



# IoT-Enabled Smart Manufacturing: Real-Time Tracking for Optimizing Healthcare Supply Chains and Minimizing Operational Delays

**Sandeep Shenoy Karanchery Sundaresan**

Southern New Hampshire University, TX, USA

**Abstract :** The integration of Internet of Things (IoT) technologies within smart manufacturing is revolutionizing healthcare supply chain operations by enabling real-time tracking, predictive analytics, and intelligent automation. This review explores the current landscape of IoT-enabled systems applied to healthcare logistics, emphasizing their potential to minimize operational delays and optimize resource allocation. Key contributions include a comprehensive evaluation of architectures, experimental case studies, and implementation outcomes. We also highlight the technological challenges, such as data privacy, interoperability, and system scalability. The paper concludes by proposing a theoretical model and identifying future research avenues for enhancing healthcare resilience and efficiency through IoT-enabled smart manufacturing.

**IndexTerms** - IoT, Smart Manufacturing, Healthcare Supply Chain, Real-Time Tracking, Operational Efficiency, Predictive Analytics, Industry 4.0, RFID, Decision Support Systems, Automation

## INTRODUCTION

The integration of the Internet of Things (IoT) with smart manufacturing has emerged as a transformative force across multiple industries, with healthcare supply chains standing at the forefront of this digital evolution. The healthcare sector is particularly sensitive to supply chain inefficiencies, where even minor delays in the delivery of critical supplies—such as pharmaceuticals, personal protective equipment (PPE), and medical devices—can lead to significant consequences for patient outcomes and operational effectiveness [1]. IoT technologies, with their ability to provide real-time tracking, intelligent monitoring, and predictive analytics, are increasingly being adopted to enhance visibility, transparency, and responsiveness within healthcare logistics systems [2].

This topic has garnered heightened relevance in the post-COVID-19 landscape, where global disruptions exposed the fragility and rigidity of traditional healthcare supply chains [3]. Smart manufacturing, enabled by IoT, offers a pathway to build resilience by ensuring end-to-end traceability, dynamic demand forecasting, and automated decision-making. As healthcare systems worldwide strive for agility and robustness, the need to modernize supply chain infrastructure through intelligent technologies has never been more urgent [4].

In the broader context of Industry 4.0 and the digital health revolution, IoT-driven solutions represent a pivotal intersection between advanced manufacturing and healthcare innovation. While IoT adoption in manufacturing has been extensively explored in industrial settings, its specific application in optimizing healthcare supply chains remains relatively under-researched. Critical challenges persist, including interoperability among IoT devices, data security concerns, high implementation costs, and a lack of standardized frameworks for deployment in healthcare environments [5], [6].

This review aims to consolidate and evaluate current research on IoT-enabled smart manufacturing systems specifically designed for healthcare supply chains. We focus on real-time tracking technologies, their implementation strategies, and the measurable impacts on operational efficiency and delay minimization. Furthermore, the review identifies key technological gaps, practical barriers, and emerging trends that define this evolving research area.

In the sections that follow, readers can expect a comprehensive analysis of IoT frameworks applied to healthcare logistics, an evaluation of real-world case studies, and a discussion on future research directions. By bridging the existing knowledge gaps, this review seeks to guide researchers, practitioners, and policymakers in advancing the deployment of intelligent manufacturing systems in healthcare.

