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IMPLEMENTING BLOCKCHAIN TECHNOLOGY FOR PROJECT BUFFER MONITORING AND PROGRESS SHARING IN CRITICAL CHAIN PROJECT MANAGEMENT

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A B S T R A C T

Construction and engineering projects often face delays and inefficiencies, which can be attributed to various factors. CCPM, a resource-focused project management technique, utilizes buffers strategically to mitigate delays. By leveraging blockchain's shared and secure ledger capabilities, this study proposes a framework for effectively measuring, monitoring, and controlling CCPM projects. The integration of blockchain technology aims to provide a more efficient approach to meeting project milestones and supporting project plan success. This paper explores the implementation of blockchain technology to enhance project buffer monitoring and progress sharing in Critical Chain Project Management (CCPM).

1. INTRODUCTION

Efficient project scheduling is crucial for successful project management. The Critical Path Method (CPM) is a commonly used scheduling method that calculates Early Start and Finish dates, as well as Late Start and Finish dates, to create project schedules. However, CPM does not propagate time gains to subsequent activities if an activity is completed ahead of schedule. This limitation can lead to delays and changes in the critical path. To address these issues, the Theory of Constraints (TOC) introduced Critical Chain Project Management (CCPM), which aims to complete projects faster, optimize resource utilization, and ensure project deliverables (Kannan & Chitra 2017). CCPM recognizes human behaviors that can affect project outcomes, such as student syndrome and Parkinson's Law, and recommends shortening task duration estimates and eliminating safety time buffers (Goldratt, 1997).

Buffer management is a critical aspect of CCPM and plays a key role in project success (Sinaga & Husin 2021). Effective buffer monitoring and management techniques are needed to accurately track project progress and identify potential risks (Mishra, 2020). The consumption of buffers provides valuable insights into project performance and areas for improvement. However, there is a research gap in developing more robust and efficient approaches for buffer monitoring and management in real-world project settings. There is also limited research on integrating advanced technologies like artificial intelligence or machine learning into these practices (Zhang & Han 2022).

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The integration of blockchain technology into project management offers potential benefits for buffer monitoring and management in CCPM. Blockchain provides a secure and reliable platform that can enhance project stability by reducing the risks of data manipulation and unauthorized changes. By leveraging blockchain and smart contracts, a decentralized network can be created where all stakeholders have access to the same information in real-time. This enables automated notifications, efficient tracking of buffer consumption, and proactive decision-making. Blockchain technology can improve the transparency, immutability, and efficiency of buffer monitoring and management, leading to better project performance and outcomes.

In summary, the research problem in buffer monitoring and management in CCPM lies in the need for more effective and efficient approaches. Previous research has focused on improving techniques, exploring the impact of buffer sizing methods, and assessing the effectiveness of these practices in different project environments. However, there is a lack of empirical studies and research on integrating advanced technologies. The proposed approach integrates blockchain technology and smart contracts to develop a secure and reliable buffer monitoring and management system. This framework aims to enhance project stability, facilitate proactive decision-making, and optimize resource allocation. By addressing these research gaps, the study contributes to the knowledge on buffer monitoring and management in CCPM and explores the potential benefits of blockchain integration in project management.

2. LITERATURE REVIEW

2.1 Critical Chain Project Management

Critical Chain Project Management (CCPM) is a project management methodology that helps monitor essential resources and prioritize dependent tasks to complete projects efficiently. It was developed by Dr. Eliyahu M. Goldratt in 1997 and is derived from the Theory of Constraints (Şimşit, Günay & Vayvay 2014).

CCPM focuses on identifying the critical chain, which is the longest sequence of dependent tasks that determines the overall duration of the project. By implementing CCPM in projects, tasks' durations will be cut in half, and the float (reserve) will be placed at the end of the schedule as a buffer to protect the schedule against delays in performing the tasks with reduced duration and also to aggregate time savings if it can be implemented (Anastasiu, Câmpian & Roman 2023).

