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Evaluating the Implementation Cost of Blockchain in Organizations through System Dynamics

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ABSTRACT

One of the main obstacles to the adoption of blockchain is the cost of its adoption. The application of this technology in an organization requires the costs of development, design, maintenance, hardware, software, and energy consumption according to its adoption rate. This study uses system dynamics (SD) and machine learning (ML) methods to predict the final cost of blockchain implementation. Compared to mathematical programming, simulation techniques for estimating costs are scarce. However, SD modeling is suitable to account for the complexity and dynamic of systems and support long-term, strategic decision-making. To better understand the system behavior, it is necessary to formulate the relationships between the variables and simulate the values of the variables over time. The relationship between these variables is analyzed using the qualitative SD modeling method with stakeholders through questionnaires and 15 interviews. After identifying the variables, their effect on each other and the implementation cost are investigated. Since the charts obtained from the SD give us the behavior of state and flow variables for time, linear regression applying cross-validation, as one of the ML methods, is used to get a graph showing the system's state as a rate function. Thus, this research provides a reasonable basis for estimating the cost function of blockchain implementation. The validity of the suggested method's results is investigated through sensitivity analysis. The results demonstrate the effectiveness of the proposed model. Simulation results indicate that implementing scenarios such as changes in the average block creation time significantly enhances transaction cost, hardware cost, and software cost, leading to increased implementation cost of blockchain for organizations. The results of this research can significantly help decision-makers develop and apply blockchain technology in organizations.

Keywords

System dynamics, Blockchain, Cost management, Transaction.

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1. Introduction

Blockchain technology is a relatively new concept initially introduced by Haber and Stornetta in 1991 (Haber & Stornetta, 1991). It reached its peak of prominence with the introduction of Bitcoin. Blockchain is a decentralized digital ledger database composed of informational blocks that are all interlinked. Each block is connected to the previous one in this structure, creating a chain-like data structure (Rajabi et al., 2022). In blockchain-based tracking systems, every transaction and action is recorded and observable, and they can be tracked and retrieved by multiple parties at any given time (Dasaklis & Casino, 2019). Traditional supply chain systems rely on centralized information systems like enterprise resource planning, which typically store all data in a central location. These information systems have several limitations, including a lack of trust among supply chain members. They use centralized databases susceptible to attacks, corruption, and hacking (Roozkhosh et al., 2023b). In traditional database systems, records are usually maintained in a single location within an organization. A central authority controls the database, ensuring transaction integrity and managing user access. Six key features distinguishing blockchain technology from traditional information systems are decentralization, immutability, security, auditability, accessibility, and smart contracts.

Blockchain is, by its nature, a decentralized platform, eliminating the need for third-party validation, regardless of the activities conducted on the platform. No strong central entity exists in blockchain to establish rules, centralize accounting, and maintain a general ledger. The most essential part of blockchain technology is the consensus algorithms used to determine how network participants agree on adding information blocks to the blockchain. Blockchain supports advanced concepts like smart contracts and assets (Moosavi et al., 2021). Smart contracts are a significant technology that enables valid transactions without third-party involvement. Smart contracts are agreements between companies in a supply chain process (e.g., senders and carriers in a transportation chain) encoded in code and automatically executed by computers after specific conditions are met (e.g., the arrival of a product at a telecommunications company). The code is stored and replicated in a blockchain. The benefits of smart contracts include increased accuracy, speed, security, trust, transparency, traceability, and efficiency (Khan et al., 2021).

Different blockchain architecture configurations make it possible for various use cases in the business sector. Blockchain comes with challenges and limitations that need to be considered before its adoption and implementation. One of the primary challenges associated with blockchain is its scalability. Scalability refers to the network's ability to process many transactions and meet demand (Durach et al., 2021). This issue concerns the network's computational and operational capacity in processing operations and transactions. In other words, the higher the scalability of blockchain, the more influential the network is in supporting transactions. As the use of blockchain expands and the number of blockchain networks increases, computational power for solving more complex algorithms also increases, leading to improved scalability. It means that more transactions can be processed simultaneously, resulting in a substantial increase in the amount of data that can be shared (Kamble et al., 2020).

Before implementing a blockchain system, how much of the information can be shared among participants should be determined. It can vary based on the advantages and limitations associated with blockchain implementation. For instance, increasing the adoption rate of blockchain may lead to increased costs for an organization, but it can also reduce costs in other aspects (Bafandegan et al., 2023). Therefore, one of the main obstacles to implementing blockchain is the cost associated with its execution. Fixed and variable costs play a significant role in using blockchain. One of the primary costs of implementing blockchain pertains to the initial development and maintenance expenses. Implementing blockchain requires a high level of capital investment. Additionally, additional costs will be incurred if companies need to change their systems and train their employees to acquire blockchain knowledge.

One of the main disadvantages of blockchain is its high energy consumption and the associated costs. The more complex smart contracts are, the more they use more sophisticated consensus algorithms, which require higher computational power (Golosova & Romanovs, 2018). Therefore, they need more time and incur higher costs for coding, which necessitates individuals with advanced programming skills, further increasing the cost of creating a blockchain. Organizations that use more complex smart contracts also require the development of more extensive databases and hardware. More complex consensus algorithms require more powerful hardware.

Additionally, higher computational power consumes more energy, leading to increased energy costs. Another significant issue that increases the cost of blockchain, particularly with the use of extensive smart contracts, is the cost of code inspection and testing and human error in the coding phase. It is evident that as the complexity of smart contracts increases, human error also rises.

Due to the complex nature of blockchain technology development, experts within organizations often struggle to predict costs accurately, considering varying adoption rates (Roozkhosh et al., 2023a). Predicting costs and establishing a relationship between costs and adoption rates is unsuitable for mathematical modeling and analytical methods, as numerous factors and variables influence adoption rates and their associated costs (Modares et al., 2024; Modares et al., 2023b). Additionally, the relationship between influential variables and feedback mechanisms is complex and dynamic (Modares et al., 2023). In this research, the behaviors of various variables are identified using an SD approach, considering all factors related to adoption rates and their associated feedback mechanisms within the study's time frame. All variables that impact blockchain adoption are identified by employing an SD approach. After identifying these variables, their impact on each other and the adoption rate is examined. Hence, utilizing the SD approach, the behavior of variables is displayed concerning each other over time, and the effect of variables on each other is well-reflected in simulating the behavior. After implementing this approach and validating the model, the behavior of model variables is simulated for future intervals. Since the chart derived from systems dynamics shows the states and flows as functions of time, machine learning-based validation methods are used to obtain a chart representing the system's state as a function of the net rate. In essence, because the changes in the state variables over time are determined as the sum of input rates positively and output rates negatively, relationships between state variables and flows are maintained at each moment, and variable values can be expressed in terms of each other.

By adopting a comprehensive approach that integrates statistical analysis and systemic modeling, this research endeavors to fill critical gaps in existing literature. Through its detailed exploration of the influence of adoption rate on the cost of blockchain implementation, this study seeks to provide a robust framework for understanding and optimizing the intricate dynamics at play within blockchain. In this research, the cost function of blockchain implementation has been estimated, and its relationships with other related costs have been obtained. These relationships have been estimated using the method of SD and regression, which has yet to be addressed in any research so far. The relationship between the costs of blockchain implementation has yet to be explored in the literature. Therefore, this motivates us to examine them in the organizations. Based on conducted studies, three factors will be highlighted that are the main contribution and motivation in this study:

(1) Examining the relationship between the influencing variables on the cost of blockchain implementation is surprisingly unsettled in the literate.
(2) Estimating the cost of blockchain implementation functions could be more compelling to the literate.
(3) To our knowledge, system dynamics, and regression techniques are simultaneously considered in blockchain implementation for the first time in this paper.

