BLOCKCHAIN IN HEALTHCARE TODAY

APPLICABILITY OF BLOCKCHAIN-BASED IMPLEMENTATION FOR RISK MANAGEMENT IN HEALTHCARE PROJECTS

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Abstract

Hospitals provide diverse tasks essential for the delivery of patient care and are comprised of many functional units. This makes healthcare projects in construction highly complex among other types of building projects due to the specific regulations, multiple functions it must provide, complicated mechanical and electrical systems, and so on. This complexity embodies potential risk events during its construction, which not only influences the completion of the project but can impact the patients' safety and health conditions even after the project is finished. To prevent such outcomes, risk management is a crucial process that can identify, evaluate, and properly mitigate risks along the project lifecycle. A key aspect of risk management is that it requires the interaction and contribution from multiple stakeholders of the project. Various frameworks and tools that enable collaborative management of risks among multiple stakeholders have been developed in the past. However, the developed frameworks are not suitable in the sense that it does not protect the confidentiality of individual inputs from the stakeholders. Moreover, these frameworks are centralized systems, which can bring issues related to the security and transparency of the information that is being stored. Blockchain technology is an emergent distributed ledger technology (DLT) that can provide solutions to the listed problems found in centralized systems. It is a novel system that records information on a decentralized, distributed ledger, where transactions are constantly duplicated and updated. This study explores the applicability of blockchain technology for healthcare risk management. The key functional elements of blockchain that can resolve the challenges faced by prior risk management frameworks have been identified and discussed. Based on the discussions, a conceptual information management model for managing healthcare project risks on a blockchain has been conceived. The development of the initial prototype has been explained. The research study illustrates the process, benefits, and limitations of adopting the blockchain technology for collaborative risk management in healthcare projects.

Keywords: *blockchain technology*; *distributed ledger technology (DLT); healthcare construction projects*; *risk management*; *smart contracts*

Section: Original Research

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INTRODUCTION

Healthcare projects in construction refer to projects that design, build, or renovate healthcare facilities where medical services are provided, such as hospitals, clinics, and long-term care facilities. Healthcare projects are generally very complex compared with other types of construction projects for a number of reasons. These facilities offer a wide range of spaces that are necessary for the diagnosis and treatment of the patients. (1) Medical spaces can range from surgical rooms and patient rooms to laboratories, and these spaces need unique systems for the clinical care of patients. Many facilities, especially hospitals, have continuous operations throughout the year, which requires thorough planning, especially when it is a renovation project. (2, 3) Healthcare projects have special codes and regulations to follow in addition to typical building codes. (2) Each state normally has its own hospital code and agency that regulate the design and construction of healthcare facilities. Other organizations, such as the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the National Fire Protection Association (NFPA), provide specific regulations that address healthcare facilities.

According to the US Census Bureau, total construction spending in healthcare projects has been continuously

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increasing and was close to 48 billion dollars in 2020. (4) This total cost includes the construction work done on new and existing structures, including the cost of labor, materials, design and engineering work, overhead costs, interest, and taxes paid for the project. More funds are being allocated for healthcare projects in both the public and private sectors. Considering the complexity of these projects, rigorous risk management should be made throughout the project lifecycle to better manage the cost of these projects.

Due to its complexity and unique characteristics, there are very specific risks when it comes to the risk management of healthcare projects. Hospitals have to be in a convenient location for the patients, often being located in crowded metropolitan areas. This makes workface planning very difficult, especially the delivery of materials and heavy equipment. Also, many risks can arise from the coordination between multiple disciplines, as hospitals have very complex mechanical, electrical, and plumbing systems. It is very common for healthcare facilities to go through expansions, which can cause multiple risks due to the ongoing operation in the existing facility. Hospitals may require extensive fire alarm or sprinkler systems, and the procurement and installation of medical equipment can become very troublesome for the project team.

All the aforementioned risks, when not managed properly, could result in cost overruns, schedule delays, and quality problems for a project. (5) There have been numerous cases in construction where things got out of hand due to poor risk management. According to a news article, the construction of the Veterans Affairs' newest medical center in Colorado was initially planned to be completed by 2013, with an estimated project cost of $328 million. (6) However, the final cost turned out to be $1.73 billion, which was more than $1 billion over budget. The project was also completed 5 years behind the schedule. This example shows that risk events in construction should be taken seriously and managed for the project to be completed on time under the estimated cost.

