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QUANTUM COMPUTERS IN THIRD-PARTY LOGISTIC ACTIVITY – GENUINE CHANGE OR TECHNOLOGICAL GIMMICK?

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Purpose: The objective of the conducted research is to respond to the investigative question related to delineating potential areas of 3PL (third-party logistics) activities that could be supported by quantum computing.
Design/methodology/approach: This study focuses on the exploration and analysis of literature, utilizing both the SCOPUS database and Google Scholar, to identify potential application areas of quantum computers in the 3PL sector. The literature review is based on a systematic approach that includes defining the aim, selecting, and critically assessing existing materials, with particular focus on digitalization, security of information flow, external transport planning, warehousing, and VAS (Value-Added Services).
Findings: The analysis has demonstrated that quantum computers hold the potential to significantly influence 3PL businesses, contributing to innovation and enhancing operational efficiency. Specifically, this technology can revolutionize aspects such as supply chain optimization, data security, warehouse management, and the creation of added value through advanced analytics and personalized services.
Research limitations: The study encountered constraints related to access to comprehensive databases, which may have influenced the thoroughness of the literature review. Furthermore, the scarcity of literature focusing directly on the application of quantum computers within the 3PL context indicates a need for additional, more in-depth empirical research in this field.
Value of the paper: This paper holds both theoretical and practical value, indicating potential innovations and competitive advantages that can be achieved in the 3PL sector through the application of quantum computers. The paper highlights not only opportunities but also challenges and possible directions for future research, providing a foundation for upcoming research initiatives that may contribute to the development and transformation of operational standards in third-party logistics. This article can inspire future research in the area of using quantum computers in external logistics activities.
Keywords: quantum computer, supply chain management, technology, logistics, 3PL.
Category of the paper: Literature review.

1. Introduction

A quantum computer is a device designed to utilize the principles of quantum mechanics for computing (Chertkov et al., 2023). Quantum mechanics is fundamental to modern physics and chemistry, accounting for phenomena such as atomic structure, semiconductor properties, and interactions between elementary particles. Although its predictions are incredibly accurate and have been validated through many experiments, the very nature of quantum mechanics and its interpretation remain subjects of debate and scientific investigation. Quantum computers are considered a relative novelty in the business world. This is another prime example of science ahead of its time, as attempts to scientifically describe the functioning of quantum computers were made before the year 2000 by researchers like Chuang and Yamamoto (1995), who proposed a simple quantum computer in their work, or Jones et al. (1998), who discussed implementing algorithms on such computers. Authors like Zalka (1998), Boghosian and Taylor (1998), and Somaroo et al. (1999) simulated quantum systems and quantum mechanics in action in such computers. Researchers are currently identifying various advantages and disadvantages in the functioning of these computers. When it comes to features that distinguish such equipment from contemporary computers, speed and superiority in creating simulations are often cited (Sarkar et al., 2022; Tan et al., 2022; Huang et al., 2022). Quantum computers have the potential to solve certain problems much faster than traditional computers. An example is the factorization of large numbers, which is crucial in cryptography. Additionally, quantum computers allow for more precise simulations of quantum systems, which is challenging for traditional computers.

Despite the many benefits of quantum computers, researchers often point out their flaws, which could pose challenges and problems in their future potential commercial application. Scholars like Rahaman and Islam (2015) and Zhao (2023) highlight the potential fragility, difficulty in construction, and limited application of such computers. Quantum computers are very sensitive to external disturbances and must operate in a sealed environment where a very low temperature is required. The construction and programming of quantum computers are very complex, and not every problem will be solvable on this type of computer. Authors often focus on identifying and searching for new areas where quantum computers would be applicable. Among the most frequently mentioned are cryptography (Zhao, 2023), i.e., encryption and decryption of information; drug discovery (Batra et al., 2021), i.e., simulating chemical particles at the quantum level; optimization (Zhu et al., 2022), i.e., solving complex optimization problems; and physical simulations (Al-Mohammed et al., 2020), i.e., studying the behavior of particles and materials at the quantum level. Researchers like Jaeger (2007); Gyongyosi and Imre (2019), and Kavokin et al. (2022) emphasize elements that give a quantum computer an advantage over a traditional, classical computer. The main advantage of a quantum computer is its ability to store and process vast amounts of information simultaneously thanks to

something called "quantum superposition". In short, while a traditional computer uses bits (0 or 1) to store information, a quantum computer uses qubits, which can exist simultaneously in both states. This allows quantum computers to solve certain tasks in ways traditional computers cannot achieve.

Researchers are already pointing out various problems that may arise in the perspective of implementing quantum computers on a larger scale and note that it may not always be profitable. Quantum computers are potentially revolutionary computing devices, but there are certain areas where they currently have no application or are not economical to use. Such issues have already been discussed by Rahaman and Islam (2015); Marella and Parisa (2020); Liu (2021), and Zaidi and Sushma (2022). For simple, small-scale calculations, like using a basic calculator or browsing web pages, quantum computers are decidedly too complicated and expensive compared to traditional computers. Typical office tasks, such as text editing, creating spreadsheets, or email handling, do not require the computing power of quantum computers and are successfully managed by standard computers. For video games, multimedia, and other consumer applications, there is currently no need for quantum computers because traditional computers are sufficiently efficient. If data processing is limited and there is no need for complex, large-scale computations, quantum computers may be overly sophisticated and expensive. For the average user, there is currently no practical need to use quantum computers for user-level cryptography. Traditional cryptography methods are secure enough for most applications.

The current state of knowledge in the field of 3PL (third-party logistics) indicates a growing interest in the use of new technologies such as artificial intelligence, the Internet of Things (IoT), and big data analytics. However, the scientific literature still treats the application of quantum computers in this sector to a limited extent. Quantum computers, thanks to their unique properties, can offer significant improvements in areas such as route optimization, inventory management, demand forecasting, and data security. In the era of rapid technological progress, the development and application of quantum computers is becoming one of the key topics in many fields, including 3PL logistics. This study focuses on exploring the potential and challenges associated with the implementation of quantum technologies in the 3PL logistics sector, which is an integral part of the global supply chain. This state of affairs has necessitated posing and considering the following research question:

RQ.1: Are there potential areas of application for quantum computers in the business practices of third-party logistics (3PL) companies operating in supply chains?

Answering the research question will allow for achieving the main goal of the article, which is to find areas of 3PL activity that could be supported by quantum computers. In the first stage, the author will begin searching for an answer to the posed question by constructing a procedure to conduct an analysis of the subject literature.

2. Literature review

3PL enterprises

A logistics operator is typically characterized as a service provider contracted to optimize asset utilization and enhance operational processes (Skowron-Grabowska, 2007). These operators, acting on behalf of manufacturers or large retailers, offer various logistics services (Guminski, Dohn, 2017). When selecting a logistics operator, considerations like task time, overall process duration, need for technical and human resources, and process method and cost are crucial (Kramarz, Slupina, 2013). Modern market competition among operators focuses on more than just the lowest price; it involves ensuring supply chain visibility, reliability, and a proactive approach to innovation (Cichosz et al., 2017). The logistics services industry is trending towards more comprehensive service offerings, encapsulated in contract logistics or bundled services (Saniuk et al., 2011). This trend includes fundamental services like transport and forwarding, with various additional activities (Witkowsk, Kiba-Janiak, 2014). Companies are moving away from single-service contracts towards providers offering multiple services. Thus, logistics operators can gain a competitive edge not only through logistics services but also through supplementary services, possibly including product demand forecasting. They are increasingly influential in shaping entire distribution networks and seen as potential leaders in supply chains (Kawa et al., 2018). Their roles may encompass managing transportation, distribution, customer service, warehousing, continuous improvement, and reconfiguring distribution networks and supply chains to align with customer needs (Antonowicz, 2011).

In contract logistics, 3PL operators are central (Ślusarczyk et al., 2020). 3PLs are external entities providing various logistics functions (Marasco, 2008), commonly including third-party transportation, freight contract negotiation and conclusion, warehousing, and freight consolidation. Some logistics operators expand their offerings to include additional services like product assembly and installation. The primary objective of 3PLs is to deliver logistics services. The theory of third-party logistics originates from its position as an intermediary between the product's producer/supplier and the recipient (Thakkar et al., 2005). 3PL companies play a significant role in contemporary markets and distribution networks, shaping modern distribution networks and undertaking increasingly complex functions. These functions often extend beyond logistics to gain competitive advantage and provide customers with the basis for co-creating flexible and dynamic market systems through reliable distribution networks. Market trends and academic research indicate the growing importance of 3PL in managing material and information flows within distribution networks.

