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(Research Paper)

Improving Supply Chain Performance Using Blockchain-Enabled Smart Contract: a discrete- Event -Simulation

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Abstract

Purpose: The lack of information systems, use of manual correspondence, as well as lack of proper transparency and traceability of information throughout the computer supply chain in Isfahan's education schools, have created challenges for the organization that have reduced efficiency and supply chain responsiveness. This study tries to investigate the effects of implementing blockchain technology on a supply chain through which computer parts are provided for Education & Development organizations in Isfahan, Iran.

Design/methodology/approach: In this study, through a discrete-event simulation of smart contracts based on the Ethereum network, the effects of this technology on the performance of the mentioned supply chain are investigated. First, by examining the current structure of the supply chain, members and processes, the relevant subsystems affecting supply chain performance are identified. The smart contracts corresponding to the selected subsystems are then developed using the Solidity programming language for the Ethereum blockchain network. Finally, using discrete event simulation, two different models of supply chain process are devised, one for representing current-method and the

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other which is based on blockchain technology for both of which, the performance results are extracted.

Findings: The comparison of the results shows that blockchain technology has the capacity to have a positive effect on the supply chain performance and while increasing transparency and improving traceability, it can also improve performance indicators in terms of time and cost.

Practical implications: Implementing blockchain not only streamlines processes but also enables a more agile response to market demands, ultimately enhancing competitiveness. Furthermore, the findings underline the importance of investing in training and development for staff to navigate and utilize these new technologies effectively. Managers should also consider the significant role of real-time data visibility in enhancing collaboration and efficiency in their supply chains.

Originality/value: Due to the emerging nature of blockchain, especially its applications in the supply chain, most of the research done in this regard is theoretical and there are few practical implementations to investigate the effects of this technology on supply chain management and performance. In this study, using smart contracts within the Ethereum network, showcasing a practical simulation rather than a theoretical framework, the traditional structure of the supply chain is compared with the blockchain-enabled supply chain.

Keywords: Blockchain technology, Supply chain performance, Smart contract, Discrete-event simulation, Anylogic

1. Introduction

Supply chain management is one of the main activities of a company that is responsible for moving goods and services from one point to another through various stakeholders. This process involves a networked arrangement of different entities, such as producers, distributors, wholesalers, retailers, and final customers. Every entity in the supply chain must do its job properly to meet customer needs. Traditional supply chain management is a centralized, top-down approach. In this model, processes are determined at the centre and received by branch offices for execution. However, traditional supply chains often lack transparency for all stakeholders. The lack of transparency can reduce confidence in the supply chain and the goods it provides. Another challenge in the supply chain is the lack of product traceability. This issue can lead to the distribution of counterfeit goods instead of genuine goods along the supply chain. Failure to properly perform the duties of any entity along the supply chain can lead to increased customer dissatisfaction. Supply chain management in this style can bring many challenges, including a lack of transparency, an inability to trace products, the risk of counterfeiting, non-cooperation of stakeholders in the distribution cycle, delays in distribution, instability, and a lack of accurate, timely, and correct information sharing between people and offices in the process of distributing goods and services from origin to destination. Some of these challenges are discussed by Agarwal et al. ([2022](#)).

Information sharing is an essential element in the survival of companies and in maintaining the integrity of their supply chain. This need for information sharing becomes

clearer with the growth and development of information technology ([Lotfi et al., 2013](#)), as well as the increasing complexity of supply chain networks ([Bartlett, Julien & Baines, 2007](#)). Sharing information throughout the supply chain allows each member to access pertinent information, enabling more effective decision-making at different levels of management ([Huong Tran et al., 2016](#)). A lack of accurate and timely information leads to inaccurate demand forecasting, which increases supply costs along the supply chain, causes inefficient use of resources, and results in a lack of alignment between supply and demand, referred to as the Bullwhip Effect in supply chain literature ([Longo et al., 2019](#)).

Information sharing affects supply chain performance ([Lin, Huang, & Lin, 2002](#)), and while reducing costs, it enables effective inventory control, and efficient use of resources, and reduces the cycle time from demand to receipt, increasing transparency and traceability throughout the chain. Sharing information throughout the supply chain has always faced challenges; issues related to privacy, reliability, and accuracy of shared information, as well as IT costs, are among those challenges. Distrust between supply chain members requires the establishment of a secure information system to ensure that important information is available for all members of the supply chain network ([Lotfi et al., 2013](#)). The complexity and decentralization of supply and distribution chains have led to several challenges across the network.

In recent years, blockchain technology has become a popular term in information technology. It is expected that all industries will use blockchain more in the coming years, making this technology an important part of business operations ([Kurdi et al., 2022](#)).

Information security, transparency, availability and the ability to track information in a decentralized peer-to-peer network such as blockchain have increased the number of research projects focusing on the effect of this technology on supply chain management and performance ([Nandi et al. 2021](#)). Blockchain is an open, distributed, writing-only, transparent, and time-stamped general ledger ([Grover et al., 2019](#); [Batta et al., 2021](#)). This technology operates as a distributed general ledger (a shared, tamper-proof digital database that records transactions and is visible to all network participants) system in which the data used are stored as digital blocks on public networks and accessible to all ([Kimani et al., 2020](#)). Blockchain can be thought of as a peer-to-peer distributed general ledger (a shared, tamper-proof digital database that records transactions and is visible to all network participants) consisting of ordered (sequential) data blocks ([Hughes et al., 2019](#)).