RISK MANAGEMENT IN CONSTRUCTION

Risk management is an essential process in complex construction projects, such as healthcare projects. With proper risk management, projects can prevent cost overruns and schedule delays, and improve the overall quality of construction. (5) The importance of risk management has been emphasized over the years through numerous studies. It has been selected as one of the best practices in construction by the Construction Industry Institute (CII) and as one of the knowledge areas developed by the Project Management Institute (PMI). (5, 7)

A typical risk management process is done through five steps: identification, assessment, analysis, mitigation, and monitoring. (5) In the first step, project team members would share their ideas on what could be potential risks in the project based on their knowledge and experience. The identified risk events will then be assessed based on how each of them could influence the project. These assessments are usually made in terms of the likelihood of occurrence and its relative impact on project cost, schedule, safety, and quality. The third step is risk analysis, which can be conducted in a variety of methods. A common practice for risk analysis is to compute the mean values (i.e. probability × impact), rank, and visualize the mean values using heat maps.(8) Another approach that can better account for the uncertainty of the risks is the probability risk analysis, which solicits three-point estimates (Best case, most likely, and worst case) from the stakeholders. Using the estimates, the project team can run a Monte Carlo simulation to capture a probable range of outcomes. (9) Knowing the potential outcomes of risks, the project team would implement mitigation strategies to manage, eliminate, or minimize risk impacts to an acceptable level. The last part of the process is monitoring; the status of the risk should be monitored as long as the risk exists, so that right measures can be taken before things go wrong. (5)

A crucial part of risk management is the collaboration among the project stakeholders. To reach a common solution for the group of experts, different points of view, backgrounds, and levels of expertise that they have on project risks should be reflected. (10) Click or tap here to enter text. Thus, there is a need for a platform where stakeholders can have a joint risk management practice. A conventional way of performing this is by holding a Risk Workshop, where project team members gather to brainstorm and share their thoughts on potential risks in a comprehensive way. (11) Based on the Risk Workshop discussions, project teams often use a Risk Register, a tool that enables the project risks to be documented and maintained. (12)

However, such practices hold challenges for the stakeholders to fully trust and rely on the process. While effective risk management should facilitate open communication to leverage the participants' experience and knowledge, in an environment such as a Risk Workshop, there could be undesired influences between them. (13) Participants who have different opinions may be pressured to attain a required level of agreement, and personality traits can have a huge impact on the outcome of the discussion. (14) Participants may even prefer not revealing their perspectives on project risks, as they are closely aligned with their individual objectives in a project. Hence, there is a need to capture the individual viewpoints of the participants but at the same time keep them private.

Several studies have developed web-based tools that further facilitate the communication between geographically distributed team members and utilize a decision support system for collaborative risk management. (15-17) Web-based tools can ease communication

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and integrate team members' views through algorithms. However, the web-based tools are centralized systems, which lays several concerns related to data privacy, security, and transparency. According to Nair and Sebastian, (18) centralized systems have a single point of control and ownership. All transactions in a centralized system can be accessed and managed by the central authority, which would prevent the stakeholders from providing their most candid inputs on project risks.

Moreover, centralized systems may cause problems related to the security and transparency of data. In cases when a centrally owned ledger is lost or destroyed by a malicious attack, it is entirely up to the central authority to back up and restore the data manually. In a centralized system, there are no restrictions for the ledger owner to change or append data. If the central owner of the ledger decides to manipulate data, it is extremely difficult for the users to make sure that past transactions have been validated properly. Considering all the issues above, a novel system should be developed to provide a better setting for multiple stakeholders working in collaborative risk management.

BLOCKCHAIN TECHNOLOGY AND SMART CONTRACTS

Blockchain is a distributed ledger technology (DLT) that enables members in the network to digitally record and access transactions. (19) The users interact with each other through a peer-to-peer network, removing the need for a central authority that controls every transaction. Participants take part in validating the transactions through various consensus models and make sure that the entries have been appended in the right order. The information submitted through transactions is added to the network in blocks, and these blocks are added in a chronological order. A cryptographic hash function is used to generate a unique output of the previous data. The header of the block contains the hash of the previous block, which makes all the blocks hash linked from the genesis block to the most current block. (20) Thus, blockchain is a linked list via hash pointers, which is append-only and tamper resistant, also allowing the users to trace the previous transactions on the network. (21)

In addition to blockchains, smart contracts have the potential to make the technology more powerful. By definition, smart contracts are computerized transaction protocols that execute the terms of a contract. (22) These written lines of code can be deployed on the blockchain network using cryptographically signed transactions. (21) Just like other transactions on the network, smart contracts cannot be changed once they are endorsed by the users and installed on the blockchain. Once the predefined conditions are met, smart contracts are automatically executed to record, execute, and distribute transactions across the blockchain network. (20) Not only does this add more transparency to the technology but it has the potential to extend and leverage the blockchain technology, as it creates an environment of trust among the users and removes unnecessary third parties for transactions. (23)

Although blockchain technology became widely known with the advent of cryptocurrencies like Bitcoin, it has a lot more to offer beyond the financial sector. Blockchain technology can implement a distributed ledger system, which can solve the issues of centralized systems. If the benefits of this emerging technology can be integrated properly, it has the potential to revolutionize systems in various sectors.

RESEARCH OBJECTIVE

The aim of this research study was to develop a system that can enable collaborative risk management among multiple stakeholders. The earlier section of the article identified the problems in a conventional risk management process and the deficiencies of previous web-based tools for risk management. The system should allow the users to preserve the confidentiality of their individual inputs on risks while providing transparent and traceable transactions. Hence, a blockchain-based implementation has been conceived as the basis for the development of the prototype of the system.

