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Research Article

AHP-Based Approach in Quantum Computing Difficulties in the Software Sector

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ABSTRACT

The development of quantum computers, which leverage quantum effects, has faced significant challenges, hindering technological progress due to a lack of clarity on how to harness these phenomena to improve computing performance. It wasn't until Peter Shor made a groundbreaking announcement in 1994, introducing a polynomial-time quantum algorithm for integer factorization, that the field of quantum computing gained momentum. Shor's factorization method utilizes this innovative concept, while Grover's search algorithm employs a technique that modifies the quantum state to increase the probability of obtaining the desired output. This study provides comprehensive explanations of quantum parallelism and strategies for its application. The objective of the research was to identify and evaluate the challenges within the software sector using a fuzzy analytic hierarchy process (F-AHP).

A thorough analysis was conducted to explore the obstacles associated with quantum computing. In line with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, we executed a systematic literature review (SLR) to present our findings. An SLR enables researchers to critically assess the existing literature on a given topic, identify relationships among investigated phenomena, uncover limitations of current studies, and suggest pathways for advancing academic inquiries. Through our review, we filtered out 0.37% of papers on software modeling and 0.63% of articles regarding quantum algorithms and various technical perspectives after removing duplicates and applying specific criteria to the remaining 478 articles. We employed the F-AHP method (illustrated in Fig. 1) to prioritize the key elements and their categories, facilitating a thorough understanding of decision-making issues across multiple criteria. As noted in the previous section, a focus on management capabilities essential for expediting the development of algorithms necessary for rapid digitization represents a promising area for future research in quantum computing literature. Our findings reveal that the consistency ratio (CR) for the specified criteria falls within the acceptable threshold of 0.10, indicating a collective agreement among respondents regarding group decisions. Employing the outlined methodology, we assessed the provided CR.

Our results underscore the complex challenges associated with adopting quantum computing, many of which are tied to existing practices and expectations, such as the importance of scalability and evaluating resource performance. We encourage researchers to investigate the potential for technological integration processes to alleviate the organizational challenges and support the acceptance of new technologies, as the adoption of quantum computing remains a persistent obstacle for various sectors.

Keywords: analytic hierarchy process, quantum algorithm, resource performance, quantum computing.

INTRODUCTION

Early in the 1980s, Richard Feynman noted [Feynman 1982] that some quantum mechanical phenomena cannot be effectively replicated on a conventional computer [1]. This discovery sparked a discussion that potentially using these quantum effects will improve computation's overall efficiency [2]. Building quantum computers, which employ these quantum effects, proved difficult, and the technology advanced slowly because no one knew how to exploit the phenomena to accelerate computing. The science of quantum computing didn't truly take off until Peter Shor shocked the world in 1994 by revealing a polynomial-time quantum algorithm for factoring integers [3]. This revelation sparked a rush of activity among theoretical researchers looking for a different quantum algorithm and experimentalists aiming to construct quantum computers [4].

Recent news stories about quantum teleportation and the demonstration of a 3-bit quantum computer have increased interest in the subject [5]. This work aims to introduce computer scientists and other nonphysicists to quantum computing by guiding them through the conceptual and notational barriers that separate quantum computing from conventional computing [6]. Understanding these new breakthroughs is crucial for the computer science community because they could fundamentally alter how we think about computation, complexity, and programming. Traditionally, using parallel processors can reduce the amount of time needed to complete certain computations [7]. The number of processors must exponentially rise in order to accomplish an exponential reduction in time, and as a result, physical space must also exponentially expand. But as the scale of the system increases, the parallelism in quantum systems grows exponentially [8]. As a result, a linear increase in the required physical area can accommodate an exponential increase in parallelism. Quantum parallelism is the name of this phenomenon [Deutsch and Jozsa 1992]. The catch is there, and it's a huge one at that. Although a quantum system is capable of doing extremely parallel calculations, access to the results is constrained [9].