Blockchain technology quickly found its way into other non-financial areas ([Nawari and Ravindran, 2019a](#); [Ravindran et al, 2021](#), [Shikder et al, 2022](#), [Plevris et al, 2022](#)). These include health, property registration, electronics, and especially the Internet of Things. One

area that blockchain technology is expected to change is supply chain and related issues ([Kawaguchi, 2019](#)), as Wamba and Queiroz ([2020](#)) consider the blockchain as a prominent technology that is changing traditional business models and creating new opportunities. Blockchain is such a technology which increases the transparency, accountability, trust, security and efficiency of the supply chain and reduces its costs.

The use of blockchain technology in the supply chain can increase accessibility to the market and, while increasing fair trade, bring about price equality for the parties throughout the entire supply chain ([Kurdi et al., 2022](#)). One of the inseparable components of blockchain technology is smart contracts. Supplier packages for blockchain technology that use smart contracts to control security supply processes can lead to increased product traceability, transaction tracking, product tracking, and more ([Alazab et al. 2021](#)).

As blockchain is an emerging technology, its practical effects on different business areas, particularly supply chain performance, need more research projects to be conducted ([Di Vaio and Varriale 2020](#); [Longo et al. 2019](#)). So, implementing blockchain and studying the effects of this technology and its capabilities on supply and distribution networks is considered a necessity.

This study tries to investigate the effects of implementing blockchain technology on a supply chain through which computer parts are provided for Education & Development organizations in Isfahan, Iran. First, the details of this supply chain are described and by identifying the members, processes and subsystems of the chain, two subsystems that have the most impact on the process in terms of time and cost are selected. Then, by developing a Smart Contract in the Ethereum network using the Solidity programming language, those subsystems will be implemented. Finally, with the help of a simulation tool, the smart contract model based on blockchain technology which is called Blockchain-Method(BM) is simulated for the above-mentioned supply chain and the extracted performance results are compared to the current supply chain in which all processes are conducted without any decentralized technology, the latter is referred to as Non-Blockchain-Method(NBM) in this study.

2. Case description

2.1 Supply network for procuring computers in Education Organization of Isfahan Province

The Ministry of Education has the critical responsibility of providing computers for its affiliated districts and schools. In Isfahan Province, the Education Organization oversees this duty. Isfahan Province comprises 41 districts and over 5,000 public schools exhibiting great diversity. The rapid growth of new technologies necessitates replacing obsolete hardware

with newer models, and the variety of schools and regions requires a robust procurement mechanism aligned with Supply Chain Management (SCM) principles, including just-in-time delivery and demand forecasting.

Interviews with ten subject matter experts, including procurement specialists and educators, indicated that the current supply structure for procuring and distributing computers in districts and schools is poorly functioning, resulting in processes that can take several months. This inefficiency imposes significant cost overheads on the organization and adversely affects students' access to technology, thereby impacting educational outcomes. During the budget allocation process, the Ministry of Education distributes funds to subordinate regions through the provincial budget department, which communicates these funds for application collection up to the pre-specified budget limit. The districts then allocate this budget to their respective schools.

Schools send their requests to the district, where procurement experts summarize and review them before forwarding them to the provincial procurement department. This department consolidates the information from all regions to initiate the purchase process via tendering, with subsequent shipments to the provincial warehouse. Finally, required items for each district are transferred to regional warehouses before being sent to the specific schools.

The most significant challenges in this entire process relate to budget allocation and request collection, whose approximate time values are shown in Table 1.

Table 1- Approximate time values in the budget allocation and collection subsystem

Process	Minimum time (working day)	Maximum time (working day)
1. Distribute and communicate budgets to regions	8	10
2. Distribute and communicate budgets to schools	8	10
3. Announce the need for the area by the school	4	5
4. Review, and resolve discrepancies and final summary by the district and send to the province	12	15
5. Review, resolution of discrepancies and final summary by the province	12	15
Total	44	55

As shown in Table 1, the budget allocation, communication, and requirement collection take approximately two months. This duration can be analyzed through SCM theories emphasizing process optimization. Key reasons contributing to this lengthy timeframe include:

- Heavy reliance on paperwork for notifications, registrations, and other necessary activities.
- Lack of accuracy in request preparation from schools and regions leads to extensive re-examinations and re-work.

The absence of precise data on previous applications and currently available computers results in extensive time spent assessing actual needs in schools and districts.

Such extensive timelines increase supply chain costs in the province, further exacerbated by employee salaries and delays. Price fluctuations within a two-month may necessitate adjustment of requests, repeating the process from the beginning. Furthermore, challenges such as a lack of transparency regarding equipment inventories and difficulty tracking resource distribution contribute to unfair resource allocation, imposing additional costs on the organization.

Figure 1 illustrates the structure of the computer equipment supply chain, detailing the flow of information and goods among its members.

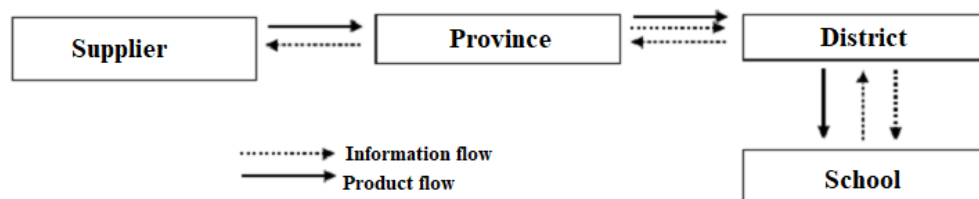


Fig. 1- Computer equipment supply chain

In this supply chain, the province collects requests from subsidiary regions based on a predetermined budget. Districts consolidate school requests for the provincial organization. Subsequently, these aggregated requests are used to conduct tenders and select suppliers. The purchased equipment first enters regional warehouses; following approval from the provincial procurement department, items are delivered to the districts, which then distribute them to the schools based on the recorded requests.

