Advancing U.S. Retail Supply Chain Efficiency and Resilience by Integrating IoT Sensing, Artificial Intelligence (AI)-driven BI Analytics, and Robotic Automation.

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Abstract

The global retail supply chain ecosystem has been restructuring with the digital transformation driven by demand volatility, geopolitical instability (recent tariff and counter tariff effects), and consumer preference. The U.S. retail faces challenges like persistent inflation squeezing consumer spending, skilled labor shortages, operational inefficiency and supply chain volatility. Traditional retailers are struggling to manage inventory, adapt to shifting consumer demands for omnichannel experiences, and cope with high operational costs and increased security risks. Therefore, the integration of IoT (Internet of Things) sensing, BI (Business Intelligence) analytics, and robotic automation is crucial here in improving U.S. retail supply chain efficiency and strengthen resilience.

This article focuses on developing framework by integrating IoT sensing, BI analytics, and robotic automation to enhance efficiency and resilience in U.S. retail supply chains. The framework enables retailers with comprehensive knowledgebase on how to capture quality data through IoT devices, transforming streaming signals into predictive and prescriptive *insights using BI system, and executing optimized responses autonomously by integrating robotic platforms. This integration will facilitate retail operations in evaluating performance impacts across stock/inventory accuracy, fulfillment speed, downtime reduction, forecast precision, and disruption recovery. The findings demonstrate that integrated IoT–BI–robotics architectures represent a strategic pathway for strengthening U.S. retail competitiveness and supply chain resilience.*

Keywords: IoT Sensing, BI Analytics, Robotic Automation, Business Intelligence, Retail Supply Chain.

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1. Introduction

The U.S. retail has become one of the largest sectors in the country, contributing trillions of dollars per annum to GDP, employing millions of employees and workforces (skilled, semi-skilled, seasoned) across various segments like logistics, warehouse and distribution networks. The retail industry is undergoing digital transformation following consumer choice and technological advancements. Retailers tend to rely on digital platforms, e-commerce, omnichannel rather than traditional store concepts considering buyers preference and buying behavior. However, recent disruptions in retail supply chains due to tariff and counter-tariff effects, Covid-19 pandemic-induced supply shocks, port congestion, skilled-labor shortfall, and inflationary pressures exposed structural weaknesses in conventional supply chain management models (Ivanov & Dolgui, 2020).

Traditional retailers rely heavily on ERP (Enterprise Resource Plan) system, which generates historical reports based on operational data for a specific period. These traditional systems are most likely reactive rather than proactive, limiting agility in dynamic market environments (Waller & Fawcett, 2013). Therefore, U.S. retail industry faces various challenges like inventory count errors, congestion in warehouse operations, inaccuracies in demand forecasting, increased equipment downtime etc. To address these challenges, supply chain resilience, defined as the capacity to anticipate, respond to, and recover from disruptions (Christopher & Peck, 2004), has become a strategic imperative.

Digital transformation initiatives emphasize the integration of advanced technologies, including IoT sensing, big data analytics, AI-driven Business Intelligence, and robotics automation (Hofmann & Rüsch, 2017). While each technology independently contributes to operational improvement, limited research has examined their unified integration within a cyber-physical supply chain ecosystem.

This research work aims to address issues like how the integration of IoT, BI analytics, and robotics optimizes real-time operational visibility in retail supply chains, how does BI analytics convert streaming data into predictive and prescriptive intelligence, how robotic automation operationalize analytical insights etc.

2. Literature Review

Modern U.S. retail supply chain management systems tend to integrate with sophisticated cutting-edge technologies to optimize operational efficiency and excellence consumer experience. Retail sector has been evolving over the period, heading towards omnichannel, e-commerce platforms, especially after the Covid-19 outbreak. This sector generates huge amounts of operational data every day. Therefore, the necessity for Business Intelligence (BI) systems in retail sector has become eminent from static reporting to predictive and prescriptive analytics (Rahman et al., 2026). We have experienced an increasing trend in e-commerce, and high-tech omnichannel retail outlets attracting more customers with better consumer experience (Rahman et al., 2025).