The quantum state is disturbed when the findings are accessed because doing so is the same as making a measurement. Since we can only receive the results of 1 parallel thread and probabilistic measurement, we are unable to even choose the one we get, the situation appears to be even worse than it was in the classical case [10]. However, during the past few years, a number of creative solutions to the measurement issue have been developed in an effort to fully utilize quantum parallelism [11]. There is no classical parallel for this type of manipulation, hence unconventional programming techniques are needed. One method involves changing the quantum state in order to read off a characteristic that applies to all output values, like symmetry or functional period [12]. The factorization method developed by Shor employs this concept. Another method alters the quantum state to enhance the likelihood that the desired output will be read. Such an amplification method is used by Grover's search algorithm. In-depth explanations of quantum parallelism and methods for utilizing it are provided in this study [13]. Decoherence, or the distortion of the quantum state brought on by environmental interactions, is the biggest obstacle to the construction of quantum computers. For a while, it was fearful that quantum computers would never be created because it is thought to be impossible to sufficiently shield them from the outside world [14]. Through the development of quantum error-correcting techniques, the breakthrough occurred on the algorithmic side instead of the physical side. It turns out that it is possible to create quantum error-correction of codes that identify specific types of mistakes and enable the restoration of the exact quantum state that is free of errors, contrary to what many initially believed because it is difficult to accurately reproduce unknown quantum states [15].

Aims and Objectives

1. To determine the main difficulties in the software sector by extensive literature search.

2. To evaluate and determine the position of the difficulties and formulate some possible solutions

Questions of the study

1. What are the institutional challenges in the software sector?

2. What is the significance of QC research and the need of these researches in bringing out findings for academicians and practitioners?

Significance of the study

To support this digital transition, we think that future scholars' concentration on specialized QC applications, like blockchain and cryptography, must increase. The efforts of academics and professionals to address global concerns, including data protection, would be greatly aided by such advancements. Despite the limits of our study, we encourage future researchers to use our findings to enhance research in QC, an emerging yet important field of study. Our findings serve as a foundation for this research.

LITERATURE REVIEW

The emergence of Noisy Intermediate-Scale Quantum (NISQ) devices for Quantum Computing (QC) and the popularisation of Machine Learning (ML) provided fresh motivation for the pursuit of methods for accelerating computation in mechanics [16]. As a computationally efficient surrogate model for otherwise time-consuming simulations of the human liver, we analyze artificial neural networks (ANNs) using a multiscale and multiphase model [17].

With concurrent increases in funding in several fields, quantum computing is developing into a more mature field. All engineering sectors will undergo a transformation thanks to quantum technologies [18]. For instance, businesses will need to gradually incorporate quantum computing into minimum or all of their regular activities. It is obvious that no current classical systems of information can be eliminated [19]. It is anticipated that some quantum algorithms will be incorporated place of it so that they can coexist with conventional information systems. To yet, no organized approach to resolving this issue has been proposed. In order to create target environments that integrate both of these computational paradigms, this research suggests a software modernization strategy meant to rebuild classical systems in a way that they can cooperate with quantum systems [20].

The suggested strategy is methodical and is based on accepted guidelines for software engineering, such as the Knowledge Discovery Metamodel and the Unified Modelling Language. As a result, it might be used in industry in a way that it combines with the current processes for software evolution. This proposal's independence from quantum programming environments is also ensured, which makes it possible to implement it in the dynamic context of the current quantum industry. The key technological and financial implications of this strategy are that it speeds up new quantum-based initiatives while allowing the reuse of knowledge buried in legacy systems [8].

An investigation is made into how quantum computers can be used to solve optimization issues with energy systems, as well as some of the difficulties they confront and how to deal with them. It also covers the fundamental ideas behind quantum computation and how those ideas differ from their classical equivalents [21]. As a starting step for delving into the new world of programming quantum computers for tackling systems optimization problems, an example using open-source software tools is offered together with various hardware architecture descriptions of two quantum systems that are commercially available[22]. Energy systems optimization is a challenging task for the majority of current algorithms due to the complex nature of energy systems as a result of their structure and numerous design and operational limitations. Both classical models are developed based on conventional computers that are CPU-based and quantum algorithms realized on quantum computing hardware are used to solve problems that come under the category of optimization of energy systems, such as facility layout allotment for energy technology infrastructure investment, unit commitment of electricity supply system applications, and heat exchanger network synthesis [23,24]. Their plans, execution, and outcomes are given. The constraints of cutting-edge quantum computers are also discussed, along with their enormous potential to influence the optimization of energy systems [25].

A post-quantum cross-layer key agreement system that is resistant to Man in the Middle (MitM) attacks and the widespread use of quantum computers was proposed in a study. Best effort security is provided by our security system, which combines cryptographic security and physical layer measures [26,27]. Physical layer security often makes no assumptions about Eve's computational capability or the information she has access. It can be proved, quantified, and is unbreakable [28]. However, physical layer security is constrained and difficult to demonstrate, and researchers typically take a passive attacker model into account. As an alternative, conventional cryptography has proven effective in reality but is vulnerable to the widespread use of quantum computers because it is built on the supposition that Eve has finite computational capability [29,30].