In a service-oriented organization like this, while external suppliers of computer equipment operate outside the organization, other supply chain members are internal. The key components of the province's computer equipment supply chain encompass the supplier, the provincial office, the region, and the school, with four subsystems: budget sharing and communication, request collection, tendering and supplier selection, and the distribution subsystem.

Among these subsystems, budget allocation and communication, along with request collection, face the most considerable challenges. The traditional and centralized methods employed in distributing budgets and gathering requests hinder the flexibility and responsiveness necessary for effective supply chain operation. Local decision-making empowerment is advisable as agile supply chain principles suggest.

The use of Excel files for request submissions is a significant inefficiency due to its inherent errors and lack of standardization, conflicting with lean management practices

designed to minimize waste. Furthermore, the absence of a real-time monitoring system leads to bottlenecks, making it imperative to implement a digital procurement platform to enhance visibility and control throughout the request collection process.

By modernizing processes and adopting recognized SCM best practices, addressing these challenges is crucial for enhancing the efficiency and effectiveness of computer procurement and distribution in a public educational context in Isfahan. With the incorporation of technology and decentralized decision-making, the organization can create a more agile supply chain, ultimately improving educational outcomes across the province.

Figure 2 illustrates the processes associated with these subsystems, underlining the necessity for improved communication and information management in the supply network.

Challenges Highlighted by SCM Theories

- i) **Centralized Decision-Making:** The centralized approach to budget allocation restricts responsiveness and flexibility, which are crucial for effective supply chain management. Agile supply chain principles recommend a more decentralized approach that empowers local decisions.
- ii) **Inefficient Data Management:** Relying on Excel files for request submissions is prone to errors and lacks standardization, which contradicts lean management practices aimed at minimizing waste and errors.
- iii) **Lack of Transparency and Control:** The absence of a real-time monitoring system for applications leads to bottlenecks. Implementing a digital procurement platform could enhance visibility and control throughout the request collection process.

Addressing these challenges through modernizing processes and adopting best practices in supply chain management is essential for improving the efficiency and effectiveness of computer procurement and distribution in the Education Organization of Isfahan Province. By leveraging technology and decentralized decision-making, the organization can ensure a smoother and more responsive supply chain, ultimately enhancing educational outcomes across the province.

The method of carrying out activities in these two subsystems has caused a lot of time and consequently costs to the organization.

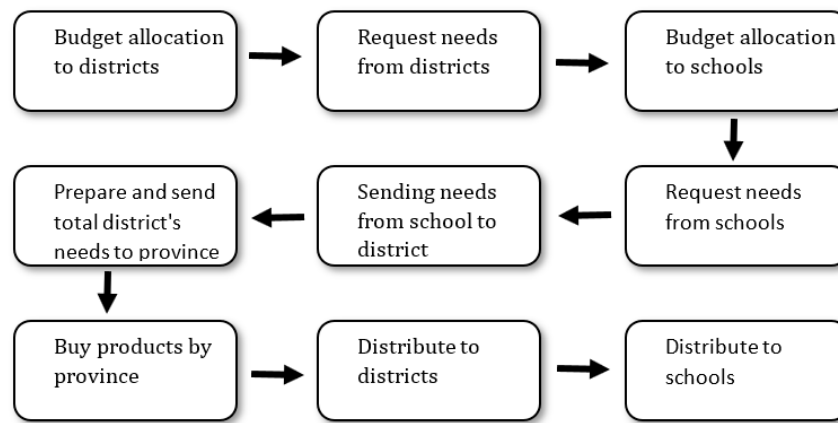


Fig. 2- Budget allocation and request collection processes

3. Implementation

We use the Ethereum network to implement the current supply chain with a blockchain approach. The Ethereum network is a complete Turing machine that provides the ability to program on the network using smart contracts. Before the Ethereum network, programmers had to use the Bitcoin network. The Bitcoin network was introduced to provide digital currencies. For this reason, comprehensive facilities for the development of applications were not provided in it. Several limitations in the Bitcoin network, such as types of data, types of transactions, data size, etc., led to the introduction of the Ethereum network in 2013 by Vitalik Buterin. In the Ethereum network, a concept called smart contracts was introduced. Smart contracts on the Ethereum network are tools that allow developers to create applications on the Ethereum network platform. Programs written by smart contracts are immutable. This property makes it possible to prevent the intentional change of conditions during a supply chain by any member of the chain. Therefore, it can increase confidence among the stakeholders of the supply chain. Since smart contracts are executed and managed by the Ethereum network, all blockchain capabilities such as encryption, transparency, traceability, reliability and more effective sharing of information can be used on applications developed on the blockchain network platform. The programming language of smart contracts in the Ethereum network is the Solidity language. Solidity is an object-oriented programming language to implement smart contracts in various blockchain networks, especially the Ethereum network. This language was created in 2014 by Gavin Wood to write applications in decentralized environments ([Antonopoulos and Wood 2018](#)).

A smart contract called *ComManagement.sol* was created to implement the budget allocation and request collection subsystems using the Solidity programming language on the Ethereum network platform.

In solidity language, creating a smart contract is done using the *contract* keyword. The basic structure of the smart contract is shown in the following commands. Full contract instructions are provided in Appendix 1.

```
contract ComManagement {
    address owner;
    constructor() public {
        owner = msg.sender;
    }
}
```

After defining and coding the smart contract, it must be implemented in the blockchain network to ensure its correct operation. There are several ways to do this, one of the simplest which does not require complex configurations, is to use the Remix Online Integrated Development Environment (IDE). The Remix tool was developed by Atrium Group and is available to all developers for free at <https://remix.ethereum.org/>. Remix is an integrated, open-source web and desktop development environment that allows developers to manage all smart contract processes. In the remix environment, in addition to the ability to write and edit smart contract codes, there is also the possibility of debugging, distributing and executing smart contracts (Chittoda, 2019).