Technological advancements have reshaped the logistics sector significantly. Digitalization and automation have altered the methods and operations of 3PL. They play a crucial role in supply chains, offering a wide range of services including transportation, warehousing,

inventory management, packaging, and information management. They serve as vital links between shippers and carriers, improving supply chain efficiency with additional services such as order fulfillment, consolidation, and customs clearance (Mangan, Lalwani, 2016; Ajakaive, 2012; Griffis et al., 2007; Herold et al., 2021). This paper highlights LSPs as crucial third-party logistics entities, focusing on how Value Added Services (VAS) impact their customer base. 3PLs have embraced digitalization, using it to enhance their operations, increase efficiency, and provide better client experiences. The adoption of digital technology and data analytics allows them to present more effective solutions. For example, automating tasks like order processing and inventory management improves operational precision and speed, leading to cost savings and enhanced efficiency. Automation also reduces human errors and frees up resources for more strategic tasks. As key players in various sectors, LSPs are fundamental to the global supply chain. They have incorporated digital advancements to improve efficiency and customer service. A significant shift is the digitization of information along with the integration of sophisticated software, improving shipment tracking, inventory control, and facilitating real-time data sharing, thereby increasing visibility and transparency in supply chains. Additionally, data analytics and predictive models enable LSPs to make more informed choices, optimizing routes and refining operations to improve service quality and cost effectiveness (Sanchez-Rodrigues, Kumar, 2019). The rapid growth of e-commerce and the increasing demand for prompt, reliable delivery have spurred innovation, especially in last-mile logistics. Technologies like route optimization software, mobile apps, and real-time tracking have become essential for 3PLs, enhancing delivery methods and providing clients with up-to-date information. The logistics industry is also adopting emerging technologies such as the Internet of Things (IoT), blockchain, and artificial intelligence (AI), revolutionizing the supply chain with improved visibility, traceability, and automation. Technology is a critical element in the ongoing evolution of the logistics sector, and 3PLs are leveraging this digital shift to refine their operations, enhance customer service, and remain competitive in the ever-changing global supply chain landscape.

Logistics and supply chains in the quantum era

For the constructed query, 118 items in the SCOPUS database were extracted. The results, after limiting only to English-language publications of the types conference paper, article, book chapter and book, were reduced to 101 items. The largest number of publications was attributed to computer science (69 items), while those that could be thematically related to this article, i.e. embedded in social science, decision science or business, management and accounting contained a total of 28 items. However, it is worth keeping in mind that the articles could have been assigned to several scientific disciplines. In addition, due to the relatively small number of items in the database (101 items), the author decided not to narrow down the articles by scientific discipline. As can be inferred from figure 2, it is possible to search for individual articles that could probably be matched to the subject matter undertaken as early as 2002.

However, the first major increase in articles occurred in 2019, with the largest increase from 2021 to the present.

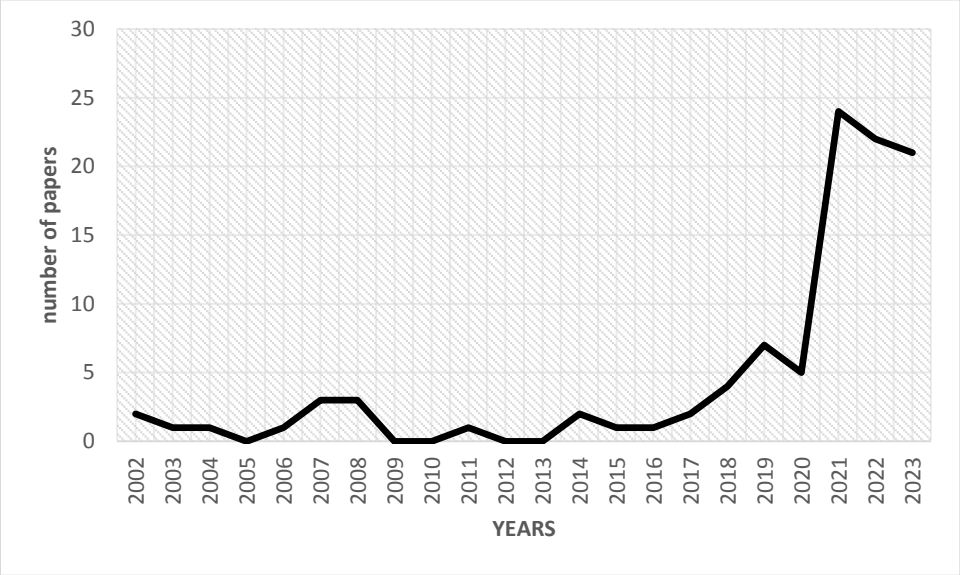

Figure 2. Number of papers per years based on SCOPUS database.

Source: own elaboration based on SCOPUS database.

Based on the analysis of authors' keywords and keywords assigned by publishers for 101 selected items from the SCOPUS database, it can be concluded that quantum computers is most often considered from the point of view:

- Blockchain technology and network security;
- AI, machine learning and IoT;
- Problem solving and optimization;
- Cryptography.

Based on the analysis of keywords and created relationship maps using the VOSviewer software (figure 3), it can be seen that supply chain is also a subject in which the use of quantum computers has begun to be seen.

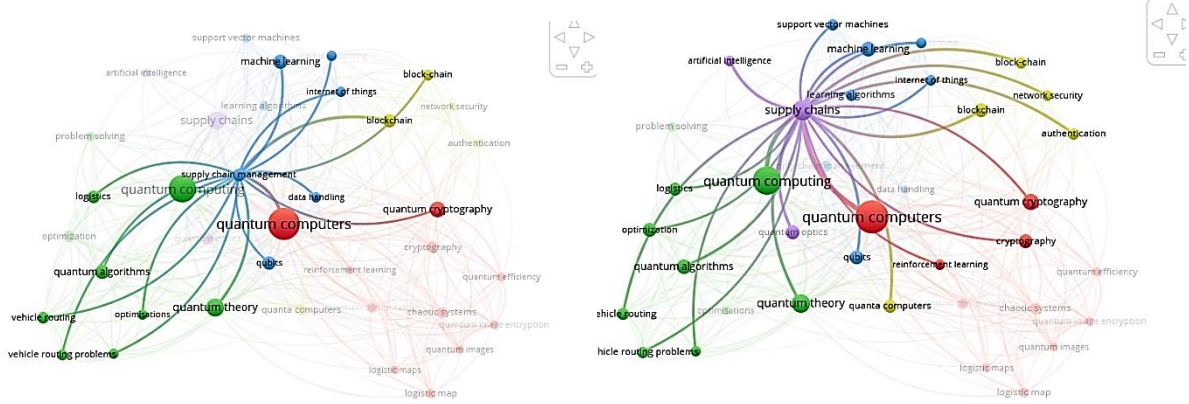

Figure 3. Relations map (key clusters as “supply chain management” or “supply chain”).

Source: own elaboration based on SCOPUS database.

Based on the bibliometric analysis, it can be concluded that topics related to supply chains are usually addressed with topics related to blockchain, network security, cryptography, transportation and vehicle routing problem, quantum algorithms, problem solving, optimization and AI & ML. In what follows, the detected areas were used as a baseline, and from the previously mentioned 101 items, items were manually selected that represent subject matter that will achieve the review objective set in the article. The collected results are presented in Table 1.

Table 1.
Main areas of quantum computers in logistics and supply chains

Papers	Main areas of quantum computer usage in the context of logistics or supply chains						
	Blockchain	**Network security & cryptography**	**Transportation & vehicle routing problem**	**Quantum algorithms**	**Silmulations**	**Optimization**	**AI & ML & ANN**
Bednar, Drager (2007)		x				x	
Masum et al. (2022)		x					
Rad (2021); Jain, Lamba (2023); Banupriya et al. (2021); Li et al. (2023)	x						
Ebert (2016); Mohanty et al. (2019); Hamdy et al. (2022); Correll et al. (2023); Kjamilji et al. (2021)							x
Slane (2019)	x	x					x
Rana et al. (2022); Ajagekar et al. (2020)						x	
Cheung et al. (2021); Moskyin (2022)		x					
Brandmeier et al. (2021); Xu, Gao (2009); Date et al. (2019); De Andoin et al. (2022); Zaman et al. (2023)				x			
Bogdanov et al. (2019)					x		
Longo et al. (2022)	x	x					
Yarkoni et al. (2021); Polikarpov et al. (2021); Lo, Shih (2021); Engel et al. (2022); Osaba et al. (2022); Hulianytskyi et al. (2022); Bentley et al. (2022); Dixit et al. (2023); Alsaiyari, Felemban (2023); Qu (2023); Azad et al. (2022)			x				

Source: Own elaboration.

In addition to the main areas of use of quantum computers in logistics and supply chains listed in Table 1, the author, based on a review of the literature items, also identified other areas that were not included in the initial phase because they were not visible on the automatically created relationship map. These areas are:

- Improving resilience and planning under uncertainty in supply chains (Abdelgaber, Nikolopoulos, 2021; Garcia Garcia, Galan Jativa, 2023);
- Supply chain finance (Griffin, Sampat, 2021);
- Efficient applications for logistics (Humble, 2018);

- Use within Industry 4.0 solutions (Agarwal, Alam, 2022), including specifically IoT enhancements (Kjamilji et al., 2021; Hu et al., 2021; Satamraju, Malarkodi, 2021);
- Combining quantum computing capabilities with RFID (Assidi et al., 2018; Zhu et al., 2018; Lu, Li, 2021);
- Delivery plan optimization (Masuda et al., 2023) and transportation network design (Dixit, Niu, 2023).