According to Chung, (24) the system should adopt a private permissioned blockchain where only permitted users can access and transact on the network. Among multiple platforms that provide a private permissioned blockchain, Hyperledger Fabric has shown the highest privacy and throughput with minimal latency from a comparative study. (25) Therefore, Hyperledger Fabric was selected as the platform where the system prototype has been designed. The workflow of the prototype is described step by step with examples to help readers understand the process. The working prototype under development has been demonstrated to further elaborate how Hyperledger Fabric and smart contracts have been used. Based on the findings, limitations and future work are discussed along with the applicability of the prototype to other problems in the healthcare industry.

CONCEPTUAL MODEL

In this study, Hyperledger Fabric has been adopted to build a private permissioned blockchain for the proposed risk assessment system. There are specific terms that are essential for understanding how a Fabric network works. First, a Fabric blockchain network is comprised of a set of peer nodes, which are network entities that each host a ledger. (26) The peers also have individual containers to run the chaincode, also known as the smart contract. An orderer node is an entity required in Hyperledger Fabric for validating the blocks created by the peers, and a channel is a private 'subnet' of communication between the network members for conducting private and confidential transactions. (26) In our use case, a single channel will be set up for the peers to access and transact on the network. To implement proper risk management among a group of stakeholders, the Project Creator assigned to the network plays a role in the process as a middleman but does not intervene with any of the inputs provided by the stakeholders (Figure 1). Figure 2 demonstrates how the permissioned identities are added to the blockchain to be trusted and recognized by the rest of the network.

Figure 3 illustrates each step of the conceptual model process. Step 1 starts with the Project Creator starting up a project entity on the blockchain along with a brief description of the project. The description should include some basic project information along with the total cost and duration so that the stakeholders have a good understanding of the project. Step 2 includes the solicitation of potential risk events from the stakeholders. Each user who is a participant of the project should have been added to the Fabric channel to perform this function. Thus, the Project Creator will send requests to the stakeholders through the blockchain channel, and the stakeholders should submit a list of risk events, which they think might impact the overall cost of the project.

Figure 4 shows an example of risk event solicitation from the stakeholders. Assuming that there is a project for the construction of a medical office building, User 1, in this case, identified multiple risks relevant to the

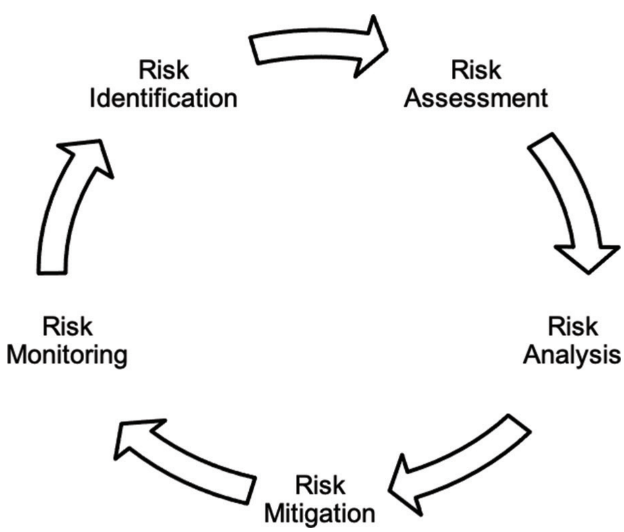

Fig. 1. Risk management process.

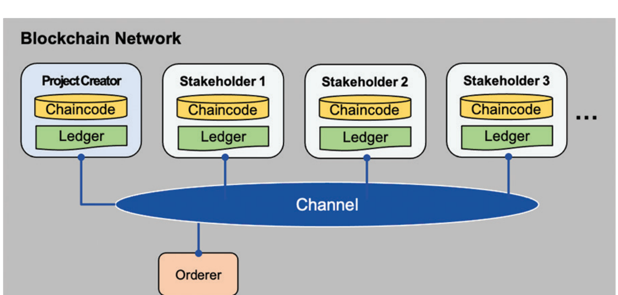

Fig. 2. Hyperledger fabric network configuration.