Research Highlight	References
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Advantage and disadvantage of CCPM	• Herroelen, W., & Leus, R. (2001). On the merits and pitfalls of critical chain scheduling. *Journal of Operations Management,* 19(5), 559-577
Application of Critical Chain Management in Construction Projects	• Yang, J. B. (2007). How the critical chain scheduling method is working for construction. *Cost Engineering*, 49(4), 25-32 • Georgy, M., Marzook, A., & Ibrahim, M. (2013). Applicability of critical chain scheduling in construction projects: An investigation in the middle east. In The 19th Cib World Building Congress, Queensland University of Technology (pp. 1-13). • Araszkiewicz, K. (2017). Application of critical chain management in construction projects schedules in a multi-project environment: A case study. *Procedia Engineering*, 182, 33-41.
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Evaluation performance of CCPM	• Su, Y., Lucko, G., & Thompson, R. C. (2016, December). Evaluating performance of critical chain project management to mitigate delays based on different schedule network complexities. In 2016 Winter Simulation Conference (WSC) (pp. 3314-3324). IEEE.

Table 1- Previous Literature on CCPM

Previous studies investigating CCPM methodology have mainly highlighted the problems of traditional methods of planning and scheduling for projects followed by the reasons for applying critical chain, merits and pitfalls of CCPM, Application of Critical Chain Management in Construction Projects, Factors that influence CCPM implementation success, and evaluation performance of CCPM to mitigate delay. Table 1 summarizes some of the key references that highlighted the formerly mentioned topics.

CCPM has received significant attention recently in project management literature, especially in improving the efficiency of buffer monitoring, and recent efforts focus on proposing new methods for buffer monitoring. Consequently, the application of CCPM requires a renewed vision and a change in the paradigm for doing projects and business.

2.1.1 Recent efforts in buffer management

Zhang, Shi, and Diaz (2015), suggested a method for utilizing an effort buffer to effectively monitor and manage the efforts involved in software projects. The method outlines the process of determining and distributing the effort buffer across various stages of the project. It also describes the establishment of an effort deviation monitoring and control model based on the grey prediction model. Furthermore, the method is applied to a real project and compared against actual project data.

In terms of future research, it is emphasized that there is room for enhancing buffer monitoring and implementing an early warning mechanism for project execution.

Xuejun, Nanfang and Demeulemeester (2015) propresed new control procedure has been introduced, building upon the CC/BM framework, which assesses the likelihood of successfully completing a project in relation to the cost of expediting activities. This procedure determines the optimal timing for expediting specific activities in a cost-effective manner. The authors conducted experiments to demonstrate the effectiveness of the proposed method, showing its superiority over the commonly used BM approach in terms of project time and cost performance.

By utilizing the proposed buffer management-based expediting method, project due dates and cost performance can be substantially improved. This method enables the monitoring of schedule variations throughout project execution, empowering managers to make better-informed decisions. Ultimately, it ensures timely project delivery while minimizing crash costs.

Junguang, Saike & Estrella (2018). discussed various buffer monitoring methods, including static buffer monitoring methods (SBMM), relative buffer monitoring method (RBMM), and dynamic buffer monitoring methods (DBMM).

Static buffer monitoring methods, such as SBMM based on the Theory of Constraints, solely consider the consumption of the buffer and overlook the actual progress of the project. In contrast, dynamic buffer monitoring methods incorporate the real-time progress of the project when monitoring buffer utilization. In particular, the relative buffer monitoring method (RBMM) places emphasis on the relative consumption of the buffer between consecutive activities. RBMM has demonstrated greater effectiveness and efficiency compared to static buffer monitoring methods.

