization*, *27*(1), 181-198.

[25] Chen, K. Z., Joshi, P. K., Cheng, E., & Birthal, P. S. (2015). Innovations in financing of agri-food value chains in China and India: Lessons and policies for inclusive financing. *China Agricultural Economic Review*, *7*(4), 616-640.

[26] Chua, C., Danyluk, M., Cowen, D., & Khalili, L. (2018). Introduction: Turbulent circulation: Building a critical engagement with logistics. *Environment and Planning D: Society and Space*, *36*(4), 617-629.

[27] Collier, S. J., & Lakoff, A. (2015). Vital systems security: Reflexive biopolitics and the government of emergency. *Theory, culture & society*, *32*(2), 19-51.

[28] Correa, J. S., Sampaio, M., Barros, R. D. C., & Hilsdorf, W. D. C. (2020). IoT and BDA in the Brazilian future logistics 4.0 scenario. Production, 30, e20190102.

[29] De Vass, T., Shee, H., & Miah, S. J. (2018). Internet of Things for improving supply chain performance: A Qualitative study of Australian retailers. *ACIS2018 Proceedings*.

[30] Edgeman, R. (2013). Sustainable enterprise excellence: towards a framework for holistic data-analytics. *Corporate Governance*, *13*(5), 527-540.

[31] Eksoz, C., Mansouri, S. A., & Bourlakis, M. (2014). Collaborative forecasting in the food supply chain: a conceptual framework. *International journal of production economics*, *158*, 120-135.

[32] El Haimar, A. (2015). *Stochastic risk analysis of influenza pandemic on interdependent workforce sectors using input-output modeling*. The George Washington University.

[33] Espinosa, J. A., & Armour, F. (2016, January). The big data analytics gold rush: a research framework for coordination and governance. In *2016 49th Hawaii International Conference on System Sciences (HICSS)* (pp. 1112-1121). IEEE.

[34] Fagbore, O. O., Ogeawuchi, J. C., Ilori, O., Isibor, N. J., Odetunde, A., & Adekunle, B. I. (2020). Developing a Conceptual Framework for Financial Data Validation in Private Equity Fund Operations.

[35] Ferreira, G. O., Arruda, E. F., & Marujo, L. G. (2018). Inventory management of perishable items in long-term humanitarian operations using Markov Decision Processes. *International journal of disaster risk reduction*, *31*, 460-469.

[36] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2020). Developing a financial analytics framework for end-to-end logistics and distribution cost control. IRE Journals, 3(07), 253–261.

[37] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2021). A strategic model for reducing days-on-hand (DOH) through logistics and procurement synchronization. IRE Journals, 4(01), 237–243.

[38] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2021). A framework for gross margin expansion through factory-specific financial health checks. IRE Journals, 5(05), 487–495.

[39] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2021). Developing internal control and risk assurance frameworks for compliance in supply chain finance. IRE Journals, 4(11), 459–467.

[40] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2021). Building an IFRS-driven internal audit model for manufacturing and logistics operations. IRE Journals, 5(02), 261–271.

[41] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2020). Designing a financial planning framework for managing SLOB and write-off risk in fast-moving consumer goods (FMCG). IRE Journals, 4(04), 259–266.

[42] Fiemotongha, J. E., Olajide, J. O., Otokiti, B. O., Nwani, S., Ogunmokun, A. S., & Adekunle, B. I. (2020). Designing integrated financial governance systems for waste reduction and inventory optimization. IRE Journals, 3(10), 382–390.

[43] FutureScape, I. D. C. (2018). IDC FutureScape: Worldwide IT industry 2019 predictions. *IDC FutureScape*.

[44] Gbenle, T. P., Akpe-Ejielo, O.-E., Owoade, S., Ubanadu, B. C., & Daraojimba, A. I. (2020, December). A conceptual model for cross-functional collaboration between IT and business units in cloud projects. IRE Journals (Iconic Research and Engineering Journals), 4(6), 99–114.

[45] Gligor, D., Tan, A., & Nguyen, T. N. T. (2018). The obstacles to cold chain implementation in developing countries: insights from Vietnam. *The International Journal of Logistics Management*, *29*(3), 942-958.

[46] Grover, V., Chiang, R. H., Liang, T. P., & Zhang, D. (2018). Creating strategic business value from big data analytics: A research framework. *Journal of management information systems*, *35*(2), 388-423.