Quantum computing is considered by some authors to be a futuristic technology that can be used for supply chain management (Nagaiah, 2022). Authors such as Sotelo (2021) indicate that quantum computing could have many advantages in logistics, and at least Jiang et al. (2022) confirm the thesis cited earlier that the technology could be useful in supply chain management. The technology itself is relatively new, but some of the authors argue that it will have a very large impact on logistics (Gupta, Sharma, 2023). Of course, questions of empirical verification of the cost-effectiveness of implementing such solutions remain unresolved, but theory has already shaped certain elements of the operation of supply chains, or logistics flows, in which quantum computers may have a particular application.

According to the literature, quantum computers offer new capabilities in secure computation, trusted data storage, and efficient applications (Humble, 2018). The issue related to the possibility of providing advanced applications for logistics is also addressed by Verduro et al. (2021). In turn, Bednar and Drager (2007) emphasize the capability for rapid image processing, rapid optimization of logistics, protecting information, secure distributed simulation, and massively parallel computation. A significant role quantum computers can play in cyber security. For example, Abdelgaber and Nikolopoulos (2021) stress that such technology can increase the resilience of supply chains, and Cheung et al. (2021) emphasize the special role of quantum computers in cyber security. Algorithms based on so-called Quantum Machine Learning (QML) (Masum et al., 2022), technologies related to AI and blockchain (Slane, 2019), or blockchain and cryptography (Longo et al., 2022), where cryptography itself has been analyzed, for example, in terms of the security of transport document flows by Moskvin (2022), could be of great importance in the field of cyber security.

The combination of blockchain technology with quantum computing is the subject of many works such as Rad (2021); Jain and Lamba (2023); Banupriya et al. (2021), who analyzed the combination of these technologies in supply chains, or in the work of Li et al. (2023). Who have been discussing the topic of using the two technologies using the specific example of a cold-chain logistics system.

Another area of potential application of quantum computers in logistics is related to the support of technologies used in Industry 4.0 (Agarwal, Alam, 2022). In this regard, the most commonly mentioned here is support of ML algorithms (Ebert, 2016; Mohanty et al., 2019) including support of ML algorithms to support operations in the seaport of transshipment (Hamdy et al., 2022), there is even sometimes talk of quantum machine learning (QML) (Masum et al., 2022) or quantum neural networks (Correll et al., 2023) as the next level of

sophistication of these solutions. Additionally, quantum computers are very often mentioned in general terms as tools to support AI (Ebert, 2016; Mohanty et al., 2019). Among the solutions specific to Industry 4.0 that can be supported by quantum computers, IoT (Kjamilji et al., 2021; Hu et al., 2021; Satamraju, Malarkodi, 2021) or the robotization of logistics processes in general (Ebert, 2016) or the Combination of quantum computing capabilities with RFID (Assidi et al., 2018; Zhu et al., 2018; Lu, Li, 2021) are also mentioned very often.

Some authors also address the topic of finance in supply chains, which could be supported and streamlined by quantum computing technologies (Griffin, Sampat, 2021) however, a much more frequently mentioned area is support for optimization of operations (Ajagekar et al., 2020), so as to facilitate at least planning supply chain operations under high uncertainty (Garcia Garcia, Galan Jativa, 2023). As for optimization, some authors point out that quantum computers could improve simulation models and analysis (Bogdanov et al., 2019), but the largest percentage of papers are devoted to using quantum computers for transportation and distribution issues. Such issues include:

- Solving the shimpent rerouting problem (Yarkoni et al., 2021);
- Transport optimization (Polikarpov et al., 2021; Rana et al., 2022);
- Routing problem (Engel et al., 2022; Osaba et al., 2022; Hulianytskyi et al., 2022; Bentley et al., 2022; Dixit et al., 2023; Alsaiyari, Felemban, 2023; Qu, 2023; Azad et al., 2022);
- Pollution routing problem in sustainable logistics and supply chains (Lo, Shih, 2021);
- Delivery plan optimization (Masuda et al., 2023);
- Transportation network design problem (Dixit, Niu, 2023) or designing logistics network (Ding et al., 2019).

An interesting question of the future operation of quantum computers is that of algorithms, the foundations of which have often been laid for their future implementation on this type of hardware. The literature points to several algorithms that could have applications in supply chains and logistics. Xu and Gao (2009) show the concept of real-coded quantum evolutionary algorithm (RQEA) for optimization problem with the characteristics of high-dimension, non-linear, non-convexity, a large number of local optima. Brandmeier et al. (2021), on the other hand, point to the possibility and potential benefits that could revolutionize armed forces logistics after using the Grover algorithm. Date et al. (2019) point to the possibility of solving QUBO (Quadratic Uncostrained Binary Optimization) and thus generating large savings for the logistics industry. Another issue is the Bin Packing Problem (BPP) stands out as a paradigmatic combinatorial optimization problem in logistics which could also be solved by quantum computing (De Andoin et al., 2022). The next one, Harrow-Hassidim-Lloyd (HHL) quantum algorithm, which can solve linear system problems with exponential speed-up over the classical method and is the basis of many important quantum computing algorithms (Zaman et al., 2023). Quantum approximate optimization algorithm (QAOA), as a variational Quantum algorithm for

approximately solving discrete combinatorial optimization problems can be deployed into the smart logistics dilemma to improve the scalability of the system, decrease the time, thus reducing the carbon footprint and smart manufacturing system cost. QAOA was proposed by Azzaoui et al. (2021). All of this outlines specific areas related to business activity in supply chains where the application of quantum computers could make sense.

However, the main element related to this article is a specific group of supply chain companies, namely 3PL (third-party logistics) companies. The author's attention has been devoted to these very companies for the reason that nowadays a very large percentage of logistics services are outsourced, so in providing value to supply chain participants such companies will take an active part. Thus, it is worthwhile to analyze the potential areas of application of quantum computers precisely in such types of business models of 3PL enterprises.

3. Methods

The purpose of this article is to conduct research in the context of finding an answer to the research question related to delineating potential areas of 3PL (third-party logistics) activity that could be supported by quantum computing.

The research is carried out based on a literature review, which enables a correct and broad understanding of the topic from the point of view of conducting a good analysis and drawing conclusions. One of the requirements for conducting a literature review is to properly design the research being conducted. (Snyder, 2019). The construction phase of the literature review was created based on the methodology presented by Czakon et al. (2022) and Klimas et al. (2021) and is shown in Figure 1.

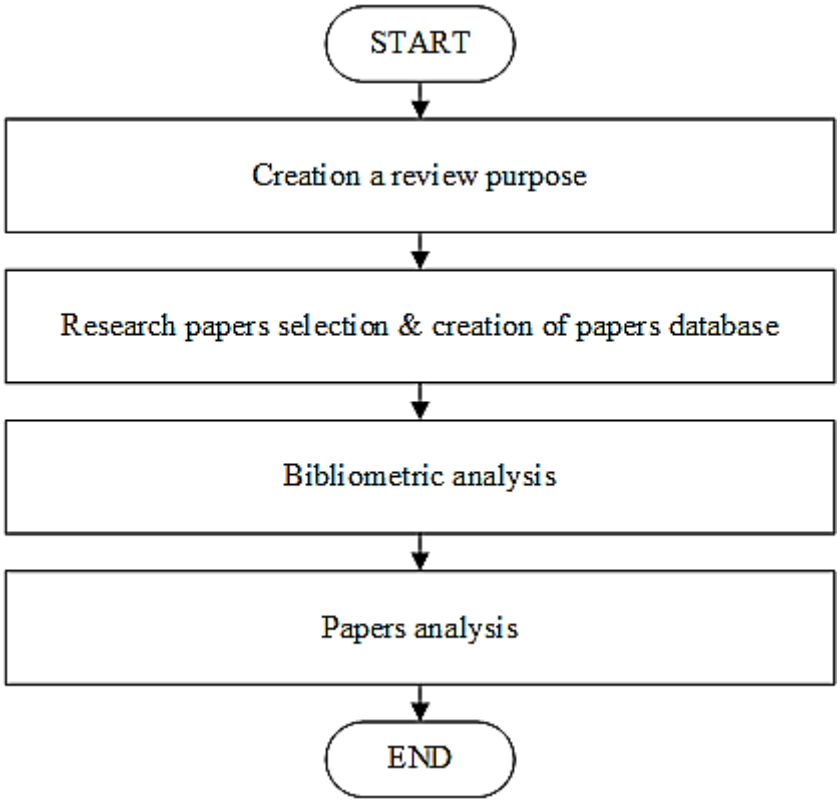

Figure 1. Literature review workflow.

Source: adopted from Czakon et al. (2022) and Klimas et al. (2021).

Literature research in this article will be conducted in a similar way to the proposed phases of a systematic literature review, which can be found as a research method. In the first step, the purpose of the conducted literature review was defined, which is to find potential areas of application of quantum computers to support actions in the field of logistics in supply chains and among 3PL companies. The scope of the research is aimed not only at reviewing literature but also at its critical assessment by the author. The next stage of literary research was related to the selection of articles and the creation of a database for further analysis. This stage, in the case of this article, was mainly related to the appropriate selection of keywords to create a database of articles thematically related to the scope of research. For this purpose, the author used a database of articles indexed in SCOPUS and arbitrarily selected articles from the Google Scholar search engine database. The author is aware that this is a certain limitation of the review conducted, unfortunately, it is caused by the author's access to databases. The author decided to base the research on a database of articles to which he has free access. The data from the review concern the range of articles available from the beginning of indexing in the SCOPUS database until October 2023. The keywords used for searching in the database concerned the authors' keywords, words given by journals, and phrases appearing in abstracts. Only English-language publications were taken into account for analysis, which is also a kind of limitation. The keywords taken into account were assigned according to the logic:

(TITLE-ABS-KEY ("quantum computers" OR "quantum computing") AND TITLE-ABS-KEY ("3PL" OR "third-party logistics" OR "logistics service provider" OR "supply chain" OR "logistics" OR "LSP"))

Thus, for the first round of analysis, articles were taken that included phrases related to quantum computer or quantum computing and any of the phrases to identify a publication related to logistics, 3PL or supply chains in the authors' keywords, the keywords given by the publisher or the abstract.