Internet of Things (IoT) plays crucial role in generating and compiling relevant and appropriate transactional data in real time. Based on these data-sets BI application develops performance visualization to get data-driven business insights to take strategic decisions towards achieving business objectives. Artificial Intelligence (AI) empower retailers with predictive analysis, for instance, demand forecasting, sales projections. In line with BI/AI, Robotics work toward physical execution in optimizing operational efficiency in supply chain process with more accuracy, whereas automation may assist in self-correcting loop.

2.1 Supply Chain Resilience

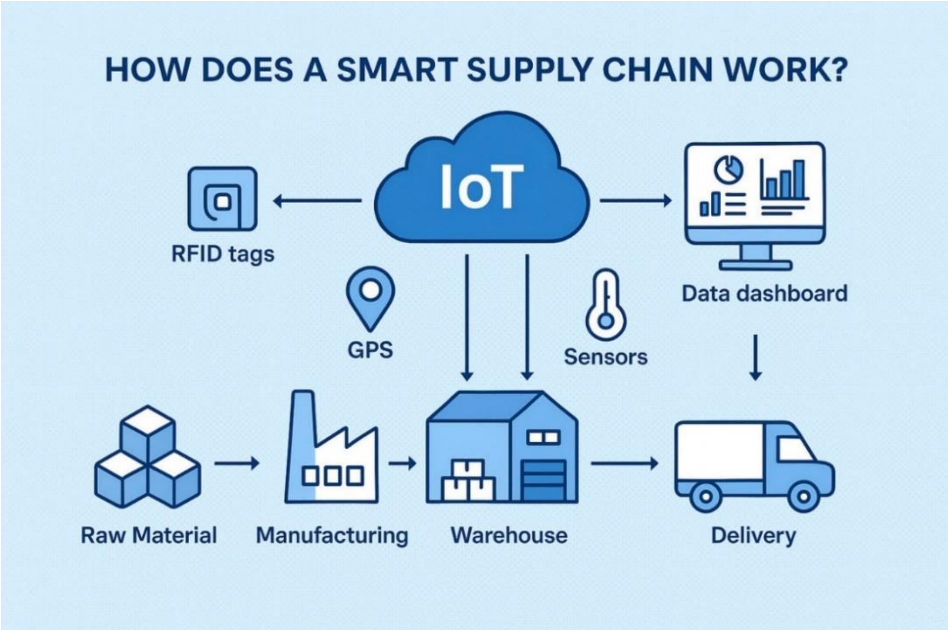
Supply chain resilience refers to the ability to anticipate, adapt to, and recover from any disruptions by minimizing likely impacts on revenue, costs, and customer satisfaction. Aspects of supply chain resilience may include anticipation and risk management, adaptability, real-time visibility, and flexibility and redundancy. Supply chain resilience strengthens the business entity in maintaining and continuing its operational activities, gaining customer trust and competitive advantages over competitors.

As per Christopher & Peck (2004), supply chain resilience involves adaptability, redundancy, flexibility, and recovery capacity of any business entity's supply chain management system. Besides, Lee (2004) developed a framework named as "Triple-A Supply Chain", which includes critical characteristics like agility, adaptability, and alignment for competitive performance. Recent research emphasizes viability and dynamic reconfiguration in interconnected supply networks (Ivanov & Dolgui, 2020). However, achieving resilience requires technological enablement capable of real-time detection and adaptive response.

2.2 Internet of Things (IoT) in Supply Chains

Supply chain IoT refers to interconnected physical devices (sensors, RFID tags, GPS trackers, smart meters, robotics systems) that collect and transmit real-time data without human intervention across logistics, warehousing, procurement, and distribution networks. IoT is a foundational data **layer** that powers AI-driven Business Intelligence platform to optimize retail supply chain efficiency and resilience. IoT enhances end-to-end visibility, enabling real-time tracking, condition monitoring, and detection of anomalies.

