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Original Article

Digital Supply Chain Visibility Using Blockchain and Iot

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ABSTRACT

Digital transformation has revolutionized supply chain management by enhancing transparency, traceability, and efficiency. This study focuses on improving supply chain visibility through the integration of Blockchain and Internet of Things (IoT). Traditional systems face challenges such as data silos, lack of transparency, fraud, and inefficiencies. IoT enables real-time data collection (e.g., location, temperature, and handling conditions), while Blockchain ensures secure, tamper-proof, and transparent data storage. The integration of these technologies allows end-to-end tracking of products and information across the supply chain. Smart contracts automate processes, reducing the need for manual intervention. The study also examines system architectures, consensus mechanisms, and key challenges like scalability, latency, and interoperability. Despite limitations such as high costs and technical complexity, the combined use of Blockchain and IoT significantly improves visibility, trust, and operational efficiency. Overall, this approach offers strong potential for building reliable, data-driven, and transparent supply chain systems.

KEYWORDS

Blockchain, Internet of Things (IoT), Supply Chain Visibility, Smart Contracts, Traceability, Digital Transformation, Distributed Ledger.

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1. INTRODUCTION

1.1. Background

The supply chain management has been greatly transformed with the intense development of digital technologies that have modified the mode of flow of goods and information throughout industries. Globalization has resulted in supply chains becoming very complex interactions with multiple stakeholders that include suppliers, manufactures, distributors, retailers, and customers, and in most instances they may be located in various geographical locations. This complexity demands effective coordination, quality sharing of data and real-time decision making. A major limitation with the traditional supply chain systems, however, is that they are highly reliant on central databases and legacy systems. These systems tend to work in silos and limit a smooth flow of information between them and create delays in communication and decision-making. Consequently, lack of efficiency, inventory mismanagement, late delivery and higher cost of operations are frequent. Moreover, the non-transparency of the centralized systems prevents the stakeholders to consider the movements of the product and assure the data authenticity, decreasing confidence in the participants. The susceptibility to cyber threats is the other significant issue because centralized systems expose single points of failure that might be attacked by intruders, resulting in the theft of sensitive information. In that regard, more secure, transparent and efficient supply chain solutions are in demand so as to overcome these challenges and meet the growing needs of the contemporary logistics and global trade. Digital Supply Chain is significant because it enhances and simplifies procurement, logistics, and supply chain management previously controlled by market forces and distributors.<|human|>1.2 Digital Supply Chain Importance Digital Supply Chain is important as it tries to make procurement, logistics and supply chain management, which was previously allowed to be dictated by forces and distributors, eased and simplified.

1.2. Importance of Digital Supply Chain

Fig 1 - Key Benefits of Digital Transformation in Organizations

1.2.1. Enhanced Visibility and Transparency

Digital supply chain will facilitate real-time monitoring of all supply chain operations. Stakeholders are able to know the whereabouts of goods, the inventory quantities and receive correct data at any given time with the aid of sophisticated technologies. Such transparency lowers the level of information asymmetry, creates trust between group members and enables quicker problems like delays and disruption to be detected.

1.2.2. Improved Efficiency and Automation

Digital supply chains engage automation and intelligent systems to improve workflow. Activities that include processing of orders, managing of stock, and forecasting demand may be automated eliminating human intervention and errors. This causes quicker processing hours, better use of available resources, and general efficiency in the entire operation process.

1.2.3. Better Decision-Making

The decision-making is better informed through real-time and data-driven insights which are available to organizations. Analytics and predictive capabilities have been offered by the digital systems aiding in the demand planning, risk management, and performance evaluation. This helps in ensuring that the businesses are pro-active to the market changes and the needs of the customers.

1.2.4. Increased Security and Risk Management

The digital technologies advance the security of the supply chain data encryption, secure networks and advanced monitoring systems. They also assist in recognizing any possible risks like case of disruptions in the supply, fraud, or cyber threats. Management of risks is performed at the onset, and therefore, the efficiency of organizations can be promoted, and the vulnerability of information can be minimized.

1.2.5. Enhanced Customer Satisfaction

Digital supply chain enhances the customer experience, in general, by guaranteeing the timely delivery, proper tracking of orders, and improved communication. The customers are allowed to receive real-time information on their orders, making it more reliable and trustworthy. More efficient and faster services would eventually result to customer satisfaction and loyalty.

1.2.6. Scalability and Flexibility

Digital supply chain is very scalable and responsive to business change requirements. Organizations can easily diversify, adopt new technologies or modify the processes depending on the demands of the market easily. The flexibility is critical in this current dynamism in the business environment, with quick changes requiring a fast pace and responsive supply chain.