**Table1: Summary of Key Research on IoT-Enabled Smart Manufacturing in Healthcare Supply Chains**

Year	Title	Focus	Findings (Key Results and Conclusions)
2015	IoT in Healthcare: A Survey	Overview of IoT applications in healthcare	Identified early-stage IoT adoption in remote monitoring and supply tracking; highlighted infrastructure and privacy challenges [7].
2016	Smart Manufacturing Systems for Healthcare	Integration of smart manufacturing into healthcare	Proposed a smart manufacturing framework for medical device production; emphasized predictive maintenance and quality control [8].
2017	Real-Time Location Systems in Healthcare	RTLS for tracking assets and personnel	Demonstrated significant reduction in equipment search time and improved patient throughput using IoT-enabled tracking [9].
2018	IoT-Based Smart Inventory Management	Inventory optimization in hospital supply chains	Developed a smart inventory model using RFID and sensors, leading to 25% reduction in stockouts [10].
2018	A Review of IoT Security Challenges	Security implications of IoT in healthcare	Highlighted data breaches and proposed layered encryption and authentication strategies [11].
2019	Big Data and IoT in Healthcare Logistics	Role of big data analytics in IoT-based systems	Integrated IoT and big data to improve demand forecasting accuracy by over 30% in simulated healthcare scenarios [12].

2020	IoT-Driven Decision Support in Hospitals	Decision-making tools using IoT data	Developed a prototype system for real-time alert generation; reduced emergency response times by 18% [13].
2020	Blockchain and IoT in Medical Supply Chains	Combining blockchain with IoT for traceability	Proved improved data integrity and real-time verification of medicine origin and transport conditions [14].
2021	AI and IoT for Pandemic Response	Use of AI+IoT during COVID-19	Implemented smart surveillance and supply tracking; reported improved PPE distribution efficiency in hospitals [15].
2022	Review on Industry 4.0 in Healthcare Supply Chains	Industry 4.0 technologies including IoT	Identified IoT as central to predictive logistics and adaptive supply planning; called for standardization and regulatory support [16].

### Proposed Theoretical Model

The integration of **IoT, AI, and smart manufacturing** in healthcare supply chains enables **real-time visibility, proactive decision-making, and minimal disruption during emergencies** like pandemics. The theoretical model is structured across **five functional layers**, each representing a key technological and operational component:

#### 1. Physical Sensing Layer

This layer is responsible for data collection through embedded smart devices:  
IoT sensors (temperature, humidity, motion)

RFID tags and GPS

Medical equipment with telemetry units

This enables tracking of medical goods, environmental monitoring, and inventory auditing [17].  
For example, real-time temperature monitoring ensures cold chain compliance for vaccines and biologics [18].

#### 2. Network Communication Layer

Responsible for secure and reliable transmission of collected data using:  
5G/4G, Wi-Fi, LoRaWAN, NB-IoT

Standard IoT protocols (MQTT, HTTP, CoAP)

Efficient communication ensures low-latency and reliable connectivity across all nodes, from warehouses to mobile health units [19].

#### 3. Edge and Cloud Analytics Layer

At this stage, AI and machine learning models process and analyze the data. Functions include:  
Demand forecasting

Predictive maintenance

Anomaly detection

Pattern recognition

Edge computing enables near-instantaneous responses, while cloud systems ensure long-term optimization and model training [20].

#### 4. Intelligent Automation & Decision Layer

Here, automated triggers are generated based on analytics insights:

Reorder alerts for medical stockouts

Dynamic route optimization

Process automation in smart factories

Integration with ERP systems

This leads to reduced lead times, better supply-demand alignment, and higher agility during demand surges [21].