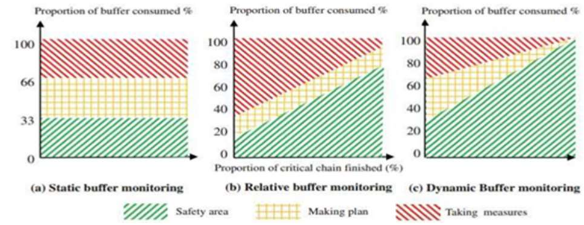

Figure1: Buffer Monitoring Methods

Also, proposed a dynamic buffer monitoring model that takes into account the phase attributes of a project, aiming to optimize both project duration and cost. The model also addresses the issue of student syndrome, monitors project schedules, and avoids unnecessary costs caused by excessive measures. Additionally, the paper identifies several future research directions, including enhancing the accuracy of the dynamic buffer management process, considering multi-project environments, and integrating various sources of uncertainty in buffer sizing and monitoring.

While existing dynamic buffer monitoring methods analyze the buffer consumed at monitoring points, they fail to consider the impact of subsequent buffer consumption trends. To address this limitation, (Junguang & Dan 2019) suggested an integrated buffer monitoring method that incorporates a prediction model based on a "grey neural network." This prediction model anticipates future buffer consumption, while a buffer integrated monitoring system enables comprehensive project progress control and minimizes project duration fluctuations.

Sinaga and Husin (2021) provided insights into the factors that influence project success. The study identified buffer time as a key factor in Critical Chain Project Management (CCPM), with several sub-factors related to buffer time. These sub-factors include identifying the project's timing, the impact of project buffers, feeding buffers, and buffer resources, eliminating safety time, risk management, understanding the stages of work, and the relationship between each stage of work. Managing the buffer is crucial for ensuring timely project completion. This involves regular monitoring of the buffer status, assessing risks, and taking appropriate actions to maintain the defined buffer levels. Effective buffer management allows project managers to keep the project on track, even when unexpected issues or delays occur during the project lifecycle

Zhang and Wang (2022) proposed a method aims to enhance buffer monitoring efficiency by considering differences in activity reliability, such as duration, cost, and quality. This new dynamic monitoring method was compared with traditional monitoring methods, and simulation results demonstrate its ability to optimize overall performance and improve buffer monitoring effectiveness.

Peng and Peng (2022) focused on a buffer zone setting method based on fragility theory in critical chain project management. The objective of this method is to reduce construction time, increase productivity, and analyze the brittleness of the construction process. It introduces a risk-integrated impact rate to describe process uncertainty and establishes a brittle risk entropy function to enhance buffer zone calculation.

The importance of buffer monitoring in critical chain project management was highlighted in Zhang and Han (2023). Buffer monitoring helps track critical chain activities and predict their durations to ensure project adherence to the schedule. A proposed dynamic monitoring method combines buffer monitoring and forecasting using support vector machine prediction. This method creates a duration prediction model by predicting the duration of subsequent activities based on completed activity data. The buffer consumption rate is then calculated using the predicted activity duration, and the corresponding monitoring frequency is determined. This method enables adaptive buffer allocation based on the project's actual situation and adjusts monitoring time points to detect and control deviations in a timely manner. By accurately predicting critical chain activity durations, buffer allocation and monitoring frequency can be optimized using support vector machine prediction.

Budeli (2020) highlighted the potential of blockchain technology to enhance the efficiency of traditional project management tools such as the earned value method (EVM), CPM, program evaluation and review technique (PERT), and CCPM. The integration of blockchain technology is expected to result in reduced project costs and improved project performance.

And suggested the utilization of blockchain technology specifically for CCPM and buffer management by creating a blockchain-based project monitoring and control system that can effectively manage the buffer and provide real-time updates to project stakeholders. However, a generalized model for buffer monitoring was not presented in the study.

Furthermore, the research suggested the exploration of smart contracts in project management, automated project performance reporting, and data analytics as means to enhance performance insights. These applications could potentially leverage blockchain technology to improve project management efficiency and decision-making processes.

Based on previous research efforts, it is recommended to investigate the application of blockchain technology in buffer management for the CCPM approach.