Image_01: *shows how does a smart supply chain works.*



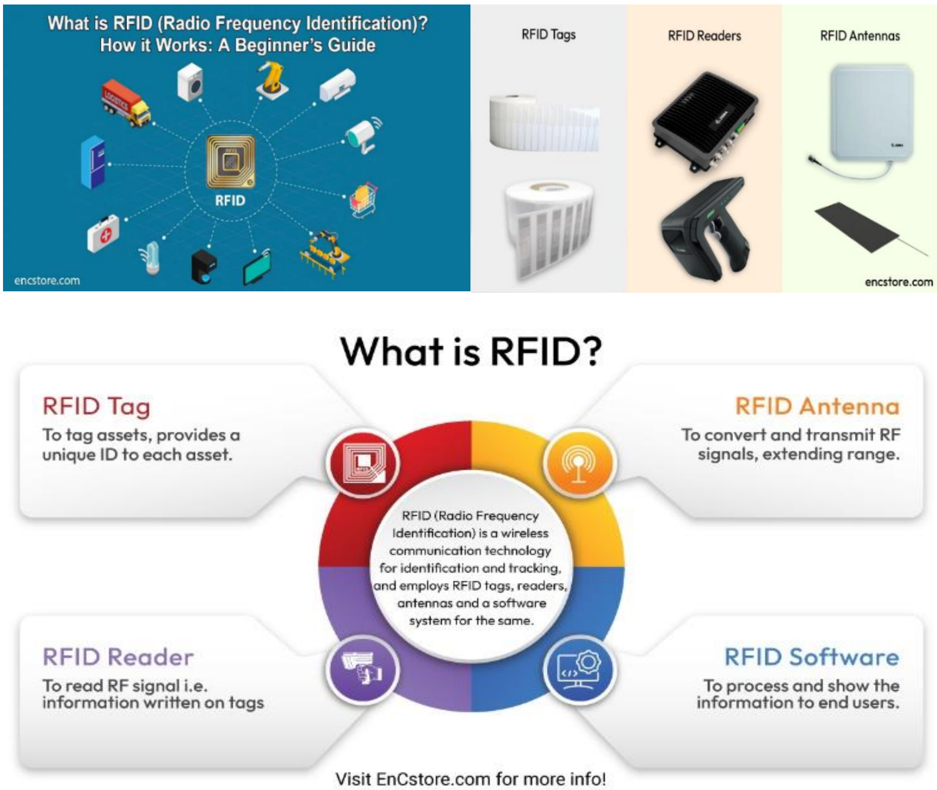
(Source: IoTDunia.com, https://iotdunia.com/how-smart-supply-chain-works/)

IoT technologies facilitate real-time monitoring of assets, inventory, vehicles, and environmental conditions (Ben-Daya et al., 2019). RFID systems enhance inventory accuracy, while GPS tracking improves route optimization. Environmental sensors ensure cold-chain compliance and reduce spoilage. The economic value of IoT in logistics has been estimated in billions of dollars through improved asset utilization and risk mitigation (Manyika et al., 2015). However, IoT-generated data requires advanced analytics to extract actionable insights.

2.2.1 RFID (Radio Frequency Identification)

RFID refers to wireless communication technology for identification and tracking the inventory and assets of the business entity. It comprises of RFID tag, reader, antenna and related software. Retailers can install and integrate this system to automate their inventory tracking, which enables them to real-time stock visibility, and reduces shrinkage and manual counting. Retailers like Walmart use this technology for tacking inventory in real-time and inventory counts accuracy.

Image_02: *shows the components of RFID and how it works.*



(Source: EnCstore.com, https://www.encstore.com/blog/5200-what-is-rfid)

2.2.2 GPS & Telematics Tracking

GPS and telematics tracking devices in U.S. retail offer real-time vehicle location, route history, geo-fencing, and driver behavior monitoring via OBD-II or portable battery-powered units. Common features include real-time location tracking and fleet monitoring via cellular data, route optimization, monitoring driver's behavior, driving speed, harsh braking, and rapid acceleration etc. U.S. retailers like Amazon, FedEx use this technology for their shipment visibility.