The remainder of the paper is organized as follows. The literature review is presented in section 2. Section 3 discusses the method. The model and data analysis are presented in section 4. The conclusion is given in section 5.

2. Literature review

Previous studies have presented that most blockchain studies focus on the benefit of BT, how it works, and its potential benefits (Kamble et al., 2021). In recent years, many studies have examined the application facilities of BT in any organization from the perspective of the supply chain due to its lack of knowledge and immaturity (Kamble et al., 2020; Kamble et al., 2021). Yadav et al. (2020) proposed the adoption of BT in the supply chain. In this work, the main component of the adoption of BT related to the supply chain was identified. These components were examined and used to model the efficient supply chain using component analysis. The designed supply chain produced a more efficient result than traditional supply chain management. Li et al. (2018) analyzed the current state of BT by analyzing the various areas in the organization with the key objective of maximizing the coherent adoption of this technology. They emphasized the need for a coherent adoption of BT in the organization rather than a diverse adoption. Olawumi et al. (2021) considered the complex causal interrelationship of the main factors affecting the adoption of BT using the system dynamics method in the construction industry. The findings presented that users' awareness and satisfaction, standard development, and top management support are solutions that would improve adopting BT in construction companies and the construction industry. Tipmontian et al. (2019) examined the impact of the adoption of BT for safe food supply chain management through the SD method. The preliminary discussion and survey were carried out with the participants from food expert companies, and causal loop charts and stock and flow charts were validated. The opportunities, challenges, and trade-offs of applying BT to the global food supply chain have been examined throughout the system dynamics model.

Tian (2018) considered a supply chain traceability system for real-time food tracing according to the Internet of Things, Hazard Analysis and Critical Control Points (HACCP), and BT. They also consider the challenges of the future adoption of BT in food supply chain systems. Chang (2019) proposed a blockchain-enabled newsvendor model to maximize total profit. The authors presented a newsvendor problem to study how adopting BT affects inventory decisions and how to obtain optimal adoption. The cost and demand functions in their model depend on the adoption rate. However, they did not obtain the cost and demand functions and

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defined them based on some assumptions. Chang et al. (2021) considered adopting technology for the newsvendor problem, as exemplified by BT. Their goal was to determine how adopting BT impresses the optimal profit and the corresponding optimal ordering decisions. Also, the authors considered the optimal technology adoption for profit maximization while examining the cost of adoption. Like Chang (2019), the cost and demand functions depend on the adoption rate, while the cost and demand functions are considered a priori known based on some assumptions.

Keskín et al. (2023) have examined the newspaper vending problem in which a retailer and a seller are connected through blockchain technology. In this scenario, the retailer receives information about the status and quality of products from the seller moment by moment. The authors have analyzed and compared the model under two conditions: in one case, the retailer uses blockchain for information sharing, while in the other, they use a traditional supply chain without blockchain. The results indicate that costs are significantly reduced when the retailer and the seller are connected via blockchain.

Kouhizadeh and Sarkis (2018) examined the obstacles to blockchain adoption from technology-environment-organization perspectives. They provided an overview of the barriers to implementing blockchain for supply chain control based on existing literature in organizational methods, technology, and sustainability. After collecting data, they used the DEMATEL technique to analyze and identify the most significant factors. Omar et al. (2020) explored a blockchain-based supply chain with inventory management policies by sellers using smart contracts. The results of this study suggest that considering blockchain for supply chain operations increases the profitability of the case study and provides a secure, transparent, reliable, and efficient communication channel among various stakeholders. Garg et al. (2021) proposed a solution for system designers to predict the successful adoption of blockchain technology in organizations using machine learning methods. In this research, factors affecting blockchain adoption were considered within the framework of technology-organization-environment, and a decision support system was designed using Bayesian network analysis with important criteria that managers can use to predict the likelihood of blockchain adoption in their company. De Giovanni (2020) designed a blockchain-based supply chain with two members: a seller and a retailer. This supply chain can be managed through the adoption of blockchain technology. The results show that blockchain eliminates all potential risks and uncertainties in the supply chain, significantly reducing order costs. The authors used game theory to analyze the expected profits generated by retailers and suppliers from blockchain adoption.

2.1. Blockchain

Blockchain possesses essential features such as decentralization, traceability, and tampering prevention. The blockchain tracking system is built on a secure database and a reliable monitoring system. With the capability to use smart contracts, blockchain is a comprehensive information system that can be easily shared among participants (Ahmadi et al., 2021). The process of registering, transferring, and tracking products is executed through the collaboration of smart contracts. Tracking systems, enabled by smart contracts, can share information related to material specifications for predicting final products, environmental conditions, product maintenance, and information about the entire production and distribution processes. Product quality requirements must be met per predetermined conditions through smart contracts, and these standards will be automatically enforced. Conditions encompass all the requirements that suppliers must fulfill to ensure product quality. Since data in this network is transparent and visible to all without intermediaries, both parties in the contract can have confidence in its reliability. The agreements between the two parties are automatically executed in each of these contracts. When a specified condition is met, the contract execution process begins automatically. In this way, contracts are executed via automation (Gurtu & Johny, 2019). Smart contracts provide the necessary infrastructure for real-time tracking and transparency in the supply chain of goods. These contracts can take various forms, such as production product processing, sales, transportation, and quality contracts. Figure 1 shows the types of Contracts in exchanges.

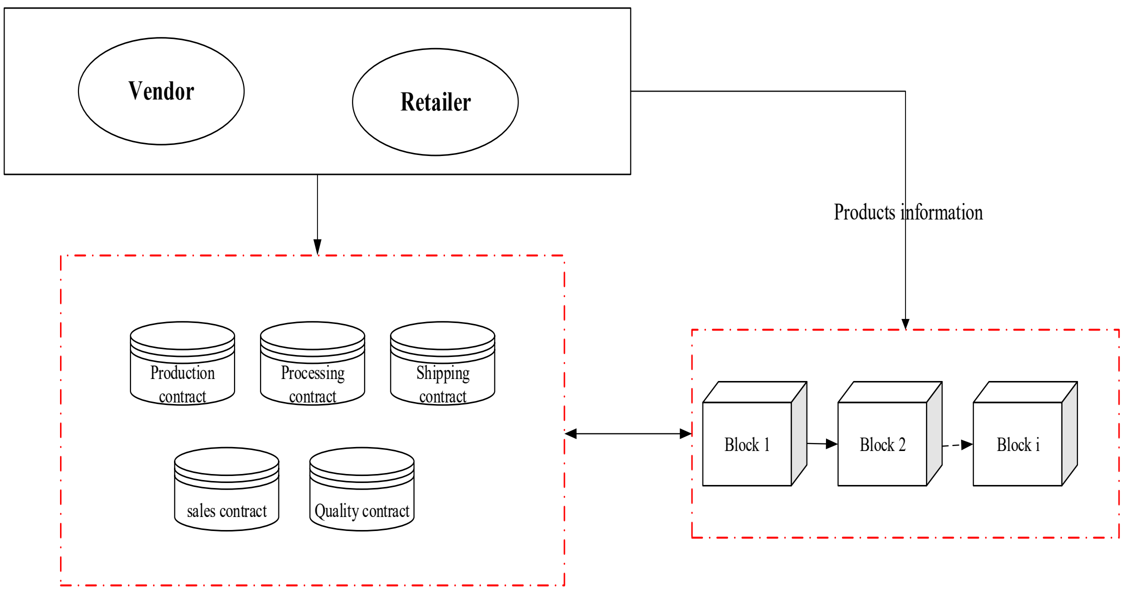

Figure 1. Types of contracts in exchanges

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3. Research method

In this paper method, the costs of implementing the blockchain are using the SD. For this purpose, technical variables influencing blockchain implementation are first identified. Then, their relationships and feedback are determined, and cause and effect and stock charts are drawn. After that, the relationship between the blockchain implementation costs and the variables affecting it is investigated using machine learning. Figure 2 shows the steps related to the research method.