[47] Gunawardena, T. D. V., Shee, H., & Miah, S. J. (2018). Internet of Things for improving Supply Chain Performance: A Qualitative study of Australian retailers.

[48] Haleem, A., & Javaid, M. (2019). Additive manufacturing applications in industry 4.0: a review. *Journal of Industrial Integration and Management*, *4*(04), 1930001.

[49] He, H., Maple, C., Watson, T., Tiwari, A., Mehnen, J., Jin, Y., & Gabrys, B. (2016, July). The security challenges in the IoT enabled cyber-physical systems and opportunities for evolutionary computing & other computational intelligence. In 2016 IEEE congress on evolutionary computation (CEC) (pp. 1015-1021). IEEE.

[50] Henke, N., & Jacques Bughin, L. (2016). The age of analytics: Competing in a data-driven world.

[51] Henkey, T. (2017). *Urban emergency management: Planning and response for the 21st century*. Butterworth-Heinemann.

[52] Isa, A., & Dem, B. (2014). Integrating Self-Reliance Education Curriculum For Purdah Women In Northern Nigeria: A Panacea For A Lasting Culture Of Peace.

[53] Jha, M. K. (2010). Natural and anthropogenic disasters: An overview. *Natural and anthropogenic disasters: vulnerability, preparedness and mitigation*, 1-16.

[54] Kalisetty, S. (2017). Dynamic Edge-Cloud Orchestration for Predictive Supply Chain Resilience in Smart Retail Manufacturing Networks. *Global Research Development (GRD) ISSN: 2455-5703*, *2*(12).

[55] Kapucu, N., & Özerdem, A. (2011). *Managing emergencies and crises*. Jones & Bartlett Publishers.

[56] Karaesmen, I. Z., Scheller–Wolf, A., & Deniz, B. (2010). Managing perishable and aging inventories: review and future research directions. *Planning production and inventories in the extended enterprise: A state of the art handbook, Volume 1*, 393-436.

[57] Kumar, S., Mookerjee, V., & Shubham, A. (2018). Research in operations management and information systems interface. *Production and Operations Management*, *27*(11), 1893-1905.

[58] Kwaramba, C., Meyer-Goldstein, S., Lowry, P. B., & Nottingham, Q. (2019). metaphorical transfer," Production and Operations Management (POM)(accepted 11.

[59] Lee, M. K. (2018). Understanding perception of algorithmic decisions: Fairness, trust, and emotion in response to algorithmic management. *Big data & society*, *5*(1), 2053951718756684.

[60] Lehmacher, W. (2017). *The global supply chain*. Springer.

[61] Lei, S., Wang, J., Chen, C., & Hou, Y. (2016). Mobile emergency generator pre-positioning and real-time allocation for resilient response to natural disasters. *IEEE Transactions on Smart Grid*, *9*(3), 2030-2041.

[62] Mangan, J., & Lalwani, C. (2016). *Global logistics and supply chain management*. John Wiley & Sons.

[63] March, H., & Ribera-Fumaz, R. (2016). Smart contradictions: The politics of making Barcelona a Self-sufficient city. *European urban and regional studies*, *23*(4), 816-830.

[64] Marin Bustamante, D. F. (2019). The role of new technologies in international business in the context of Covid-19: A literature review.

[65] Meijer, A., & Bolívar, M. P. R. (2016). Governing the smart city: a review of the literature on smart urban governance. *International review of administrative sciences*, *82*(2), 392-408.

[66] Mgbame, A. C., Akpe, O. E. E., Abayomi, A. A., Ogbuefi, E., Adeyelu, O. O., & Mgbame, A. C. (2020). Barriers and enablers of BI tool implementation in underserved SME communities. Iconic Research and Engineering Journals, 3(7), 211-220.

[67] Mohanty, S., Jagadeesh, M., & Srivatsa, H. (2013). *Big Data imperatives: enterprise Big Data warehouse, BI implementations and analytics*. Apress.

[68] Mohanty, S., Jagadeesh, M., Srivatsa, H., Mohanty, S., Jagadeesh, M., & Srivatsa, H. (2013). "Big Data" in the Enterprise. *Big Data Imperatives: Enterprise Big Data Warehouse, BI Implementations and Analytics*, 1-24.