Image_03: *shows the image of GPS & Telematics Tracking system.*

(Source: Amazon, https://www.amazon.com/US-GPS-Tracker-Magnetic-Equipment/dp/B0C9DZS6N6)

2.2.3 Smart Sensors

In modern manufacturing compounds, IoT applications have given birth to the concept of Industry 4.0, where the manufacturers install innovative IoT sensors in warehouses, trucks, containers, and production units so that we can monitor stock position, fuel level, measure temperature, and humidity. Overall, retailers use IoT sensors to monitor equipment performance, improve production efficiency, and predictive maintenance. This has enabled companies to minimize downtime, reduce costs, and increase overall productivity. IoT sensors are more likely applicable for pharmaceutical and perishable retail supply chains.

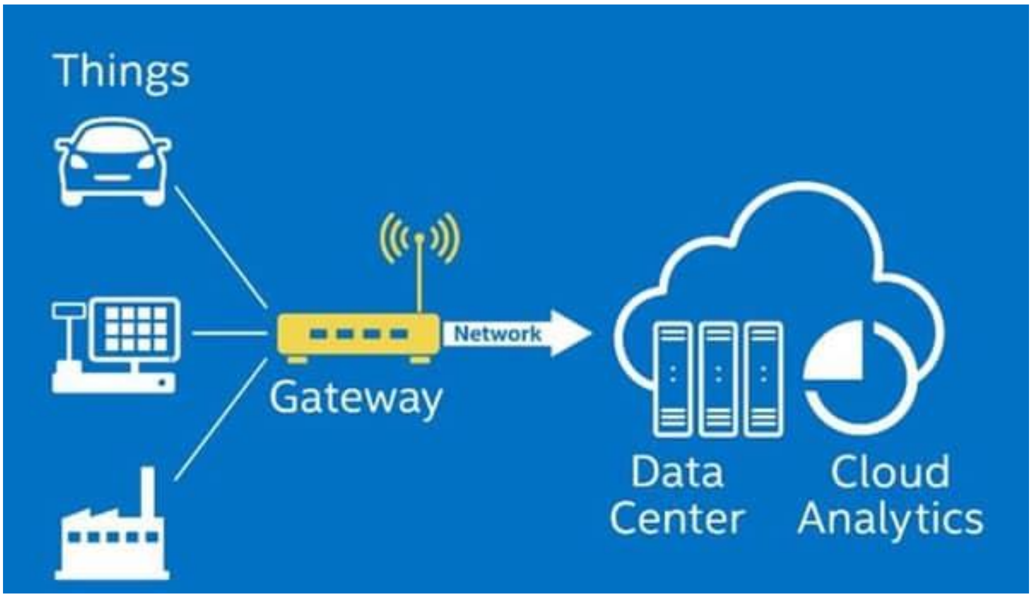
Image_04: *shows the potential uses of smart sensors in every aspect of U.S. retail operation.*

(Source: Softobotics Gaurav Kunal, https://www.softobotics.org/blogs/revolutionizing-iot-applications-with-sensor-technologies/)

2.2.4 IoT Gateways

IoT Gateway works as a bridge between edge devices and cloud BI systems. It is employed to collect data from sensors, filter them and generate preprocess information, finally transform to cloud platforms for further analysis using BI analytics.

Image_05: *shows how the Gateway works as a bridge between edge devices and cloud BI systems.*

