International Journal of Computational and Experimental Science and ENgineering
(IJCESEN)
Vol. 12-No.1 (2026) pp. 582-588
http://www.ijcesen.com
ISSN: 2149-9144

Research Article

Real-Time Visibility and Intelligent Orchestration in Healthcare Supply Chain Management: An Architectural Framework

Shandilya Avadhanam Venkata Krishna Sastry*

Y&L Consulting Inc., USA
* **Corresponding Author Email:** shandilya.avadhanam@gmail.com - **ORCID:** 0000-0002-0047-4050

Article Info:

DOI: 10.22399/ijcesen.4868
Received : 02 December 2025
Revised : 30 January 2026
Accepted : 02 February 2026

Keywords

Healthcare Supply Chain,
Real-Time Visibility,
Intelligent Orchestration,
Asset Management,
Inventory Optimisation,
Condition Monitoring

Abstract:

The healthcare supply chain management industry is also facing the issue of visibility despite investing heavily in enterprise resource planning and tracking technologies. Essentially, the issue lies in the lack of overall situational awareness rather than in the collection of information. Medical institutions are facing shortages of life-critical stock while the same item is expiring in the stores. Healthcare professionals also spend a considerable part of their work schedule looking for devices rather than attending to the patients. Traditional point solutions do not solve the specific issue but are all isolated. Existing systems collect data without interpretation and report historical states rather than enabling prospective intervention. The article presents a comprehensive architectural framework for transitioning healthcare operations from static tracking to intelligent orchestration. The proposed framework comprises four interconnected processing layers, including physical signal acquisition through miniaturized sensors, intelligent capture mechanisms utilizing existing infrastructure, artificial intelligence interpretation through cloud-based machine learning, and purpose-built clinical applications delivering actionable workflows. The tool tackles precision in asset management, inventory optimization, and condition monitoring within pharmaceutical supply chain networks. Real-time visibility helps healthcare systems transition from reactive firefighting to predictive optimization. Clinical settings need systems that can constantly analyze information and take action on their own, instead of just gathering more data.

1. Introduction

Healthcare delivery infrastructure is now producing an unprecedented volume of data. A paradox exists in the fact that there are inherent gaps between the availability and accessibility of the resource with regard to healthcare. This failure stems not from procurement inadequacy but from fragmented information architectures. Literature on supply chain management identifies integration and coordination as essential elements for operational effectiveness. Burgess et al. conducted a structured literature review examining supply chain management evolution. The review highlighted that supply chain performance depends on information flow quality rather than mere data volume [1]. The healthcare sector presents a specific level of complexity in relation to demand variations and the criticality of product offerings. A healthcare supply chain has the challenge of achieving both efficiency and responsiveness in light of uncertain demands from patients.

The operational implications intensify and impact patients directly. More than 80% of healthcare providers report challenges in receiving critical supplies when needed. These resources often exist somewhere within systems but remain functionally unavailable. Clinical staff face significant time burdens in locating necessary equipment and supplies. Westbrook et al. conducted a longitudinal study quantifying hospital nurses' task time distribution. The research revealed substantial portions of nursing time devoted to non-direct care activities [2]. More than one-third of nurses spend at least an hour per shift locating assets. This represents a burden on clinical capacity that conventional accounting frameworks fail to capture. The time spent searching for equipment directly reduces time available for patient interaction. Healthcare organizations require architectural solutions addressing this visibility-to-orchestration transition. Such solutions must enable proactive rather than reactive supply chain operations.

2. Related Work

Healthcare supply chain visibility has gained considerable attention within academic and practitioner communities. Burgess et al. established a foundational understanding of supply chain management through a structured literature synthesis. The synthesis highlighted information flow quality as a determinant of supply chain performance rather than data volume alone [1]. Westbrook et al. quantified task time distribution patterns among hospital nurses. The findings revealed substantial clinical time devoted to non-direct care activities, including equipment and supply location [2]. Swarnakar et al. identified information system integration as essential for operational excellence in hospital environments [3]. Humphreys et al. emphasized integrated visibility across resources as fundamental for effective capacity management [4].