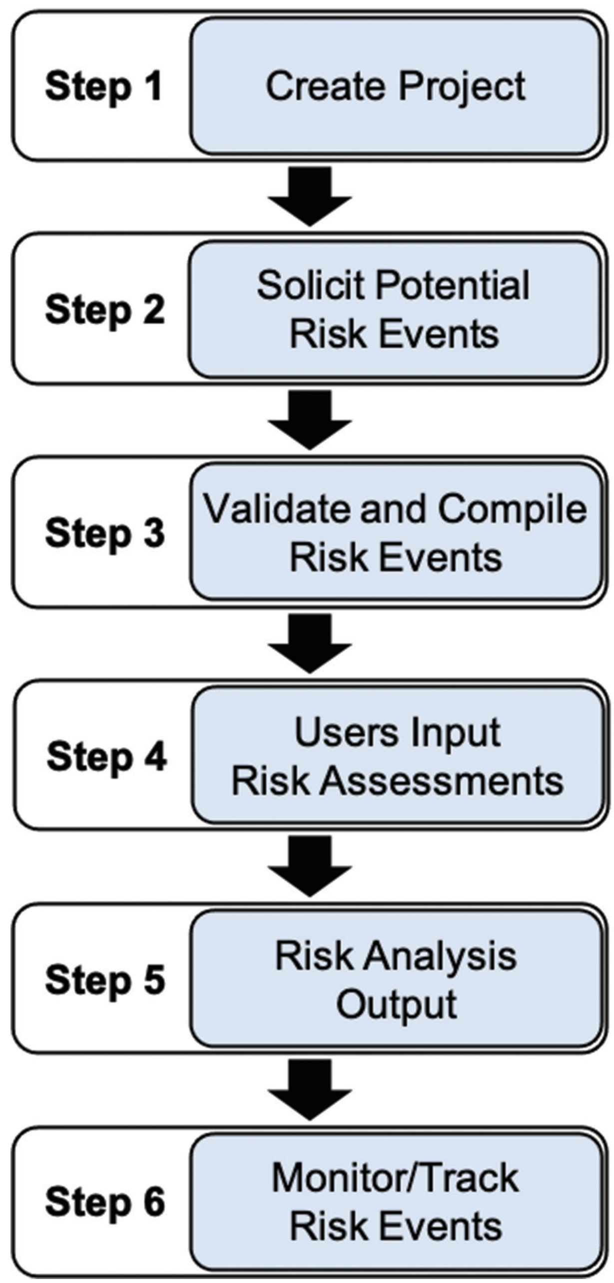

Fig. 3. Conceptual model process.
MEP: mechanical, electrical and plumbing

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project such as 'request for additional medical gas outlets', 'delays due to installation of fire alarm systems', and 'building requirements for safety and infection control'. Each user should provide his or her own set of risk events to the Project Creator. The process will be followed by Step 3, where the Project Creator validates the risk events that have been collected from the stakeholders and compiles a single list of risks as shown in Figure 4. This step is very important, as there can be risk events irrelevant to the project, and more than one user can identify the same risk event in the earlier step. The Project Creator should make sure that all risk events are valid, and there is no overlap between the risk events when organizing this single list. The list should be distributed back to the users through the blockchain. When users receive the completed list, they should recognize the influence of each risk event to make a proper risk assessment in the next step.

In Step 4, the users assess risk events by providing their likelihood of occurrence and the relative impact of the risk on project cost. In this model, the likelihood of occurrence represents a percentage of certain risk events happening. The relative impact is also given by a percentage of how much cost would increase compared with the initial cost of the project without any risk event happening. The impact will be evaluated by a three-point estimate, which represents the minimum, most likely, and maximum impact that the risk event could have on the project cost. Table 1 provides an example of such risk assessment input. While the model in this article focused on the impact on project cost, it can also be applicable for finding the impact on project schedule, safety, or quality. It all depends on what is the main focus and interest of the project team.

An interesting feature of Hyperledger Fabric that plays a huge role in Step 4 is the private data collection. This feature enables the organizations to store private information away from other organizations on the channel. Private data collection can be executed through a chaincode definition and removes the need for creating separate channels for keeping private data. (27) Figure 5 shows an example of how a private data collection structure can be used in the risk management process. The stakeholders will share the public collection where general information about the project, list of risk events, and risk analysis output is stored. However, any sensitive information related to risk assessment will be kept confidential as it is saved in each peer's private collection. The feature only allows the organization that actually owns the data to access the information, which fits the research objective of preserving confidentiality on risk assessment inputs.

Risk analysis takes place in Step 5 of the model process. While the risk assessment inputs are kept at a private state, smart contracts can utilize aggregation methods to generate combined numbers and publish these in the public collection of the shared ledger. The aggregation