Digital currency or tokens are required to execute transactions in the blockchain network. Digital currencies are like physical ones but are exchanged virtually in a blockchain network and can be converted into non-digital and real currencies. To maintain digital currencies, various hardware and software wallets have been developed for this purpose. One of the simple tools that can be used for this purpose, especially for testing programs is the Metamask Wallet. Metamask is a software wallet for digital currencies designed for a block network and can be used as a browser extension. Metamask wallet was introduced in 2016 by the software company Consensys². This plugin can be easily installed on various browsers and has the ability to connect to the main Ethereum network as well as to test networks on the Ethereum platform.

After coding the smart contract and compiling it, if there is no error, it should be deployed on the Ethereum network. For this purpose, the main Ethereum network is used which requires a wallet with digital currency assets. Test networks developed on the Ethereum platform can be used to avoid spending real currency before the final settlement of the smart contract. Among all, the four most popular networks are Rinkeby, Kovan, Ropsten and Goerli, of which the Rinkeby network is used in this study.

² <https://metamask.io/>

After setting up Metamsk and creating a digital wallet, using the Injected Web3 method via Remekis, the wallet connects to Metamsk in the Rinkeby test network and through the Deploy button the smart contract will be implemented on the blockchain network.

3.1 State variables

Given that the long process time is one of the most important challenges of the NB method, one of the state variables in system modelling, which will be the main basis of the analysis is the time parameter. Time variables will also affect the cost of the process. Therefore, in addition to measuring the time parameter, the process cost has been modelled and measured in both methods.

3.2 The time function of the process of budget allocation and request collection in the NB method

In the NB method, the total process time function is obtained from the sum of the following activity times:

- Time required for the budget allocation for each district t_{rb}
- Time required for budget allocation for each school's t_{ub}
- Time required for collecting school requests t_{uq}
- Time required to review, modify and aggregate the requests of each school and send them to the province t_{ouch}
- Time required to review, improve and aggregate the requests of each district t_{ech}

Therefore, the function for calculating the total process time in NB method will be obtained from the following equation:

$$T_{NB} = \sum_1^{nr} (t_{rb} + t_{rch}) + \sum_1^{nu} (t_{ub} + t_{uq} + t_{uch}) \quad (1)$$

In relation 1, nr means the number of districts and nu means the number of schools. Table 2 shows the mean time values for all parameters in relation to 1

Table 2. Meantime values of the budget allocation and request collection process in the NB method

Parameter	Per	Min Time (Second)	Max Time (Second)
t_{rb}	District	5620	7024
t_{ub}	School	1889	2361
t_{ub}	School	944	1180
t_{uch}	School	2833	3541
t_{rch}	District	8429	10537

3.3 The total time function for budget allocation and requests collection in Blockchain Method (BM):

In BM, the time variable is obtained from the sum of the following activity times:

- Time required to register the budget of the province and be approved by blockchain Network t_{pb}
- Time required to record the forecast price of a computer device and being confirmed by blockchain t_{mf}
- Time required to enter district information, check the validity of each district and be confirmed by blockchain network t_{rb}
- Time required to enter school information, check the validity of each school and confirm by blockchain network t_{ub}
- Time required for each school to submit a request and have it approved by the blockchain network t_{uq}

Therefore, the function of calculating the total process time in BM will be obtained from the following equation:

$$T_B = t_{pb} + t_{mf} + \sum_1^{nr} t_{rb} + \sum_1^{nu} (t_{ub} + t_{uq}) \quad (2)$$

Table 3 shows the average time values of all parameters in Equation 2.

Table 3- The average time of budget allocation and request collection in BM

Parameter	Per	Min Time (Second)	Max Time (Second)
t_{pb}	Only one	351	27
t_{mf}	Only one	351	27
t_{rb}	District	702	54
t_{ub}	School	702	54
t_{uq}	School	702	54

3.4 The total cost function of budget allocation and request collection in Non-Blockchain Method (NBM):

In the NBM, the total cost is obtained from the sum of the costs of the following activities:

- The cost of manpower required to allocate budget to each region, C_{rb}
- The cost of manpower required to allocate budget to each school, C_{ub}
- The cost of manpower required to receive requests from each school send the request to the relevant region, C_{uq}
- The cost of manpower required to review, modify and aggregate school requests and send them to the province, C_{uch}
- The cost of manpower required to review, modify and aggregate regional requests, C_{rch}

Therefore, the function of calculating the total cost of the NBM will be obtained from the following equation:

$$C_{NB} = \sum_1^{nr} (c_{rb} + c_{rch}) + \sum_1^{nu} (c_{ub} + c_{uq} + c_{uch}) \quad (3)$$

Table 4 shows the cost of all parameters in Equation 3.

Table 4- The average cost of budget allocation and request collection processes in NBM

Parameter	Per	Min Cost (Rials)	Max Cost (Rials)
c_{rb}	District	533900	667280
c_{ub}	School	179455	224295
c_{uq}	School	89680	112100
c_{uch}	School	269135	336395
c_{rch}	District	800755	1001015

3.5 The total cost of the budget allocation and request collection in BM.

In BM, the total cost is obtained from the sum of the costs of the following activities:

- The cost of manpower required to complete the provincial budget allocation and its approval by the blockchain network, C_{pb}
- The cost of manpower required to forecast the price of a computer device and its approval by the blockchain network, C_{mf}
- The cost of manpower required to complete the regional budget allocation and its approval by the blockchain network, C_{rb}
- The cost of manpower required to complete the school budget allocation and its approval by the blockchain network, C_{ub}
- The cost of manpower required to receive the school request and its approval by the blockchain network, C_{uq}

Therefore, the total cost of the process in BM will be obtained from the following equation:

$$C_B = c_{pb} + c_{mf} + \sum_1^{nr} c_{rb} + \sum_1^{nu} (c_{ub} + c_{uq}) \quad (4)$$

Table 5 shows the cost of all parameters in Equation 4.

