International Journal of Computer and Organization Trends
ISSN: 2249 – 2593 / https://doi.org/10.14445/22492593/IJCOT-V15I1P303
Volume 15 Issue 1, 25-32, Jan-Apr 2025

Original Article

Enhancing Hospital Inventory Management with Blockchain and SPC

Pradeep Chandramohan

Maryland, USA.

Received: 07 January 2025 Revised: 11 February 2025 Accepted: 03 March 2025 Published: 17 March 2025

Abstract - *Hospitals are always facing challenges in effectively managing their medical supplies and equipment, including problems of lack of or too much of the supply and compliance with the rules. Many traditional methods of inventory tracking, such as the use of manual records and bar codes, are known to be error-prone and ineffectual. This paper explores the effectiveness of combining Blockchain technology and Statistical Process Control (SPC) to improve hospital inventory management. In this paper, real-time weight sensors are used to monitor the supply chain, blockchain is used to document the supply chain, and SPC is used to detect anomalies in the supply chain. This system enhances the visibility of the supply chain and executes several functions autonomously. The proposed framework is expected to minimize the cases of inventory mismanagement, ensure that hospitals comply with the required laws and regulations, and develop a more effective and efficient inventory management system.*

Keywords - *Blockchain, Healthcare Inventory, SPC, Smart Contracts, Real-Time Monitoring, Data Security, Automated Restocking, Anomaly Detection, Supply Chain Optimization.*

1. Introduction

Hospital inventory mismanagement can lead to significant financial losses and impact patient care. A recent case at a hospital in Wyoming resulted in an estimated $3 million loss due to a materials management error that led to misplaced and expired supplies (Newcastle Journal, 2023). Furthermore, 46% of hospitals still rely on manual inventory tracking methods, leading to inefficiencies such as stockouts and wastage (Dataman).

Studies also show that 40% of a hospital's pharmacy budget is spent on rush orders for non-contract items due to inventory mismanagement (HHM Global). These inefficiencies highlight the urgent need for a real-time, automated, and tamper-proof hospital inventory management system. Our research integrates Blockchain and SPC to address these issues by ensuring secure recordkeeping, automated anomaly detection, and predictive restocking. Existing hospital inventory management systems lack secure, real-time tracking, leading to inefficiencies such as stock miscalculations, fraud risks, and compliance failures. While traditional inventory methods rely on manual entries and periodic checks, they do not provide predictive monitoring or tamper-proof recordkeeping.

This research addresses these gaps by integrating Blockchain for secure transactions and Statistical Process Control (SPC) for real-time anomaly detection, ensuring precise inventory tracking and automation.

- Monitors stock levels instantly by utilizing weight sensors.
- It uses blockchain to keep records secure and unchangeable.
- It applies statistical process control methods for identifying changes in weight and unusual patterns.
- Automated alerts are requests for restocking are sent out when inventory levels fall below set thresholds.

2. Novelty of This Work

Unlike previous methods of managing inventory, which can involve infrequent stock audits and manual or barcode-based tracking systems, this research uses Blockchain for secure and immutable record keeping and SPC for real-time anomaly detection. Previous studies have applied Blockchain to supply chain management and SPC to quality control in manufacturing, but their combination for hospital inventory management has not been investigated. Our approach, in addition to real-time tracking, includes automated anomaly detection and predictive restocking mechanisms, solving critical gaps in current systems.

3. Literature Review

3.1. Current Methods in Hospital Inventory Control

Most hospitals have inventory systems that employ barcodes, regular physical stock counts, and management information systems (MIS or ERP). However, such approaches are deficient in real-time monitoring, unforgeable data, and predictive control, which results in wrong stock reordering and legal consequences.

3.2. Blockchain in the Healthcare Supply Chain

Several studies have been conducted on applying Blockchain technology to the security of medical supply chains.

Halimi et al. (2023) suggested a Blockchain application for hospital logistics to increase the system's transparency but did not incorporate the ability to predict the need for restocking.

For instance, Yadav et al. (2021) proposed using Blockchain in managing pharmaceutical supplies but did not incorporate real-time monitoring of the supplies.