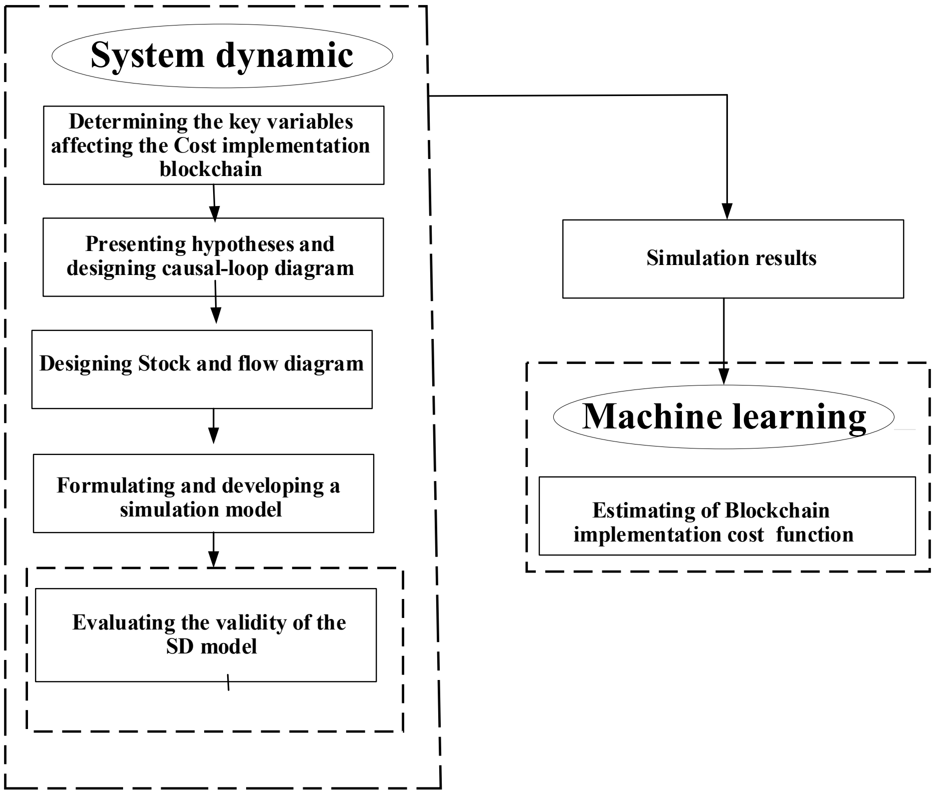

Figure 2. General steps of research

3.1. System dynamics (SD)

The simulation technique is efficient for predicting system behavior. Imitating the operation in a real-world system over time is called simulation. Simulation is the re-enactment of real-world scenarios for different reasons, including education, preparing for a predicated event, or troubleshooting an issue (Durach et al., 2021). One of the essential simulation methods is system dynamics simulation. SD aims to aid people in finding out about dynamic and complex systems and help them make better decisions. SD provides methods to analyze dynamic systems (Emroozi et al., 2022). The main character of the SD models is to consider the system behavior.

SD modeling is used to model non-linear dependencies in the real world. The use of feedback, scenario-making, and considering the sensitivity of parameters are essential reasons for the efficiency of these techniques (Modares et al., 2021). Non-linear and complex relationships and the uncertainty of system behavior are usually specified as feedback loops. Forrester initially introduced the SD technique concerning supply chain management (Roozkhosh & Pooya, 2023). The supply chain contains different factors, including the flow of goods and materials with information sharing available in the system (Modares et al., 2023c; Modares et al., 2023d). The supply chain processes have a complicated structure; the system's behavior is also dynamic. A comprehensive understanding of the relationships between system components by providing a holistic attitude of entire systems is provided using SD by modeling real-world problems (Modares et al., 2023e; Emroozi et al., 2024). System dynamics methods are built by connecting the adequate components of a system structure and simulating the behavior obtained from that system structure (Roozkhosh, 2023b). The system structure consists of feedback, flows, and stock. Feedback loops are used to analyze the relationship between variables (Kamble et al., 2020). Stocks and flows impact each other using feedback loops and causal relationships. Also, they produce effects and show system characteristics. SD based on causal relationships and feedback examines system dynamics behavior. SD modeling with emphasis on the relationships among the system components is applied to consider the system's dynamic behavior. Analyzing system behavior using various hypotheses gives policymakers feedback to make policies effective.

3.1.1. Identifying the key variables and their relationships

After identifying the problem's key variables, the dynamic nature of the problem is presented in the form of feedback loops by identifying the relationships of the variables. Then, feedback is generated in each subsystem. Finally, dynamic hypotheses are developed by utilizing a causal–loop chart. To better understand the system behavior, it is necessary to formulate the relationships between the variables and simulate the values of the variables over time. The relationships between these variables were analyzed using the qualitative SD modeling method with stakeholders through questionnaires and 15 interviews. Figure 3 shows the causal-loop chart of the model. The causal–loop diagram related to the present study is shown in Figure 3 to illustrate the hypotheses and describe the dynamic nature of the problem. Feedback loops can be of two varied kinds, either negative or positive. The values related to the two nodes within the related change in the positive feedback loop are in the same direction. In the negative

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causal loop, the two nodes change in opposite directions, so if the node where the link starts decreases, the other node increases conversely (Sterman, 2002). The dynamic hypotheses of the model are stated as follows**:**

Loop R1: As the number of transactions increases, the transactions per capita increase. The increase in transactions per capita reduces the cost of transactions. Then, reducing the transaction cost increases the number of transactions.

Loop R2: As the number of transactions increases, communication increases and creates more trust between the members involved in the blockchain. Then, trust increases participation, and participation increases the retailer's demand from the seller. It also increases the number of transactions.

Loop R3: As the number of transactions increases, the number of blocks increases, and the increase in blocks increases the size of the blockchain. Then, increasing the size of the blockchain increases the number of transactions.

Loop B1: The more transactions are used in the blockchain, the more specialized human resources are needed. Therefore, with the increase in workforce costs, the costs of implementing the blockchain will increase, and as a result, the number of transactions will decrease.

Loop B2: Loop B2 is contrary to expectation, so the more transactions are used in the blockchain, the more the need for more advanced hardware increases. Therefore, the cost of setting up the hardware increases, which leads to an increase in the cost of blockchain operations, and as a result, the number of transactions decreases.

Loop B3: The size of the blocks used in the blockchain increases, the speed of transactions reduces, and as a result, the numbers of transactions decrease. Then, decreasing the number of transactions leads to a decrease in the size of the blockchain.