Supply chain resilience literature provides additional theoretical grounding. Kumar et al. identified predictive capabilities as essential for supply chain resilience during disruption [5]. Mensah and Merkuryev emphasized early disruption detection through enhanced sensing capabilities [6]. Technology-focused contributions include Weinstein's technical assessment of radio frequency identification for enterprise asset tracking [7]. Mikalef et al. demonstrated that analytics capabilities enhance operational effectiveness through improved decision-making [8]. Salem and Haouari addressed supply chain network design under uncertainty conditions [9]. Mustaffa and Potter highlighted coordination requirements between clinical and logistics functions for effective healthcare supply chain management [10]. The article builds upon these foundations to propose an integrated architectural framework addressing real-time visibility and intelligent orchestration requirements.

3. The Visibility Gap in Healthcare Supply Systems

3.1 Manifestations of Fragmented Awareness

Healthcare organizations operate with incomplete situational awareness despite deploying multiple tracking and management technologies. The visibility gap manifests through several interconnected operational challenges. Inventory management remains problematic across clinical environments. Between 5 and 10% of inventory value risks expiration monthly. This waste occurs while other departments experience shortages of identical items. It is possible for up to 25% of owned clinical supplies to go unused for more than a year. Such patterns indicate fundamental disconnections between physical asset states and organizational decision-making processes. Equipment utilization suffers from similar visibility limitations. Assets purchased to support clinical operations remain idle due to location uncertainty. Departments request additional equipment purchases while existing inventory sits underutilized.

The root causes of fragmented awareness stem from historical system design approaches. Resource planning systems capture transactional events at discrete intervals. This creates temporal gaps between physical reality and recorded information. Swarnakar et al. examined critical success factors for sustainable process improvement in hospitals. The research identified information system integration as essential for operational excellence [3]. The healthcare supply chain has a multitude of stakeholders who have diverse information needs. Different information needs exist for physicians, nursing staff, supply chain managers, and the finance teams. Present systems are unable to provide end-to-end visibility for such diverse needs. The fragmentation extends beyond internal operations to supplier relationships. There are distinct systems for purchase orders, deliveries, and consumption records. There are delays and manual labor involved in reconciling these records.

3.2. Systemic Causes of Information Fragmentation

The systemic causes of information fragmentation trace to fundamental architectural decisions in healthcare technology deployment. Hospital information systems evolved incrementally over decades. Each new system addressed specific departmental requirements without enterprise-wide integration planning. This created information silos that persist despite subsequent integration efforts. Clinical systems prioritize patient care documentation over supply chain visibility. Financial systems focus on cost accounting rather than real-time inventory status. Materials management systems track procurement transactions but lack consumption visibility.

Capacity planning in healthcare requires coordination across multiple operational dimensions. Humphreys et al. provided an overview of hospital capacity planning and optimization approaches. The research emphasized that effective capacity management requires integrated visibility across resources [4]. Supply chain visibility connects directly to capacity utilization. Equipment availability affects procedure scheduling and patient throughput. Medication availability impacts treatment protocols and discharge timing. Current systems fail to adequately address the interdependencies between supply chain performance and clinical operations. Healthcare organizations require architectural approaches that unify visibility across operational domains. Such approaches must accommodate the real-time nature of clinical decision-making.

4. Limitations of Current Technological Approaches

4.1 Architectural Constraints of Point Solutions

Existing technologies addressing healthcare supply challenges exhibit common limitations preventing comprehensive visibility achievement. Solutions tend toward narrow problem resolution. Asset tracking systems monitor equipment location without integration to utilization data. Inventory management systems track stock levels without connection to clinical consumption patterns. Integration platforms connect disparate systems but lack interpretive intelligence. The result is increased data volume without a corresponding improvement in actionable insights.

Hardware-centric approaches focus on data collection infrastructure. Barcode scanners, sensor networks, and radio frequency identification (RFID) readers generate substantial data streams. However, data collection alone provides limited operational value. The critical capability lies in interpreting data to support decision-making. Kumar et al. examined lessons from pandemic response for humanitarian supply chain management. The research identified that supply chain resilience requires predictive rather than reactive capabilities [5]. Healthcare supply chains face similar requirements for anticipatory management. Point solutions designed for stable operating conditions prove inadequate for dynamic healthcare environments. The architectural constraints of existing approaches prevent the integration necessary for comprehensive visibility.

4.2 Reactive Operational Paradigms

Current approaches predominantly report historical states rather than enabling prospective intervention. Batch processing models introduce latency between event occurrence and organizational awareness. Daily inventory reports reflect yesterday's status rather than current availability. Equipment location updates occur periodically rather than continuously. This temporal gap prevents a timely response to emerging supply conditions. Clinical operations require real-time information to support immediate decision-making. The mismatch between information system design and operational requirements creates persistent visibility gaps.

