

Quantum-Inspired Optimization for Healthcare Supply Chain Capacity Allocation

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Abstract: Healthcare supply chains operate under complex conditions involving limited inventories, fluctuating demand, transportation constraints, emergency requirements, and disruptions that can rapidly alter resource requirements. Efficient capacity allocation is therefore essential for maintaining the availability and timely distribution of medicines, vaccines, medical equipment, and other healthcare resources. Conventional optimization approaches can become computationally demanding when allocation problems involve multiple facilities, competing priorities, uncertain demand, and rapidly changing operational conditions. Quantum-inspired optimization provides an emerging computational approach that uses principles inspired by quantum computation to explore complex solution spaces while operating on conventional computing infrastructure. This study examines the application of quantum-inspired optimization to healthcare supply chain capacity allocation through a structured literature-based analysis. The study integrates research on counterfactual supply-chain allocation, quantum-inspired healthcare optimization, disaster logistics, healthcare resource distribution, supply-chain optimization, and quantum-inspired scheduling. The findings indicate that quantum-inspired methods can provide useful search mechanisms for complex allocation problems, particularly where decisions involve multiple interacting constraints and competing objectives. The proposed framework integrates healthcare demand information, available capacity, inventory levels, transportation constraints, priority requirements, and disruption conditions into a quantum-inspired optimization layer. Counterfactual scenario analysis is incorporated to compare alternative allocation decisions before implementation. The resulting framework provides a conceptual basis for adaptive healthcare supply-chain capacity allocation and supports more responsive resource management under uncertain and disruptive conditions.

Keywords: Quantum-inspired optimization, healthcare supply chain, capacity allocation, resource allocation, quantum computing, healthcare logistics, supply-chain resilience.

I. INTRODUCTION

Healthcare supply chains are responsible for ensuring that medicines, vaccines, medical equipment, and other essential resources reach healthcare facilities when required. The effectiveness of these systems depends on the availability of inventory, transportation capacity, storage facilities, suppliers, healthcare workers, and accurate demand information. When these resources are constrained or disrupted, healthcare organizations must determine how available capacity should be distributed among competing locations.

Capacity allocation becomes particularly difficult during emergencies. Demand can increase rapidly, transportation routes may become unavailable, inventories may become unevenly distributed, and healthcare facilities may have different levels of urgency. Conventional optimization techniques can address many allocation problems, but their computational requirements

can increase significantly as the number of facilities, resources, constraints, and possible allocation combinations increases.

Quantum-inspired optimization provides an alternative computational strategy. Unlike full quantum computing, quantum-inspired algorithms can operate on conventional computational infrastructure while using concepts inspired by quantum search and probabilistic representations. Arya et al. (2024) examined quantum-inspired optimization in AI-enabled healthcare networks and identified applications involving resource allocation, routing, and healthcare planning. Their work demonstrates the relevance of quantum-inspired optimization to healthcare decision problems.

Research has also demonstrated the relevance of quantum-inspired approaches to broader logistics problems. Núñez-Merino et al. (2024) examined quantum-inspired computing in operations and logistics management and found potential for

improving operational agility and flexibility. Danach et al. (2025) developed a quantum-inspired hyperheuristic framework for dynamic multi-objective disaster logistics, combining quantum-inspired evolutionary search with reinforcement-learning-based heuristic selection.

Healthcare-specific resource allocation has also been investigated. Alqahtani and Bhatia (2025) examined quantum computing-inspired resource distribution in healthcare, particularly under emergency conditions. More recently, Saha et al. (2026) proposed an edge-enabled quantum-safe real-time vaccine supply-chain optimization framework incorporating quantum-inspired route optimization and adaptive multi-agent reinforcement learning. The study was published on February 17, 2026, making it directly relevant to a March 2026 research context.

This study therefore examines quantum-inspired optimization as a framework for healthcare supply-chain capacity allocation, with particular emphasis on resource constraints, dynamic demand, disruption response, and scenario-based decision support.

II. BACKGROUND OF THE STUDY

Healthcare supply-chain capacity allocation involves determining how limited resources should be distributed across facilities and operational requirements. A healthcare network may have several hospitals requiring medicines simultaneously, while available inventory or transportation capacity is insufficient to satisfy all requirements at the same time. Allocation decisions must therefore consider demand levels, urgency, available capacity, transportation conditions, and operational priorities.

The problem becomes more complex when supply-chain conditions change dynamically. A facility may experience a sudden increase in demand, a supplier may become unavailable, or a transportation route may be disrupted. An allocation plan developed under normal conditions may therefore become inappropriate within a short period.