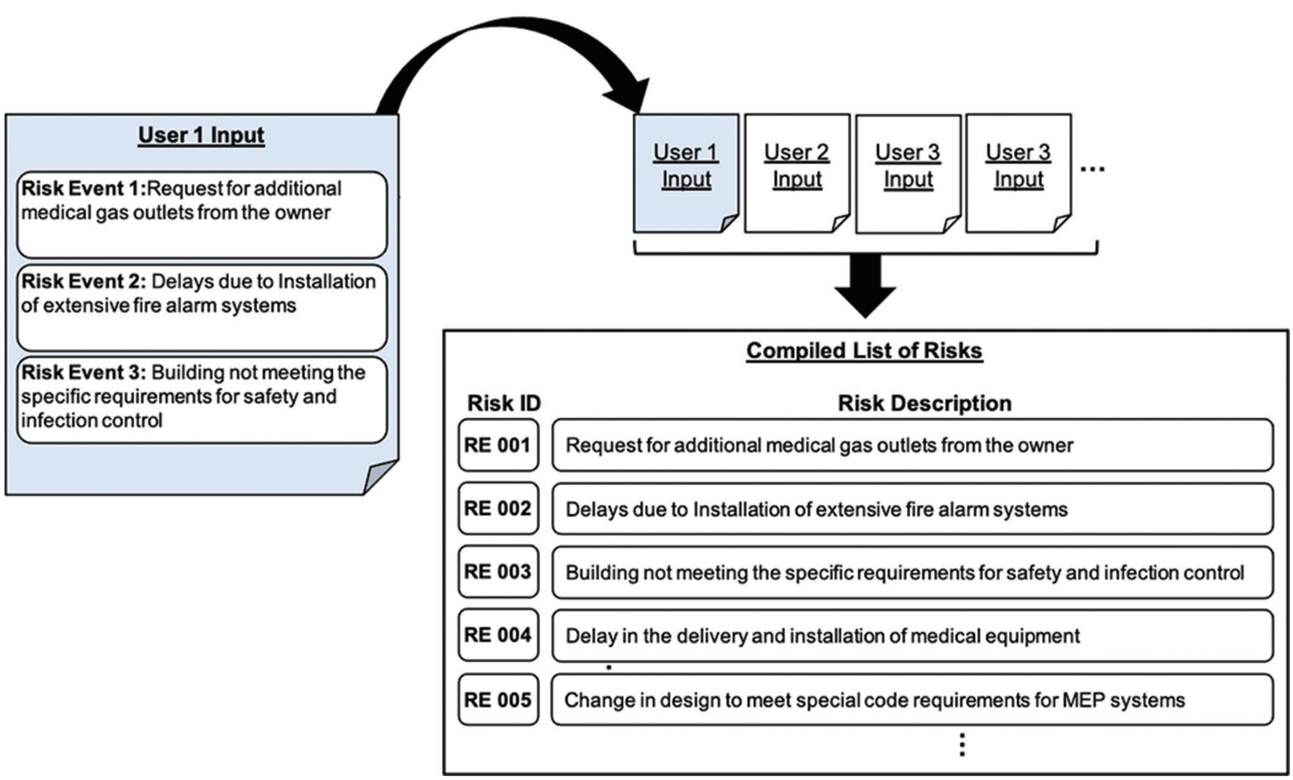

Fig. 4. An example of user input and compiled list of risks.

Table 1. An example of risk assessment input

Risk ID	Risk description	Likelihood (%)	Impact on cost		
			Minimum (%)	Most likely (%)	Maximum (%)
RE 001	Request for additional medical gas outlets from the owner	5.0	3	5	7
RE 002	Delays due to installation of extensive fire alarm systems	8.0	5	7	10
RE 003	Building not meeting the specific requirements for safety and infection control	5.0	2	5	10
RE 004	Delay in the delivery and installation of medical equipment	10.0	8	12	15
RE 005	Change in design to meet special code requirements for MEP systems	8.0	5	8	12

MEP: mechanical, electrical and plumbing.

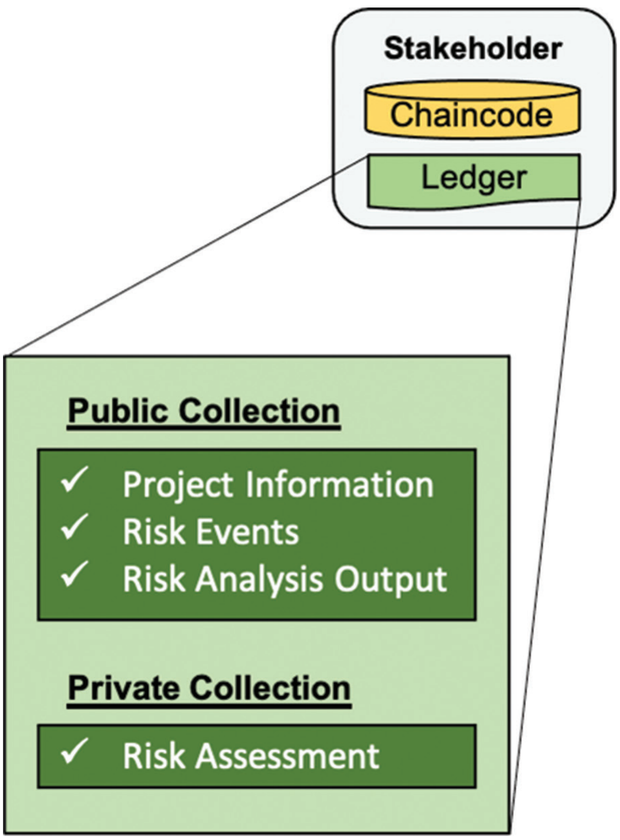

Fig. 5. Public and private data collection in ledgers.

methods can be as simple as averaging the risk assessment inputs, to using various opinion pooling methods. The combined numbers will not reveal the individual inputs, which eventually protects the confidentiality of the data. Using the combined numbers, project teams can run risk analysis off-chain using a method of their choice such as Monte Carlo simulation. The outputs from the risk analysis can be posted on the blockchain to be shared among the stakeholders and help them collaborate on making a project decision.