METHODOLOGY

Study Design

A systemic study was conducted for analyzing quantum computing challenges. To perform our systemic literature review (SLR) and present its findings, we referred to the PRISMA (preferred reporting items for systematic reviews and meta-analyses) standards. Because it can help with (a) synthesizing the existing literature and providing a reference point for determining future research goals and (b) recognizing recent developments in a particular field of inquiry, the SLR is an acceptable tool for our study. An SLR can be used by researchers to critically and exhaustively evaluate the body of work on a topic, find associations of any phenomena being investigated, explore the constraints of the existing study, and provide a potential avenue for furthering scholarly endeavors. Studies in information science and software development benefit greatly from SLRs.

Study Planning

We used the three-stage literature search methodology described in [57] to locate, define, and assess the SLR evidence. In order to find suitable databases and search phrases for the current context and associated topics, we consulted previously published SLRs.

Inclusion criteria

1. The articles must examine the present state of advancement in the crucial applications of quantum computing.

2. Articles must go over application implications and difficulties.

3. An adequate overview of QC trends and difficulties must be included in the article.

4. Certain literary works must only be written in English.

5. Selected works, including book chapters (with citations), conference proceedings, and grey literature, must be published as peer-reviewed publications.

Exclusion criteria

1. Articles written from QA theory and other technical perspectives were excluded.

2. Editorials, prefaces, presentation papers, extended abstracts, and studies published at doctoral symposiums were among the papers we eliminated as being non-peer-reviewed and unrelated to modern quality control.

Selecting relevant articles

Using pre-established inclusion (IC) and exclusion (EE) criteria modified from earlier SLRs, 1920 articles from the original search were examined. The final sample selection produced 103 papers that were published in journals, books, and conference proceedings after duplication removal (using Mendeley), screening, and snowballing processes (including 9 articles identified from snowballing). Because these can be valuable sources of up-to-date knowledge, we choose to add book chapters (with citations) and conference papers. Additionally, conference proceedings that are included in lecture series notes are incredibly well-liked venues for information systems-related dissemination. The fact that the chosen conferences were listed in numerous reputable databases made them extremely beneficial. We utilized the titles to eliminate 0.37% of the papers on software modeling and 0.63% of the articles on the theory of QAs and other technical viewpoints after eliminating duplicates and applying the specific criteria to the remaining 478 articles.

RESULTS

We used the F-AHP technique (see Fig. 1 for the process flow model), which allowed for a complete comprehension of decision-making concerns via many criteria, to prioritize the discovered critical elements and their categories. The idea of management capabilities for speeding and creating the algorithms required for rapid digitization is one of future research in the QC literature, as the preceding section noted.