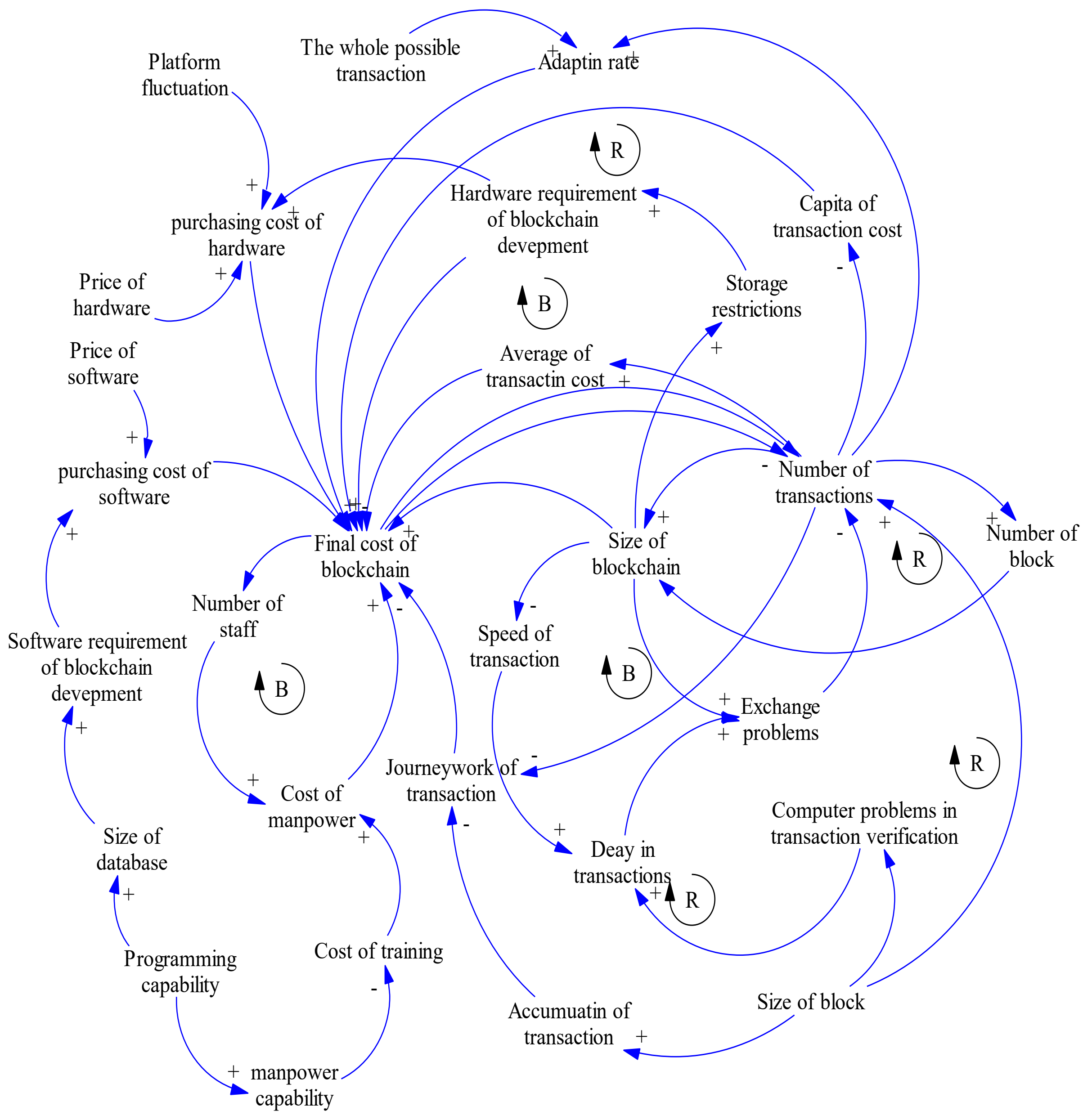

Figure 3. Causal-loop chart

In this phase, through data collection, mathematical relationships between variables and initial values are formulated using the VENSIM simulation software. A Stock and flow model helps managers and system designers quantitatively analyze the system. Stocks and flows are the foundation of SD modeling. Stocks can accumulate information, materials, or energy over time. Stock shows a part of a system whose value in time at a given instant depends on the system's past behavior. The stock's value in time at a particular instance cannot be specified by measuring the value of the other variables of the system in time at that instant. It has been obtained by measuring how it changes every instant and adding up all these changes. Flows, on the other hand, are entities that make stocks decrease or increase. Flows show the rate at any given instant when the stock changes. The stock variables are defined by equation (1).

$$\text{Stock}(t) = S(t_0) + \int \text{inflow}(t) - \text{outflow}(t)\, d(t) \quad (1)$$

Stock (t) is the accumulation value of stock variables at t moment, illustrated by stocks in feedback charts. Inflow (t) or outflow (t) are flow variables. Also, S (t0) is the initial value of the stock variables. As it turns out, flow variables are derived from the instantaneous changes of the stock variables. Stock variables in the present study include the number of transactions, the implementation cost of blockchain, and the number of blocks. The stock and flow chart related to the present study is shown in Figure 4. By completing the model simulation and also entering the relationship between the variables in the VENSIM software, the model outputs are obtained by simulation. This simulation was performed over 100 days.

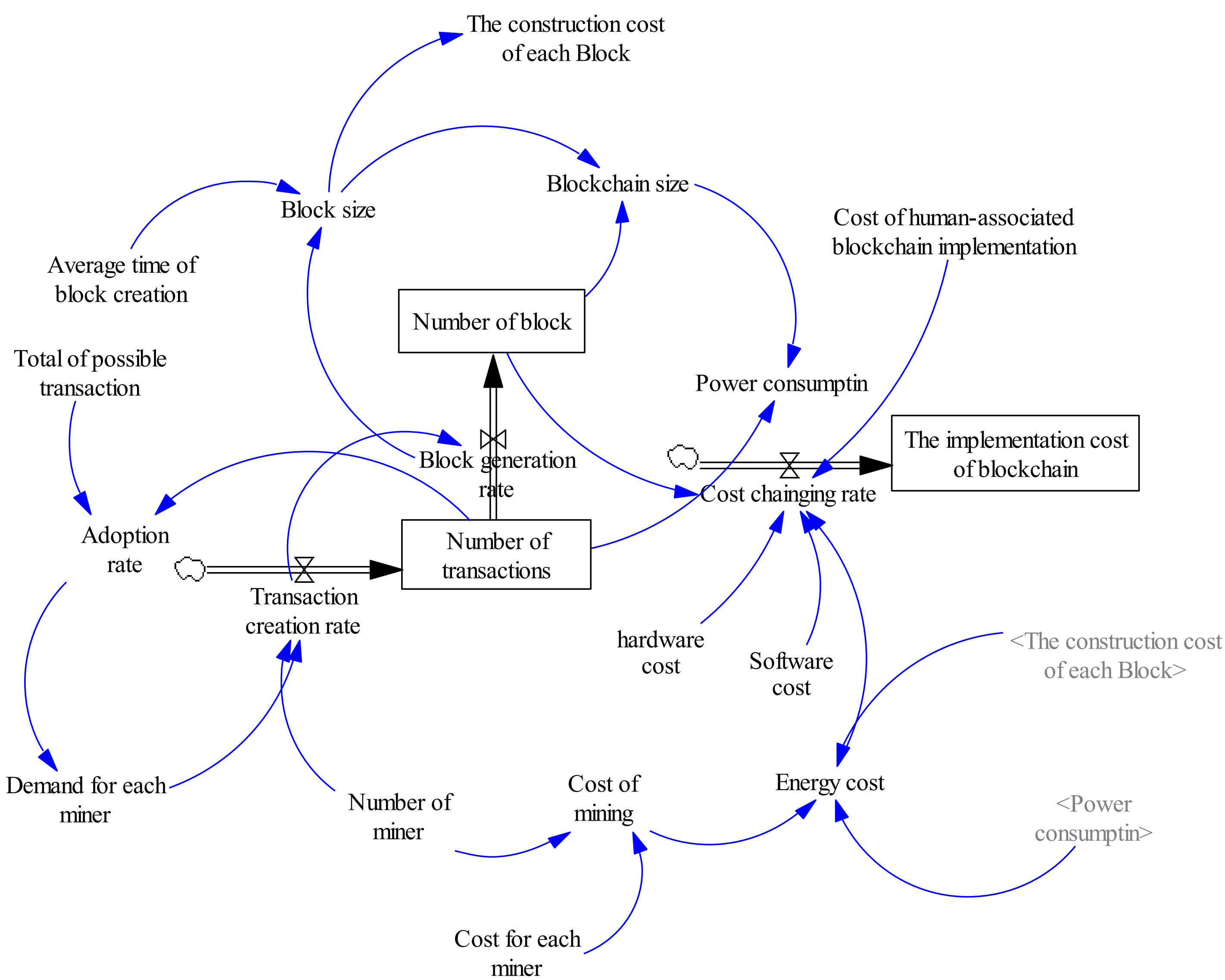

Figure 4. Stock and flow chart design for evaluating key factors affecting the cost of blockchain