Resilient supply chain design requires capabilities beyond traditional planning approaches. Mensah and Merkuryev examined principles for developing supply chain resilience. The research emphasized that resilience requires sensing capabilities that detect disruptions early [6]. Healthcare supply chains face continuous disruption from demand variability and supply uncertainty. Traditional planning cycles cannot accommodate the pace of change in clinical environments. Reactive paradigms respond to problems after clinical impact has occurred. Proactive paradigms detect emerging issues before patient care suffers. The fundamental requirement is not expanded data collection but systems capable of understanding, correlating, and acting upon information continuously. Architectural transformation must address this shift from reactive reporting to proactive orchestration.

5. Intelligent Orchestration Architecture

5.1 Four-Layer Framework Design

The proposed architectural framework comprises interconnected processing layers enabling transition from passive tracking to active orchestration. The first layer involves physical signal generation through miniaturized sensors. These sensors attach directly to supplies, equipment, and shipments. Assets transform into continuously communicating entities. The sensor layer provides the foundation for real-time visibility. Advances in sensor technology allow effective and economic deployment in multiple asset classes. Temperature sensors monitor pharmaceutical storage. Location sensors track equipment movement through clinical spaces. Motion sensors detect asset utilization patterns.

Radio frequency identification (RFID) provides foundational capabilities for asset tracking. Weinstein provided a technical overview of RFID and enterprise applications. The research detailed how RFID enables automatic identification without line-of-sight requirements [7]. Healthcare environments benefit from this capability due to high asset mobility. Equipment moves between departments, floors, and buildings during normal operations. Manual tracking methods cannot maintain accuracy under such dynamic conditions.

The sensor layer must accommodate diverse asset types with varying tracking requirements. High-value equipment requires precise location tracking. Consumable supplies require inventory level monitoring. Pharmaceuticals require condition monitoring alongside location tracking. The architectural framework must support this heterogeneity through flexible sensor deployment options.

5.2 Signal Processing and Intelligence Generation

The second layer encompasses intelligent capture utilizing existing infrastructure. Wireless networks provide connectivity for sensor data transmission. Mobile devices serve as portable readers for local data collection. Cellular connectivity extends coverage to areas beyond enterprise network reach. This infrastructure-leveraging approach minimizes deployment complexity. Healthcare organizations avoid extensive hardware installation requirements. The capture layer aggregates data from distributed sensors into unified streams. Data normalization ensures consistent formatting across sensor types. Temporal alignment enables correlations between events across different sources.

The third layer applies cloud-based artificial intelligence and machine learning. Real-time pattern recognition entails the identification of both normal and abnormal situations. Predictive modeling uses previous observations to forecast the future. Anomaly detection highlights situations requiring human attention. Mikalef et al. explored relationships between big data analytics capability and competitive performance. The research demonstrated that analytics capabilities enhance operational effectiveness through improved decision-making [8]. Healthcare supply chains benefit from similar analytical approaches. Machine learning models learn consumption patterns specific to each clinical environment. Seasonal variations, procedural schedules, and patient census fluctuations inform predictive models. The fourth layer delivers purpose-built applications that translate intelligence into actionable clinical workflows. Alerts notify appropriate personnel of situations requiring intervention. Automated responses handle routine situations without human involvement. Recommendation engines suggest optimal actions for complex situations.

6. Real-Time Asset and Inventory Intelligence

6.1 Continuous Asset Awareness

Real-time visibility transforms asset management from estimation-based approaches to precision operations. Healthcare organizations gain live location awareness with room-level or zone-level accuracy. Automatic tracking monitors assets entering and exiting clinical spaces. Utilization intelligence reveals actual equipment usage patterns rather than assumed patterns. The transformation enables new operational questions. Instead of asking where equipment is located, teams can ask which asset should be used next. Utilization data reveals which equipment is Maintenance records combined with usage data identify assets nearing end-of-life thresholds.