2.2 Blockchain Technology

Blockchain is an innovative technology that has the potential to disrupt traditional systems by establishing trust between parties without the need for intermediaries. It operates through a network of computers using complex algorithms, ensuring that once a transaction is recorded on the ledger, it cannot be retroactively altered or deleted. This characteristic provides a highly secure, transparent, and tamper-proof system for exchanging and recording value. Blockchain possesses various capabilities, including immutability, transparency, security, privacy, and decentralization, which can revolutionize numerous industries and domains. By combining these capabilities, blockchain enables multiple parties to share trusted data without intermediaries, reducing inefficiencies and enhancing productivity in our economy.

Numerous researchers have extensively explored and discussed the applications of blockchain technology across diverse domains such as construction, healthcare management, supply chain management, banking and financial services, e-voting, insurance accountability and liability management, project management, internet-of-things, distributed access control, and energy supply.

2.2.1 Recent efforts in the application of blockchain technology

Turk and Klinc (2017) proposed that blockchain technology can be integrated with Building Information Modeling (BIM) to enhance the construction process. This integration can improve privacy, provenance tracking, change tracing, multiparty aggregation, data ownership, non-repudiation, traceability, and inter-organizational record-keeping. The use of blockchain in conjunction with BIM offers potential solutions to the challenges that hinder the construction industry's adoption of BIM.

In the context of construction management, it has been suggested in Safa, Baeza, and Weeks (2019). that blockchain technology can address existing issues. Specifically, the implementation of smart contracts based on blockchain can transform construction projects from document-driven to data-driven environments, resolving current technological challenges.

Researchers have also discussed the potential of blockchain in the planning and management of intelligent transport systems. Eremina, Mamoiko, and Bingzhang (2020) proposed a self-sufficient and decentralized vehicle coordination system based on peer-to-peer networks and community consensus. This system offers a novel model for decentralized intelligent transportation systems (ITS) by providing an efficient and sophisticated mechanism for transportation management and planning. Blockchain technology ensures security and trust in decentralized ITS, potentially enhancing the efficiency of logistics processes and enabling innovative services and business models.

In the maritime supply chain domain, an integrated blockchain-based system was proposed by Liu, J., Zhang and Zhen (2023) to support global economic development. The system aims to improve coordination among members and achieve intelligent operation of the maritime supply chain.

Furthermore, the integration of machine learning and blockchain technology in the healthcare field, particularly in cancer survivorship care, has been explored by Cheng et al. (2021). The study concluded that both technologies can be effectively and feasibly integrated in this context.

A machine learning-based approach was described for predicting blockchain adoption in supply chain management Kamble et al. (2021). The researchers developed a decision support system using Bayesian network analysis to forecast the probability of successful blockchain adoption. The system considered factors influencing blockchain adoption behavior based on the Technology Acceptance Model and the Technology-Organization-Environment framework. The study identified competitor pressure, partner readiness, perceived usefulness, and perceived ease of use as significant factors for predicting blockchain adoption.

A management system for construction firms was introduced in Adel, Elhakeem and Marzouk (2022), leveraging blockchain technology and chatbots. The system tracks work progress in construction projects and provides guidance on setting up the system. This includes configuring a private blockchain network, coding a smart contract, developing a chatbot, and linking the blockchain network and chatbot through a serverless cloud function and database. The performance of the system was discussed, along with its potential future capabilities.

The use of blockchain technology in the construction industry was explored to decentralize AI applications and improve data transparency and traceability (Adel, Elhakeem & Marzouk 2022, May).. The proposed system utilizes blockchain as a decentralized record medium to exchange and analyze textual and numeric data, incorporating mathematical algorithms and machine learning models in the chain codes. IBM's Blockchain-as-a-Service solution, based on Hyperledger Fabric, was employed to establish the blockchain network layer, benefiting from permissioned blockchain networks' high performance, scalability, and API support. The system validated and audited decision-making processes, recorded and shared input data and outcomes, facilitated a distributed AI repository, and addressed the distribution problem faced by AI applications.