3.1.2. Formulating and developing a simulation model

All the studied variables in the proposed model are formulated based on the relationships between them. It can describe the behavior of stock and flow variables using mathematical functions; if the graph of changes in the behavior of the flow variable is available, the behavior of stock variables can be inferred using it. The formula for some of the most critical variables is given in Tables 1 and 2.

Table 1. Formulas and values used for stock variables in the simulation

Variable	Formula	Type of variable
The implementation cost of blockchain	$\text{Fc}(t_1) = Fc(t_0) + \int \text{cost changing rate}$	Stock variable
Number of blocks	$\text{SBT}(t_1) = \text{SBT}(t_0) + \int \text{block generation rate}(t)$	Stock variable
Number of transactions	$NT(t_1) = \int NT(t_0) + \text{Transaction creation rate}(dt)$	Stock variable

Table 2. Formulas and values used for flow and auxiliary variables in the simulation

Variable	Formula	Type of variable
Cost of mining	$\text{Number of miner} \times \text{cost for each miner}$	Flow variable
Cost changing rate	hardware cost+software cost+energy cost +cost of human-assosiated blockchain implementation	Flow variable
Block generation rate	$\text{transaction creation rate} \times \text{cofficient of transaction creation rate}$	Flow variable
Adaption rate	$\text{Number of transaction} / \text{Total of possible transactions}$	Flow variable
Power consumption	Blockchain size×number of transactions	Flow variable
Rate of increase in blocks	$\dfrac{\text{Number of blocks} \times \text{Rate of increase in demand}}{\text{Average time of block creation}}$	Flow variable
blockchain size	(Block size*Number of block)	Flow variable
Block size	Number of transactions/Blockchain size	Flow variable

Table 3 shows the initial value of some variables. These values have been obtained from expert specialists in the field of blockchain who have been working on its implementation for years.

Table 3. Values used for stock and constant parameters in the simulation

Variable	Type of variable	Initial value
Cost of human associated blockchain implementation	Constant	500000
Software cost	Constant	150000
Energy cost	Constant	21000000
Hardware cost	Constant	450000
software cost	Constant	6743200
Cost of miner	Constant	300
Constructing cost of each block	Constant	7654
Total possible of transaction	Constant	76543207

3.1.3. Estimating the relationships between costs of blockchain implementation and other variables

In this study, the behavior of variables over time is first estimated using a dynamic approach. Given that this method is time-dependent and considers the system's dynamics, it can be said that the behavior of variables during similar times is the same. Since varied variables in SD and their effect on system behavior are investigated, the status of each variable under the effect of other variables is shown at any point in time. In fact, at any given moment, all variables are expressed in terms of other variables and their effects on system dynamics. It means that the state variable changes are specified in terms of time (a derivative of the state variable) from the sum of the input rate variables as positive and the output rate variables as negative. So, at any given time, the connections between the variables are established, and the values of the variables are expressed in terms of each other. Therefore, since the SD approach only gives the process of graphing variables and points, a method that can perform the estimated function of the dynamics approach. The regression technique is used to evaluate the functions using the data provided by the dynamics approach is required.

Regression algorithms approximate a mapping function from input variables to continuous output variables. Some error metrics are used to evaluate the performance of the model. Mean squared error (MSE) is the most common method. In MSE, the error is obtained by squaring the difference between the actual value (y_i) and the predicted value and averaging it across the dataset. The cost function using this method in the regression is as follows:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(y_i - f\left(x_i;\omega\right)\right)^2 \tag{2}$$

This method aims to find the best regression function ($f\left(x_i;\omega\right)$) that is equivalent to the best ω. Where ω are the optimal linear parameters of the regression function.

4. Results

4.1. Simulation results

Based on the simulation model presented in the present study, the simulation of the proposed variables is followed in Figures 5 and 6. The results show that the implementation cost of blockchain will reach 800M currencies from the beginning to the end of the simulation period and will increase the implementation cost of blockchain at different times. Because the number of transactions increases during the simulation period, the number of blocks also increases.

