Conceptual Framework for the Adoption of Quantum Computing in Supply Chain Management: An Integrative Literature Review (2020–2025)

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Abstract: The growing complexity of the supply chain demands innovative technological solutions capable of solving complex problems and enabling real-time decisions. Quantum computing, with its ability to process large volumes of data and solve combinatorial problems, emerges as a promising alternative in this context. This article proposes a three-level conceptual framework to guide the progressive adoption of quantum computing in supply chain management. The research adopts an exploratory and propositional approach, based on an integrative literature review of the Scopus and Google Scholar databases, focusing on studies published between 2020 and 2025. Nine articles were selected that present practical applications of quantum algorithms such as QAOA, QUBO, and QWOA in areas like vehicle routing, inventory control, and logistics simulation. The results indicate that quantum algorithms show superior performance in handling NP-hard logistical problems, with hybrid quantum-classical models already demonstrating efficiency gains in inventory management and vehicle routing. In addition, the literature reveals a clear trajectory for adoption: diagnosis of technological maturity and problem mapping, testing and integration with quantum models in simulated environments, and gradual operational implementation with measurable impacts on KPIs. The proposed framework consolidates these findings, offering a theoretical and practical guide to support organizations in progressively adopting quantum computing in logistics contexts. Its application is recommended in case studies for empirical validation, as well as deeper analysis of economic, ethical, and regulatory aspects. This study contributes to advancing knowledge on the use of quantum computing in supply chain management, highlighting concrete benefits and the challenges for real-world implementation.

Keywords: Quantum computing. Supply chain. Logistics. Optimization. Emerging technologies.

1. Introduction

Over the years, logistics has undergone a technological diversification and valorization, aimed at optimizing operations, improving efficiency, responding quickly to demands, minimizing costs, and increasing profits, which has generated new market opportunities and strengthened competitiveness [1]. Technology has become an essential tool in logistics management, enabling the rapid processing of data and order tracking to ensure customer satisfaction, leading companies to invest heavily in innovations to adapt to a volatile market and overcome the obsolescence of manual processes [2] and [3].

The increasing complexity of supply chains, combined with the need for agile responses, pressures organizations to explore emerging technologies. Among them, quantum computing has gained prominence for its ability to solve complex problems, especially those of a combinatorial nature, more efficiently than traditional methods [4] and [5].

Despite the growing volume of research on quantum computing, there is still a scarcity of studies that systematically structure a progressive model for the adoption of this technology in logistics contexts. Fragmented technical analyses focused on specific applications or isolated simulations are predominant. In this sense, this article aims to fill this gap by proposing an integrative framework that organizes the critical stages of applying quantum computing in the supply chain.

This article seeks to answer the following guiding question: how can quantum computing contribute to the supply chain? Thus, the general objective is to propose a conceptual framework based on a literature review, structured in three levels to guide the progressive adoption of quantum computing in the supply chain.

The specific objectives are: to map the main concepts and emerging applications of quantum computing that show potential for optimizing processes and solving complex problems in supply chain management, and to develop a three-level conceptual framework, based on the literature, that serves as a guide for the progressive adoption of this technology in supply chain operations.

1.1. Concepts and applications of quantum computing in the supply chain

The supply chain, a concept commonly discussed in the literature, encompasses everything from suppliers and manufacturers to distributors, wholesalers, retailers, and consumers [6]. In this context, managing inventory, optimizing transportation routing, coordinating points of sale, and forecasting consumption rates are constant challenges for its management. As a result, interest in the analysis of large volumes of data (Big Data) has grown, with the aim of making more assertive predictions and decisions. The application of quantum algorithms to these challenges is emerging as a promising way to achieve more scientific and efficient decisions.

Recent studies, such as those by [5] and [7], highlight the viability of quantum simulations in experimental environments. Additionally, authors like [8] present reviews that reinforce the potential of quantum computing as a catalyst for the transformation of supply chains in terms of urban transport optimization, routing, smart logistics, and smart cities.

Added to this is a growing body of work exploring hybrid quantum-classical models and technological maturity frameworks, such as those proposed by [9]. This evidence reinforces the relevance of this research, which seeks to explore how quantum computing can contribute to supply chain management.

2. Methodology

This study used an exploratory and propositional approach, based on a literature review. For the review, a combination of descriptors was used in the Scopus and Google Scholar databases, including: “quantum technology AND logistics OR inventory management OR demand forecasting”; “quantum computing OR quantum technology AND supply chain”; and “optimization OR planning OR simulation OR prediction”.

The selection of studies followed the principles of an integrative review as proposed by [10]. Initially, 150 results were identified in the Scopus and Google Scholar databases using the defined descriptors. The following inclusion criteria were applied: (I) studies published between 2020 and 2025; (II) an explicit focus on applications of quantum computing in the context of the supply chain or logistics; (III) full-text access; and (IV) methodological and thematic relevance verified by reading the title, abstract, and, when necessary, the full text. As for exclusion criteria, duplicate studies were eliminated, along with works outside the thematic scope (such as purely theoretical applications in quantum physics) or without a concrete application to logistics. After screening and critical reading, nine relevant articles were selected.

The analysis of the articles was conducted through thematic analysis, which allowed for the identification of conceptual patterns, emerging applications, and gaps in the literature. The process began with open coding, where the articles' contributions were categorized into three main axes: applied algorithms, logistical applications, and technical limitations. To ensure validity and reduce interpretive bias, the codings were independently validated by two researchers. The main contributions were then synthesized into a summary (Table 1 in the next section), which served as the basis for the construction of the proposed conceptual framework.