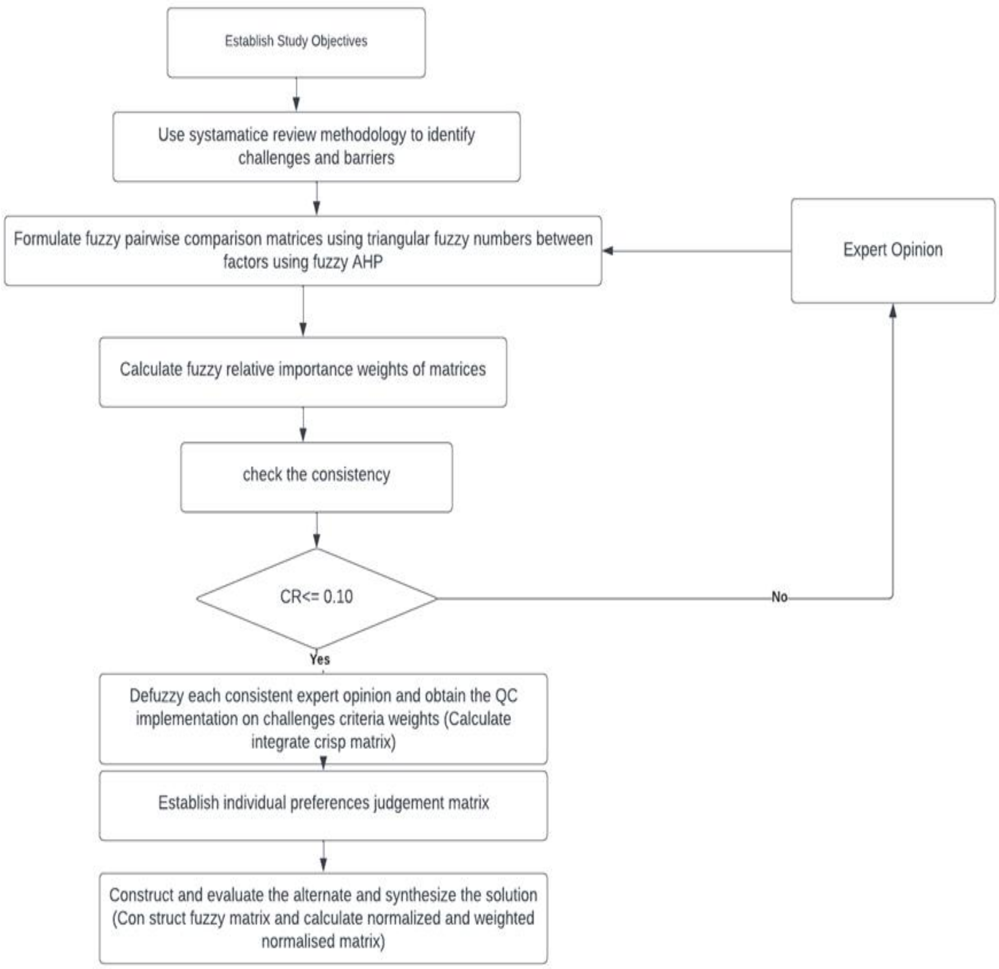

Fig 1: F-AHP process flow model

Table 1: Random Consistency Index (RI) in this study

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.56	0.8	1.13	1.26	1.33	1.42	1.47	1.51

Our findings demonstrate that the CR for the specified criterion is within the threshold value 0.10, indicating that respondents generally agree on group decisions. Using the procedure described, we evaluated the provided CR. Recently, a great number of scholars across several domains have adopted this strategy. The membership function and output interval fuzzy scale for rating criteria and sub-criteria are shown in Table 2.

Table 2: For grading criterion and sub-criteria, membership function and output interval fuzzy scale

Degree of significance	**Definitions**	**Triangular fuzzy numbers**	**Triangular fuzzy reciprocal numbers**
1	Same amount of importance	1, 1, 1	1, 1, 1
2	Moderate importance	2, 3, 4	0.5, 0.3, 0.25
3	Strong importance	4, 5, 6	0.5, 0.20, 0.16

4	Very strong importance	6, 7, 8	0.16, 0.14, 0.12
5	Very strong to extreme importance	7, 8, 9	0.14, 0.12, 0.11
6	Extreme importance	9, 9, 9	0.11, 0.11, 0.11

There were some interesting results when each criterion was prioritized using the F-AHP global weight (GW) as opposed to other local weights. Significant planning and multi-stakeholder collaboration, for instance, are among the top-ranked global variables, as shown in Table 3 (IB2). The findings also demonstrate that respondents identified a key barrier as a lack of commitment to research and development projects (MB1). Lack of government backing for commercialization (IB3), one of the most important elements for implementing QC, is the third most important obstacle.

Table 3: Local and global priorities and rankings

Category	Category weight	Success scores	Local weight	Global weight
Management barriers (MB)	0.347	MB1	0.671	0.2316
		MB2	0.095	0.0321
		MB3	0.178	0.0634
Software technology barriers (STB)	0.086	STB1	0.643	0.0539
		STB2	0.111	0.0092
		STB3	0.195	0.0163
		STB4	0.053	0.0042
Institutional barriers (IB)	0.534	IB1	0.124	0.0673
		IB2	0.647	0.3434
		IB3	0.129	0.0677
		IB4	0.108	0.0564
Organizational barriers (OB)	0.045	OB1	0.634	0.0267
		OB2	0.132	0.0057
		OB3	0.118	0.0045
		OB4	0.126	0.0176

DISCUSSION

AHP is a tool for solving issues. It is a method that creates a verifiable, hierarchical analysis for challenging issues. In essence, AHP dissects and assesses a problem into different components that may be examined and assessed independently using the same methods that led to the problem's current form [31,32].

When it comes to simultaneously process big quantum algorithms with numerous quantum bits (qubits), quantum computing provides the greatest choice. The fact that quantum computers can only hold a small number of qubits at once is a drawback. They find it challenging to process algorithms that require simultaneous processing of all data due to this [33].