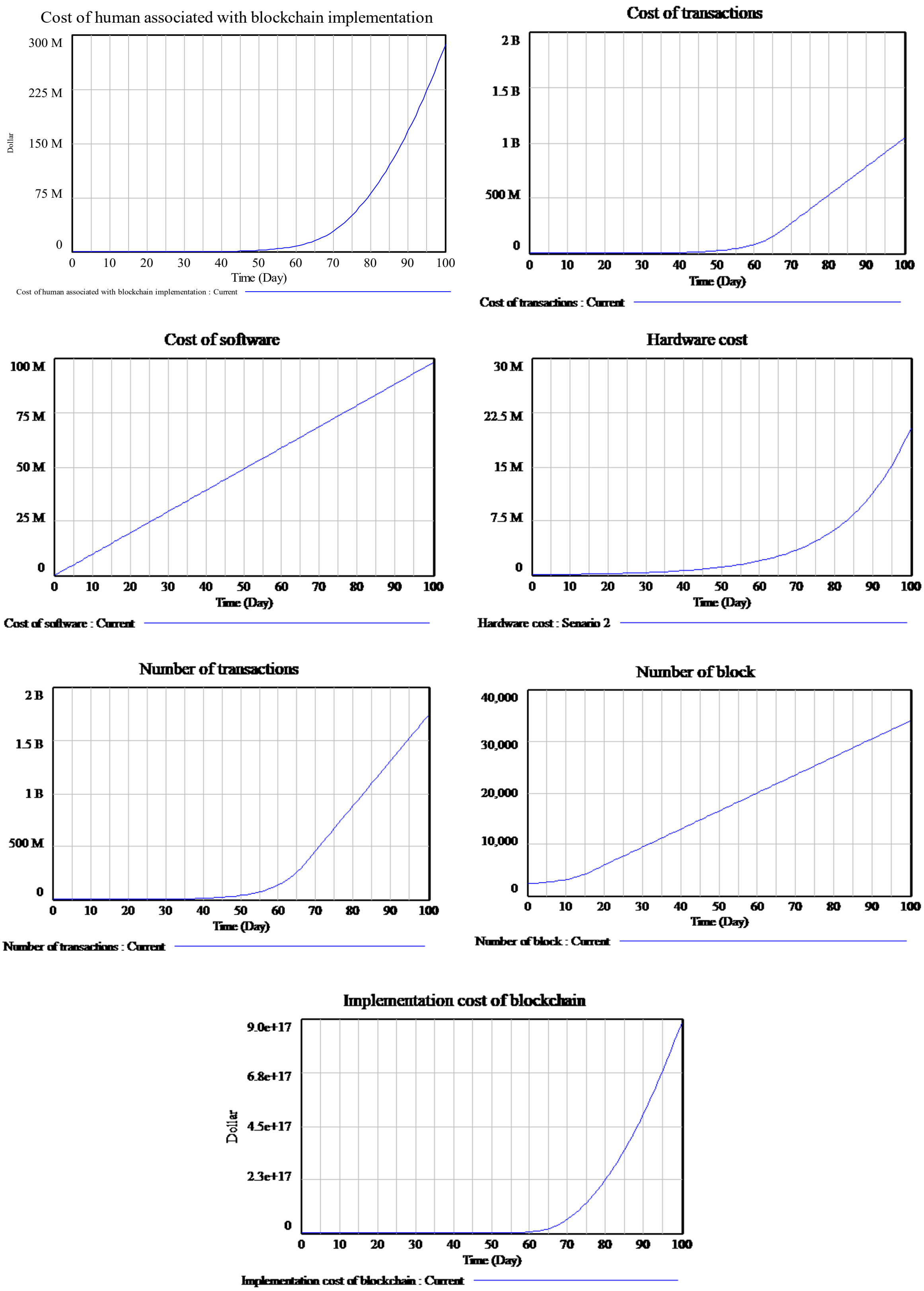

Figure 5. Simulation results

From Figure 5, it can be seen that over time, as the number of transactions increases due to greater participation, the number of blocks also increases, and this causes the cost of implementing the blockchain to increase over time.

Figure 5 encapsulates a comprehensive portrayal of the model's execution spanning a substantial 100-day timeline, offering insights into the evolving dynamics within the studied system. The ensuing findings shed light on the multifaceted outcomes of this extensive simulation. The discernible correlation observed between the increasing adoption rate and its parallel influence on the implementation cost of blockchain is of particular significance. The depicted trends underscore the exponential cost growth, signifying robust development. With the increase in the adoption rate, it can be seen that the software cost increases linearly, and the rest of the costs increase non-linearly. As a result, the total cost of blockchain implementation increases non-linearly.

4.1.1. Different scenarios

Scenario design goes beyond changing parameter values; scenario design involves decision-making strategies, structures, and rules. Because real systems are highly nonlinear, the effect of scenario combinations is usually not equal to the sum of the effects of each scenario alone. Most policies overlap, sometimes reinforcing each other and significantly increasing and decreasing each other (Sterman, 2002). System behavior in the past reflects the reality of the system structure, but different scenarios can be assumed for the future. Changes strongly influence the system's future behavior in model variables, constants, system rules, relationships between variables, and model leverage points. Product quality requirements must be met per predetermined conditions through smart contracts, and these standards will be automatically enforced. According to the structure and perceived behavior of the model, in this study, the constants are changed to provide new scenarios. In this study, two different scenarios have been stated that these scenarios lead to improved system behavior. In other words, by simultaneously making the changes mentioned in the three scenarios, a structure can be created that leads to improved system behavior.

In other words, an optimal scenario should be implemented to improve the studied variables in the model. The simulated model can be used to design and evaluate policies for improvement. Scenario design involves the creation of entirely new strategies, structures, and decision rules. Policies' strength and sensitivity to parameter uncertainties should be evaluated in a wide range of scenarios. To simulate a dynamic model, one must first select several main variables to study and then evaluate their results based on scenarios.

The differences in the variables are shown in Table 4. The diagrams related to the comparison of the variables in different scenarios are shown in Figure 6. In the main scenario, based on the available data at the community level, the coefficient of block generation is equal to 10%. Also, the average time of block creation is 50%. By creating special infrastructures and instructions, it is possible to improve the two variables mentioned more than the other variables. Therefore, the focus is on these two variables to analyze different scenarios. In the first scenario, the average time of block creation variable increased by 60%, and the coefficient of block generation increased by 20%. In the second scenario, the coefficient of block generation has increased by 3%, and the average time of block creation has increased by 70%. This change has enhanced the cost of implementing blockchains.

Figures 6 illustrate that changes in each variable have improved system behavior. A change in any of the variables is expected to improve the system behavior. However, since the system dynamics examines nonlinear relationships and the effect and variability of variables on each other, it is not obvious without providing a suitable model to examine the relationships and their effect on system behavior. Therefore, by running these scenarios, the influence of the block's creation time on the costs of implementing blockchain can be seen.

Table 4. Values of variables based on different scenarios

Type of scenario	Coefficient of block generation	Average time of block creation
The main scenario	0.1	0.5
The first scenario	0.2	0.6
The second scenario	0.3	0.7

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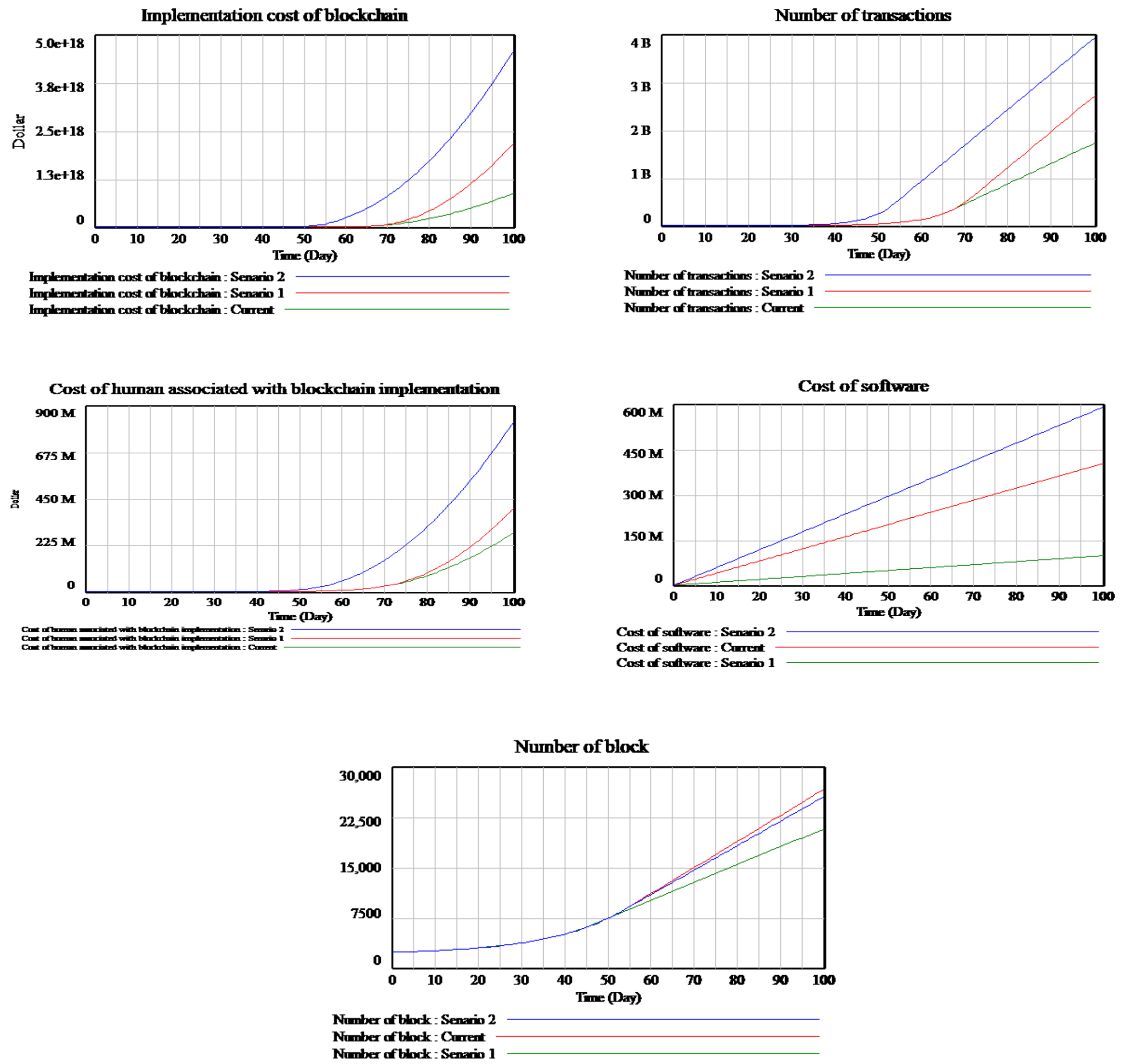

Figure 6. Scenario design and evaluations

4.2. Regression results

Figure 7 shows the relationship between blockchain implementation and human costs.