Designing supply chain networks under uncertainty requires sophisticated analytical approaches. Salem and Haouari presented a simulation-optimization approach for supply chain network design. The research addressed how uncertainty in supply and demand affects optimal network configuration [9]. Healthcare asset networks face similar uncertainty challenges. Patient volumes fluctuate unpredictably across clinical departments. Procedure schedules change based on emergency cases and physician availability. Equipment demand varies accordingly. Real-time visibility enables a dynamic response to these fluctuations. Assets can be redeployed based on current demand rather than static allocation rules. The outcome is fewer delays and faster procedures. Patient outcomes improve without requiring additional equipment purchases.

6.2 Predictive Inventory Capabilities

Automated inventory intelligence eliminates manual cycle counting requirements. Spreadsheet reconciliations become unnecessary with always-current inventory data. Reactive replenishment patterns transition to predictive approaches. Organizations can prevent stockouts of critical supplies before they occur. Overstock situations and expiration-driven waste are reduced substantially. Par levels align to actual consumption patterns rather than historical estimates. Supplier invoicing gains accuracy through real-time usage data integration. Enterprise systems receive near real-time replenishment signals. Inventory transforms from a lagging indicator to a predictive capability.

Healthcare supply chain management requires integration across diverse stakeholders and processes. Mustaffa and Potter examined healthcare supply chain management through case study analysis. The research highlighted that effective supply chain management requires coordination between clinical and logistics functions [10]. Condition monitoring extends visibility for pharmaceuticals, vaccines, and biologics. Location tracking alone proves insufficient for temperature-sensitive products. Environmental sensors monitor storage conditions throughout the supply chain. Temperature excursions trigger immediate alerts before product integrity is compromised. Transit delays and dwell times are monitored alongside location tracking. Real-time alerts enable intervention before excursions cause loss. Product integrity, regulatory compliance, and financial outcomes benefit from proactive condition management. Waste prevention replaces waste documentation as the primary operational focus.

Table 1. *Healthcare Supply Chain Visibility Challenges and Systemic Causes [3, 4].*

Visibility Gap Manifestation	Systemic Cause	Operational Impact
Inventory expiration while shortages occur elsewhere	Enterprise systems capture transactional events at discrete intervals	Temporal gaps between physical reality and recorded information
Owned clinical supplies remain unused for extended periods	Clinical systems prioritise patient documentation over supply chain visibility	Equipment ownership status diverges from availability status
Equipment purchased but functionally unavailable	Financial systems focus on cost accounting rather than real-time inventory	Inventory records diverge from actual consumption patterns
Multiple tracking technologies without unified awareness	Information silos from incremental system deployment	Manual reconciliation efforts introduce delays
Critical supplies exist but inaccessible to care teams	Separate systems for purchase orders, deliveries, and consumption	Interdependencies between supply chain and clinical operations remain inadequately addressed

Table 2*. Limitations of Point-Solution Technologies in Healthcare Supply Chain Management [5, 6].*

Limitation Category	Characteristic	Consequence
Narrow Problem Resolution	Asset tracking systems monitor location without utilisation integration	Increased data volume without actionable insights
Hardware-Centric Focus	Data collection infrastructure without interpretive capability	Limited operational value from sensor networks
Integration Dependency	Platforms connect systems but lack interpretive intelligence	Data aggregation without decision support
Batch Processing Models	Daily reports reflect previous status rather than current availability	Temporal gap prevents timely response
Periodic Updates	Equipment location updates occur at intervals rather than continuously	Mismatch between information design and operational requirements
Historical Reporting	Systems report past states rather than enabling prospective intervention	Reactive response after clinical impact occurs

Table 3. *Architectural Framework Components for Real-Time Healthcare Visibility [7, 8].*

Architecture Layer	Core Function	Implementation Elements
Physical Signal Generation	Transform assets into continuously communicating entities	Miniaturised sensors attached to supplies, equipment, and shipments
Intelligent Capture	Aggregate data from distributed sensors into unified streams	Wireless networks, mobile devices, cellular connectivity
Artificial Intelligence Interpretation	Real-time pattern recognition and predictive analytics	Cloud-based machine learning, anomaly detection, opportunity identification
Purpose-Built Applications	Translate intelligence into actionable clinical workflows	Alerts, automated responses, and recommendation engines

Table 4. *Transformation from Estimation-Based to Precision-Based Healthcare Asset Management [9, 10].*