[69] Mustapha, A. Y., Chianumba, E. C., Forkuo, A. Y., Osamika, D., & Komi, L. S. (2018). Systematic Review of Mobile Health (mHealth) Applications for Infectious Disease Surveillance in Developing Countries. Methodology, 66.

[70] Mustapha, A. Y., Chianumba, E. C., Forkuo, A. Y., Osamika, D., & Komi, L. S. (2018). Systematic Review of Mobile Health (mHealth) Applications for Infectious Disease Surveillance in Developing Countries. Methodology, 66.

[71] Nwani, S., Abiola-Adams, O., Otokiti, B.O. & Ogeawuchi, J.C., 2020. Building Operational Readiness Assessment Models for Micro, Small, and Medium Enterprises Seeking Government-Backed Financing. Journal of Frontiers in Multidisciplinary Research, 1(1), pp.38-43. DOI: 10.54660/IJFMR.2020.1.1.38-43.

[72] Nwani, S., Abiola-Adams, O., Otokiti, B.O. & Ogeawuchi, J.C., 2020. Designing Inclusive and Scalable Credit Delivery Systems Using AI-Powered Lending Models for Underserved Markets. IRE Journals, 4(1), pp.212-214. DOI: 10.34293/irejournals.v4i1.1708888.

[73] Oduola, O. M., Omole, F. O., Akinluwade, K. J., & Adetunji, A. R. (2014). A comparative study of product development process using computer numerical control and rapid prototyping methods. British Journal of Applied Science & Technology, 4(30), 4291.

[74] Ojika, F. U., Adelusi, B. S., Uzoka, A. C., & Hassan, Y. G. (2020). Leveraging transformer-based large language models for parametric estimation of cost and schedule in agile software development projects. IRE Journals, 4(4), 267–278.

[75] Olaoye, T., Ajilore, T., Akinluwade, K., Omole, F., & Adetunji, A. (2016). Energy crisis in Nigeria: Need for renewable energy mix. American journal of electrical and electronic engineering, 4(1), 1-8.

[76] Oliver, C. (2010). *Catastrophic disaster planning and response*. crc Press.

[77] Oni, O., Adeshina, Y. T., Iloeje, K. F., & Olatunji, O. O. (2018). Artificial Intelligence Model Fairness Auditor For Loan Systems. Journal ID, 8993, 1162.

[78] Osman, A. M. S. (2019). A novel big data analytics framework for smart cities. *Future Generation Computer Systems*, *91*, 620-633.

[79] Ozobu, C. O. (2020). Modeling exposure risk dynamics in fertilizer production plants using multi-parameter surveillance frameworks. Iconic Research and Engineering Journals, 4(2), 227–239.

[80] Papakostas, N., O'Connor, J., & Byrne, G. (2016, October). Internet of things technologies in manufacturing: Application areas, challenges and outlook. In *2016 International Conference on Information Society (i-Society)* (pp. 126-131). IEEE.

[81] Phillips-Wren, G., Iyer, L. S., Kulkarni, U., & Ariyachandra, T. (2015). Business analytics in the context of big data: A roadmap for research. *Communications of the Association for Information Systems*, *37*(1), 23.

[82] Pundir, A. K., Jagannath, J. D., & Ganapathy, L. (2019, January). Improving supply chain visibility using IoT-internet of things. In *2019 ieee 9th annual computing and communication workshop and conference (ccwc)* (pp. 0156-0162). IEEE.

[83] Qadir, J., Ali, A., ur Rasool, R., Zwitter, A., Sathiaseelan, A., & Crowcroft, J. (2016). Crisis analytics: big data-driven crisis response. *Journal of International Humanitarian Action*, *1*, 1-21.

[84] Ragini, J. R., Anand, P. R., & Bhaskar, V. (2018). Big data analytics for disaster response and recovery through sentiment analysis. *International Journal of Information Management*, *42*, 13-24.

[85] Raj, P., Raman, A., Nagaraj, D., & Duggirala, S. (2015). High-performance big-data analytics. *Computing Systems and Approaches (Springer, 2015)*, *1*.

[86] Rathore, M. M., Ahmad, A., Paul, A., Wan, J., & Zhang, D. (2016). Real-time medical emergency response system: exploiting IoT and big data for public health. *Journal of medical systems*, *40*, 1-10.

[87] Ratzesberger, O., & Sawhney, M. (2017). *The sentient enterprise: The evolution of business decision making*. John Wiley & Sons.