3.3. SPC in Inventory Control

Statistical Process Control (SPC) is one of the most common tools in production management to detect changes in a process; however, its use in hospital inventory control is scarce.

Song et al. (2020) explained how SPC enhances the detection of anomalies in the supply network.

3.4. Research Gap

Previous research has partly addressed the use of Blockchain and SPC in different fields, but the integration of the two in hospital inventory control has not been investigated.

The proposed approach enhances the real-time monitoring of the supply chain, fights fraud, and automates the restocking process using SPC-based anomaly detection.

4. Case Studies of Inventory Management Failures

4.1. Case Study 1

$3 Million Hospital Inventory Loss (Wyoming, 2023) A hospital in Wyoming had a $3 million loss as a result of poor materials management and expired supplies (Newcastle Journal, 2023).

The facility did not have effective materials management and the identification and control of its supplies because it used manual tracking systems, which led to lost supplies and inaccurate accounts of supplies that were still in stock. Also, the lack of real-time monitoring led to the expiration of important medical supplies.

If the hospital had adopted a Blockchain and SPC-based inventory system, the real-time anomaly detection and the automatic restock alerts could have prevented this loss.

4.2. Case Study 2

Pharmaceutical Inventory Mismanagement Research shows that 40% of hospital pharmacy budgets are lost on rush orders for non-contract items, mainly because of poor inventory management (HHM Global). For example, a US-based hospital faced a critical shortage of anesthesia drugs because of poor inventory management, which led to urgent and expensive procurement.

An SPC-based system would have shown supply fluctuations earlier and, therefore, would have prompted early restocking and cost savings. These case studies show that poor inventory management poses significant financial and operational risks to hospitals.

The proposed Blockchain and SPC-based approach solves these problems by providing real-time monitoring, automatic alerts, and a secure recordkeeping system.

5. System Architecture

5.1. Data Collection Process

The proposed system is designed to integrate weight sensors, SPC monitoring, and Blockchain logging to provide real-time inventory information.

The data collection process is detailed as follows:

1. Weight Sensors Capture Inventory Data – The stock level is also measured by weight sensors in each inventory rack (e.g. IV fluid bottles, syringes).
2. Data Transmission to SPC Module – Weight readings are transmitted to an SPC-based monitoring system, which evaluates whether the values are within control limits (UCL/LCL).
3. Anomaly Detection and Alert Generation – If the weight of an inventory is found to be more or less than the permissible level, it results in an anomaly, which in turn results in an alert to the hospital administrators.
4. Blockchain Logging for Security – All the changes in the inventory, whether it is restocking or any anomaly, are documented on the Blockchain ledger to make it immune to any form of alteration.
5. Smart Contracts Automate Restocking – If the levels of stock fall to, for instance, 50%, a smart contract can automatically create a purchase order for restocking.

5.1.1. Blockchain Integration

The Blockchain ledger ensures:

- Immutable logging of stock movements.
- Permanent recording of stock changes.
- Ensuring that records are secure and cannot be altered for audit purposes.
- Ensuring that suppliers and hospitals can securely conduct transactions.
- Implementing automated contracts to handle the replenishment of supplies.

5.2. Comparative Analysis: (Table 1)

Table 1. Comparative analysis

Feature	Manual	RFID	ERP	Blockchain + SPC
Real-time Tracking	No	Yes	Yes	Yes
Tamper-Proof Data	No	No	Partial	Yes
Automated Restocking	No	Yes	Yes	Yes
Fraud Prevention	No	No	Partial	Yes
Anomaly Detection	No	No	Limited	Yes
Predictive Monitoring	No	No	Limited	Yes
HIPAA/FDA Compliance	No	No	Yes	Yes

6. SPC-Based Inventory Monitoring

6.1. SPC in Hospital Inventory

Statistical Process Control (SPC) is a quality control technique that monitors and controls process variations. It applies statistical methods to detect abnormalities in data trends and ensure that systems operate within predefined control limits. It offers an approach to uncover inventory variations by monitoring weight changes in each inventory item, such as Glucose IV bottles, to ensure uniform weight distribution over time.