Intelligence Domain	Traditional Approach	Real-Time Visibility Capability
Asset Location	Manual tracking and periodic audits	Live location awareness with room-level or zone-level accuracy
Equipment Movement	Static allocation rules	Automatic tracking of assets entering and

		exiting clinical spaces
Utilisation Patterns	Assumed usage based on historical estimates	Utilisation intelligence revealing actual equipment usage
Inventory Counting	Manual cycle counts and spreadsheet reconciliations	Automated always-current inventory data
Replenishment	Reactive ordering after stockouts	Predictive prevention of stockouts before occurrence
Par Level Setting	Historical estimates and fixed thresholds	Alignment to actual consumption patterns
Condition Monitoring	Periodic manual checks	Real-time temperature, environmental exposure, and transit monitoring
Waste Management	Documentation of losses after occurrence	Intervention before excursions cause product loss

7. Conclusions

The transformation of healthcare supply chain operations demands fundamental architectural reconceptualization beyond incremental technology deployment. Fragmented visibility across healthcare systems represents an interpretive and orchestration deficiency rather than a data acquisition problem. Point-solution technologies, despite substantial investment, cannot achieve the continuous situational awareness necessary for proactive clinical support. The four-layer architectural framework establishes a clear pathway from physical signal acquisition through intelligent interpretation to autonomous action. Healthcare organizations can evolve from estimation-based asset management to precision-based operations through real-time visibility implementation. Inventory management transforms from a lagging indicator into a predictive capability. Condition monitoring enables waste prevention rather than mere loss documentation for pharmaceuticals and biologics. The most valuable outcome of intelligent visibility remains human rather than operational. Clinical staff redirect time previously spent searching for equipment toward direct patient treatment. Teams in charge of supply chains go from crisis management to strategic optimization. Finance departments gain forecasting confidence through real-time consumption data. Patients receive timely, uninterrupted care delivery. Systems capable of thinking, adapting, and acting continuously will define future healthcare operations. Such systems connect physical and digital domains with intelligence at the core. To achieve sustainable excellence in health delivery, there must be end-to-end visibility within the health supply ecosystem in real time.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

References

[1] Kevin Burgess et al., "Supply chain management: a structured literature review and implications for future research," International Journal of Operations & Production Management, 2006. [Online]. Available: https://www.researchgate.net/profile/Kevin-Burgess-4/publication/27480781

[2] Johanna I. Westbrook et al., "How much time do nurses have for patients? a longitudinal study quantifying hospital nurses' patterns of task time distribution and interactions with health professionals," BMC Health Services Research, 2011. [Online]. Available: https://link.springer.com/content/pdf/10.1186/1472-6963-11-319.pdf

[3] Vikas Swarnakar et al., "Modeling critical success factors for sustainable LSS implementation in hospitals: an empirical study," International Journal of Quality & Reliability Management, 2021. [Online]. Available: https://www.researchgate.net/profile/Vikas-Swarnakar/publication/353340729

[4] Peter Humphreys et al., "An Overview of Hospital Capacity Planning and Optimization," MDPI, 2022. [Online]. Available: https://www.mdpi.com/2227-9032/10/5/826

[5] Pravin Kumar et al., "Learnings from COVID-19 for managing humanitarian supply chains: systematic literature review and future research directions," Annals of Operations Research, 2024. [Online]. Available: https://link.springer.com/content/pdf/10.1007/s10479-022-04753-w.pdf

[6] Peter Mensah and Yuri Merkuryev, "Developing a resilient supply chain," ScienceDirect, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877042813055158

[7] Ron Weinstein, "RFID: A Technical Overview and Its Application to the Enterprise," IEEE Computer Society, 2005. [Online]. Available: https://web.archive.org/web/20131020194755id_/http://www.cs.sunysb.edu/~jgao/CSE370-spring07/RFID.pdf

[8] Patrick Mikalef et al., "Exploring the relationship between big data analytics capability and competitive performance: The mediating roles of dynamic and operational capabilities," ScienceDirect, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378720618301022

[9] Roba W. Salem and Mohamed Haouari, "A simulation-optimization approach for supply chain network design under supply and demand uncertainties," International Journal of Production Research, 2016. [Online]. Available: https://www.researchgate.net/profile/Mohamed-Haouari-3/publication/301305779

[10] Noorfa Haszlinna Mustaffa and Andrew Potter, "Healthcare supply chain management in Malaysia: a case study," Supply Chain Management: An International Journal, 2009. [Online]. Available: https://www.researchgate.net/profile/Noorfa-Mustaffa-2/publication/235270454