The next step, bibliometric analysis, was carried out using the VOSviewer tool to automatically create relationship maps related to the words that appear in the keywords (in the case of this article, in the keywords assigned by the authors and those assigned by the publishers). The map was developed using the association strength method with weights total link strength. Clustering was performed with the following settings: resolution equal to 1 and min. cluster size equal to 1. Discussions on whether to use automated or semi-automated tools to perform bibliometric analysis are growing as new technologies and capabilities increase. Opponents and critics of the method blame qualitative limitations and the frequent lack of context for the analysis. Enthusiasts of such methods, such as Bacinger et al. (2022); Portenoy and West (2020); Tsang and Lee (2022) and Silva et al. (2022), on the other hand, point out that they offer time savings, efficiency, speed and the ability to visualize quickly. The final stage, the analysis will be based on the analysis of the selected articles and their critical evaluation and elaboration of potential applications and further research on the topics taken up.

4. Results - quantum computers in 3PL activity

In today's dynamic business environment, 3PLs are a key element in the efficient operation of companies. With the increasing complexity and globalization of supply chains, there is an urgent need for innovations that can revolutionize this area. One of the most promising breakthroughs in this area is the use of quantum computers. As shown earlier in the article, quantum computers could have significant applications in supply chains. However, the author is curious about what applications they may bring directly to 3PL companies, because as Giri and Sarker (2017) and Vasiliauskas and Jakubauskas, (2007), among others, point out, logistics service providers are extremely important to the proper functioning of modern supply chains. Interestingly, the SCOPUS database does not show any returns for item search results that include both the phrase "3PL" (or "third-party logistics" or "logistics service provider") and the phrase "quantum computer" (or "quantum computing") in the keywords or abstract. Thus, the author has attempted to translate the currently available theory on the application of quantum computers in supply chains and logistics and to match this theory to the operation of 3PLs. The author's conceptual proposal for supporting 3PL activities provided to service

providers is presented in Figure 4. The author has selected several key areas related to 3PL activities in which he believes the future impact of quantum computers can be sought. Among the key areas of 3PL activity, the author chose to mention:

- Digitization, or rather, the ability to adapt new technologies and provide services based very much on digitization. Digitization is recognized as an important area of 3PL's business by Zhou et al. (2023) and Hofmann and Osterwalder (2017), among others;
- Information flow security, i.e., 3PLs' attention to maintaining high security of data exchanged with contractors. Many times in supply chains, 3PLs have access to sensitive data as part of their integration with other entities. The importance of the importance of taking care of information security by 3PLs is emphasized by Aguezzoul (2013) and Malkus and Wawak (2015), among others;
- External transportation planning, or the planning of transportation execution activities between links in the supply chain. Issues related to the fact that transportation planning is usually one of the core activities of logistics operators is highlighted in Kmiecik (2022) and Memon et al. (2014), among others;
- Warehousing is also recognized as one of the most commonly provided services by 3PLs, so some quantum computing-related solutions should be sought there as well. Warehousing as a business process particularly important in the context of 3PLs is shown by Karagiannis et al. (2023) and Darko and Vlachos (2022), among others;
- In general, also VAS services related not only to warehousing and transportation, and other services provided at least as part of logistics service packages are of great importance to 3PLs. Special attention to the role of VAS selection and delivery by 3PLs is given by Jum and Basheer (2023) and Mou and Wang (2023), among others.

The author has attempted to outline what value could be delivered in specific areas of 3PL operations through quantum computers. Figure 4 conceptually illustrates a key research initiative, addressing the interdisciplinary intersection between advanced quantum technologies and the third-party logistics (3PL) sector. The analysis highlights five areas where quantum computers can have a significant impact, contributing to innovation in 3PL practices and improving operational efficiency across the supply chain.

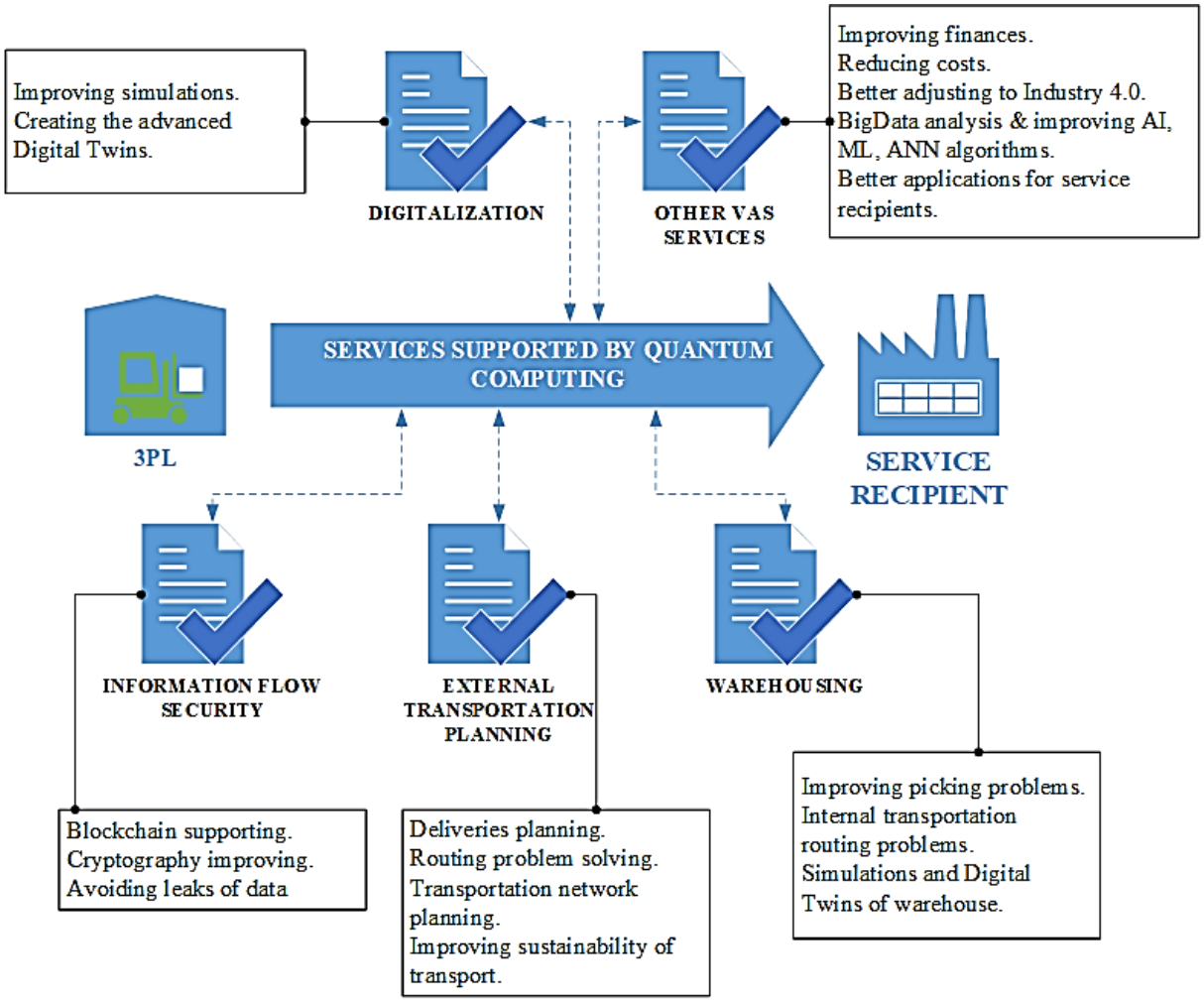

Figure 4. Conception of supporting 3PL actions by quantum computers.

Source: Own elaboration.