The last step of the process is the monitoring and tracking of risk events which are further empowered using the blockchain technology. Risk management is not a one-time process, as it is iterated multiple times over the project life cycle. (5) New risk events can be identified in later phases of the project, and risk assessments are bound to change as the project proceeds. In a blockchain network, blocks are added in a chronological order. Each block references the previous block and the transaction data that have been stored. (23) Hence, all transaction history is kept on the network, which makes the information to be transparent and traceable. As a result, users can easily track and monitor how risk events and assessments have changed over time through the transaction history kept on the blockchain network.

PROTOTYPE DEVELOPMENT

This section elaborates on the initial prototype that is being developed. As proposed in the conceptual model section, Hyperledger Fabric was selected for the prototype and has been set up on the local machine. The network has been configured as in Figure 2, with each of the four peers having access to the network through the gateway on the local machine. Client user interface (UI) has been developed to enable user interaction to be as simple and efficient as possible, and an application programming interface (API) layer has been added, which works as a bridge between the Fabric network and the UI.

Smart contract algorithms have been programmed in Go Language (version 1.15.4), which is an open-source programming language used for distributed systems. The functions of the smart contract have been aligned with the conceptual model process presented in Figure 3.

The smart contract functions can be categorized into two types, which are 'Query' and 'Invoke' functions. 'Query' function will retrieve information from the ledger like getting the list of identified risk events before risk assessment. The 'Invoke' function creates new blocks and update the ledger. An example of this would be the stakeholder entering a potential risk event or providing a risk assessment on the ledger. The developed smart contract will be packaged and deployed to the channel, allowing each of the channel member

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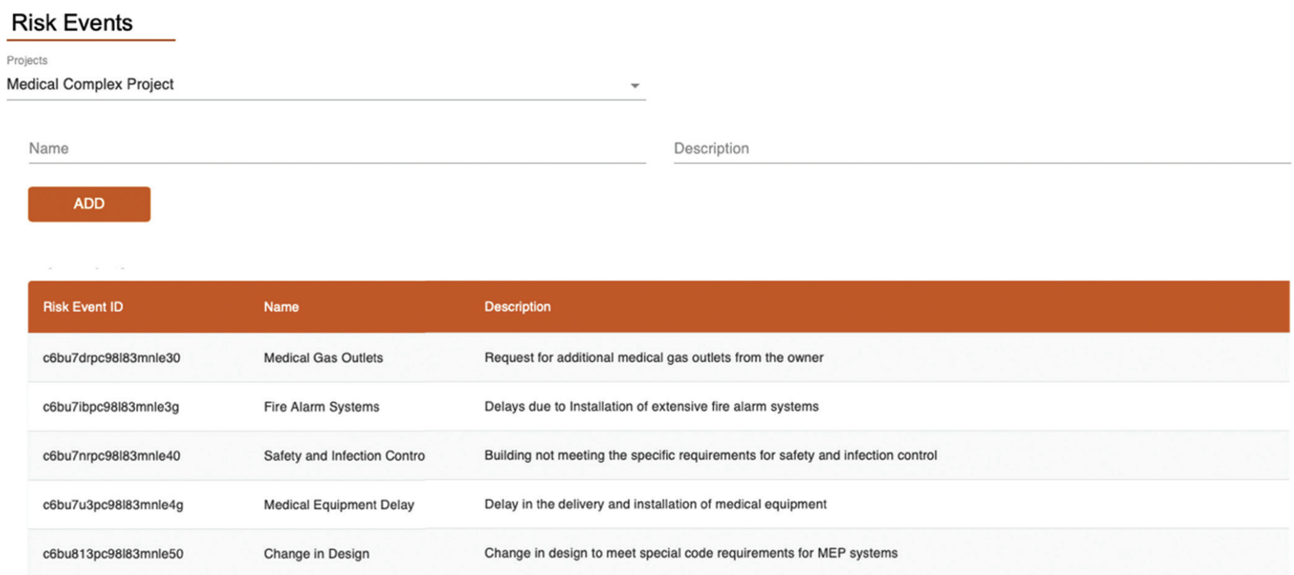

Fig. 6. User interface (adding risk events).