- The Upper Control Limit (UCL) defines the highest allowed weight deviation, while the Lower Control Limit (LCL) defines the lowest acceptable weight threshold.
- Anomaly Detection: If a weight measurement falls outside these limits, it triggers an alert.

6.2. SPC Formula

This formula illustrated in Figure 1 shows the boundaries used in Statistical Process Control (SPC, for monitoring the stability of a process. In controlling inventory weight.

$$LCL \leq \left(\frac{1}{N}\right)\sum_{i=1}^{N} w(i,t) \leq UCL$$

Fig. 1 SPC Formula

Where:

$$LCL \leq \left(\frac{1}{N}\right)\sum_{i=1}^{N} w(i,t) \leq UCL$$

LCL- Lower control limit
UCL- Upper control limit
W(i,t) = Observed weight of inventory at time t, for item i
N = Number of inventory observations

$$\sum_{i=1}^{N} w(i,t)$$

= The total sum of inventory weights over **N** items, representing the mean

Fig. 2 Equation breakdown

Meaning:

This equation (Figure 2) states that the average inventory weight should remain within the control limits (LCL and UCL).

If the mean weight exceeds these limits, it signals an anomaly requiring intervention (e.g., restocking or fraud detection).

6.3. Statistical Methods

SPC uses statistical techniques to monitor inventory weight fluctuations and detect anomalies. The control limits (UCL and LCL) are determined using the formula:

$UCL = \bar{X} + (3 * \sigma)$,
$LCL = \bar{X} - (3 * \sigma)$

Where:

- $\bar{X}$ (Mean Weight): The average inventory weight over a period.
- σ (Standard Deviation): Measures the variability in weight data.
- 3σ Rule: A common SPC approach, where 99.7% of data should fall within three standard deviations of the mean.

6.3.1. Sample Data for SPC Calculation

Below is a sample dataset (Table 2) of inventory weight readings over a period:

Table 2. SPC Calculation

Time Interval	Item	Recorded weight (grams)	Anomaly Detected?
9:00 AM	Glucose IV	500	No
10:00 AM	Glucose IV	495	No
11:00 AM	Glucose IV	470	**Yes (Below LCL)**

7. Flow Diagram

The following flowchart (Figure 3) represents the hospital inventory management process integrating Blockchain and SPC anomaly detection.