In the context of the autonomous vehicles (AV) industry, the application of blockchain technology and smart contracts to enhance sustainable supply chain operations was studied (Arunmozhi et al. 2022). A Margin Indicator (MI) was developed to obtain reliable predictive analytics results using machine learning algorithms. The framework, supported by advancements in blockchain and AI technologies, aims to improve product traceability, transaction transparency, and sustainable economic growth in AV supply chains. The study provided managerial implications for supply chain and logistics operations managers, including improving energy and cost monitoring systems, achieving logistics efficiency in sustainable environments, and reducing reliance on third parties. The MI offers the potential to reduce ambiguity, uncertainty, and complexity in operations, leading to a sustainable socio-economic balance. Future research interests may focus on ranking and assessing key sustainability risk factors customizable within AI-enabled environments across supply chains, particularly in the sustainable logistics domain.

The relationship between blockchain adoption and firm performance was investigated from a dynamic capabilities' perspective in Sharma, Shukla, and Raj, 2023. The study examined the impact of blockchain adoption on Tobin's Q (a measure of firm value) and current accounting performance, considering the moderating roles of intangible capital and environmental dynamism. The findings indicate that firms with high intangible capital are better positioned to benefit from blockchain adoption. Moreover, blockchain adoption enables firms to proactively and innovatively respond to a dynamic business environment.

Previous studies have shown that blockchain technology enhances business performance and process efficiency. However, there is a research gap in the application of blockchain for project monitoring and control. consequently, there is a need for further research to develop a comprehensive framework that leverages blockchain technology to support the monitoring and control of critical chain project management..

3. METHODOLOGY

3.1 Conceptual Overview

In this section, the process of creating a framework for monitoring and controlling project schedules using blockchain technology is described. The proposed model consists of two main clusters:

1 - CCPM Time Schedule Module: This module involves the creation of a CCPM time schedule. It includes the prediction and allocation of project buffers to effectively manage project uncertainties and ensure timely completion.

2 - Blockchain Module: This module utilizes blockchain technology to enhance project monitoring, control, and overall performance. The blockchain technology provides transparency, immutability, and security to the project data, enabling stakeholders to have a real-time view of the project progress and facilitating effective collaboration.

Figure 2 illustrates the sequential steps involved in implementing the framework. The primary objective of the framework is to enhance project scheduling, monitoring, and control by harnessing the potential of blockchain technology and incorporating the principles of Critical Chain Project Management (CCPM). The research methodology employed in this study is presented in the accompanying flow chart. It is important to note that the framework is currently at a conceptual stage and has not yet been implemented or tested in real-world scenarios.

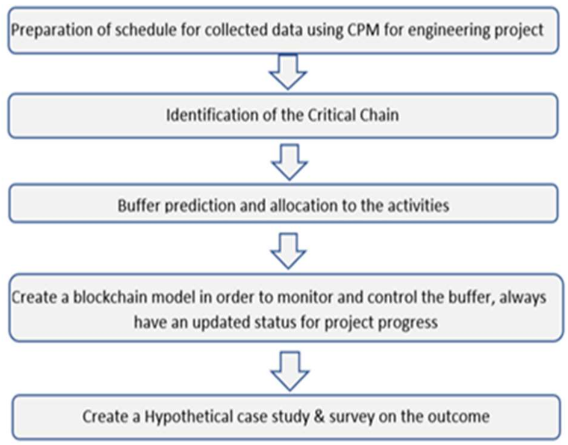

Figure 2. Methodology Flowchart

3.2 Key Components and Functionality

The key components and functionalities that leverage blockchain's features to enhance project management practices are:

Distributed Ledger Technology (DLT) is the underlying concept of blockchain, as described in Belle (2017). It aims to establish trust in a peer-to-peer network without the need for intermediaries. This trust is achieved through the use of verifiable mathematical evidence. DLT provides a decentralized and transparent framework wherein participants can validate and verify transactions and data stored on the blockchain. By removing the reliance on central authorities, DLT enhances security and trustworthiness in digital transactions.