Table 5- The cost of the budget allocation and request collection processes in BM

Parameter	Per	Min Cost (Rials)	Max Cost (Rials)
c_{pb}	District	87105	101685
c_{mf}	School	87105	101685
c_{rb}	School	174210	203370
c_{ub}	School	174210	203370
c_{uq}	District	87105	101685

4. Model building

Based on NBM and BM, two models are drawn in the Analogic software. Figure 3 shows the two models. Figure 3a shows the model based on NB and 3b shows the model based on BM

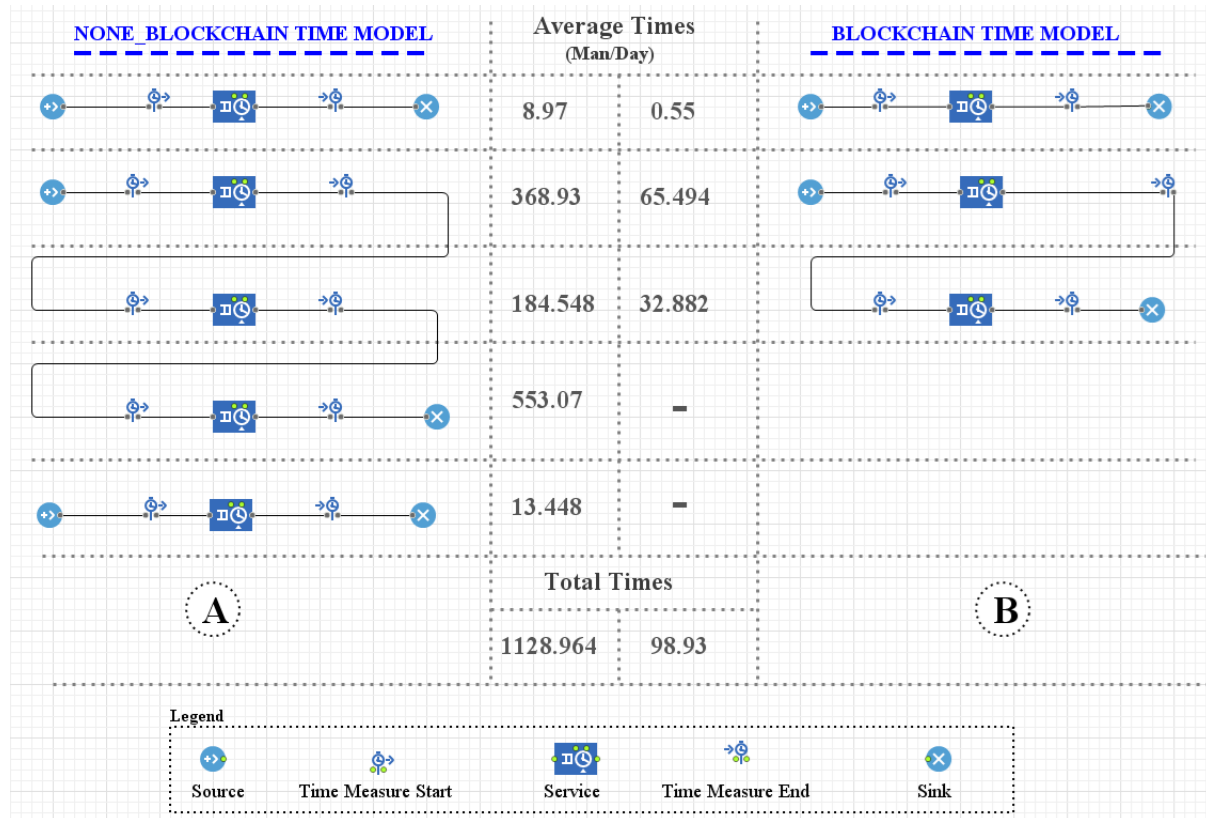


Fig. 3- Simulation model in NBM and BM

In NBM, five services including district budget allocation, school budget allocation, school request, school request review and finally district request review are designed. In BM there is no need to perform school and district request review services because these services are controlled by the rules written in the smart contract, and therefore no separate time and cost will be imposed on the system. Therefore, in BM, there is only a need for district budget allocation and also school budget allocation and request collection.

4.1. Model assumptions

In this research, some assumptions are considered to form the base of all model calculations, which will be mentioned below.

- Of the all subsystems throughout the supply process, only two subsystems including budget allocation and request collection have been examined.
- Two types of costs are considered as the basis of measurement in this study. These costs are manpower costs and the cost of blockchain transaction verification.

- Manpower costs are calculated based on the salary paid to an employee. The average monthly salary of an employee for 176 hours per month is estimated at sixty million Rials. In other words, for each employee, 95 Rials per second have been included in the simulation calculations.
- The cost of approving transactions in the blockchain network is based on Ethereum currency. The rate of each Ethereum (ETH) at the time of measurement and simulation calculations is estimated at \$ 375.
- The rate of each Rial at the time of the simulation is estimated at \$ 0.000005.
- The average time (in seconds) and cost (in terms of Ethereum) for approving transactions in the blockchain network are calculated based on the values provided at <https://ethgasstation.info/calculatorTxV.php>, which are the values at the time of the simulation. The cost of gas and the amount of gas used in medium-priority transactions were: 202 GW and 25,000, respectively.
- Isfahan province has about 5000 schools in 41 regions. In the simulation, on average, 122 schools are considered for each region.