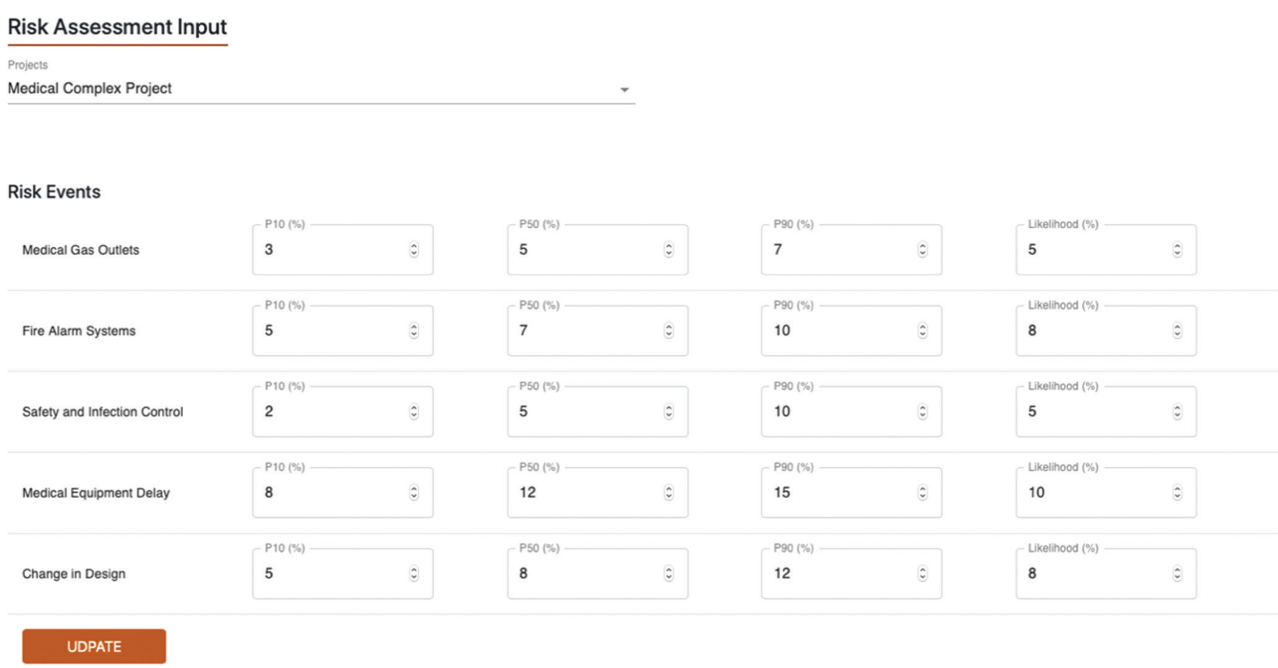

Fig. 7. User interface (entering risk assessments).

organizations to install the smart contract on their peer node.

Screenshots of the UIs are shown in Figures 6–8. In Figure 6, the user can select the project and add any risk event that has the potential to impact the project. The name and description of the risk events must be entered, and the risk event ID will be autogenerated. When the list of risk events is compiled and validated, the users will be able to enter their assessment as shown in Figure 7. The likelihood of occurrence and the three-point estimates of the impact on cost are provided by each user, which will be aggregated. Figure 8 shows an example of an aggregated output that has been posted on the prototype. This output can be retrieved by the users so that they can eventually run a risk analysis of their choice.

All of the transactions will be marked on the chain while preserving the confidentiality of each user's input. The prototype has been demonstrated to subject matter experts and is being tested in a local environment. After