Hashing, as defined in Basden and Cottrell (2017), is a cryptographic function that takes an input of any length and produces a fixed-length string of characters. This one-way function generates a unique output for each unique input, serving as a digital fingerprint or identifier for the input. While collisions, where different inputs produce the same output, are rare, they can occur. Hashing plays a crucial role in blockchain technology by ensuring the integrity and immutability of data stored on the blockchain.

Within a blockchain, each block contains multiple transaction chains, as explained in Turk and Klinc (2017). These transaction chains represent the transfer of value from one participant to another. By linking these transaction chains, the blockchain maintains a comprehensive record of all transactions, ensuring transparency and accountability.

Distributed consensus mechanisms are employed in blockchain systems, as highlighted in Wang et al. 2017. These mechanisms enable network participants to collectively agree on the state of the blockchain. The most widely adopted consensus protocol is Proof-of-Work (PoW), but alternatives like Proof-of-Stake (PoS) and Proof-of-Authority (PoA) exist, as mentioned in Lee and Yoon (2019). These consensus mechanisms ensure that all participants reach a consensus on the validity of transactions and the overall state of the blockchain.

Smart contracts, as defined in Budeli (2020)., are programmable logic rules embedded in the blockchain. They automatically execute transactions when predefined conditions or tasks are met. Smart contracts eliminate the need for intermediaries, enabling secure and automated transactions. They are written in languages such as Solidity for the Ethereum blockchain, as explained. Smart contracts offer various features like conditions, triggers, variables, functions, and modifiers, which allow for the automation of processes, enforcement of rules, and secure execution of predefined functions. They provide transparency, security, efficiency, and cost savings by reducing the risk of manipulation and human intervention.

In summary, DLT, hashing, transaction chains, distributed consensus, and smart contracts are fundamental components of blockchain technology. Together, they create a decentralized and secure system for storing and managing data, enabling trust, transparency, and automation in digital transactions.

3.3 Integration with Project Management Processes

The integration of blockchain technology with project management has the potential to revolutionize the monitoring and control of project progress. This integration involves various steps, starting with the development of a well-structured schedule based on Critical Chain Project Management (CCPM) principles. This schedule allows for the identification of the critical chain, which represents the sequence of tasks that determine the project's overall duration. By considering uncertainties in project execution, the duration of the project buffer can be determined.

To enable effective monitoring, a smart contract is developed using specialized tools for smart contract development. This contract incorporates relevant project data and functions necessary for tracking project progress. It encompasses task details, resource allocation, and buffer duration. Subsequently, the smart contract is deployed to a private blockchain network, ensuring secure and efficient communication among project stakeholders.

Through the smart contract, project participants from different disciplines can update project progress, monitor buffer consumption, and retrieve outcomes. This collaborative approach fosters transparency and accuracy in project management. As project tasks are updated in the blockchain, the smart contract automatically calculates buffer consumption and updates the remaining buffer accordingly. This serves as a trigger for notifications to the project manager, enabling proactive decision-making and timely corrective actions.

The integration of blockchain technology with project management improves transparency, accuracy, and collaboration among project disciplines. By leveraging blockchain's capabilities, project managers can make informed decisions based on real-time data, leading to more efficient project management and successful outcomes.