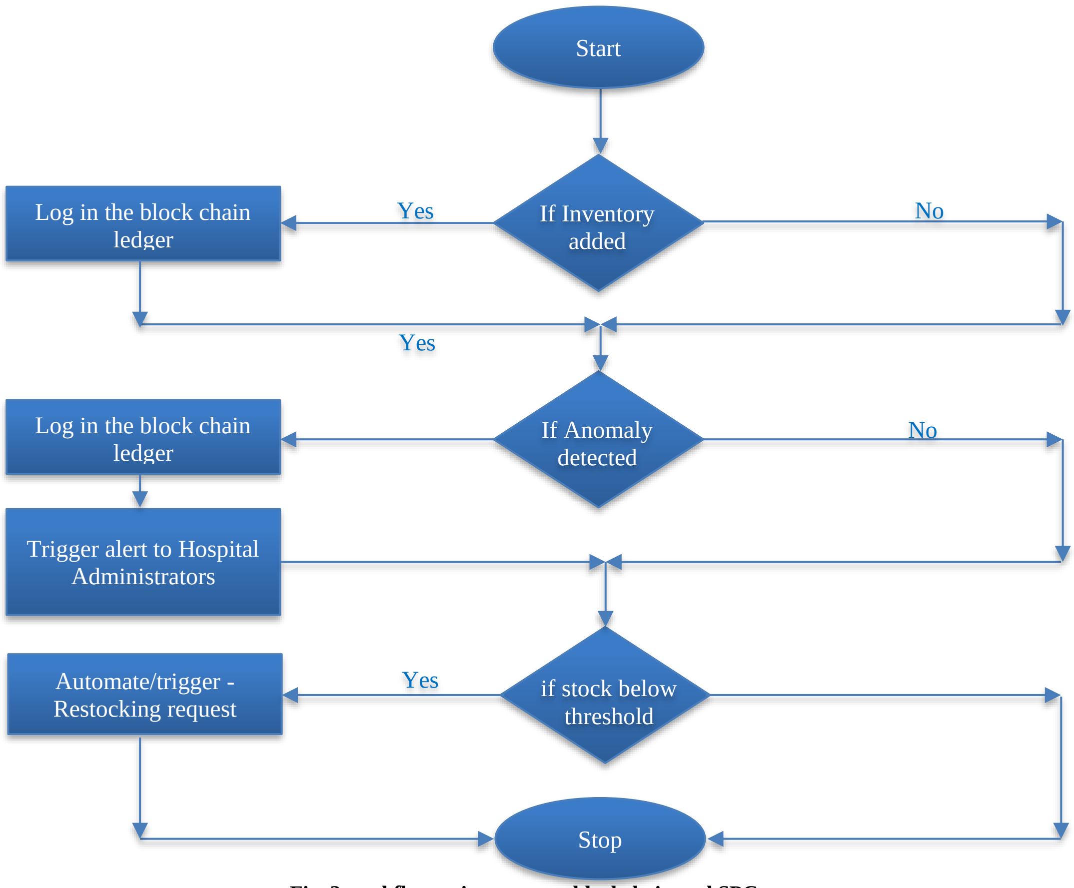


Fig. 3 workflow to incorporate blockchain and SPC

7.1. Flowchart Breakdown

Step-by-Step Process

Inventory System Tracks Weight via Sensors- The system continuously monitors weight data from inventory racks.

SPC Monitors Weight for Anomalies- If a weight measurement is outside control limits (UCL/LCL), it is flagged.

IF 'Inventory Added' → Log in Blockchain Ledger

- Every stock update, including new inventory arrivals, is recorded in the Blockchain Ledger.

IF 'Anomaly Detected' → Log in Blockchain + Trigger Alert

- If inventory weight is inconsistent, an alert is sent to hospital administrators.

IF 'Stock Below Threshold' → Automate Restocking

- If the stock drops below 50%, an automated restocking request is initiated.

7.2. SPC-Based Inventory Monitoring

Statistical Process Control (SPC) techniques, including X̄ (X-bar) charts (Figure 4)and R (Range) charts (Figure 5), play a crucial role in monitoring hospital inventory levels by detecting anomalies in weight fluctuations.

This chart (Figure 4 and Figure 5) helps identify supply chain inefficiencies, fraud, and restocking issues.

Key SPC Techniques Used in Inventory Monitoring

- X̄ Chart (Mean Chart) – Monitoring Average Inventory Weight
- The X̄ chart tracks inventory items' mean (average) weight over time.
- If the mean weight shifts above or below control limits (UCL/LCL), it signals a potential anomaly such as theft, improper restocking, or loss.

Formula for X̄ Chart:

$$\bar{X} = \left(\frac{1}{N}\right)\sum_{i=1}^{N} w(i,t)$$

Fig. 4 Formula for X̄ Chart

X¯ = Mean weight
W(i,t) = weight of item i at time t
N = Number of inventory observations
R Chart (Range Chart) – Monitoring Weight Variability

- The R chart tracks the range (difference between maximum and minimum weight values) within a specific time frame.
- If weight variability exceeds control limits, it may indicate errors in packaging, storage issues, or fraud.

The formula for the R chart

$$R = x_{\{max\}} - x_{\{min\}}$$

Fig. 5 Formula for R chart

7.3. SPC Algorithm Steps

- Initialize Parameters – Define SPC control limits and configure blockchain.
- Monitor Inventory – Continuously record weight data.
- Detect Anomalies – Identify deviations beyond control limits.
- Verify via Blockchain – Authenticate inventory transactions.
- Automate Response – Trigger alerts or restocking as needed.
- Audit & Reporting – Maintain logs for compliance and fraud prevention.

8. Python-based Implementation (Sample Simulation)

A Python-based SPC monitoring and blockchain logging system is implemented.