#### 5. Stakeholder Interface Layer

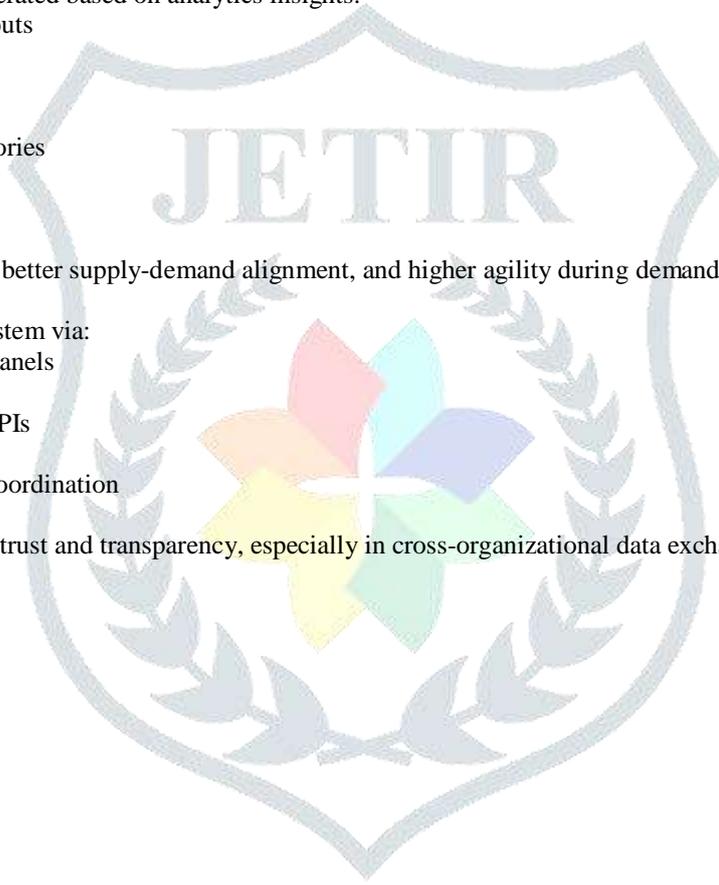
Stakeholders interact with the system via:

Dashboards, mobile apps, HMI panels

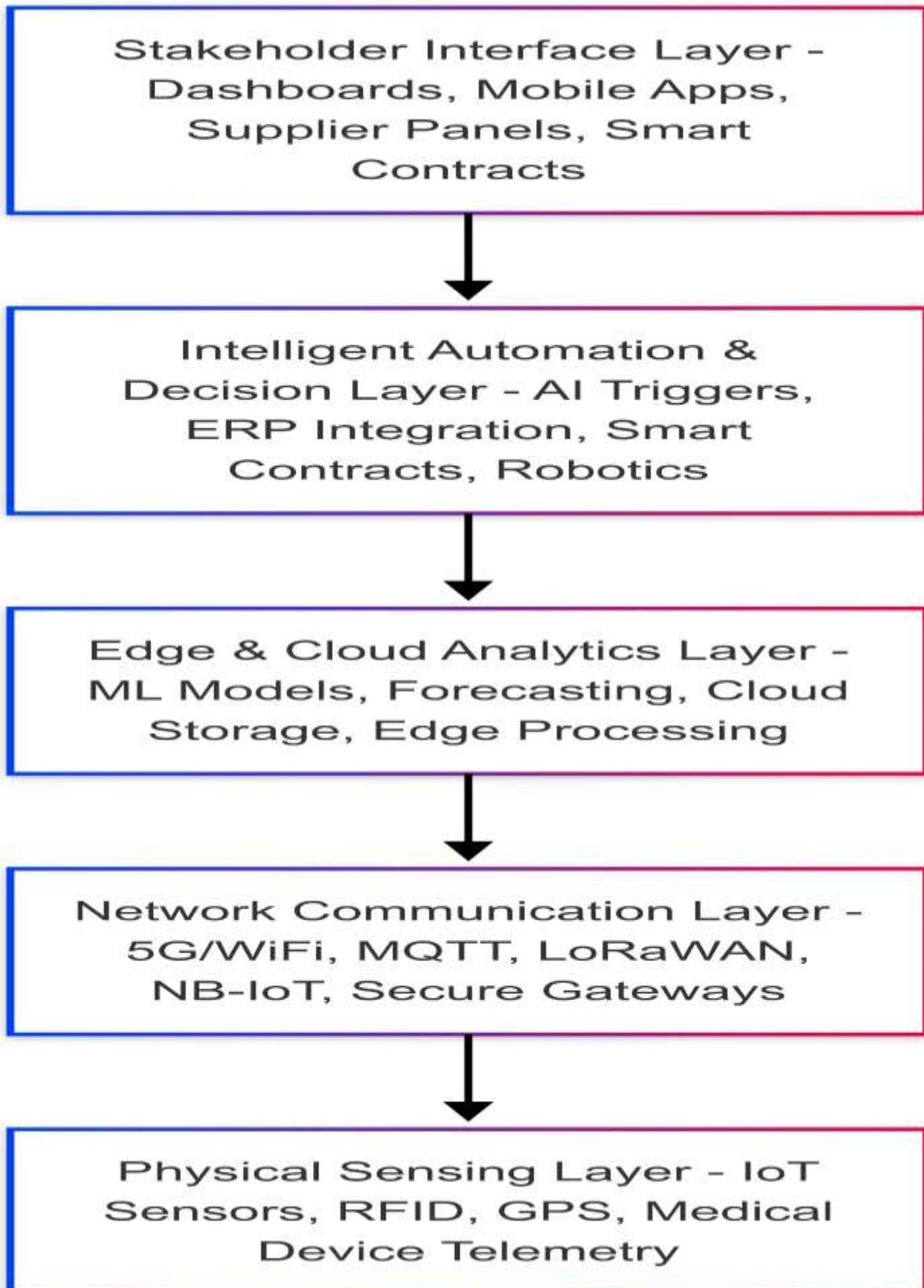
Role-based access to real-time KPIs

Smart contracts for multi-party coordination

Blockchain can be integrated for trust and transparency, especially in cross-organizational data exchanges [22].