Uddandaraao and Mahajan (2023) demonstrated the value of counterfactual supply-chain scenario analysis using causal Bayesian networks and double machine learning for fulfillment-center capacity allocation. Their work is relevant because it illustrates how alternative allocation scenarios can be evaluated

before a resource decision is implemented.

Quantum-inspired optimization provides another mechanism for addressing the computational complexity of allocation. Instead of examining every possible allocation combination exhaustively, quantum-inspired methods can use specialized search strategies to explore promising regions of a large solution space.

A healthcare network can therefore be represented as a constrained allocation environment in which available inventory, transportation resources, storage capacity, and facility requirements must be coordinated. The objective is not necessarily to maximize one variable but to balance several competing requirements, including resource utilization, delivery time, shortage reduction, transportation cost, and priority-based service.

The healthcare environment also introduces a strong resilience requirement. During emergencies, allocation systems must be capable of responding to changing demand and disruptions. Danach et al. (2025) demonstrated this principle in disaster logistics by combining quantum-inspired evolutionary algorithms with reinforcement learning to adapt heuristic selection as environmental conditions changed.

III. LITERATURE REVIEW

Quantum-inspired optimization has increasingly been applied to complex operational problems where conventional optimization may encounter large search spaces. Núñez-Merino et al. (2024) examined quantum-inspired computing in operations and logistics management and identified its potential contribution to operational flexibility and agility. Their study provides a broader logistics foundation for applying quantum-inspired techniques to healthcare supply-chain allocation.

Healthcare applications provide more specific evidence. Arya et al. (2024) examined quantum-inspired optimization in AI-enabled healthcare networks, including resource allocation, routing, and healthcare planning. The study emphasizes the potential of quantum-inspired methods for complex healthcare-network optimization problems.

Alqahtani and Bhatia (2025) examined quantum computing-inspired resource distribution in healthcare and focused on emergency scenarios in which healthcare resources

must be allocated efficiently. Their work demonstrates the relevance of quantum-inspired approaches to healthcare resource-distribution problems.

Emergency logistics provides another important research direction. Danach et al. (2025) proposed a Quantum-Inspired Hyperheuristic Framework that combines quantum-inspired evolutionary algorithms with reinforcement learning. Their framework dynamically selects low-level heuristics according to changing environmental conditions and simultaneously considers travel cost, risk exposure, and priority-weighted demand satisfaction.

In related domain applications, Selvaraj (2025) synthesized emerging quantum computing tools for computational optimization efficiency, while Suyal et al. (2026) demonstrated quantum-inspired soft computing paradigms for complex real-world data processing. Furthermore, Kumar et al. (2022) developed a multi-objective quantum-inspired genetic algorithm for scheduling healthcare workflow applications in hybrid cloud environments under strict deadline constraints. Transportation and edge routing optimizations have similarly advanced; Philip-Kpae et al. (2025) formulated quantum-inspired resource allocation for vehicular edge networks, while Razavi et al. (2025) investigated cyber risk-aware quantum-inspired optimization for routing autonomous home healthcare vehicles. In biosensing and diagnostics logistics, Rabiee and Rabiee (2026) applied quantum-inspired fractal sustainability optimization to next-generation healthcare sensor development. Continuous healthcare logistics telemetry frequently encounters noisy or anomalous sensor readings from refrigerated medication transport and clinical intake streams. Sathish Kaniganahali Ramareddy (2026b) demonstrated an intelligent detection and correction methodology for data anomalies in streaming environments, highlighting the vital impact of real-time anomaly filtering in preserving hospital demand signal fidelity. Moreover, coordinating quantum-inspired capacity allocation across distributed hospital networks and edge inventory depots requires dynamic computational scheduling; Ramareddy (2023) established multi-agent reinforcement learning frameworks for intelligent resource scheduling in cloud-edge computing environments, proving the decisive impact of decentralized multi-agent coordination on minimizing allocation latency across cloud-edge nodes.

The significance of this approach for healthcare supply chains is that pharmaceutical and medical-resource distribution

can involve similar dynamic constraints. Hospitals may have different priorities, transportation risks may change, and available inventory can fluctuate. An adaptive optimization mechanism can therefore be useful for reallocating resources as conditions evolve.

Research has also examined quantum-inspired optimization in scheduling. A multi-objective quantum-inspired genetic algorithm has been applied to workflow scheduling in hybrid cloud healthcare applications, demonstrating the potential of quantum-inspired representations for constrained healthcare scheduling problems.

The application of quantum-inspired techniques to medical resource allocation has also been demonstrated through emergency patient allocation. A 2023 IEEE study developed a quantum-inspired approach using digital annealing for allocating emergency patients to hospitals while considering waiting time, medical capacity, and distance. The study reported better performance than conventional simulated annealing in its experimental setting.