8.1. SPC Algorithm Implementation in Python

```
# SPC-Based Inventory Monitoring Simulation
np.random.seed(42)
num_boxes = 100  # Simulating 100 inventory boxes
mean_weight = 10  # Average weight of a box (e.g., 10 kg per box)
std_dev = 0.5  # Standard deviation for minor fluctuations

# Generate weight values for inventory tracking
weights = np.random.normal(mean_weight, std_dev, num_boxes)

# Define SPC control limits (3-sigma control limits for normal variation)
UCL = mean_weight + (3 * std_dev)
LCL = mean_weight - (3 * std_dev)

# Identify anomalies (weights outside control limits)
anomalies = [(i, w) for i, w in enumerate(weights) if w < LCL or w > UCL]
```

Fig. 6 SPC algorithm implementation in Python (simulated)

8.2. Blockchain Implementation in Python

```
import hashlib
import time
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd

# Blockchain Implementation for Hospital Inventory Tracking
class Block:
    """Represents a block in the blockchain ledger tracking inventory transactions."""
    def __init__(self, index, timestamp, box_id, items, weight, department, action, previous_hash):
        self.index = index
        self.timestamp = timestamp
        self.box_id = box_id
        self.items = items
        self.weight = weight
        self.department = department
        self.action = action
        self.previous_hash = previous_hash
        self.hash = self.calculate_hash()

    def calculate_hash(self):
        """Generates a SHA-256 hash for block integrity."""
        block_data = f"{self.index}{self.timestamp}{self.box_id}{self.items}{self.weight}{self.department}{self.action}{self.previou
        return hashlib.sha256(block_data.encode()).hexdigest()

class Blockchain:
    """Implements a simple blockchain for tracking hospital inventory movements."""
    def __init__(self):
        self.chain = [self.create_genesis_block()]

    def create_genesis_block(self):
        return Block(0, time.time(), "GENESIS", 1000, 1000, "None", "No Action", "0")

    def add_block(self, box_id, items, weight, department, action):
        previous_block = self.chain[-1]
        new_block = Block(len(self.chain), time.time(), box_id, items, weight, department, action, previous_block.hash)
        self.chain.append(new_block)

# Initialize Blockchain
inventory_blockchain = Blockchain()
```

Fig. 7 Blockchain implementation in Python (simulated)

8.3. SPC Algorithm Mapping Table

The Mapping Table in the image establishes a structured link between Statistical Process Control (SPC) concepts, mathematical formulas, and their Python implementations for hospital inventory monitoring. Refer (Table 1 and Table 2).

Table 1. Key highlights of the mapping

SPC Concept	Key Explanation
Mean Weight (X̄ Calculation)	Measures the average inventory weight to detect fluctuations.
Standard Deviation (σ Calculation)	Quantifies inventory weight variations to ensure consistency.
Upper Control Limit (UCL)	Defines the maximum acceptable weight threshold in SPC monitoring.
Lower Control Limit (LCL)	Sets the minimum inventory weight limit to prevent understocking.
Anomaly Detection Condition	Identifies anomalies when the weight exceeds UCL or falls below LCL.
Alert System for Anomalies	Triggers a notification if anomalies are detected in inventory data.
Blockchain Logging of Inventory	Ensures secure, tamper-proof logging of inventory movements.
Restocking Trigger	Automatically initiates reorder when inventory falls below a threshold.
Graphical Visualization of Anomalies	SPC charts are used to visualize weight deviations and flagged anomalies.

Table 2. Python feature vs Implementation

Python Feature	Implementation Description
Mean Weight Calculation	Uses np.random.normal() to generate simulated inventory weight values.
Standard Deviation Computation	Computes deviations using np.random.normal(mean_weight, std_dev, num_boxes).
UCL & LCL Implementation	Implements control limits with: UCL = mean_weight + (3 * std_dev), LCL = mean_weight - (3 * std_dev).
Anomaly Detection Condition	Identifies anomalies using: anomalies = [(i, w) for i, w in enumerate(weights) if w < LCL or w > UCL].
Automated Alert System	Sends alerts when anomalies are detected using send_alert(f" {len(anomalies)} anomalies detected!").
Blockchain Integration for Inventory Logs	Stores transactions using: inventory_blockchain.add_block("Box-001", 10, 10, "ICU", "Dispatched").
Restocking Trigger Mechanism	Reorders stock when low using: if current_stock < reorder_threshold: print("Restocking initiated").
Graphical SPC Charting	Uses matplotlib to visualize inventory trends with:plt.plot(weights, marker='o', linestyle='-', color='b').