3. Results and discussions

From the literature review, it was possible to understand that there are opportunities for the use of quantum computing in supply chain management, as supported by the works compiled in table 1 below:

Table 1: Nine articles used to develop the Framework

Article Title	Contribution	References
Quantum Computing in Logistics and Supply Chain Management: An Overview	An overarching view on quantum computing applications in logistics, focusing on quantum algorithms like QAOA and Quantum Annealing, and the use of hybrid solutions for complex logistical problems.	[11]
Quantum Computing in Supply Chain Management State of the Art and Research Directions. Asian Journal of Logistics Management	Review of the state of the art on quantum computing applied to logistics and supply chain management, with a mapping of trends and future research directions.	[12]
Supply Chain Logistics with Quantum and Classical Annealing Algorithms	Hybrid study between classical setbacks and quantum computing for the optimization of multi-truck routing at the corporate level.	[13]
Optimization Algorithm for Inventory Management on Classical, Quantum and Quantum-Hybrid Hardware	The study presents the QUBO algorithm for inventory management in warehouses with flow racks, evaluating its performance on both quantum and hybrid hardware.	[14]
Quantum-Assisted Vehicle Routing: Realizing QAOA-based Approach on Gate-Based Quantum Computer	Presents the application of QAOA for VRP (Vehicle Routing Problem) on real quantum hardware, highlighting the limitations of noise and circuit depth.	[15]
Adiabatic Quantum Computing for Logistic Transport Optimization	The study compares classical and quantum approaches (annealing) for last-mile optimization, proposing hybrid scenarios in logistics.	[16]

Quantum Walk-Based Vehicle Routing Optimisation	Demonstrates the use of QWOA in the CVRP (Capacitated Vehicle Routing Problem), with simulations showing more efficient convergence than classical methods.	[17]
Applying Quantum Approximate Optimization to the Heterogeneous Vehicle Routing Problem	Presents QAOA applied to HVRP (Heterogeneous Vehicle Routing Problem), with a mapping to the Ising Hamiltonian and an analysis of the scalability of the number of qubits.	[18]
Quantum Computing Methods for Supply Chain Management. IEEE/ACM Symposium on Edge Computing	Presents a quantized policy algorithm for inventory control, showing results with IBM Qiskit and qBraid and discussing implementation challenges.	[4]

Source: Author, 2025.

The contributions from the consulted works were of great value in understanding how quantum computing can assist in supply chain management, from data prediction and analysis to scenario simulation that supports decision-making.

In these nine studies, we identified three quantum algorithms with potential application for supply chain management, namely: QAOA, QUBO, and QWOA.

The Quantum Approximate Optimization Algorithm (QAOA) is a hybrid quantum-classical algorithm aimed at combinatorial optimization problems. It uses parameterized quantum gates to explore the solution space, adjusting the parameters via classical optimization. It is widely applied in solving problems such as vehicle routing and resource allocation [15].

QUBO (Quadratic Unconstrained Binary Optimization) is a mathematical formulation that expresses optimization problems as a quadratic function of binary variables, without explicit constraints [14].

The Quantum Walk Optimization Algorithm (QWOA) is an algorithm based on the dynamics of quantum walks, used to solve complex combinatorial problems. Unlike QAOA, QWOA does not depend on classical parameter optimization, as it explores the solution space through probabilistic quantum propagation on graphs. This approach allows for a more efficient and parallel exploration of possible states, making it promising for search and optimization problems in structures with strong connectivity, such as logistics networks and decentralized supply chains [17].

Based on this, this work proposes a three-level conceptual framework (Table 2 below) based on the literature as an initial step for the progressive adoption of quantum computing in supply chain management.

Table 2: Proposed framework – quantum computing in the supply chain

Framework Levels	Literature Base
Level 1: Diagnosis and Mapping Identify logistical challenges that can be benefited by quantum computing Assessment of the supply chain's digital maturity Value stream mapping Identification of NP-hard problems Formation of multidisciplinary teams	[4], [12], [16] e [17]
Level 2: Integration with Quantum Models Test quantum algorithms in simulators before real implementation Modeling of logistical problems for	[13], [14], [15], [17] e [18]

quantum simulations Development of quantum algorithms Proofs of concept Comparison with classical solutions	
Level 3: Operational Adoption Integrate quantum solutions into the real environment and evaluate their impact on KPIs. Implementation on cloud-based quantum hardware/partnerships Integration with legacy systems Monitoring of KPIs Continuous improvement	[4], [11], [14] [17] e [18]

Source: Author, 2025.

The reviewed studies provided evidence that the introduction of quantum computing into logistics requires a progressive path, moving from diagnosis and mapping (level 1), to integration with quantum models (level 2), and finally to operational adoption (level 3).

4. Final considerations

The increasing complexity of the supply chain and the search for more efficient solutions place quantum computing at the center of a new technological paradigm. Although still in its maturing phase, this technology already presents concrete applications for complex logistical problems, especially those of a combinatorial nature, which challenge classical methods.

This article contributed to the advancement of the topic by proposing a three-level conceptual framework, based on recent evidence from the scientific literature. This framework provides a guide toward the adoption of quantum solutions, by suggesting a path that goes from the diagnosis of maturity and logistical challenges to the implementation and performance evaluation based on KPIs.

In addition to the theoretical contribution on the process of adopting quantum computing in logistics, this study also offers a guide for professionals and academics who wish to explore this technological frontier within their organizations. The modularity and progressive nature of the proposed framework allow for adaptations based on the context and available resources, encouraging a gradual integration of the technology into the corporate environment.

For future perspectives, it is suggested to apply the framework in real case studies to validate its applicability across different industrial segments. Furthermore, it is recommended to deepen the discussion on the economic, ethical, and regulatory aspects associated with quantum computing to broaden its acceptance and guide public and private policies in the field of logistics innovation.

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