3.4 Rationale for Blockchain Integration

The framework's design incorporates several key aspects that justify the integration of blockchain technology in project progress monitoring and control. These aspects contribute to the effectiveness and efficiency of the framework in achieving its objectives. Firstly, the establishment of well-structured schedules serves as the foundation for implementing the blockchain model. This ensures that project timelines and dependencies are clearly visualized, allowing for optimized resource allocation and improved planning processes. Secondly, the selection of a suitable blockchain network is considered. Considering the nature of construction projects, a local private network is chosen to ensure privacy, security, and efficient communication and collaboration among project stakeholders. Thirdly, the utilization of developer tools for testing and development purposes is emphasized. These tools provide a simulated blockchain environment, enabling the testing of smart contracts and transaction execution without incurring costs associated with the main blockchain network. This enhances development efficiency and reliability. Fourthly, the use of integrated development environments specifically designed for smart contract development is highlighted. These environments offer user-friendly interfaces and efficient coding environments, facilitating the creation and deployment of smart contracts. Their compatibility with the blockchain ecosystem and support for programming languages specific to smart contracts contribute to seamless development and deployment processes. Lastly, the focus on the project buffer within the framework is emphasized. By concentrating on the buffer, the framework provides accurate and timely information on buffer status, enabling proactive decision-making and risk mitigation. This targeted approach ensures effective management of buffer resources and contributes to the overall success of the project.

Collectively, these aspects establish a rationale for integrating blockchain technology in project progress monitoring and control. By leveraging appropriate tools and focusing on key project elements, the framework enables efficient and transparent project management, fostering collaboration among project stakeholders and facilitating informed decision-making.

3.5 Framework Limitations and Challenges

One potential limitation could be the complexity of implementing and managing the blockchain infrastructure. Blockchain technology requires specialized knowledge and expertise, and setting up a local Ethereum blockchain network using Ganache may involve technical complexities. Additionally, ensuring the security and privacy of the blockchain network and smart contracts is crucial, as any vulnerabilities or breaches could have significant consequences for the project. Another challenge could be the adoption and acceptance of the blockchain framework by all project stakeholders. It may require a cultural shift and a willingness to embrace new technologies and processes. Resistance to change and a lack of understanding about the benefits of blockchain integration could hinder the successful implementation of the framework. Furthermore, the scalability of the blockchain network could be a potential challenge. As the project grows in size and complexity, the blockchain network needs to handle an increasing number of transactions and updates. Ensuring that the network can handle the scalability requirements of the project without compromising performance and efficiency is essential. Lastly, integrating blockchain technology into project management may require additional resources and investments. This includes the cost of implementing and maintaining the blockchain infrastructure, training project stakeholders on blockchain concepts and tools, and ensuring ongoing technical support and maintenance.

It is important to note that these limitations and challenges are not insurmountable and can be addressed with proper planning, expertise, and stakeholder engagement. By carefully considering these challenges and implementing appropriate strategies, the benefits of blockchain integration in project management can be realized while mitigating potential risks.

4. IMPLICATIONS AND BENEFITS

The implementation of the system is expected to have significant practical implications across various domains. It offers valuable benefits in resource management by providing more accurate predictions and enabling strategic allocation of resources. Through the automation of buffer monitoring using blockchain technology, project managers can make well-informed decisions about resource utilization, ensuring optimal allocation to meet project milestones effectively. In terms of risk management, the system plays a crucial role in reducing risk and fostering improved collaboration among project teams. The transparent and accountable buffer management facilitated by blockchain technology minimizes the chances of delays and disruptions. Stakeholders have access to the complete history of project data changes, empowering them to make timely and informed decisions. This transparency also promotes better collaboration among team members as real-time buffer status becomes readily available to all, allowing proactive identification and resolution of potential issues and risks. Additionally, the system provides real-time updates and notifications, alerting project teams promptly when a task or constraint impacts the buffer. This enables timely intervention and proactive measures to address buffer-related issues and mitigate risks. By staying informed about buffer status changes, project teams can take appropriate actions to prevent potential delays or disruptions. The audibility and traceability of blockchain technology also contribute to improved decision-making. Stakeholders can review the historical data of project changes, gaining a comprehensive understanding of project progress and buffer management modifications. This enhanced visibility and access to accurate and up-to-date information support informed decision-making in a timely manner. Moreover, the implementation of smart contracts in automated monitoring processes enhances work efficiency by streamlining project management tasks. Smart contracts execute predefined rules and conditions, eliminating the need for manual intervention. This streamlining improves overall efficiency and reduces the occurrence of human errors, ensuring accurate and efficient buffer monitoring and management.