4.2 Model Execution

These two models are simulated using the discrete event method in Analogic software. Due to the fact that the province has 41 regions and 5000 schools, the models were executed with a value of 41 for the number of regions and 122 for the number of schools in each region. Table 6, shows the time results and Table 7, shows the cost results extracted for both NBM and BM models. Time amounts are in terms of person per working day and cost amounts are in terms of millions of Rials.

Table 6- Time values for both NBM and BM models

Title	Run1		Run2		Run3		Run4		Run5		μ		σ	
	NBM	BM	NBM	BM	NBM	BM	NBM	BM	NBM	BM	NBM	BM	NBM	BM
District budget allocation	8.780	0.550	9.040	0.600	9.000	0.590	9.020	0.530	9.010	0.500	8.970	0.550	0.100	0.040
School budget allocation	368.930	65.370	368.930	65.860	369.210	65.550	368.720	65.110	368.860	65.580	368.930	65.494	0.160	0.250
School requests	184.560	33.280	184.260	32.410	184.730	32.890	184.680	32.840	184.510	32.990	184.548	32.882	0.160	0.280
School requests control	552.660	0.000	553.030	0.000	552.870	0.000	553.490	0.000	553.290	0.000	553.070	0.000	0.290	0.000
District request control	13.500	0.000	13.440	0.000	13.660	0.000	13.500	0.000	13.140	0.000	13.450	0.000	0.170	0.000
Total	1128.430	99.200	1128.710	98.860	1129.460	99.040	1129.410	98.480	1128.810	99.070	1128.960	98.930	0.400	0.250

Table 7. Cost values for both NBM and BM models.

Title	Run1		Run2		Run3		Run4		Run5		μ		σ	
	NBM	BM	NBM	BM	NBM	BM	NBM	BM	NBM	BM	NBM	BM	NBM	BM
District budget allocation	24.00	9.28	24.00	9.32	24.00	9.39	24.00	9.19	24.00	9.07	24.00	9.25	0.00	0.11
School budget allocation	1009.00	1129.73	1009.00	1124.22	1010.00	1123.85	1008.00	1122.46	1009.00	1123.95	1009.00	1124.84	0.63	2.52
School requests	504.00	562.54	504.00	560.70	505.00	562.12	505.00	561.75	504.00	562.85	504.40	561.99	0.49	0.75
School requests control	1512.09	0.00	1513.10	0.00	1512.64	0.00	1514.36	0.00	1513.80	0.00	1513.20	0.00	0.81	0.00
District request control	36.92	0.00	36.77	0.00	37.38	0.00	36.93	0.00	35.96	0.00	36.92	0.00	0.46	0.00
Total	3087.37	1694.74	3088.14	1694.43	3090.21	1695.56	3090.05	1693.59	3088.42	1696.06	3088.83	1694.87	1.11	0.86

Figures 4 and 5 show the time total cost of the budget allocation and request collection for both NBM and BM models.

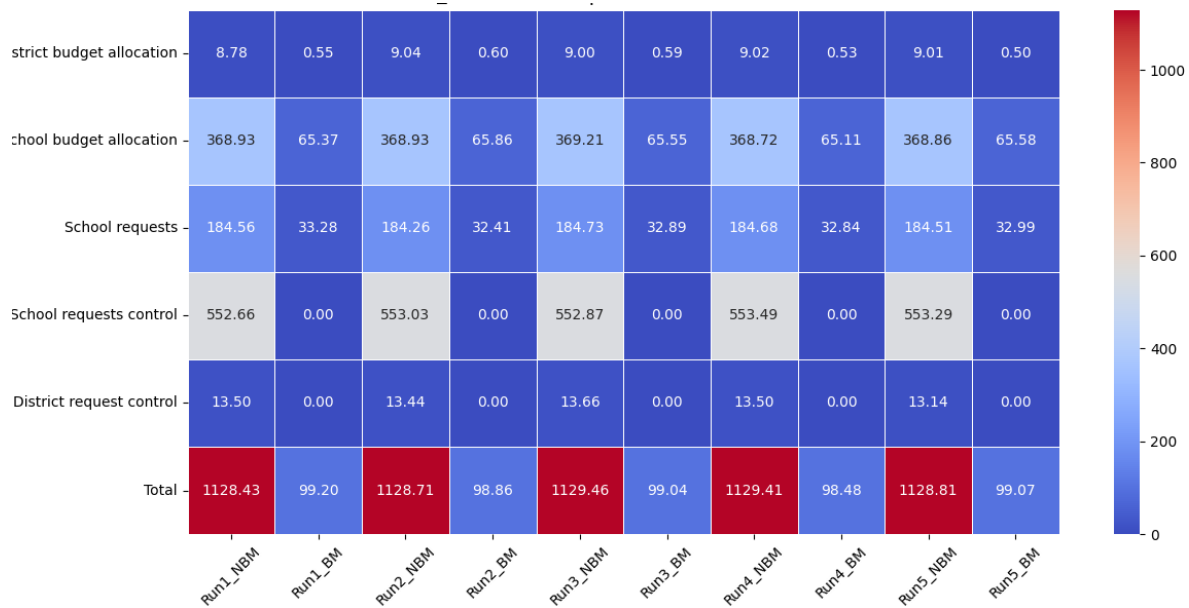


Fig. 4- Time values for budget allocation and request collection.