The use of quantum computers in simulations and the creation of advanced Digital Twins is opening up new horizons for accurate modeling of logistics systems. Quantum computing has already been associated with the Digital Twin by Margarita and Schieweck (2022), among others.The ability to simulate complex scenarios in near real time can accelerate decision-making and optimization, contributing to a more efficient and flexible supply chain. In the era of digitization, data security is becoming a priority. The use of quantum technology to secure blockchain transactions, improve cryptography and prevent data leaks increases the resilience of strategic information against cyber threats. Protecting sensitive and confidential data is not only a compliance issue, but also a competitive advantage. Quantum computers have the potential to revolutionize aspects of logistics planning, such as optimizing deliveries, solving complex transportation problems and advanced network planning. Jain (2021) makes it clear that quantum computers can be used to solve traveling salesman problems. In addition, by supporting sustainability strategies, these technologies can help minimize the carbon footprint and optimize resource consumption in transportation. Operational efficiency in warehousing can be significantly improved by quantum data processing. In particular, quickly

and efficiently solving problems related to picking paths, internal logistics, as well as implementing Digital Twins for warehouse simulation, will contribute to increased efficiency and reduced operating costs. The quantum approach to financial analysis, cost management, as well as to understanding and adapting to the requirements of Industry 4.0 is setting new directions in value creation. By analyzing Big Data, optimizing AI, ANN, ML algorithms, and creating personalized applications, 3PLs can offer more customized services. Zajac et al. (2022) also indicate that it is possible to integrate traditional AI solutions with quantum technology and thus create hybrid-quantum applications. Quantum computers can also be used to create quantum neural networks for prediction (Jahin et al., 2023), where demand forecasting and predictive activities are also often mentioned as a new VAS service in 3PL operations (Kmiecik, 2022). The conclusions of this analysis suggest that the integration of quantum technologies in the 3PL sector will not only accelerate the evolution of operational standards, but will also cause a disruption in traditional supply chain management models. Although the literature on the use of quantum computers in 3PLs is still limited, the current study is an important contribution to filling this gap, providing ground for future empirical research and theoretical discussions. However, attention should also be paid to potential challenges, such as high upfront costs, implementation complexity, and the need for further development of safety standards.

Further research should also consider the ethical and social implications of introducing these advanced technologies into logistics practice. In addition, considerations should be made related to whether data encryption with current solutions such as blockchain will not be sufficient in the subject matter. In addition, the implementation of solutions related to cloud computing in the long term is also of concern to the author. Quantum computing in the long term has been considered by Ferraro and Prati (2020), among others. It is known that machine learning algorithms mostly tend to deteriorate over time (Vela et al., 2022), so the direction of sustainability of quantum computing-related solutions over time should also be considered.

Quantum computers, with their advanced computational capabilities, offer a paradigm shift in how 3PL (third-party logistics) companies can address their operational challenges and opportunities. The intersection of quantum computing and 3PL, as outlined in previous sections, has the potential to transform the logistics industry in several significant aspects. Quantum computers can greatly improve predictive analytics in 3PL operations. By utilizing quantum algorithms, 3PL companies can process vast data sets more efficiently than traditional computers, leading to more accurate demand forecasting and inventory management. This enhanced capability is key in adapting to market fluctuations and real-time customer demands, ensuring optimal inventory levels and reducing waste. The computational power of quantum computers lies in their ability to quickly solve complex optimization problems. For 3PL companies, this means the potential to design more efficient supply chain networks. Quantum computers can analyze numerous variables and constraints to suggest optimal routes, transportation methods, and warehouse locations. This optimization contributes to cost savings, reduced transit times, and improved service levels. Quantum computers can also assist 3PL

companies in achieving their sustainable development goals. Through route optimization and load consolidation, quantum computing can help reduce fuel consumption and greenhouse gas emissions. Additionally, it can support more efficient recycling and reuse of materials, managing reverse logistics more effectively, and thus promoting a circular economy. With quantum computers, 3PL service providers can offer more personalized logistics solutions. By analyzing data and customer preferences at quantum speed, companies can tailor their services to individual needs, improving customer satisfaction and loyalty. This approach can extend to personalized pricing strategies, delivery options, and additional services. Although the integration of quantum computers in 3PL is promising, it is not without challenges. The high costs of quantum computers and the complexity of their operation require significant investments in both financial and human capital. Moreover, the current stage of quantum technology development still requires considerable advancements before it finds widespread application in the logistics sector.

According to the study, the technology associated with the development of quantum computers, based on the current state of knowledge, has a good chance of bringing real benefits to the 3PL business. Incorporating quantum computers into 3PL activities represents a significant leap forward in logistics innovations. As the technology matures and becomes more accessible, significant improvements in efficiency, sustainable development, and service personalization are expected. The future of 3PL, intertwined with quantum computing, opens exciting prospects for transforming the logistics landscape, although the challenges and implications of this technological merger must be carefully considered.

5. Conclusions

The research presented in this research paper indicates that quantum computers have the potential to significantly transform the supply chain management sector, particularly in the area of 3PL logistics. The ability to rapidly process data, optimize, secure information and innovate in logistics planning and execution indicates that quantum computers could bring revolutionary changes to the way 3PL companies operate. A synthetic summary of the literature analysis and potential applications indicates that quantum computers can contribute to: intensifying the digitization process, by fostering the adaptation of new digital technologies and services; enhancing the security of information flows, through advanced cyber-security applications that can protect sensitive data and logistics operations; optimizing external transportation planning, through the ability to process and analyze large amounts of data in real time; improving warehouse processes, through more efficient management of resources and space, and rapid adaptation to changing market conditions; developing value-added services, through innovation

and personalization of offerings, which can increase the competitiveness and efficiency of 3PL service providers.

This work contributes to the management sciences by expanding the current understanding of the role that quantum technologies can play in the future of logistics, particularly in the context of 3PL companies. It also presents a research initiative that integrates advanced technologies with the practical needs of the sector, highlighting the interdisciplinary opportunities and potential benefits for supply chain management. Moreover, the findings suggest that future research should focus on empirical verification of theoretical assumptions, as well as the development of specific tools and implementation strategies. Thus, this work has the potential to inspire further in-depth research on the application of quantum computers to business practice, driving innovation and efficiency in global logistics. The research presented in this scientific article indicates that quantum computers have the potential to significantly transform the supply chain management sector, especially in the area of 3PL logistics. The ability to quickly process data, optimize, secure information, and innovate in planning and implementation of logistics suggests that quantum computers can bring revolutionary changes in the way 3PL companies operate. A synthetic summary of the literature analysis and potential applications indicates that quantum computers can contribute to: intensifying the digitization process, by supporting the adaptation of new technologies and digital services; increasing the security of information flows, through advanced cybersecurity applications protecting sensitive data and logistics operations; optimizing external transport planning, thanks to the ability to process and analyze large amounts of data in real time; improving warehouse processes, through more efficient resource and space management and quick adaptation to changing market conditions; developing value-added services, through innovation and personalization of the offer, which can increase the competitiveness and efficiency of 3PL service providers.

Various new perspectives associated with the introduction of quantum computers can be listed. Quantum computers may offer new possibilities in analyzing large data sets, allowing 3PL companies deeper insights into market trends, consumer preferences, and purchasing behavior patterns. This will allow for better market segmentation and more effective business strategy planning. Quantum computers can contribute to creating more sustainable logistics models, by optimizing supply chains in terms of CO2 emissions reduction and efficient resource use. The use of quantum computers can streamline communication and integration between different entities in the supply chain, which is key to effective management and reduction of delays. Quantum computers enable advanced simulations of logistics operations, which can be used to test various scenarios and strategies before they are implemented. In summary, quantum computers have the potential to revolutionize the 3PL logistics sector, offering new possibilities in terms of optimization, security, personalization, and operational efficiency. However, challenges related to costs and complexity of technology require further research and development. Future research should focus on the empirical verification of the possibilities of

applying quantum computers in logistical practice and on developing strategies for adapting and implementing these technologies in real operational conditions.

The results suggest that quantum computers can significantly impact 3PL companies by driving innovation and improving operational efficiency in various areas. However, the study was limited by access to comprehensive databases and a lack of literature focused on the application of quantum computers in the 3PL sector. Future research should focus on filling these gaps by offering more detailed empirical insights into the practical implementation and benefits of quantum technology in 3PL operations. In addition, this research can inspire future researchers, encouraging further exploration of this promising area and the development of innovative solutions that can revolutionize the logistics sector.

References

1. Abdelgaber, N., Nikolopoulos, C. (2021, September). Calculating the Topological Resilience of Supply Chain Networks Using Quantum Hopfield Neural Networks. *4th International Conference on Artificial Intelligence for Industries (AI4I)*. IEEE, pp. 61-62). https://doi.org/10.1109/ai4i51902.2021.00023
2. Agarwal, P., Alam, M. (2022). Quantum-Inspired Support Vector Machines for Human Activity Recognition in Industry 4.0. *Proceedings of Data Analytics and Management: ICDAM 2021, Vol. 1*. Springer Singapore, pp. 281-290. https://doi.org/10.1007/978-981-16-6289-8_24
3. Aguezzoul, A. (2013). Overview on 3PL selection problem. *Supply Chain Management: Concepts, Methodologies, Tools, and Applications* (pp. 259-273). IGI Global. https://doi.org/10.4018/978-1-4666-2625-6.ch015
4. Ajagekar, A., Humble, T., You, F. (2020). Quantum computing based hybrid solution strategies for large-scale discrete-continuous optimization problems. *Computers & Chemical Engineering*, *132*, 106630. https://doi.org/10.1016/j.compchemeng.2019.106630
5. Ajakaiye, O.I. (2012). *The Role of Logistics Service Providers in the Logistics Firms' Supply Chain*.
6. Al-Mohammed, H.A., Al-Ali, M.S., Alkaeed, M. (2020, December). Quantum Computer Architecture From Non-Conventional Physical Simulation Up To Encryption Cracking, Machine Learning Application, And More. *16th International Computer Engineering Conference (ICENCO)*. IEEE, pp. 17-24. https://doi.org/10.1109/icenco49778.2020.9357401