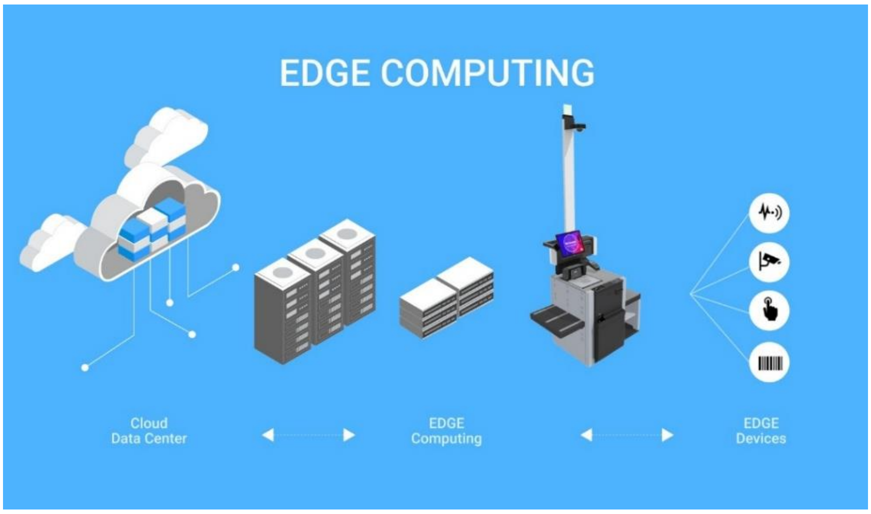


(Source: https://www.i-scoop.eu/internet-of-things-iot/iot-gateways/)

2.2.5 Edge Computing

Edge computing refers to an IT architecture which processes data near its source devices including IoT devices, local servers, or edge gateways, rather than centralized, distant cloud data center. This system helps minimizing latency, lowering bandwidth costs, and enables retailers with real-time, actionable business insights. While cloud computing offers immense, centralized, and scalable storage approach, Edge computing provides a solution for immediate, local, and, in some cases, decentralized data processing. Use case in retail sector: localized analytics for inventory management and personalized customer experiences. Important for time-sensitive retail fulfillment.

Image_06: *shows the edge computing phases and components.*



(Source: https://seechange.com/future-proofing-retail-with-edge-to-cloud-computing/)

2.2.6 Smart Warehousing Technologies

Today's U.S. retailers tend to rely on automation processes throughout their operational areas including warehouses, in-stores, as well as transporting products to make it more convenient, efficient, and timely manner. For instance, Amazon uses IoT-integrated robotics in fulfillment centers. Modern, cutting-edge smart warehouse technologies include:

→ *IoT-enabled robotics*

→ *Autonomous Mobile Robots (AMRs)*

→ *Smart conveyor systems*

→ *Automated storage & retrieval systems (AS/RS)*

IoT-enabled Robotics

IoT-enabled robotic systems can be deployed in the warehouse/fulfillment centers to automate warehouse operations by connecting robots to the Internet of Things (IoT). Integration with IoT enables robots to communicate with other devices, enhancing coordination and efficiency in tasks such as picking, sorting, packing, and even transporting goods. With real-time data exchange, warehouses can optimize workflows and reduce human intervention.

Image_07: *shows the IoT-enabled Robotics functioning in a typical warehouse.*

(Source: https://roboticsandautomationnews.com/2025/10/24/why-real-time-reporting-matters-for-autonomous-warehouse-robotics/95879/)

Autonomous Mobile Robots (AMRs)

AMRs refers to self-driven automatic vehicles developed to transport products from one place to another within the warehouse/fulfillment centers. These AMRs vehicles navigate freely within the warehouse using intelligence software that generates dynamic routes and assigns optimal paths for each task. Equipped with advanced sensors and scanners, AMRs can detect and avoid obstacles, operating safely alongside other machines and people. Their autonomy, intelligence, flexibility, scalability, and accuracy make them ideal for modern warehouse environments.

Image_08: *shows the Autonomous Mobile Robots (AMR) for factory floors.*

(Source:RoboticsBiz,https://roboticsbiz.com/autonomous-mobile-robots-amr-for-factory-floors-key-driving-factors/)

Smart conveyor systems

Smart conveyor systems in warehouses combine traditional mechanical conveyors with modern automation and IoT technologies. This smart system is designed to faster material flow, minimize repetitive human errors, and increase efficiency. With embedded sensors, automated controls, and machine learning, smart conveyors enable efficient, reliable transport of goods within the warehouse environment.

Image_09: *Smart Conveyor Systems: How They're Transforming Material Handling*

(Source: e-ENTRA, https://entra-eg.com/how-smart-conveyor-systems-are-revolutionizing-material-handling/)

Automated storage & retrieval systems (AS/RS)

Retailers use AS/RS as an advanced automated solution designed to enhance warehouse management efficiency and optimize utilization of warehouse spaces. Unlike traditional system, AS/RS system enables retailers to automatically place and retrieve items from inventory locations within warehouse compounds by using automated shuttles or vehicles. These systems optimize inventory management process by increasing speed, accuracy, and efficiency, allowing for better utilization of warehouse space, and minimizing manual handling.