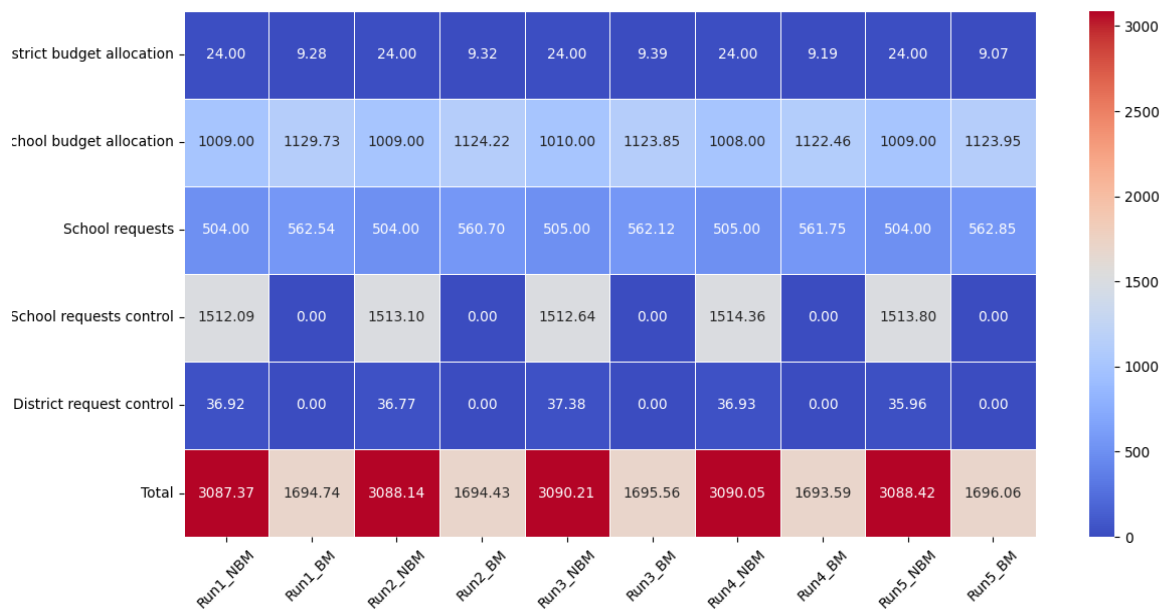


Fig. 5- Total cost for budget allocation and request collection

5. Discussion

Traditional supply chain management methods are increasingly unable to secure a reliable environment for sharing accurate and timely information. To address this, new technologies and structures are essential. Blockchain technology has significant potential to solve challenges in supply chain management ([Kouhizadeh, Saberi, & Sarkis, 2021](#)). By enabling better information sharing among supply chain members, blockchain increases cooperation and consequently enhances overall supply chain performance ([Rejeb et al., 2021](#); [Longo et al., 2019](#)).

A notable outcome of our study is how the use of smart contracts led to reduced intermediation among supply chain members. This traceability of all transactions fosters greater cooperation in decision-making ([Saurabh and Dey, 2021](#)), increases data transparency, and builds trust among network members ([Rejeb et al., 2021](#)). Valid transactions in the blockchain network, facilitated by a consensus-based validation approach, also significantly reduce transaction costs and enhance supply chain governance ([Schmidt and Wagner, 2019](#)).

The failure to share information transparently increases the costs associated with demand forecasting and lengthens lead times for order fulfilment. Within the Ethereum network, smart contracts provide effective solutions for managing these challenges.

While several studies have explored the impact of blockchain technology on supply chain management, most remain theoretical in nature ([Stranieri et al., 2021](#); [Koirala et al., 2019](#); [Rao et al., 2021](#); [Hrouga et al., 2022](#)). This study addresses that gap by providing empirical

evidence through practical simulations. By comparing traditional supply chain processes with blockchain-enabled ones, we identified key factors affecting efficiency:

- **Process Time:** The duration required to complete supply chain tasks.
- **Manual Labor Reduction:** The elimination of manual verification and record-keeping tasks.
- **Cost Efficiency:** The overall savings achieved through faster processes and reduced labour needs.

In our simulations, the results were particularly compelling. For instance, as shown in Table 6, the blockchain model (BM) demonstrated a 91% reduction in process time compared to the non-blockchain model (NBM), decreasing the total time from over 1,100 units in the NBM to less than 100 units in the BM. This drastic reduction highlights how blockchain can optimize supply chain performance by enhancing transparency and improving traceability.

5.1 Theoretical implications

The findings of this study contribute significantly to the theoretical discourse in supply chain management by bridging the gap between theory and practice regarding blockchain technology. They extend existing SCM theories by providing empirical evidence that showcases the practical application of smart contracts within a real-world supply chain context. This empirical evidence supports the theoretical frameworks that advocate for increased transparency and reduced operational costs through technological integration. Additionally, by identifying critical factors such as process time, manual labour reduction, and cost efficiency, this research enhances the conceptual understanding of the mechanisms through which blockchain technology affects supply chain dynamics. These insights can inform future theoretical developments in the field, supporting the establishment of more comprehensive models that incorporate emerging technologies like blockchain and smart contracts.

5.2 Managerial implications

From a managerial perspective, this study emphasizes the necessity for organizations to innovate their supply chain processes by leveraging blockchain technology. The ability of smart contracts to reduce intermediation, enhance transparency, and lower operational costs provides a clear strategic advantage. Supply chain managers are encouraged to adopt these technologies to improve decision-making and foster trust with supply chain partners. Implementing blockchain not only streamlines processes but also enables a more agile response to market demands, ultimately enhancing competitiveness. Furthermore, the

findings underline the importance of investing in training and development for staff to navigate and utilize these new technologies effectively. Managers should also consider the significant role of real-time data visibility in enhancing collaboration and efficiency in their supply chains. Overall, the integration of blockchain technologies offers an actionable pathway for organizations seeking to improve supply chain resilience and performance.