7. Alsaiyari, M., Felemban, M. (2023, February). Variational Quantum Algorithms for Solving Vehicle Routing Problem. *International Conference on Smart Computing and Application (ICSCA).* IEEE, pp. 1-4. https://doi.org/10.1109/icsca57840.2023.10087522
8. Antonowicz, M. (2011). Regulation and logistics in rail freight transport. *Archives of Transport, 3*. https://doi.org/10.2478/v10174-011-0018-5.
9. Assidi, H., Ayebie, E.B., Souidi, E.M. (2018). Two mutual authentication protocols based on zero-knowledge proofs for RFID systems. *Information Security and Cryptology–ICISC 2017: 20th International Conference.* Seoul, South Korea, November 29-December 1, 2017, Revised Selected Papers, 20 (pp. 267-283). Springer International Publishing. https://doi.org/10.1007/978-3-319-78556-1_15
10. Azad, U., Behera, B.K., Ahmed, E.A., Panigrahi, P.K., Farouk, A. (2022). Solving vehicle routing problem using quantum approximate optimization algorithm. *IEEE Transactions on Intelligent Transportation Systems*. https://doi.org/10.1109/tits.2022.3172241
11. Azzaoui, A.E., Kim, T.W., Pan, Y., Park, J.H. (2021). A quantum approximate optimization algorithm based on blockchain heuristic approach for scalable and secure smart logistics systems. *Human-centric Computing and Information Sciences, 11(46),* 1-12. https://doi.org/10.1186/s13673-018-0136-7
12. Bacinger, F., Boticki, I., Mlinaric, D. (2022). System for Semi-Automated Literature Review Based on Machine Learning. *Electronics, 11(24),* 4124. https://doi.org/10.3390/electronics11244124
13. Banupriya, S., Kottursamy, K., Bashir, A.K. (2021). Privacy-preserving hierarchical deterministic key generation based on a lattice of rings in public blockchain. *Peer-to-Peer Networking and Applications*, *14*, 2813-2825. https://doi.org/10.1007/s12083-021-01117-2
14. Batra, K., Zorn, K.M., Foil, D.H., Minerali, E., Gawriljuk, V.O., Lane, T.R., Ekins, S. (2021). Quantum machine learning algorithms for drug discovery applications. *Journal of chemical information and modeling*, *61(6),* 2641-2647. https://doi.org/10.1021/acs.jcim.1c00166
15. Bednar, E., Drager, S.L. (2007, April). Quantum simulator review. *Quantum Information and Computation, Vol. 6573.* SPIE, pp. 150-160. https://doi.org/10.1117/12.719758
16. Bentley, C.D., Marsh, S., Carvalho, A.R., Kilby, P., Biercuk, M.J. (2022). Quantum computing for transport optimization. *arXiv preprint arXiv: 2206.07313*. https://doi.org/10.1063/pt.5.028530
17. Bogdanov, Y.I., Bogdanova, N.A., Fastovets, D.V., Lukichev, V.F. (2019, March). Quantum approach to the dynamical systems modeling. *International Conference on Micro- and Nano-Electronics 2018, Vol. 11022*. SPIE, pp. 728-739. https://doi.org/10.1117/12.2522426

18. Boghosian, B.M., Taylor IV, W. (1998). Simulating quantum mechanics on a quantum computer. *Physica D: Nonlinear Phenomena, 120(1-2),* 30-42. https://doi.org/10.1016/s0167-2789(98)00042-6
19. Brandmeier, R.A., Heye, J.A., Woywod, C. (2022). Future Development of Quantum Computing and Its Relevance to NATO. *Connections: The Quarterly Journal*, *20*, 89-110. https://doi.org/10.11610/connections.20.2.08
20. Chertkov, E., Cheng, Z., Potter, A.C., Gopalakrishnan, S., Gatterman, T.M., Gerber, J.A., Foss-Feig, M. (2023). Characterizing a non-equilibrium phase transition on a quantum computer. *Nature Physics*, 1-6. https://doi.org/10.1038/s41567-023-02199-w
21. Cheung, K.F., Bell, M.G., Bhattacharjya, J. (2021). Cybersecurity in logistics and supply chain management: An overview and future research directions. *Transportation Research Part E: Logistics and Transportation Review*, *146*, 102217. https://doi.org/10.1016/j.tre.2020.102217
22. Chuang, I.L., Yamamoto, Y. (1995). Simple quantum computer. *Physical Review A, 52(5),* 3489. https://doi.org/10.1103/physreva.52.3489
23. Cichosz, M., Goldsby, T.J., Knemeyer, A.M., Taylor, D.F. (2017). Innovation in logistics outsourcing relationship-in the search of customer satisfaction. *LogForum, 13(2),* 209-219. https://doi.org/10.17270/j.log.2017.2.8.
24. Correll, R., Weinberg, S.J., Sanches, F., Ide, T., Suzuki, T. (2023). Quantum Neural Networks for a Supply Chain Logistics Application. *Advanced Quantum Technologies*, *6(7)*, 2200183. https://doi.org/10.1002/qute.202200183
25. Czakon, W., Klimas, P., Tiberius, V., Ferreira, J., Veiga, P.M., Kraus, S. (2022). Entrepreneurial Failure: Structuring a Widely Overlooked Field of Research. *Entrepreneurship Research Journal*, https://doi.org/10.1515/erj-2021-0328
26. Darko, E.O., Vlachos, I. (2022). Creating valuable relationships with third-party logistics (3PL) providers: a multiple-case study. *Logistics, 6(2),* 38. https://doi.org/10.3390/logistics6020038
27. Date, P., Patton, R., Schuman, C., Potok, T. (2019). Efficiently embedding QUBO problems on adiabatic quantum computers. *Quantum Information Processing*, *18*, 1-31. https://doi.org/10.1007/s11128-019-2236-3
28. Ding, Y., Chen, X., Lamata, L., Solano, E., Sanz, M. (2019). Logistic network design with a D-Wave quantum annealer. *arXiv preprint arXiv: 1906.10074.* https://doi.org/10.1007/s42979-021-00466-2
29. Dixit, V.V., Niu, C. (2023). Quantum computing for transport network design problems. *Scientific Reports, 13(1),* 12267. https://doi.org/10.1038/s41598-023-38787-2
30. Dixit, V., Rey, D., Waller, T., Levin, M. (2021). Quantum Computing to Solve Scenario-Based Stochastic Time-Dependent Shortest Path Routing. *Available at SSRN 3977598*. https://doi.org/10.2139/ssrn.3977598

31. Ebert, M. (2016). Quantum computing academy trains future researchers to optimize applications for spaceflight. *Proceedings of the International Astronautical Congress (IAC)* https://doi.org/10.2514/6.iac-04-t.1.06
32. Engel, S., Münch, C., Schinkel, F., Holschke, O., Geitz, M., Schüller, T. (2022, April). Segment routing with digital annealing. *NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium*. IEEE, pp. 1-9. https://doi.org/10.1109/noms54207.2022.9789782
33. Ferraro, E., Prati, E. (2020). Is all-electrical silicon quantum computing feasible in the long term? *Physics Letters A, 384(17),* 126352. https://doi.org/10.1016/j.physleta.2020.126352
34. Garcia Garcia, J., Galan Jativa, P. (2023, July). Application of Quantum Annealing to Supply Chain Planning under Uncertainty. *Proceedings of the Companion Conference on Genetic and Evolutionary Computation*, pp. 2216-2223. https://doi.org/10.1145/3583133.3596350
35. Giri, B.C., Sarker, B.R. (2017). Improving performance by coordinating a supply chain with third party logistics outsourcing under production disruption. *Computers & Industrial Engineering, 103*, 168-177. https://doi.org/10.1016/j.cie.2016.11.022
36. Griffin, P., Sampat, R. (2021, September). Quantum computing for supply chain finance. *IEEE International Conference on Services Computing (SCC)*. IEEE, pp. 456-459. https://doi.org/10.1109/scc53864.2021.00066
37. Griffis, S.E., Goldsby, T.J., Cooper, M., Closs, D.J. (2007). Aligning logistics performance measures to the information needs of the firm. *Journal of business logistic*s, *28(2)*, 35-56. https://doi.org/10.1002/j.2158-1592.2007.tb00057.x
38. Gumiński, A., Dohn, K. (2017). *LMFEA method for the identification of key determinants to improve the efficacy of a logistics operator in transport processes*. Carpathian Logistics Congress, 185-196.
39. Gupta, S., Sharma, V. (2023, May). Effects of Quantum computing on Businesses. *4th International Conference on Intelligent Engineering and Management (ICIEM).* IEEE, pp. 1-6. https://doi.org/10.1109/iciem59379.2023.10166880
40. Gyongyosi, L., Imre, S. (2019). A survey on quantum computing technology. *Computer Science Review, 31,* 51-71. https://doi.org/10.1016/j.cosrev.2018.11.002
41. Herold, D.M., Nowicka, K., Pluta-Zaremba, A., Kummer, S. (2021). COVID-19 and the pursuit of supply chain resilience: Reactions and "lessons learned" from logistics service providers (LSPs). *Supply Chain Management: An International Journal, 26(6),* 702-714. https://doi.org/10.1108/scm-09-2020-0439
42. Hofmann, E., Osterwalder, F. (2017). Third-party logistics providers in the digital age: towards a new competitive arena? *Logistics, 1(2),* 9. https://doi.org/10.3390/logistics1020009