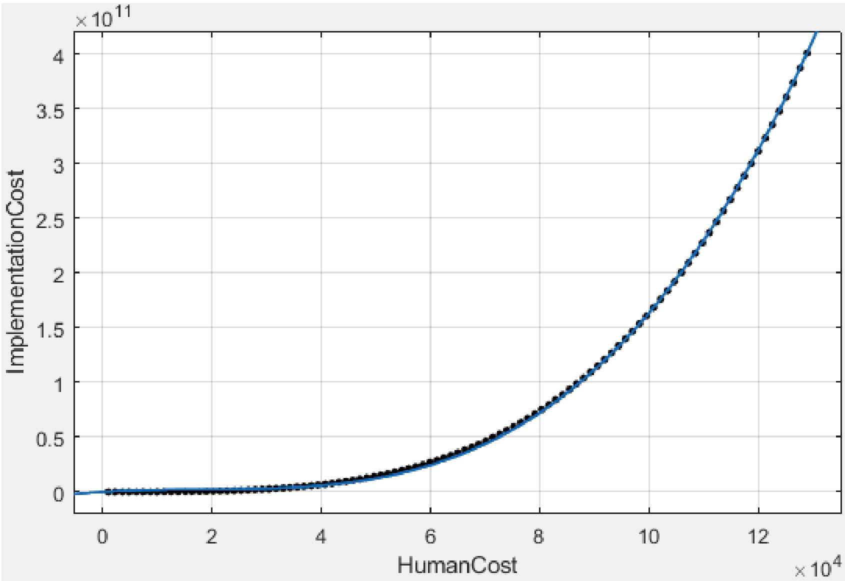

Figure 7. The relationship between human cost and blockchain implementation cost

The value of the coefficient and intercept of the cubic function is given in Table 5.

Table 5. Coefficients of the quadratic function
(The relationship between the implementation cost of BT and human cost)

Coefficients	**Coefficient of α_1^3**	**Coefficient of α_1^2**	**Coefficient of α_1**	**Intercept**
Value	-3015	3.28e+05	-16.33	0.0002939

According to the results obtained from Table 4, the final cost terms of human cost are as follows:

$$FC_{\alpha_1} = -3015\alpha_1^3 + 3.28e + 05\alpha_1^2 + -16.33\alpha_1 + 0.0002939 \quad (3)$$

Figure 8 shows the relationship between hardware and blockchain implementation costs using the quadratic function.

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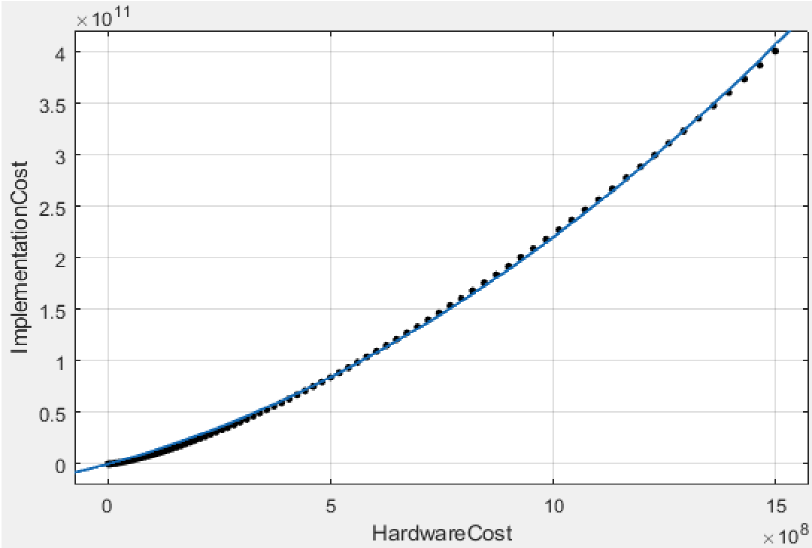

Figure 8. The relationship between hardware cost and blockchain implementation cost

The value of the coefficient and intercept of the quadratic function is given in Table 6.

Table 6. Coefficients of the quadratic function
(The relationship between the implementation cost of BT and hardware cost)

Coefficients	**Coefficient of α_2^2**	**Coefficient of α_2**	**Intercept**
Value	0.452	117.7	1.026e-07

According to the results obtained from Table 5, the final cost terms of hardware cost are as follows:

$$FC_{\alpha_2} = 30.452\alpha_2^2 + 117.7\alpha_2 + 1.026e - 07 \quad (4)$$

Figure 9 shows a relationship between software and blockchain implementation costs using the quadratic function.

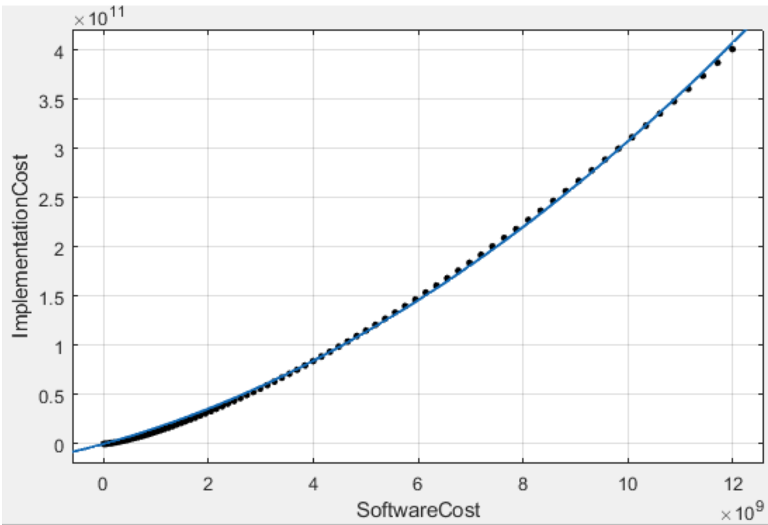

Figure 9. The relationship between software cost and blockchain implementation cost

The value of the coefficient and intercept of the quadratic function is given in Table 6.