Considering these practical implications, project managers and industry professionals can leverage the power of blockchain technology to enhance project performance, collaboration, risk management, and decision-making. However, it is essential to carefully evaluate factors such as scalability, cost-effectiveness, and integration with existing systems during the implementation process.

5. DISCUSSION AND LIMITATION

This study explores the application of blockchain technology in the context of critical chain project management (CCPM) for engineering projects. The research introduces a framework for blockchain-based CCPM buffer monitoring. Through this study, valuable insights into the benefits and feasibility of this approach have been gained.

By leveraging the distributed ledger technology and smart contracts provided by blockchain, the proposed framework enables automated project management tasks, including buffer monitoring, updating task completion times, and managing buffers. The tamper-proof nature of blockchain ensures a high level of audibility and traceability, allowing stakeholders to access the history of changes made to project data. This enhances decision-making by providing timely and informed decisions. In CCPM schedules, buffers are strategically placed to protect project timelines from uncertainties and variations. The use of blockchain technology in buffer management provides project managers with a reliable system for tracking buffer consumption, reviewing historical data, identifying patterns, and analyzing buffer utilization over time. The transparency and accountability of the data recorded on the blockchain contribute to maintaining a transparent and accountable buffer management process.

Blockchain facilitates real-time updates and notifications related to buffer status and changes. When a task or constraint affects the buffer, this information is recorded on the blockchain, triggering automatic notifications to the project team. This timely information improves collaboration, enabling project teams to proactively address buffer-related issues or risks.

Smart contracts play a crucial role in the proposed framework. They are self-executing contracts with predefined rules and conditions. Within CCPM schedules, smart contracts automate buffer monitoring processes. For example, when a predefined condition such as a buffer breach occurs, the smart contract can automatically trigger actions such as notifying stakeholders and updating the project plan. This automation reduces manual intervention, improves efficiency, and helps maintain buffer integrity.

There are several limitations to consider in the presented research. Firstly, the study focused on a specific project scenario, which may limit its generalizability to other project types and industries. It is important to conduct further studies and validate the framework in diverse project settings to assess its applicability and effectiveness across different domains. Secondly, the study may not accurately represent the performance and scalability of the framework in a real-world, production environment.

6. CONCLUSION

The research demonstrates that a blockchain-based CCPM buffer monitoring system can provide more precise predictions, strategic resource allocation, reduced risk, and improved team collaboration compared to traditional methods.

The study suggests that the construction and engineering industries should actively explore and adopt blockchain technology in project management practices. Collaboration among stakeholders, including project managers, contractors, and regulatory bodies, is encouraged to establish standards and guidelines for blockchain integration. Education and training programs on blockchain technology and its application in project management should be conducted to enhance understanding and skills. Integration of the blockchain-based CCPM system with other project management tools and systems is recommended to provide a holistic view of project progress and performance.

Future works proposed in the study include conducting real-world case studies to validate the effectiveness of blockchain-based CCPM buffer monitoring in different project environments. Exploring the integration of blockchain with supply chain management and investigating the feasibility of other programming languages and smart contract platforms are also suggested. Further research on the potential applications of blockchain in risk management, procurement, and supply chain management is recommended. In-depth interviews with industry experts, the integration of artificial intelligence and machine learning algorithms, and comprehensive cost-benefit analyses of blockchain-based CCPM implementations are additional areas of future exploration.

Overall, the study concludes that the integration of blockchain technology in CCPM buffer monitoring holds great promise for improving project management practices in the construction and engineering industries. With continued research, development, and collaboration, blockchain has the potential to revolutionize project management by enhancing transparency, collaboration, and efficiency, ultimately leading to successful project outcomes.

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