43. Hu, Y., Tang, F., Chen, J., Wang, W. (2021). Quantum-enhanced reinforcement learning for control: a preliminary study. *Control Theory and Technology*, *19*, 455-464. https://doi.org/10.1007/s11768-021-00063-x
44. Huang, H.L., Zhao, Q., Ma, X., Liu, C., Su, Z.E., Wang, X.L., Pan, J.W. (2017). Experimental blind quantum computing for a classical client. *Physical review letters*, *119(5)*, 050503. https://doi.org/10.1103/physrevlett.119.050503
45. Huang, Z., Qian, L., Cai, D. (2022, June). Analysis on the recent development of quantum computer and quantum neural network technology. *IEEE International Conference on Artificial Intelligence and Computer Applications (ICAICA)*. IEEE, pp. 680-684. https://doi.org/10.1109/icaica54878.2022.9844614
46. Hulianytskyi, L., Korolyov, V., Khodzinskyi, O. (2021). Solving the Problem of Vehicle Routing on Modern Quantum-Classical Cloud Services. *IT&I*, pp. 281-289. https://doi.org/10.34229/2707-451x.23.2.3
47. Humble, T. (2018). Consumer applications of quantum computing: A promising approach for secure computation, trusted data storage, and efficient applications. *IEEE Consumer Electronics Magazine*, *7(6)*, 8-14. https://doi.org/10.1109/mce.2017.2755298
48. Jaeger, G. (2007). Classical and quantum computing. *Quantum Information: An Overview*, 203-217. https://doi.org/10.1007/978-0-387-36944-0_13
49. Jahin, M.A., Shovon, M.S.H., Islam, M.S., Shin, J., Mridha, M.F., Okuyama, Y. (2023). QAmplifyNet: Pushing the Boundaries of Supply Chain Backorder Prediction Using Interpretable Hybrid Quantum-Classical Neural Network. *arXiv preprint arXiv: 2307.12906*. https://doi.org/10.1038/s41598-023-45406-7
50. Jain, E., Lamba, J. (2023). Blockades of blockchain in supply chain management. *Blockchain in a Volatile-Uncertain-Complex-Ambiguous World*. Elsevier, pp. 197-218. https://doi.org/10.1016/b978-0-323-89963-5.00005-8
51. Jain, S. (2021). Solving the traveling salesman problem on the d-wave quantum computer. *Frontiers in Physics*, *646*. https://doi.org/10.3389/fphy.2021.760783
52. Jiang, H., Shen, Z.J.M., Liu, J. (2022, December). Quantum Computing Methods for Supply Chain Management. *IEEE/ACM 7th Symposium on Edge Computing (SEC*). IEEE, pp. 400-405. https://doi.org/10.1109/sec54971.2022.00059
53. Jones, J.A., Mosca, M., Hansen, R.H. (1998). Implementation of a quantum search algorithm on a quantum computer. *Nature*, *393(6683)*, 344-346. https://doi.org/10.1038/30687
54. Jum'a, L., Basheer, M.E. (2023). Analysis of Warehouse Value-Added Services Using Pareto as a Quality Tool: A Case Study of Third-Party Logistics Service Provider. *Administrative Sciences*, *13(2)*, 51. https://doi.org/10.3390/admsci13020051
55. Karagiannis, G., Minis, I., Arampantzi, C., Dikas, G. (2023). Warehousing and distribution network design from a Third-Party Logistics (3PL) company perspective. *International Journal of Production Research*, 1-11. https://doi.org/10.1080/00207543.2023.2248280

56. Kavokin, A., Liew, T.C., Schneider, C., Lagoudakis, P.G., Klembt, S., Hoefling, S. (2022). Polariton condensates for classical and quantum computing. *Nature Reviews Physics, 4(7),* 435-451. https://doi.org/10.1038/s42254-022-00447-1
57. Kawa, A., Pieranski, B., Zdrenka, W. (2018). Dynamic configuration of same-day delivery in E-commerce. *Modern Approaches for Intelligent Information and Database Systems*, 305-315. https://doi.org/10.1007/978-3-319-76081-0_26
58. Kjamilji, A., Levi, A., Savaş, E., Güney, O.B. (2021, October). Secure matrix operations for machine learning classifications over encrypted data in post quantum industrial IoT. *International Symposium on Networks, Computers and Communications (ISNCC*). IEEE, pp. 1-8. https://doi.org/10.1109/isncc52172.2021.9615794
59. Klimas, P., Czakon, W., Kraus, S., Kailer, N., Maalaoui, A. (2021). Entrepreneurial failure: a synthesis and conceptual framework of its effects. *European Management Review, 18(1),* 167-182. https://doi.org/10.1111/emre.12426
60. Kmiecik, M. (2022). Logistics coordination based on inventory management and transportation planning by third-party logistics (3PL). *Sustainability, 14(13),* 8134. https://doi.org/10.3390/su14138134
61. Kramarz, M., & Slupina, M. (2017). Assessment of customer satisfaction in logistic operators. *Logistics and Transport*, 35.
62. Li, C., Shen, H., Shi, X., Liang, H. (2023). Quantum Secure Undeniable Signature for Blockchain-Enabled Cold-Chain Logistics System. Computers, *Materials & Continua, 75(2).* https://doi.org/10.32604/cmc.2023.037796
63. Liu, D. (2021, September). Principles and Characteristics of Quantum Computing. *Journal of Physics: Conference Series, Vol. 2014, No. 1,* p. 012012. IOP Publishing. https://doi.org/10.1088/1742-6596/2014/1/012012
64. Lo, S.C., Shih, Y.C. (2021). A genetic algorithm with quantum random number generator for solving the pollution-routing problem in sustainable logistics management. *Sustainability, 13(15),* 8381. https://doi.org/10.3390/su13158381
65. Longo, R., Mascia, C., Meneghetti, A., Santilli, G., Tognolini, G. (2022). *Adaptable Cryptographic Primitives in Blockchains via Smart Contracts. Cryptography*, *6(3),* 32. https://doi.org/10.3390/cryptography6030032
66. Lu, S., Li, X. (2021, October). Lightweight Grouping-Proof for Post-Quantum RFID Security. *IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/IOP/SCI).* IEEE, pp. 49-58. https://doi.org/10.1109/swc50871.2021.00017
67. Małkus, T., Wawak, S. (2015). Information security in logistics cooperation. *Acta logistica, 2(1),* 9-14. https://doi.org/10.22306/al.v2i1.32
68. Mangan, J., Lalwani, C. (2016). *Global logistics and supply chain management*. John Wiley & Sons.

69. Marasco, A. (2008). Third-party logistics: A literature review. *International Journal of production economics, 113(1),* 127-147. https://doi.org/10.1016/j.ijpe.2007.05.017
70. Margaria, T., Schieweck, A. (2022). Active Behavior Mining for Digital Twins Extraction. *IT Professional, 24(4),* 74-80. https://doi.org/10.1109/mitp.2022.3193044
71. Masuda, K., Tsuyumine, Y., Kitada, T., Hachikawa, T., Haga, T. (2023). Optimization of Delivery Plan by Quantum Computing. *Optimization, 85*, 1. https://doi.org/10.1007/978-3-030-54621-2_848-1
72. Masum, M., Nazim, M., Faruk, M.J.H., Shahriar, H., Valero, M., Khan, M.A.H., Ahamed, S.I. (2022, June). Quantum Machine Learning for Software Supply Chain Attacks: How Far Can We Go? *IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC).* IEEE, pp. 530-538. https://doi.org/10.1109/compsac54236.2022.00097
73. Memon, M.A., Letouzey, A., Karray, M.H., Archimède, B. (2014). Collaborating multiple 3PL enterprises for ontology-based interoperable transportation planning. *Enterprise Interoperability VI: Interoperability for Agility, Resilience and Plasticity of Collaborations.* Springer International Publishing, pp. 319-329. https://doi.org/10.1007/978-3-319-04948-9_27
74. Mohanty, J.P., Swain, A., Mahapatra, K. (2019, December). Headway in quantum domain for machine learning towards improved artificial intelligence. *IEEE International Symposium on Smart Electronic Systems (iSES*) (Formerly iNiS). IEEE, pp. 145-149. https://doi.org/10.1109/ises47678.2019.00040
75. Moskvin, V.S. (2022, November). Post-Quantum Digital Signatures in Transport Documents. *Intelligent Technologies and Electronic Devices in Vehicle and Road Transport Complex (TIRVED*). IEEE, pp. 1-5. https://doi.org/10.1109/tirved56496.2022.9965491
76. Mou, J., Wang, S. (2023). Value-Added Service for Fashion Product Supply Chain with Overseas Warehouse Logistics Outsourcing. *Mathematical Problems in Engineering*. https://doi.org/10.1155/2023/8798358
77. Nagaiah, B. (2022). Futuristic Technologies for Supply Chain Management: A Survey. In: *Quantum and Blockchain for Modern Computing Systems: Vision and Advancements: Quantum and Blockchain Technologies: Current Trends and Challenges* (pp. 283-309). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-04613-1_10
78. Osaba, E., Villar-Rodriguez, E., Oregi, I. (2022). A systematic literature review of quantum computing for routing problems. *IEEE Access, 10*, 55805-55817. https://doi.org/10.1109/access.2022.3177790
79. Polikarpov, P.V., Uvarov, N.K., Khomonenko, A.D. (2021). Characteristics of Ecosystems of Quantum Computing and Prospects for Their Use in Transport. *Intelligent Transport Systems and Transport Security, 1,* 33-41. https://doi.org/10.1109/itqmis53292.2021.9642830