9. Visualizations

9.1. SPC Chart for Inventory Weight Monitoring

The SPC Control Chart displays stock levels and flagged anomalies. Statistical Process Control (SPC) charts are essential tools for monitoring and analyzing variations in inventory weight over time. In a hospital setting, SPC charts help track the weight of critical medical supplies, such as IV fluids, syringes, and medications, to detect anomalies and ensure continuous availability.

- Real-time Weight Monitoring: SPC charts continuously record weight fluctuations of stored items, providing a clear visual representation of inventory trends.
- Upper and Lower Control Limits (UCL & LCL): These thresholds help identify normal fluctuations versus potential anomalies, such as missing stock or excessive weight changes.
- Anomaly Detection: If weight measurements fall outside the control limits, it triggers an alert, prompting administrators to investigate potential stock discrepancies.
- Improved Accuracy: The use of SPC ensures precise inventory tracking, reducing human errors and preventing supply chain disruptions.

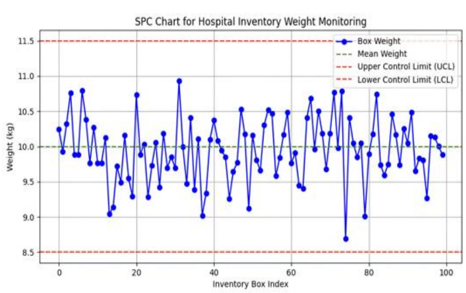


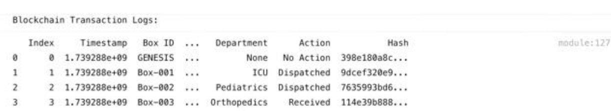
Fig. 8 SPC chart – Simulated output

By leveraging SPC charts, hospitals can proactively detect inventory issues, optimize stock levels, and prevent shortages before they impact patient care.

9.2. Blockchain Transaction Logs

Blockchain-based transaction logs provide a secure, immutable, and transparent record of all inventory movements, ensuring accountability and fraud prevention in hospital inventory management.

This Blockchain Transaction Log provides a secure, immutable record of hospital inventory transactions, ensuring accountability and preventing hospital supply chain management fraud. Each block (row) represents a transaction where an inventory item was added, dispatched, or received.



Blockchain Transaction Logs:

	Index	Timestamp	Box ID	...	Department	Action	Hash
0	0	1.739288e+09	GENESIS	...	None	No Action	398e180a8c...
1	1	1.739288e+09	Box-001	...	ICU	Dispatched	9dcef320e9...
2	2	1.739288e+09	Box-002	...	Pediatrics	Dispatched	7635993bd6...
3	3	1.739288e+09	Box-003	...	Orthopedics	Received	114e39b888...

module:127

Fig. 9 Blockchain transaction logs

9.3. Breakdown of the Log Fields: (Figure 9)

1. Index
   - ⇒ Represents the position of the transaction in the blockchain ledger.
   - ⇒ Starts at 0 (Genesis Block) and increments for each new transaction.
2. Timestamp
   - ⇒ Stores the Unix timestamp (epoch time) when the transaction occurred.
   - ⇒ The value 1.739585e+09 indicates the transaction's precise time in seconds.