Table 7. Coefficients of the quadratic function

(The relationship between the implementation cost of BT and human cost)

Coefficients	Coefficient of α_3^2	Coefficient of α_3	Intercept
Value	0.9157	14.72	1.603e-09

According to the results obtained from Table 7, the final cost terms of software cost are as follows:

$$FC_{\alpha_3} = 0.9157\alpha_3^2 + 14.72\alpha_3 + 1.603e - 09 \quad (5)$$

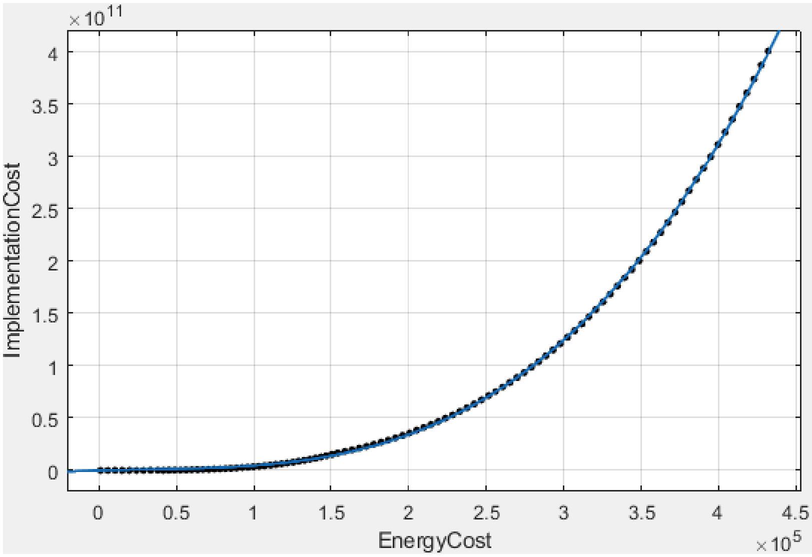

Figure 10. The relationship between energy cost and blockchain implementation cost

Figure 10 shows a relationship between energy cost and blockchain implementation cost using the quadratic function. The value of the coefficient and intercept of the cubic function is given in Table 8.

Table 8. Coefficients of the quadratic function
(The relationship between the energy cost and blockchain implementation cost)

Coefficients	Coefficient of α_4^3	Coefficient of α_4^2	Coefficient of α_4	Intercept
Value	8.268	4.111e+04	-0.5576	6.018e-06

5.

According to the results obtained from Table 7, the final cost terms of cost are as follows:

$$FC_{\alpha_4} = 4.111e + 04\alpha_4^3 + 3.28e + 05\alpha_4^2 + -0.5576\alpha_4 + 6.018e - 06 \quad (6)$$

After obtaining the cost functions in terms of blockchain implementation cost, the cost function is obtained, which depends on the cost of hardware, software, hardware, and energy costs, which is given in equation (7).

$$FC(\alpha_1,\alpha_2,\alpha_3,\alpha_4) = -3015\alpha_1^3 + 3.28e+05\alpha_1^2 + -16.33\alpha_1$$
$$+30.452\alpha_2^2 + 117.7\alpha_2 + 0.9157\alpha_3^2 + 14.72\alpha_3 + 1.603e-09 \quad (7)$$
$$+4.111e+04\alpha_4^3 + 3.28e+05\alpha_4^2 + -0.5576\alpha_4 + 4532676$$

Given the significance of blockchain implementation, this study specifically examines the relationship between human cost, software cost, hardware cost, and implementation cost of blockchain. The results indicate that a quadratic function provides a more accurate estimate of this relationship. These findings are valuable for managers as they can utilize simulation and function estimation techniques in various industries, taking into account the specific conditions of their organization. It enables managers to make informed decisions regarding the optimal level of reliability based on the prevailing human error factors. After estimating the cost function, the cost can be obtained in different amounts of hardware, software, energy, and human costs. This paper provides a solution to predict the cost of blockchain implementation.

This study is becoming increasingly important for managers and system designers to develop efficient solutions for applying blockchain. This research helps organizational planners predict the cost of blockchain implementation at any level of adoption rate and find the optimal cost according to the benefits and organizational conditions.

As observed, with the expansion of blockchain networks, computational power for solving more complex algorithms increases, and thus, the scalability of sharing information also increases. Therefore, this study determined the percentage of information that can be shared among participants before implementing blockchain, considering the advantages and obstacles in blockchain implementation. Thus, the relationship between the cost of blockchain implementation and the order cost with the blockchain acceptance rate was examined to obtain the optimal acceptance rate. Therefore, in this research, by estimating the cost function based on the acceptance rate, organizations can be helped to understand what types of smart contracts to use and with what complexities. Depending on different acceptance rates, managers can predict the cost of blockchain implementation and choose the best possible scenario for their organization. Therefore, the results can help managers select the optimal adoption rate for applying blockchain. More retailer-vendor communication leads to more transactions in the organization. However, scalability problems make it impossible to do more transactions per unit of time in the blockchain network. The results of this research examine the rate of adoption of the blockchain according to the degree of scalability of the blockchain. Using the obtained results from this study, every manager can analyze the relationship between the adoption rate and the factors affecting it and find the optimal rate for the organization where the costs are at their lowest. Therefore, organizations can analyze the effects of different rates on costs and other factors and know at what adoption rate blockchain can be used according to the issues in the organization. One of the main advantages of this designed model is that in this research, at any optimal rate that is obtained, the system planners can analyze and adjust according to the number of transactions that can be done in the organizations; they can choose the type of blockchain used in their company. It means they know whether they should use a smart contract in the blockchain they are using. Decision-makers can understand what type of smart contract and at what level of complexity they can use due to scalability. Therefore, the results of this research can significantly help planners in the development and application of blockchain technology in organizations.

5. Discussion and conclusion

It is essential to address the issue of increasing the blockchain implementation cost in various industries because it contributes to financial risks. Therefore, accurate and correct prediction of the implementation cost amount is significant. In this research the SD technique was used to calculate the implementation cost. Using the SD technique to examine the problem dynamically has provided the possibility of a better and more complete examination of the conditions of the factors according to the costs, the number of blocks, the number of transactions, and other factors. In this research, all elements were extracted according to the opinion of experts and research backgrounds. This research uses the system dynamics method to calculate the blockchain implementation cost after identifying the key variables. The systems dynamic approach can estimate the state of the desired variables and their dependent variables on the chosen horizon by examining and detecting the behavior of variables. The research horizon is 100 periods. The system behavior is reconstructed. As a result, the dynamic relationships of factors were identified, and the system's behavior was predicted favorably. By identifying the system's behavior and the obtained results from the SD method, the system's future behavior is predicted. In addition, the investigation of indirect relationships is also important in calculating blockchain implementation costs. This research uses the system dynamics method to calculate the blockchain implementation cost after identifying the key variables. As a result, using the SD technique, due to the simultaneous examination of the degree of communication between the factors and the dynamics of the probability system, the blockchain implementation cost has been calculated more optimally according to the conditions and dynamically.

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Based on this 100-day horizon, the system's behavior was simulated for future periods. The study demonstrates that the implementation cost of blockchain can be significantly increased by altering variables that affect the implementation cost of blockchain, such as hardware cost, human cost, hardware cost, transaction cost, and number of blocks and transactions. At the end of the simulation period, the total cost reaches approximately 9×10^{17}, indicating a high cost level. The regression method is utilized to estimate figures, revealing that increasing the number of transactions is crucial in increasing cost.

Although the technique used in the present research is valuable and has improved blockchain implementation costs, it still faces limitations. The presented model is a hypothetical model formed by reviewing the research background and experts' opinions. Decision-making based on experts' opinions is formed based on the mental framework, the nature of the judge, and perceptual errors based on the expert's experience and skill, and therefore, the results may be different in the same conditions (of course, to some extent, this violation can be resolved by checking the inconsistency rate). In the future, an extensive survey can be conducted to validate the findings of this study. In addition, experts' opinions have been definitively collected in this research, and verb expressions and linguistic variables have not been used in the form of fuzzy methods. It is suggested that in future research, the preparation of questionnaires and the way of data collection should be closer to real-world conditions. Since in this research, the factors affecting costs based on the research background are not complete, and there may be more factors in the scope of the problem, it is suggested that in future research, in addition to collecting factors based on the research background and opinion Industrial experts, the documents of the investigated organization and the opinions of academic and industrial experts should be used simultaneously. Collecting factors in this way will lead to a complete list of elements. The spatial scope investigated in this research is limited to the study, and it is suggested that this issue be investigated more widely in future research. One of the limitations of the research was that there was no reference data for some variables, and the researcher had to survey experts to model.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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