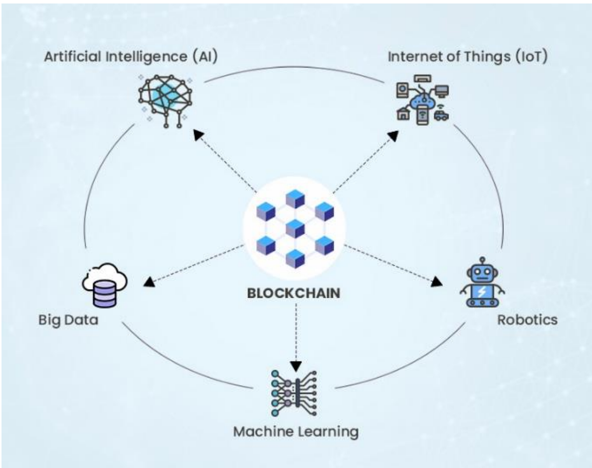
Image_10: *shows a typical warehouse using Automated storage & retrieval systems (AS/RS)*

(Source: Storage Solutions, https://storage-solutions.com/solutions/mobile-asrs/)

2.2.7 Blockchain and IoT Integration

In the U.S. retail environment, advanced blockchain technology, Internet of Things (IoT), and artificial intelligence (AI) are innovations with enormous potential to reshape traditional business processes. Blockchain technologies aim to improve network and data protection systems by restricting unauthorized access and manipulation of network data. In line with blockchain, AI can improve the IoT network's efficiency by making it smarter and more autonomous. The integration of blockchain-IoT-AI technologies can ensure secure, tamper-proof tracking system, enhance traceability, and improve compliance transparency.

Image_11: *how IoT, AI, and blockchain can work together for maximizing efficiency*



(Source: https://blockchain.oodles.io/blog/blockchain-ai-iot-business-solutions/)

2.3 Business Intelligence and Predictive Analytics

Business intelligence (BI) application extracts, transforms and load (ETL) structured and unstructured data into the system and analyze them to enable retailers to take data-driven business decisions (Rahman et al., 2025). Predictive analytics and machine learning models enable retailers to forecast demands, anomaly detection, and supplier risk analysis (Saghafian et al., 2021). Therefore, the integration between business intelligence and machine learning (predictive analytics) together can empower business managers to take strategic decisions based on critical business insights and trends following consumer future demands and can take preemptive measures as per the future demand lines. As per Waller and Fawcett (2013), data-driven retail supply chains most likely outperform traditional supply chain models because of enhanced visibility and predictive capability.