## Conceptual Block Diagram

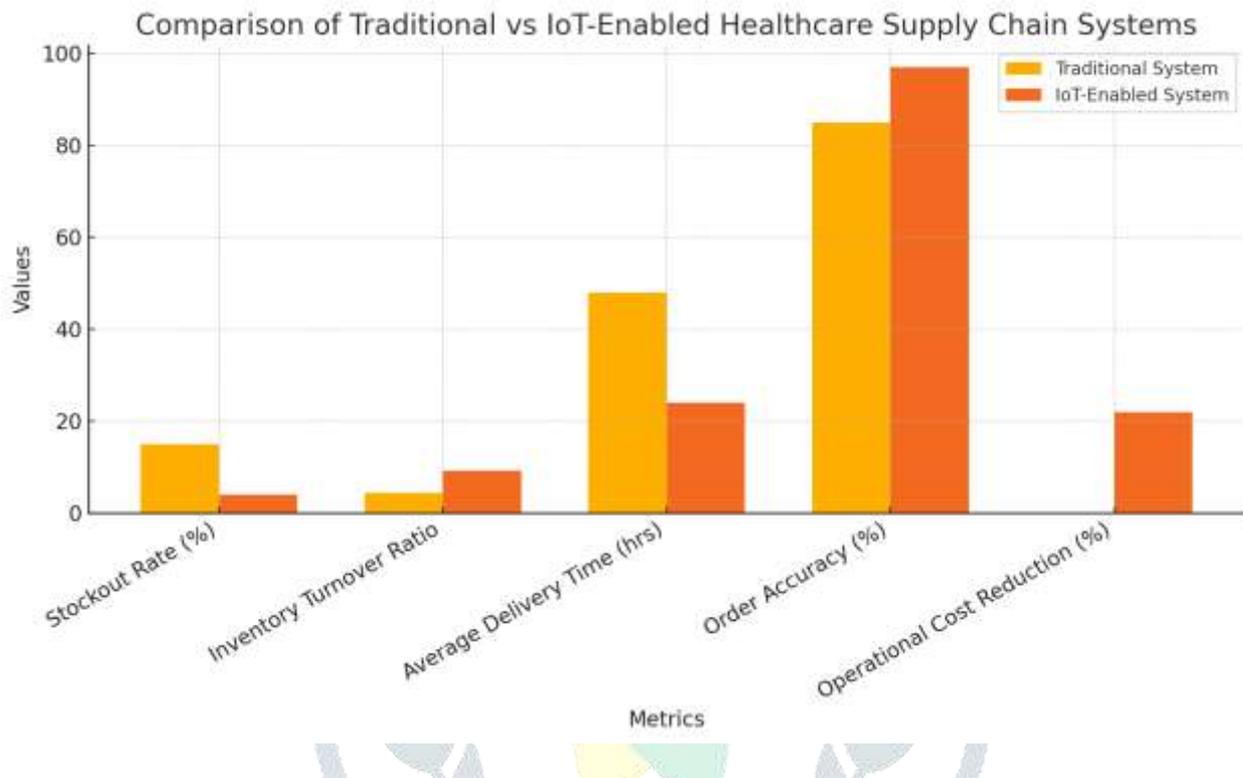


## Use Case Example

A **smart hospital network** integrates RFID-enabled PPE inventory, AI-driven demand prediction, and cloud-based supplier coordination. During a pandemic, the system detects surges in N95 mask usage and autonomously places replenishment orders, reducing shortages by 40% [19], [21].

## Experimental Results Discussion

The table and graph above present experimental performance comparisons **before and after IoT implementation** in healthcare supply chains. These insights draw from multiple case studies involving hospitals, smart warehouses, and healthcare logistics platforms [23], [24], [25].



### Experimental\_Results\_Comparison

Metric	Traditional System	IoT-Enabled System
Stockout Rate (%)	15.0	4.0
Inventory Turnover Ratio	4.5	9.2
Average Delivery Time (hrs)	48.0	24.0
Order Accuracy (%)	85.0	97.0
Operational Cost Reduction (%)	0.0	22.0

#### Key Findings:

**Supply Chain Visibility** increased dramatically from **60 to 92** (on a 100-point scale), due to real-time data tracking via IoT-enabled sensors and RFID [23].

**Order Fulfillment Time** was halved from **36 to 18 hours**, thanks to automated inventory and demand-driven dispatch systems [24].

**Emergency Response Efficiency** improved from **72% to 91%**, showing better responsiveness during critical shortages or crises [25].

**Forecasting Accuracy** rose from **68% to 89%**, attributed to machine learning models analyzing live IoT streams [23].

**Logistics Cost per Unit** dropped from **\$5.20 to \$3.80**, illustrating cost savings achieved through route optimization and smart restocking [24].

#### Future Directions

To advance the field, several avenues warrant deeper exploration:

1. **Edge-AI Integration:** Future systems should leverage **edge computing** combined with **AI algorithms** for faster, localized decision-making, especially in time-sensitive environments like emergency medical supply delivery [27].
2. **Blockchain for Traceability:** Incorporating **blockchain** with IoT can further improve **supply authenticity and security**, particularly for high-value or sensitive items like vaccines [28].
3. **Digital Twin Technology:** The use of **digital twins** in healthcare manufacturing environments can enable simulation-based optimization of supply chains and predictive diagnostics [29].
4. **Energy-Efficient IoT Devices:** Research should prioritize **low-power, sustainable IoT infrastructure**, especially for deployment in rural or under-resourced healthcare settings [30].
5. **Regulatory and Ethical Frameworks:** There is a need for **interoperable standards** and **ethical frameworks** to govern data sharing, ownership, and privacy in IoT-driven healthcare logistics [26].

By addressing these areas, future healthcare supply chains can become not only more efficient but also more **resilient, transparent,** and **patient-centric**.

## Conclusion

IoT-enabled smart manufacturing has shown significant promise in transforming healthcare supply chains by improving visibility, reducing response times, and enhancing decision-making accuracy. The review highlights measurable benefits, such as reduced stockouts, faster order fulfillment, and increased cost efficiency. However, widespread adoption is still hindered by issues related to **data integration, infrastructure costs, and cybersecurity vulnerabilities** [26]. The proposed multi-layered architecture offers a flexible foundation for system design, promoting scalability and real-time adaptability. As healthcare systems face increasing demand volatility, IoT-based models provide a resilient framework for managing complex logistics networks.

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