1.3. Problem Statement

The inability to have a real time visibility has been an acute issue in the modern supply chain systems and this has seriously affected the efficiency of operations and the confidence of the stakeholders. Typically traditional supply chains use fragmented and centralized systems of data management, in which the information is not updated on a real-time basis and is not shared properly among the participants. This creates a delay in the process of communication, ineffective monitoring of goods, poor coordination among various parties like suppliers, manufactures and distributors. It, therefore, brings about problems in organizations such as delays in delivery, stocking discrepancies and high costs of doing business. Also, lack of transparency in such systems presents random possibilities of fraudulent actions such as distortion of data, counterfeit products and transactions without authorization. As the stakeholders lack access to a single and verifiable source of information it becomes challenging to can identify and prevent such problems in good time. Not only business relationships are impacted by this lack of trust, but it also causes a lack of confidence in the process of supply chain by the customers. Today, the customers demand real-time information and guarantees concerning the authenticity and quality of goods, which is not always offered by the traditional systems. The other issue of concern is the data security. The centralized systems are more susceptible to cyberattacks and data breach since it constitutes the single point of failure. Figure 1 Data regarding

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transactions, logistics, and customer basis may be hacked resulting in losses of finances as well as reputation. Also, there is inadequate traceability, and it is difficult to trace the source and path of goods; particularly in sensitive areas such as food and pharmaceuticals where hygiene and conformity are paramount factors. Thus, there is an urgency to develop a new progress supply chain system to provide the real-time visibility, transparency, and a reliable information exchange. It must allow smooth monitoring of goods, eliminate fraud, increase trust within the stakeholders, and make the entire process more efficient, which will result in a more trustworthy and customer-focused supply chain.

2. *LITERATURE SURVEY*

2.1. Traditional Supply Chain Systems

Conventional supply chain operations are normally centralized and the transactions are handled and authenticated by only one person or middle man. Though it is a structure that has been extensively applied, it has a number of drawbacks which include the lack of transparency in the structure, slow information flow, and exposure to information manipulation. Data stored on isolated databases means that the stakeholders do not have the overall view of the whole supply chain and thus inefficiencies and lack of trust. Moreover, paperwork and hand work enhance the possibility of human error and fraud hence finding it hard to establish accountability and traceability at various levels of the supply chain.

2.2. Blockchain in Supply Chain

Blockchain technology has become a promising tool to fill most of the flaws of traditional supply chain systems. It offers a decentralized and immutable registry in which all the transactions are stored transparently, and they cannot be changed after they are verified. This will create confidence in the participants without middle men. Blockchain is also improving supply chain traceability because it enables stakeholders to have real-time visibility into the path that the goods take, on their way to the delivery location. It is also safer in terms of cryptographic principles and consensus algorithms, causing less fraud and data corruption. Consequently, blockchain leads to the enhancement of efficiency, accountability, and trust between supply chain members.

2.3. IoT in Supply Chain

Internet of Things (IoT) contributes to the transformation of how supply chains should be operated by allowing the collection and monitoring of data in real-time. The information regarding the location, state, and condition of goods during transit are acquired with IoT tools including sensors, RFID tags, and GPS trackers. This stream of data enables businesses to make sound decisions, streamline logistics and react promptly to disruption. An example is using temperature-sensitive goods such as pharmaceuticals or food items that can be tracked to ensure that they are kept in safe environment. Altogether, IoT increases the effectiveness of operations, losses, and supply chain visibility.

2.4. Integration of Blockchain and IoT

Identity blockchain and IoT are strong methods of a more transparent supply chain that can be built. The IoT devices produce massive amounts of real-time data and blockchain offers a safe and resistant system on which the data can be stored and shared across the stakeholders. When these technologies are combined, organizations are able to have end-to-end visibility, where every information documented is correct, verifiable, and reliable. This interface also allows automation using smart contracts, functions that can be initiated under specified conditions, such as delivering payments when successful delivery is done. As a result, with the help of blockchain and IoT synergy, supply chain reliability, efficiency, and trust will increase, leading to resilient and intelligent logistics networks.

3. METHODOLOGY

3.1. System Architecture

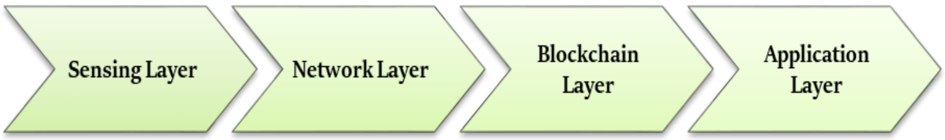

Fig 2 - System Architecture

3.1.1. Sensing Layer

The essential part of the proposed system is the sensing layer which comprises internet of things devices including sensors, RFID tags, and GPS modules. These machines play the role of gathering real time information regarding the supply chain in terms of location, temperature, humidity and product status. The sensing layer is able to detect the physical conditions by a constant monitoring to capture the data accurately and at the right time and this is necessary to sustain the quality of the products and also provides traceability to the entire supply chain.