3. Box ID
   ⇒ Unique identifier for the inventory unit (box) being tracked.
   ⇒ Example: Box-001, Box-002, etc., representing different hospital supply items.
4. Department
   ⇒ Indicates the hospital department associated with the transaction.
   ⇒ Examples:
   ICU (Intensive Care Unit)
   Paediatrics (Children's Department)
   Orthopedics (Bone and Joint Care)
5. Action
   ⇒ Specifies the type of transaction performed:
   "No Action" → (Genesis Block, initial record)
   "Dispatched" → Item sent to a department
   "Received" → Item added to inventory
6. Hash
   ⇒ Cryptographic SHA-256 hash representing the block's unique fingerprint.
   ⇒ Ensures tamper-proof recordkeeping by linking each block to the previous one.
   ⇒ Example: 9fa78ddde8... (truncated for display).

10. Ethical Considerations in Blockchain-based Healthcare System

10.1. Patient Data Privacy and Security

Blockchain ensures tamper-proof records, but deploying patient-linked inventory data on a decentralized ledger raises privacy issues. HIPAA (USA) and GDPR (EU) compliance are necessary to ensure the privacy of sensitive medical data.

10.2. Data Ownership and Control

Blockchain is immutable, and it cannot be changed once data is inserted. This poses questions about who the master of inventory-related patient data is, the hospitals, suppliers, or the patients. Smart contracts must be well written to specify the rights to data use.

10.3. Compliance with Healthcare Regulations

Hospitals have to make sure that the Blockchain records they keep are compliant with the FDA and HIPAA regulations.

The consequences of not complying with the laws and regulations could be severe, especially when dealing with cross-border healthcare supply chains.

10.4. Ethical Use of Automation

There could be unforeseen bias in automated restocking systems based on smart contracts, for instance, by favoring suppliers based on set criteria rather than the current market trends. An ethical AI-based decision-making framework has to be created in order to avoid supplier monopoly.

10.5. Potential Misuse of Data

If the Blockchain data is publicly available, malicious actors could use the information on hospital inventory trends to create supply shortages and profit from it. Permissioned Blockchain networks like Hyperledger Fabric can help restrict access to data.

11. Conclusion

The integration of Blockchain and SPC significantly enhances hospital inventory management by:

- Ensuring secure, tamper-proof stock tracking reduces the risk of fraud, loss, or human errors in inventory management.
- Automating anomaly detection for better supply chain efficiency, leading to more responsive restocking and preventing potential shortages.
- Reducing manual intervention, improving accuracy and compliance, and minimizing administrative overhead and regulatory risks.
- Enhancing real-time visibility into stock levels, allowing hospitals to make data-driven decisions on procurement and usage.
- Improving cost efficiency by reducing overstocking and understocking, optimizing financial resources, and reducing waste.
- Ensuring seamless integration with supplier networks allows for automated reordering and reduces lead times.
- Enhancing patient safety by ensuring uninterrupted availability of critical supplies, directly impacting the quality of healthcare services.
- Supporting compliance with HIPAA, FDA, and other healthcare regulations, ensuring secure and standardized audit recordkeeping.

11.1. Potential Limitations

11.1.1. Implementation Costs

There is an initial cost of implementing the necessary infrastructure for Blockchain and SPC integration, including smart sensors, blockchain nodes, and training personnel.

11.1.2. Scalability Concerns

On the positive side, Blockchain provides security, but large hospital networks may need optimization for speed and storage.

11.1.3. Data Privacy Compliance

Blockchain is secure, but the problem of ensuring HIPAA/FDA compliance with decentralized storage remains an issue.

12. Future Scope

- AI-based predictive analytics to optimize supply-demand forecasting, improve stock management, and prevent shortages.

- IoT-enabled inventory systems to further enhance real-time tracking, automation, and smart notifications.
- Integration with Electronic Health Records (EHRs) for a holistic approach to healthcare inventory and patient care.
- Machine learning models for anomaly detection to refine SPC accuracy and detect fraudulent activities with greater precision.
- Cloud-based blockchain solutions for scalable, decentralized inventory tracking across multiple hospital branches.
- Enhanced automation through robotic process automation (RPA) to streamline procurement and inventory reconciliation tasks.
- Smart contracts for dynamic pricing and supplier management, allowing cost-effective procurement and contract enforcement.
- Mobile-friendly dashboards for real-time monitoring, enabling hospital administrators to track inventory from any location.

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