2.4 Robotics and Warehouse Automation

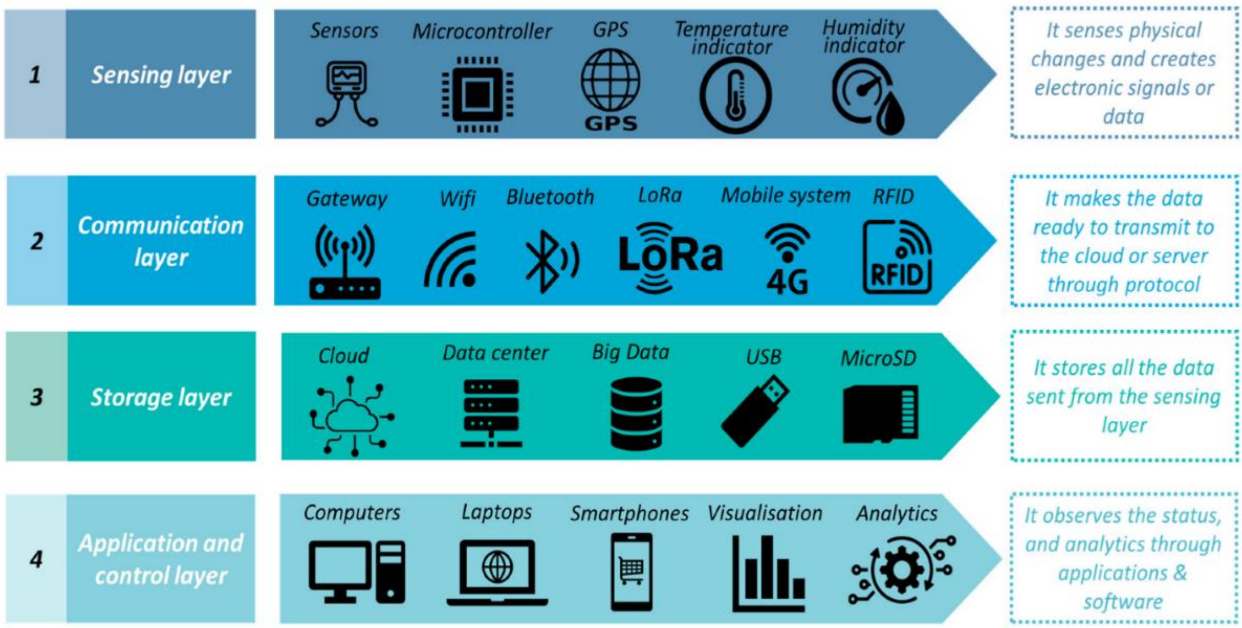
In modern retail supply chains, robotics and warehouse automation is no longer a concept only, its now reality. With the advancement of modern technologies retailers are more likely relying on robotics and warehouse automation to optimize supply chain processes. Automation in warehouses and robotics deployment empower retailers in managing increased demands for faster fulfillment, lowering operating costs by minimizing waste, and optimizing supply chains (Rahman et al., 2025).

In today's warehouse environment, robotics play every role from AS/RS (automated storage and retrieval system) in modern warehouses to transport products by AMRs (autonomous mobile robots). Intelligent manufacturing principles within Industry 4.0 emphasize cyber-physical integration between digital intelligence and physical execution (Zhong et al., 2017). While robotics improves throughput and reduces labor dependency, static rule-based automation lacks adaptive intelligence unless integrated with analytics systems.

3. Integrated IoT–BI–Robotics Architecture

The latest technologies for the integration of IoT–BI–Robotic can be classified into four sections following the components of the standard 4-layer architecture. Anything from a smartwatch to a cruise control system with sensors might be considered a "thing" in the Internet of Things (e.g., temperature, humidity, light, location, etc.). The communication devices (Wi-Fi, RFID, Bluetooth, 3G/4G, etc.) are other components of the IoT ecosystem and facilitate communication with other machines or humans and computing resources.

]**Image_12:** *Shows the 4-layer architecture arrangement with components.*



Source: https://doi.org/10.3390/su15010614

3.1 Sensing Layer

This IoT layer senses physical changes and creates electronic signals or data. It encompasses all the devices implemented in the environment, such as sensors (e.g., temperature/humidity, light, motion and location, etc.), energy supply devices (e.g., batteries, solar panels) and other devices including GPS fleet monitoring, RFID-enabled inventory tracking that can manage functionalities. These devices are used to generate streaming operational data, enhancing visibility and reducing information asymmetry (Ben-Daya et al., 2019).

3.2 Communication Layer

This layer makes the data ready to be transmitted to cloud or server through protocol. This includes devices that transmit and receive transactional data throughout the communication system directly or via gateways. It also encompasses all necessary communication technologies, wired and wireless, such as Wi-Fi, Zigbee, Bluetooth, 3G/4G, LoRaWAN, etc. It provides functionality for the network, i.e., connectivity, mobility, authentication, authorization, and accounting.

3.3 Storage Layer

It stores all the data sent from the sensing layer. This layer refers to raw data processing and storing clean datasets, as well as dedicated functionality for each application and service, since emerging services have diverse requirements. We can store our processed datasets in a cloud storage system, using data centers, USB etc. Data lakes and streaming pipelines support real-time ingestion and historical storage. ETL/ELT processes standardize sensor data for analytics.