Building frameworks for quantum computing presents difficulties for software developers and engineers. The size of the Hilbert problem is the biggest one. The number of solutions to an equation can be determined using a straightforward mathematical method, however, the Hilbert problem is difficult to calculate [34-36].

AHP can be used in conjunction with software frameworks to address this problem. In essence, AHP breaks down a complex software problem into different components so that each one may be verified independently before continuing to the next [37]. This makes it simpler for a developer or engineer to come up with a fix for a non-quantum computing issue. Programming for quantum computing necessitates a distinct strategy. This difficulty is presented to software developers since they have to consider how to reduce and simplify the Hilbert problem for conventional computers [38].

In this circumstance, the Hilbert problem can be solved using AHP. Before coming up with a solution for the larger issue, a software engineer should first start by disassembling their program into several components and then thoroughly examining each component on its own [39].

Utilizing a software framework is a further option. AHP works by dividing a large problem into smaller ones that are simpler to handle and that can be examined more thoroughly. This is all due to the fact that each software framework would experience quantum computing effects differently, hence AHP should also be used in this scenario. Before going on to the next component of an AHP analysis, each one should have been tested independently. A component should be examined if it hasn't been tested since it depends on other components [12].

Each component will be examined independently, but because they all have some influence on one another, it is necessary to examine one before going on to the others. The software framework is useful in this situation [40]. The framework acts as a starting point for the software developer to use when deciding how to partition the issue into parts for AHP analysis. There are a few factors that the software developer needs to keep in mind when using software frameworks. So that the conclusions of their study may be trusted, the framework they utilize needs to be dependable and tested. Every new version of a framework should be tested to ensure correct operation because the framework also needs to be free of errors and faults [41,42].

The Hilbert problem poses a significant barrier to quantum computing since it necessitates the simultaneous usage of numerous qubits [43]. As a result, software engineers should consider using AHP because it is a methodical way to divide an issue into its component parts and test each part separately to discover a solution. Software engineers would benefit greatly from AHP since it will enable them to build frameworks that enable developers to leverage quantum computing. They are still able to use their software framework today, but in order to make the most of it, they need to be well-versed in AHP [44-46].

Few software frameworks that enable developers to use quantum computers are now openly accessible on the market [47,48]. The Quantum Information Processing Center at the University of California, Santa Barbara has these frameworks (QIPC). How to use QIPC's software when performing an AHP analysis is covered in in-depth documentation. In addition, QIPC maintains a collection of all nontrivial techniques for solving the Hilbert problem and provides sample code for each technique [49-51].

CONCLUSION

Our results highlight how the adoption of QC is riddled with difficult problems, many of which revolve around current practices and expectations, such as the significance of scalability and the measurement of resource performance. We encourage scholars to research the possibilities of the technological assimilation process to lessen the organizational burden and facilitate organizations' acceptance of new technology because QC adoption continues to be a chronic barrier for many sectors. We also recommend that future researchers do in-depth analyses of the elements that can encourage QC adoption using ideas from disciplines like mathematics, management studies, and information systems science.

The dual-factor approach, for instance, may offer a workable framework for the parallel investigation of the drivers and restraints of QC adoption in the organizational context. Scholars can investigate additional facilitating (benefits) and inhibiting (barriers) elements discovered in existing literature in addition to those identified by our findings. Furthermore, our data show the varying degrees of difficulty that organizations may have when implementing QC. Small and medium-sized businesses (SMEs), for instance, could find it considerably more challenging to adopt QC when compared to larger companies. Thus, using the recommended theoretical frameworks may help researchers compare and contrast the enablers and difficulties of QC adoption for bigger IT organizations vs SMEs and start-ups. Our research indicates that there is growing interest in the advancement of quantum computing technology, but less focus is being placed on commercializing QC and addressing value chain challenges.

It should come as no surprise that the IT sector as a whole is focused on pursuing new computing opportunities to increase data transformation, communication, information security, and data privacy and protection [28].

RECOMMENDATIONS

The author recommends to carry out more studies of the similar kinds on various background and in different situations. The study identifies some knowledge gaps which can be fulfilled by improvement of conceptual knowledge on QC and the various applicable scenarios involving this technology. Strategy cost mechanism should be formulated for ensuring scalability and empirical exploration. Academicians and industrial experts should work together for devising management perspective by utilising the existing frameworks and indulging QC in existing business strategy and model.

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