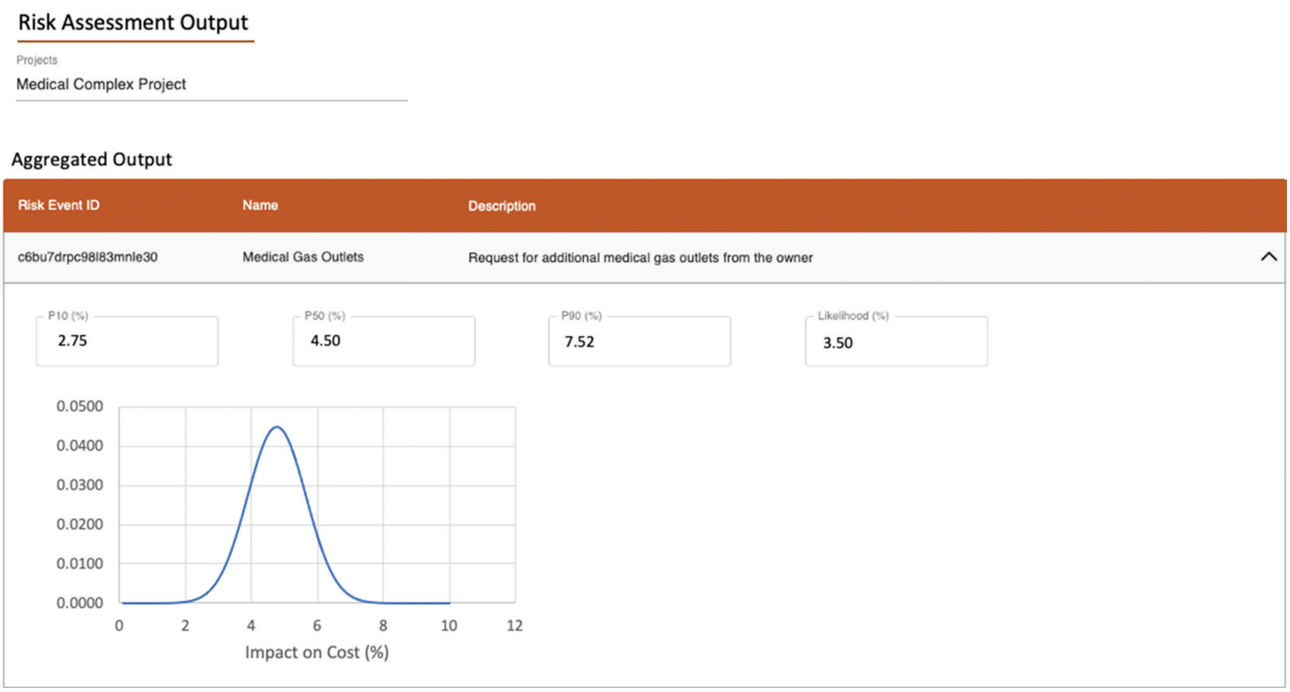

Fig. 8. User interface (risk assessment output).

going through changes, the prototype will be deployed on a cloud service so that it can be pilot tested in an actual project.

DISCUSSION

While the prototype presented in this article holds promises for risk management in healthcare projects, it has limitations that should be considered for future work. First, most functions in the prototype focus on risk identification and risk assessment at the beginning of a project. However, the blockchain-based system could impact the project throughout its lifecycle if more focus is placed on risk mitigation and monitoring. The initial prototype can be extended so that risk mitigation strategies are recorded on the blockchain as well. This way, the effectiveness of risk mitigation strategies can be monitored afterwards. Also, the prototype should enable periodic reassessment of risk events, as risks are bound to change during a project. Such features will allow the risks to be thoroughly monitored and support the delivery of a successful project.

Another limitation was that the prototype was based on the assumption that all risk events are independent, and stakeholders have equal weights on evaluating the risks. However, this is not always the case. The prototype will incorporate these features later for the project team to elicit better risk decisions.

Moreover, the prototype still relies on an intermediary, which is the Project Creator, for certain functions in the framework. Although the Project Creator has limited roles only in the earlier phases, one of the biggest purposes of blockchain technology is to remove the redundancies created by the trusted third party. (20) Further work on smart contracts should be conducted to automate the solicitation of risk events and enable risk event validation among stakeholders.

Along with addressing the mentioned limitations, future work should be focused on enhancing the working prototype which is in the early phases of development. The prototype blockchain should be tested and validated to see if all functions work properly as stated in the conceptual prototype process. Once validated, the working prototype should be deployed on a cloud service and pilot tested on an actual healthcare project to see its effectiveness in handling risks.

Although the focus of this study was on improving the risk management process of healthcare construction projects, the authors believe that the solution can be applicable to any other problems that involve preserving data confidentiality. Especially in health care, protecting the sensitive health information of the patients is essential due to ethical reasons. (28) The concept of blockchain technology and its cryptographic algorithms can play a huge role in meeting the security requirements for hospital privacy. (29) Similar to the prototype proposed in this article, studies have addressed how the technology can help clinicians make informed decisions while keeping personal health data confidential. (30) For example, Gangula et al. (31) proposed a conceptual model to facilitate the interoperability of patient health information between healthcare systems using Hyperledger Fabric. More research should be conducted in this area so that blockchain technology can maximize the safety and privacy of patient information while mediating accessibility.

CONCLUSIONS

This research study explored how blockchain technology can solve concurrent problems in the risk management of healthcare projects. Healthcare projects have unique characteristics and can be extremely complex compared with other types of construction projects. Different methods have evolved over time to support collaborative risk management; however, there still lies several issues related to security, trust, and reliability when information is shared in a centralized manner. Also, preserving the confidentiality of risk information becomes a bigger problem as stakeholders want to keep the sensitive information to themselves. The way to tackle these problems was to develop a blockchain-based implementation and utilize smart contracts to keep the risk inputs private, while using them at an aggregate level for risk management. Therefore, a conceptual model process has been conceived to enable collaborative risk management. A working prototype using Hyperledger Fabric has been demonstrated based on this conceptual process. This prototype has the potential to allow the utilization of private information for risk management and track risk events over time. The solution proposed in this article is just one of the examples of implementing blockchain for preserving confidentiality. The prototype can be altered to solve problems related to patient records and clinical decision support systems. (31, 32) More work will follow to develop a Hyperledger Fabric network based on the conceptual model. Overall, conventional risk management in healthcare construction has a huge room for improvement and blockchain-based implementation seems highly applicable.

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Conflicts of Interest

None of the authors declare any conflicts of interest.

Contributors

This study was designed and conducted by In Bae Chung under the conceptual and technical guidance of Dr Carlos H. Caldas.

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