3.4 Application and Control Layer

This layer observes the status and analytics through applications and software, i.e., this section deals with the analysis of the data retrieved from the storage layer allowing the end user to make data-driven informed decisions. Retailers use analytical and visualization tools like power BI and Tableau to analyze and visualize the critical business insights. Robotics and warehouse automation also work in line with IoT, business intelligence to optimize supply chains.

4. Integrated IoT-BI-Robotics: Advantages

Integration among IoT, BI, and Robotics can benefit retailers in numerus ways in optimizing operational efficiency, accuracy in forecasting demands, and resilience by early disruption detection, real-time inventory redistribution, and reduce downtime in operational activities.

4.1 Retail Efficiency

Retailers' efforts continue relentlessly in optimizing operational efficiency in every aspect of their business operations. Integration of IoT-BI-Robotics enhances operational efficiency by minimizing downtime, optimizing supply chains, and maximizing sales revenue. More specifically, IoT sensing eliminated blind inventory zones, whereas BI analytics converts transactional data into actionable insights, predictive intelligence, and Robotics operationalized decisions autonomously. Therefore, integration of these cutting-edge technologies can improve the accuracy in managing inventory, decrease fulfillment lead time, and reduce downtime due to predictive maintenance alerts. These findings align with research emphasizing the competitive advantage of digitally integrated supply chains (Bharadwaj et al., 2013).

4.2 Accuracy in Forecasting

Integrated IoT-BI-Robotics benefits retailers with improved forecasting accuracy by which they can take supply chain decisions more accurately to maximize sales revenues. Accuracy in forecasting can reduce wastage, avoid over or understocking situations. The ability of appropriate forecasting enhances retailers' efficiency in inventory planning accuracy.

4.3 Resilience Enhancement

Integrated IoT-BI-Robotics architecture enables retailers to control and reduce disruption recovery time by early disruption detection. It facilitates adaptive rerouting and dynamic stock balancing improves responsiveness. Besides, it enables retailers with predictive failure prevention, Automated rerouting, and real-time inventory redistribution. This supports resilience frameworks emphasizing agility and adaptability (Christopher & Peck, 2004; Ivanov & Dolgui, 2020).

5. Integrated IoT-BI-Robotics: Considerations

5.1 Investment

Retailers face high installation and integration costs which may limit SME adoption. However, cloud-based subscription models can facilitate retailers with convenient costs covering all the necessary services retailers require to optimize supply chain efficiency and resilience.

5.2 Cybersecurity

Since the retailers are going through digital transformations, they may face threat from unsecured cybersecurity. In this situation, they may consider end-to-end encryption, zero-trust architectures to remain safe from any external cybersecurity threats.

5.3 Reskilling

Retailers need to develop learning infrastructure to reskill their employees and workforces as digital transformation requires analytics and robotics management competencies.

6. Future Research Directions

The integration of IoT sensing, AI-driven BI analytics, and Robotic automation has already played significant role to transform U.S. retail supply chains in optimizing efficiency and resilience. As the advancement of these technologies continues, existing gaps and opportunities to grow further attract scholarly investigation to increase scalability, enhance resilience, and sustainability. Therefore, future research would focus on areas like AI-driven autonomous supply chains, IoRT (Internet of Robotic Things), future BI architecture, data integration process, cyber-physical systems, SME scalability.

Researchers may also focus on areas like last-mile delivery innovation and robotics, scalability and cost-benefit analysis of smart technologies, and resilience modeling and risk management processes.

7. Conclusion

The U.S. retail is going through the digital transformation in every aspect of business operational activities including supply chain management system. Today's inventory management system is heading towards robotic automation to enhance efficiency and resilience. Integration of IoT Sensing, Artificial Intelligence (AI)-driven BI Analytics, and Robotic automation represents a paradigm shift in U.S. retail supply chains that could reshape this transformation even further to maximize utilization of warehouse spaces, speed up product places and retrieval processes to ensure excellence in customer experience.

Future research should focus more on integrated, intelligent, and adaptive supply chain ecosystems. The convergence of AI-driven BI applications, IoT sensing, and Robotic automation IoRT (Internet of Robotic Things) – has the future potentials to create supply chains that are not only efficient but also resilient, sustainable, and self-optimizing.

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