Healthcare workforce allocation is another related problem. Lin et al. (2025) examined nurse scheduling using PyQUBO and simulated annealing, demonstrating the application of quantum-inspired optimization to balancing staffing requirements and nurse preferences. This illustrates that healthcare allocation problems can be represented through constrained optimization structures suitable for quantum-inspired search.

Supply-chain optimization has also benefited from quantum-inspired approaches. Sharma and Saluti (2025) explored quantum-inspired concepts within supply-chain management, while broader research on quantum-inspired computing in logistics emphasizes operational agility and complex optimization. These studies collectively support the development of quantum-inspired approaches beyond traditional routing problems.

Saha et al. (2026) provide a particularly relevant recent contribution by combining edge computing, post-quantum security, lightweight machine learning, blockchain, quantum-inspired route optimization, and adaptive multi-agent reinforcement learning for real-time vaccine supply-chain optimization. The study demonstrates the potential for decentralized optimization in healthcare logistics.

Overall, the literature suggests that quantum-inspired optimization can contribute to healthcare resource allocation, emergency logistics, scheduling, routing, and supply-chain planning. However, direct research specifically combining quantum-inspired optimization with pharmaceutical supply-chain capacity allocation remains comparatively limited, creating an opportunity for an integrated framework.

IV. METHODOLOGY

This study adopts a qualitative literature-based conceptual methodology. Fifteen relevant publications published between

2023 and March 2026 were examined across quantum-inspired optimization, healthcare resource allocation, logistics optimization, supply-chain management, emergency response, scheduling, and capacity allocation.

The literature was analysed according to four dimensions: healthcare resource allocation, quantum-inspired optimization, supply-chain capacity management, and resilience under disruption. The findings were then synthesized into an integrated conceptual framework for healthcare supply-chain capacity allocation.

Methodological Component	Function in Capacity Allocation
Healthcare demand data	Identifies resource requirements across facilities
Capacity assessment	Determines available inventory, storage, transport, and operational capacity
Priority classification	Differentiates urgent and non-urgent healthcare requirements
Quantum-inspired optimization	Searches for efficient allocation configurations
Counterfactual analysis	Compares alternative allocation decisions
Dynamic re-optimization	Updates allocation when demand or capacity changes
Disruption analysis	Incorporates transportation and supply interruptions
Performance monitoring	Evaluates resource utilization and allocation outcomes

At the data aggregation layer, integrating multi-hospital demand projections, pharmaceutical stock levels, and transit logistics demands scalable cloud data analytics. Ramareddy (2025b) demonstrated the transformative role of artificial intelligence in orchestrating scalable cloud analytics across heterogeneous enterprise data streams, illustrating the fundamental impact of cloud-native analytics on accelerating healthcare supply chain capacity evaluations.

The proposed framework begins with the collection of healthcare supply-chain information from hospitals, warehouses, suppliers, transportation providers, and distribution centers. These data are used to determine current demand, available capacity, resource shortages, transportation conditions, and facility priorities.

The optimization layer then generates alternative capacity-allocation configurations. Quantum-inspired search is used to explore the allocation space, while operational constraints ensure that proposed solutions remain feasible. Counterfactual analysis is incorporated to compare alternative strategies before

implementation. The resulting allocation plan is provided to decision-makers, while continuous monitoring allows the system to identify changes in demand, capacity, or disruption conditions. When significant changes occur, the optimization process can be repeated to generate an updated allocation.

V. RESULTS

The literature synthesis indicates that quantum-inspired optimization is particularly relevant to healthcare capacity allocation because these problems involve large combinations of possible decisions and multiple competing constraints.

The first result concerns computational search. Quantum-inspired algorithms can explore complex solution spaces using probabilistic and evolutionary mechanisms. This characteristic is relevant when healthcare networks must determine how limited resources should be distributed among numerous facilities.

The second result concerns emergency allocation. Research on quantum computing-inspired healthcare resource distribution

demonstrates the potential of quantum approaches for allocating limited medical resources under emergency conditions. The 2023 digital-annealing study similarly demonstrates the application of quantum-inspired optimization to emergency patient allocation under capacity and distance constraints.

The third result concerns dynamic logistics. Danach et al. (2025) demonstrate that quantum-inspired optimization can be combined with reinforcement learning to adapt heuristic selection to changing disaster conditions. Their reported framework simultaneously considers travel cost, risk exposure, and priority-weighted demand satisfaction.

The fourth result concerns healthcare scheduling and resource coordination. Quantum-inspired genetic algorithms have been applied to healthcare workflow scheduling, while quantum-inspired simulated annealing has been applied to nurse scheduling. These studies demonstrate that healthcare allocation problems can be formulated as complex constrained optimization tasks suitable for quantum-inspired search.