80. Portenoy, J., West, J.D. (2020). Constructing and evaluating automated literature review systems. *Scientometrics, 125(3),* 3233-3251. https://doi.org/10.1007/s11192-020-03490-w
81. Qu, P. (2022, September). Logistics Vehicle Distribution Route Planning and Management System Based on Quantum Genetic Algorithm. *International Conference on Cognitive based Information Processing and Applications*. Singapore: Springer Nature Singapore, pp. 471-478. https://doi.org/10.1007/978-981-19-9373-2_51
82. Rad, F.F. (2021). From Far East to Baltic Sea: Impact of Quantum Computers on Supply Chain Users of Blockchain. *International Journal of Enterprise Information Systems (IJEIS), 17(4),* 85-97. https://doi.org/10.4018/ijeis.2021100105
83. Rahaman, M., Islam, M.M. (2015). A review on progress and problems of quantum computing as a service (QcaaS) in the perspective of cloud computing. *Global Journal of Computer Science and Technology, 15(4).* https://doi.org/10.5815/ijmsc.2016.01.02
84. Rana, R., Thingbaijam, R., Seshadri, J., Shah, P., Sinha, A., Poojary, S. (2022, October). Quantum Powered Employee Transport and Agri-Logistics Optimization. *International Conference on Trends in Quantum Computing and Emerging Business Technologies (TQCEBT).* IEEE, pp. 1-6. https://doi.org/10.1109/tqcebt54229.2022.10041701
85. Sanchez Rodrigues, V., Kumar, M. (2019). Synergies and misalignments in lean and green practices: a logistics industry perspective. *Production Planning & Control, 30(5-6),* 369-384. https://doi.org/10.1080/09537287.2018.1501812
86. Saniuk, S., Witkowski, K., Krawczyk, S. (2011). Prototyping of manufacturing production networks in conditions of logistical constraints. *Management*, *15(2),* 316-326.
87. Sarkar, A., Chatterjee, S.R., Chakraborty, M. (2022, December). Dynamic S-box with Reversible Gates for both Classical and Quantum Computer. *IEEE 9th Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON*). IEEE, pp. 1-6. https://doi.org/10.1109/upcon56432.2022.9986426
88. Satamraju, K.P., Malarkodi, B.J.C.C. (2021). A decentralized framework for device authentication and data security in the next generation internet of medical things. *Computer Communications, 180,* 146-160. https://doi.org/10.1016/j.comcom.2021.09.012
89. Silva, H., António, N., Bacao, F. (2022, August). A Rapid Semi-automated Literature Review on Legal Precedents Retrieval. *EPIA Conference on Artificial Intelligence*. Cham: Springer International Publishing, pp. 53-65, https://doi.org/10.1007/978-3-031-16474-3_5
90. Skowron-Grabowska, B. (2007). *Development of logistics centres in Poland*. http://www. oeconomica. uab. ro/upload/lucrari/9, 20072(2).
91. Slane, F.A. (2019). Future business models for space companies. *Proceedings of the International Astronautical Congress (IAC),* 2019-October, art. no. IAC-19_E3_6_6_x54800. https://doi.org/10.1007/978-3-031-39940-4_2
92. Ślusarczyk, B., Tvaronavičienė, M., Haque, A.U., Oláh, J. (2020). Predictors of Industry 4.0 technologies affecting logistic enterprises' performance: International perspective from

economic lens. *Technological and economic development of economy*, *26(6),* 1263-1283. https://doi.org/10.3846/tede.2020.13376

93. Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of business research*, *104*, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039
94. Somaroo, S., Tseng, C.H., Havel, T.F., Laflamme, R., Cory, D.G. (1999). Quantum simulations on a quantum computer. *Physical review letters*, *82(26),* 5381. https://doi.org/10.1103/physrevlett.82.5381
95. Sotelo, R. (2021). Quantum computing entrepreneurship and IEEE TEMS. *IEEE Engineering Management Review*, *49(3),* 26-29. https://doi.org/10.1109/emr.2021.3098260
96. Tan, K.C., Bhowmick, D., Sengupta, P. (2022). Sign-problem free quantum stochastic series expansion algorithm on a quantum computer. *npj Quantum Information*, *8(1),* 44. https://doi.org/10.1038/s41534-022-00555-x
97. Thakkar, J., Deshmukh, S.G., Gupta, A.D., Shankar, R. (2005, June). Selection of third-party logistics (3PL): A hybrid approach using interpretive structural modeling (ISM) and analytic network process (ANP). *Supply Chain Forum: International Journal*, *Vol. 6, No. 1*. https://doi.org/10.1080/16258312.2005.11517137
98. Tsang, Y.P., Lee, C.K.M. (2022). Artificial intelligence in industrial design: A semi-automated literature survey. *Engineering Applications of Artificial Intelligence*, *112*, 104884. https://doi.org/10.1016/j.engappai.2022.104884
99. Vasiliauskas, A.V., Jakubauskas, G. (2007). Principle and benefits of third party logistics approach when managing logistics supply chain. *Transport*, *22(2)*, 68-72. https://doi.org/10.3846/16484142.2007.9638101
100. Vela, D., Sharp, A., Zhang, R., Nguyen, T., Hoang, A., Pianykh, O. S. (2022). Temporal quality degradation in AI models. *Scientific Reports*, *12(1),* 11654. https://doi.org/10.1038/s41598-022-15245-z
101. Verduro, J., Rodríguez, M., Piattini, M. (2021). Software Quality Issues in Quantum Information Systems. *Q-SET@ QCE*, pp. 54-59. https://doi.org/10.1007/s11219-021-09574-x
102. Witkowski, J., Kiba-Janiak, M. (2014). The role of local governments in the development of city logistics. *Procedia-Social and Behavioral Sciences*, *125*, 373-385. https://doi.org/10.1016/j.sbspro.2014.01.1481
103. Xu, G., Gao, H. (2009). Using Real-Coded Quantum Evolutionary Algorithm in Competitive Location Problem of Logistics Distribution Center. *Logistics: The Emerging Frontiers of Transportation and Development in China*, pp. 3270-3276. https://doi.org/10.1061/40996(330)480
104. Yarkoni, S., Huck, A., Schülldorf, H., Speitkamp, B., Tabrizi, M.S., Leib, M., Neukart, F. (2021). Solving the shipment rerouting problem with quantum optimization

techniques. *Computational Logistics: 12th International Conference, ICCL 2021*, Enschede, The Netherlands, September 27-29, 2021, Proceedings, 12 Springer International Publishing, pp. 502-517. https://doi.org/10.1007/978-3-030-87672-2_33

105. Zaidi, T., Sushma, B.S. (2022). An Overview of Future Applications of Quantum Computing. Artificial Intelligence, Machine Learning and Blockchain in Quantum Satellite. *Drone and Network*, 127-138. https://doi.org/10.1201/9781003250357-8
106. Zajac, M., Dang, M., Störl, U. (2022). Implementation Aspects for Linking Data in Hybrid Quantum Applications. *Informatik*. https://doi.org/10.1109/qsw55613.2022.00021
107. Zalka, C. (1998). Simulating quantum systems on a quantum computer. *Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *454(1969)*, 313-322. https://doi.org/10.1098/rspa.1998.0162
108. Zaman, A., Morrell, H.J., Wong, H.Y. (2023). A Step-by-Step HHL Algorithm Walkthrough to Enhance Understanding of Critical Quantum Computing Concepts. *IEEE Access*. https://doi.org/10.1109/access.2023.3297658
109. Zhao, Y. (2023). Demonstration and Implementation of Quantum Computing in Cryptanalysis. *Highlights in Science, Engineering and Technology, 38*, 431-436. https://doi.org/10.54097/hset.v38i.5855
110. Zhou, H., Wang, Q., Wang, L., Zhao, X., Feng, G. (2023). Digitalization and third-party logistics performance: exploring the roles of customer collaboration and government support. *International Journal of Physical Distribution & Logistics Management*. https://doi.org/10.1108/ijpdlm-12-2021-0532
111. Zhu, H., Wang, R., Liu, J. (2018). A Lightweight RFID Authentication Protocol using Qubits against Relay Attack. *J. Inf. Hiding Multim. Signal Process.*, *9(4)*, 874-883. https://doi.org/10.3390/s18030760
112. Zhu, L., Tang, H.L., Barron, G.S., Calderon-Vargas, F.A., Mayhall, N.J., Barnes, E., Economou, S.E. (2022). Adaptive quantum approximate optimization algorithm for solving combinatorial problems on a quantum computer. *Physical Review Research, 4(3)*, 033029. https://doi.org/10.1103/physrevresearch.4.033029