[88] Rejeb, A., Keogh, J. G., & Treiblmaier, H. (2019). Leveraging the internet of things and blockchain technology in supply chain management. *Future Internet*, *11*(7), 161.

[89] Russom, P. (2011). Big data analytics. *TDWI best practices report, fourth quarter*, *19*(4), 1-34.

[90] Saban, L. I. (2014). *Disaster emergency management: the emergence of professional help services for victims of natural disasters*. SUNY Press.

[91] Shah, S. A., Seker, D. Z., Hameed, S., & Draheim, D. (2019). The rising role of big data analytics and IoT in disaster management: recent advances, taxonomy and prospects. *IEEE Access*, *7*, 54595-54614.

[92] Shah, S. A., Seker, D. Z., Rathore, M. M., Hameed, S., Yahia, S. B., & Draheim, D. (2019). Towards disaster resilient smart cities: Can internet of things and big data analytics be the game changers?. *IEEe Access*, *7*, 91885-91903.

[93] Shih, C. W., & Wang, C. H. (2016). Integrating wireless sensor networks with statistical quality control to develop a cold chain system in food industries. *Computer Standards & Interfaces*, *45*, 62-78.

[94] Shrivastava, S., & Pal, S. N. (2017, March). A big data analytics framework for enterprise service ecosystems in an e-governance scenario. In *Proceedings of the 10th International Conference on Theory and Practice of Electronic Governance* (pp. 5-11).

[95] și Econometrie, D. D. S. (2018). LISTADELUCR Ă RI. *Policy*, *174*, 113469.

[96] Simchi-Levi, D., Wang, H., & Wei, Y. (2018). Increasing supply chain robustness through process flexibility and inventory. *Production and Operations Management*, *27*(8), 1476-1491.

[97] Srinivasan, V. (2016). *The intelligent enterprise in the era of big data*. John Wiley & Sons.

[98] Sun, J., & Ma, Y. (2012). Impact of Logistics on Food Industry Supply Chain Disruptions. *Academic Journal of Business & Management*, *6*(5), 249-256.

[99] Tabish, S. A., & Syed, N. (2015). Disaster preparedness: current trends and future directions. *Int J Sci Res*, *4*(6), 227-52.

[100] Thürer, M., Pan, Y. H., Qu, T., Luo, H., Li, C. D., & Huang, G. Q. (2019). Internet of Things (IoT) driven kanban system for reverse logistics: solid waste collection. *Journal of Intelligent Manufacturing*, *30*, 2621-2630.

[101] Umar, M., Wilson, M., & Heyl, J. (2017). Food network resilience against natural disasters: a conceptual framework. *Sage open*, *7*(3), 2158244017717570.

[102] Veenema, T. G. (Ed.). (2018). *Disaster nursing and emergency preparedness*. Springer Publishing Company.

[103] Wang, G., Gunasekaran, A., Ngai, E. W., & Papadopoulos, T. (2016). Big data analytics in logistics and supply chain management: Certain investigations for research and applications. *International journal of production economics*, *176*, 98-110.

[104] Wang, Y., Kung, L., & Byrd, T. A. (2018). Big data analytics: Understanding its capabilities and potential benefits for healthcare organizations. *Technological forecasting and social change*, *126*, 3-13.

[105] Wladdimiro, D., Gonzalez-Cantergiani, P., Hidalgo, N., & Rosas, E. (2016, December).

Disaster management platform to support real-time analytics. In *2016 3rd International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)* (pp. 1-8). IEEE.

[106] Yakovleva, N., Sarkis, J., & Sloan, T. (2012). Sustainable benchmarking of supply chains: the case of the food industry. *International journal of production research*, *50*(5), 1297-1317.

[107] Yamada, A., & Peran, M. (2017, December). Governance framework for enterprise analytics and data. In *2017 IEEE International Conference on Big Data (Big Data)* (pp. 3623-3631). IEEE.

[108] Yu, M., Yang, C., & Li, Y. (2018). Big data in natural disaster management: a review. *Geosciences*, *8*(5), 165.

[109] Zaman, J., Shoomal, A., Jahanbakht, M., & Ozay, D. (2014). Driving Supply Chain Transformation with IoT and AI Integration: A Dual Approach Using Bibliometric Analysis and Topic Modeling. *Computer Science*, *11*.