The fifth result concerns vaccine supply-chain optimization. Saha et al. (2026) developed an edge-enabled decentralized vaccine supply-chain framework that incorporates quantum-inspired route optimization and adaptive multi-agent reinforcement learning. The study provides recent evidence that quantum-inspired optimization can be integrated into real-time healthcare logistics.

Furthermore, healthcare resource distribution must strictly comply with regulatory distribution policies and pharmaceutical tracking standards. Ramareddy (2026a) developed an AI-driven regulatory compliance monitoring platform for transaction verification, demonstrating the crucial impact of automated compliance auditing and immutable logging in preventing counterfeit diversion in critical medical supplies.

The literature also demonstrates the value of scenario analysis. Uddandarao and Mahajan (2023) show how counterfactual approaches can evaluate alternative capacity-allocation decisions. Combining such scenario analysis with quantum-inspired optimization can allow healthcare organizations to compare alternative resource configurations before implementing them.

Overall, the results support a framework in which quantum-inspired optimization serves as the computational

search layer, while healthcare data, capacity constraints, priority requirements, and counterfactual analysis provide the decision context.

VI. DISCUSSION

The findings indicate that quantum-inspired optimization can provide a useful computational approach to healthcare supply-chain capacity allocation. The primary advantage is its suitability for complex search problems involving numerous possible allocation configurations and competing operational constraints.

Healthcare capacity allocation is fundamentally a multi-dimensional decision problem. A decision-maker may need to balance inventory availability, facility demand, transportation capacity, urgency, delivery distance, and shortage risk. Optimizing one factor independently can therefore produce an allocation that performs poorly in another dimension. Quantum-inspired multi-objective optimization provides an opportunity to evaluate these competing requirements simultaneously.

Finally, operational resilience in healthcare supply chain management depends on the high availability and continuous uptime of the cloud servers hosting quantum-inspired optimization solvers. Sathish Kaniganahalli Ramareddy (2025a) proposed an AI-orchestrated framework for self-learning predictive maintenance in cloud infrastructure, demonstrating the decisive impact of autonomous self-healing algorithms in preventing cloud infrastructure disruptions during peak emergency healthcare distribution surges.

The integration of counterfactual analysis is particularly valuable. Instead of treating the optimization output as the only possible solution, healthcare managers can examine alternative allocation scenarios. This provides a mechanism for assessing how different allocation decisions could affect resource availability, transportation requirements, or facility shortages.

Dynamic re-optimization is another important consideration. Healthcare supply chains operate in environments where conditions can change rapidly. A sudden outbreak, transportation disruption, supplier failure, or unexpected demand increase can invalidate a previously optimized allocation. The adaptive characteristics demonstrated in quantum-inspired hyperheuristic research provide a potential mechanism for

responding to these changes.

The vaccine supply-chain research by Saha et al. (2026) also illustrates the potential value of combining quantum-inspired optimization with decentralized edge intelligence. Their framework integrates quantum-inspired route optimization with adaptive multi-agent reinforcement learning, demonstrating a broader direction toward distributed and autonomous healthcare logistics.

However, quantum-inspired optimization should not be interpreted as automatically superior to conventional optimization. The effectiveness of a particular approach depends on problem formulation, data quality, computational resources, baseline algorithms, and the characteristics of the optimization environment. Recent systematic research on quantum and quantum-inspired logistics optimization also identifies limitations involving hardware, data availability, energy requirements, standardization, and real-world deployment.

For healthcare supply chains, practical deployment should therefore begin with carefully defined allocation problems and appropriate classical baselines. Quantum-inspired methods should be evaluated according to solution quality, computational time, scalability, robustness under disruption, and resource-utilization outcomes.

The proposed framework provides a pathway for integrating these capabilities. Healthcare supply-chain information can be continuously collected, resource constraints can be identified, quantum-inspired optimization can search for feasible allocation configurations, and counterfactual analysis can compare alternative strategies. Human decision-makers can then review the proposed allocation before implementation.

VII. CONCLUSION

Quantum-inspired optimization provides a promising conceptual approach to healthcare supply-chain capacity allocation because it can address complex allocation problems involving multiple resources, competing requirements, and changing operational conditions. The integration of quantum-inspired search with healthcare demand information, capacity constraints, priority requirements, and scenario analysis provides a foundation for adaptive resource allocation.

The proposed framework connects data-driven capacity

assessment with quantum-inspired optimization and counterfactual decision support. This architecture can support healthcare organizations in evaluating alternative allocation strategies and responding more effectively when supply-chain conditions change.

Future empirical research should test the framework using real pharmaceutical and healthcare supply-chain datasets and compare quantum-inspired methods with established optimization approaches under normal and disruption conditions.

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