3.1.2. Network Layer

Network layer helps in communication between the sensing layer and the upper levels of the system. It will handle the transmission of data that the IoT sensors have gathered to the blockchain and application layers via communication protocols like Wi-Fi, cellular networks or LPWAN. This layer provides a reliable and secure system to transfer data and is able to cope with such challenges as routing of data, connection and latency. The cost-effectiveness and efficiency of the network is important to facilitate real-time updates and flow of information throughout the system.

3.1.3. Blockchain Layer

The blockchain layer is the main component of the system because it is a decentralized and untrustworthy-tamper platform, where supply chain data is stored and managed. The records of all stays obtained by the network layer are ensured to be immutable in blocks and therefore transparency and security is guaranteed. It is possible to use smart contracts within this layer to automatize the verification process, release payment, and compliance checks. This layer avoids the use of middlemen and creates a trusting relationship with the stakeholders through data integrity.

3.1.4. Application Layer

Application layer is concerned with the interface of the system with the end users which in this case are suppliers, manufacturers, distributors and consumers. It offers dashboards, analytics charts and convenient applications to retrieve and see supply chain information on the blockchain. This layer allows users to monitor the movement of their products, authenticate them and make wise

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choices. It makes use of the system more useable and allows the stakeholders to effectively communicate with the system underpinning.

3.2. Data Flow Model

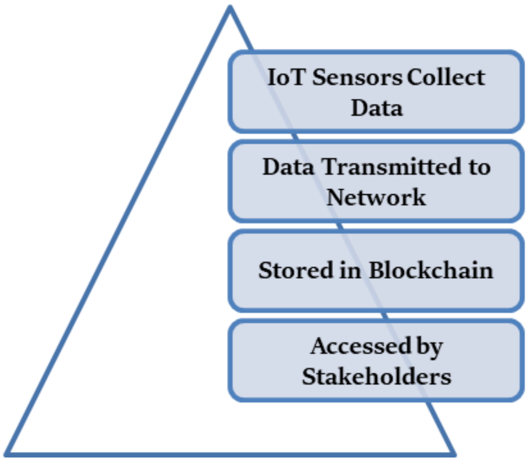

Fig 3 - Data Flow Model

3.2.1. IoT Sensors Collect Data

The flow of data commences with the IOT sensing level, where different devices and sensors receive constant data on the physical world. These gadgets record the vital data, including these parameters: temperature, humidity, location and the conditions of handling the goods. The data gathered is accurate and time stamped hence giving a good tracking record of the products within the supply chain. This will be crucial in keeping a check over quality and also allow real-time access of operations.

3.2.2. Data Transmitted to Network

After gathering the data, it is relayed via the network layer with communication technology like Wi-Fi communication, cellular communications, or any other communication protocols. This step is aimed at making sure that the information is transferred effectively between the sensing devices and centralised or distributed processing units. The network layer is also involved in data routing, reliability of transmission and other security related issues like encryption in order to ensure that sensitive information remains safe throughout transfer.

3.2.3. Stored in Blockchain

Once the transmission has been made, the data gets safely stored in the blockchain layer. Any piece of information is saved as a transaction and becomes part of a block, that is connected to the blocks that come before it and creates a never ending chain. This guarantees that once the data is recorded then it cannot be changed or tampered with. Being decentralized, blockchain leads to an improved level of trust between the members of the unit as all the parties involved can see one single, verified copy of the information.

3.2.4. Accessed by Stakeholders

At the last stage, the data stored is accessed by the different stakeholders through applications and user interfaces. These stakeholders can be the suppliers, manufacturers, distributors, retailers and consumers. They will be able to see real-time updates, monitor the flow of goods, check authenticity as well as analyze performance indicators. This access also enhances decision-making, transparency and builds trust throughout the whole supply chain.