6. Conclusions

Accurate and timely information sharing in the supply chain is crucial for effective management decisions. However, the growing complexity of supply chains, particularly the decentralization of chain members, makes traditional information systems inadequate. New technologies, including blockchain, are necessary to tackle the challenges arising from existing methods.

Information sharing often faces resistance due to a lack of trust, exacerbated by insufficient timely and accurate data, often leading to inconsistencies between supply and demand. This lack of information contributes to increased costs along the supply chain, inefficient resource utilization, and the bullwhip effect, where small changes in demand lead to large variations in order volume ([Longo et al., 2019](#)).

Moreover, traditional supply chains struggle to provide transparency for all stakeholders, resulting in diminished trust and potential for counterfeit goods. These challenges can create inefficiencies that increase lead times and overall supply chain costs.

Implementing smart contracts allows for the enforcement of predefined rules, while the data recorded in a distributed and accessible blockchain network reduces costs significantly, ensuring each member incurs the lowest possible expenses for transactions ([Omar et al., 2021](#)).

In this research, we developed a smart contract using the Solidity programming language to implement these processes. The deployment of two simulation models—a traditional structure and a blockchain technology-based model—yielded significant improvements in supply chain efficiency. The simulations evidenced that blockchain technology positively influences supply chain processes, enhancing performance metrics such as time and cost.

Based on our findings, the following are suggested future research directions:

- i) Integration with IoT: Exploring the potential of the Internet of Things (IoT) to further enhance data collection and real-time visibility in supply chains.
- ii) Larger Datasets: Testing the implementation of blockchain on larger datasets to validate scalability and performance across diverse supply chains.

iii) Automated Decision-Making: Integrating artificial intelligence (AI) to automate decision-making processes, increasing responsiveness and efficiency in supply chain operations.

These results were presented in more detail by answering the research questions:

i) What are the parameters affecting the computer equipment supply chain?

Describing the current supply chain and identifying its subsystems shows that the system is not efficient and responsive in terms of time. As shown in Table 1, the whole process takes about two months to complete. Prolonging the process time can greatly impose a high amount of cost to the organization. By comparing Tables 2 and 3, it can be seen that two parts of the process including school requests review by regions and also by province in a blockchain-based method are not required because these tasks are handled by smart contracts.

There are similar conditions in comparing Tables 4 and 5 in terms of cost. Therefore, in this research, time, cost and manual activities by human resources can be considered as critical parameters such as process time, manual labour reduction, and cost-efficiency in the supply chain.

ii) How much impact does blockchain technology have on the supply chain?

According to the data in Table 6, it can be seen that in BM compared to the NBM, the time of the process has been greatly improved. The total process time in BM is reduced by approximately 91% compared to NBM. The values presented in the tables show that the total time of the budget allocation and request collection processes has been reduced from over 1100 units in NBM to less than 100 in BM.

The comparison of the results shows that blockchain technology has the capacity to have a positive effect on supply chain performance and while increasing transparency and improving traceability, it can also improve performance indicators in terms of time and cost.

Due to the emerging nature of blockchain, especially its applications in the supply chain, most of the research done in this regard is theoretical and there are few practical implementations to investigate the effects of this technology on supply chain management and performance. In this study, using smart contracts within the Ethereum network, showcasing a practical simulation rather than a theoretical framework, the traditional structure of the supply chain is compared with the blockchain-enabled supply chain.

Appendix 1. Solidity code for smart contract

```

``solidity
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

contract SupplyChain {
    struct ComputerRequest {
        address school;
        uint256 quantity;
        bool fulfilled;
    }

    address public suppliers;
    address public province;
    mapping(address => uint256) public regionBalances;
    mapping(address => ComputerRequest) public requests;

    event RequestFulfilled(address school, uint256 quantity);

    constructor() {
        supplier = msg.sender;
        province = msg.sender;
    }

    modifier onlySupplier() {
        require(msg.sender == supplier, "Only the supplier can perform this action");
        _;
    }

    modifier onlyProvince() {
        require(msg.sender == province, "Only the province can perform this action");
        _;
    }

    function updateSupplier(address newSupplier) external onlySupplier {
        supplier = newSupplier;
    }

    function updateProvince(address newProvince) external onlyProvince {
        province = newProvince;
    }

    function submitRequest(uint256 quantity) external {
        require(quantity > 0, "Quantity must be greater than zero");
        require(requests[msg.sender].school == address(0), "Request already submitted");

        requests[msg.sender] = ComputerRequest({
            school: msg.sender,
            quantity: quantity,
            fulfilled: false
        });
    }

    function fulfillRequest(address school) external onlySupplier {
        ComputerRequest storage request = requests[school];
        Require(request.school != address(0), "Request does not exist");
        require(!request.fulfilled, "Request already fulfilled");

        request.fulfilled = true;
        emit RequestFulfilled(request.school, request.quantity);

        // Update region balances and perform other supply chain operations

```

```
// ...

// For demonstration purposes, update region balances with the fulfilled quantity
regionBalances[province] += request.quantity;
regionBalances[school] -= request.quantity;
}

function getRequest(address school) external view returns (uint256, bool) {
    ComputerRequest memory request = requests[school];
    return (request.quantity, request.fulfilled);
}
}
```

This smart contract includes the following functionalities:

1. The contract has a 'ComputerRequest' structure to store information about each school's request for computer equipment.
2. It keeps track of the supplier and province addresses, which can be updated by the respective roles ('onlySupplier' and 'onlyProvince' modifiers ensure only authorized addresses can update them).
3. Schools can submit a request for a specific quantity of computer equipment using the 'submit request' function.
4. The supplier can fulfil a request using the 'fulfil request' function, updating the request status and performing any necessary supply chain operations.
5. The contract includes a 'getRequest' function to retrieve information about a specific school's request.

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