3.3. Mathematical Model

The mathematical algorithm of data integrity assurance in the offered system has its basis on the idea of hashing. In this model, data data integrity is checked with the help of a function in which D = H of M. In this case, D is used to denote the digital hash or digest, M is the original message or data, which is collected through IoT devices and H is used to denote the hash function to apply on the data. A hash algorithm is a mathematical procedure that takes any kind of input data of all lengths and transforms it into the form of a single fixed-length character set that serves as a distinctive digital digital signature of the original data. This is the key to the preservation of security and trust in the system. Attackers use the hash function to generate the hash value when the data is created by the IoT sensors. The tiniest variation in the input data causes the output of the hash to alter completely and is also very sensitive to alterations. It is a quality that makes it possible to identify any manipulation or fraudulent change of data with ease. After the hash value is created, the data itself and its hash can be stored in the blockchain. The data integrity is further enhanced by the fact that the blockchain records are immutable meaning that the stored hash cannot be modified. When performing a verification, the system regenerates the hash of the received information, and verifies it with the already stored hash. When the two values are identical, it is said that the data is genuine and unsalvaged, when this is not the case it indicates that there could be corruption, or manipulation of data. This model does not only boost the security, but also any transparency and reliability within the supply chain. With the help of hashing techniques, the system will be able to ensure that all members of the stakeholders are using the right and reliable information, which will enhance the efficiency and trust in the digital supply chain environment in general.

3.4. Algorithm

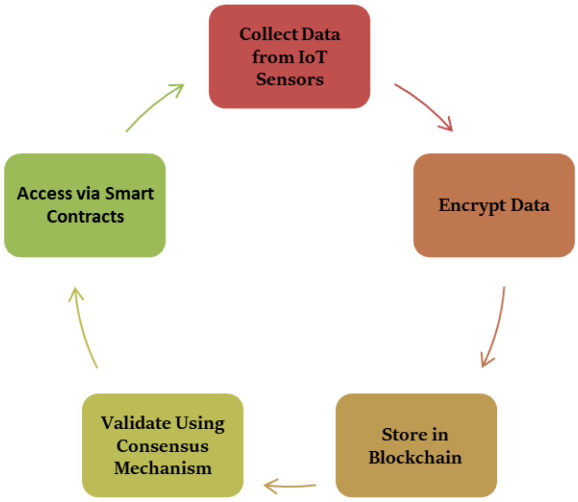

Fig 4 - Algorithm

3.4.1. Step 1: Collect Data from IoT Sensors

The algorithm starts with the first step that entails the collection of real time the information acquired through IoT sensors spread throughout the supply chain. Among other significant information acquired by these sensors are temperature, humidity, location, and handling of goods. The information obtained is registered and regularly updated thus precise tracking of goods in all

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stages. This involves the basis of the system because without high-quality input data, there will be no successful tracking and decision-making.

3.4.2. Step 2: Encrypt Data

Then after collecting the data the following step involves ensuring its security by means of encryption. Encryption converts the raw data into coded format that can exclusively be accessed or read by authorized persons. This will provide confidentiality and prevent sensitive information to be accessed by anybody or cyber attackers. Through cryptographic functionalities, the system improves the level of data security prior to its access to blockchain network.

3.4.3. Step 3: Store in Blockchain

The data is encrypted and then it is saved in blockchain as a transaction. Every piece of transaction is connected in a distinct block and integrated with the other past blocks making it a secure and non-modifiable chain. This measure is keeping the data from being modified or destroyed after it has been logged in. Decentralization of blockchain enables every member of the supply chain to access one, consistent copy of the data hence enhancing transparency and trust.

3.4.4. Step 4: Validate Using Consensus Mechanism

Prior to one block being added to the blockchain, it must be legitimized by means of a consensus process. This is done by other nodes in the network accepting authenticity and correctness of the data. Only verified transactions are noted by consensus algorithms, like proof- Based or voting-Based algorithms. This measure will stop fraud and preserve the integrity of the blockchain system.

3.4.5. Step 5: Access via Smart Contracts

The last step involves having the stakeholders retrieve the stored data using smart contracts. Smart contracts refer to automatic self-executing software kept on the blockchain that automatically executes established rules and conditions. They allow automated processes like checking the presence of specific transactions, setting alarm bells, or making payments provided some specific conditions are fulfilled. This will enhance efficiency, less manual intervention and allow all participants an easy time dealing with the system.

4. RESULTS AND DISCUSSION

4.1. Performance Metrics

The effectiveness of the proposed supply chain system could be well measured with the key metrics including transparency, traceability, and the efficiency, as a combination of which the reliability and efficiency of the entire framework could be ensured. Transparency denotes the degree to which the entire stakeholders within the supply chain are in a position to access valid and live information regarding transactions and product flow. As an advantage of using the blockchain technology, the system secures all the recorded information to be visible, consistent and irreversible, therefore limiting the information asymmetry and fostering trust among the participants. This enhanced visibility assists organizations to detect inefficiencies, do away with fraud, and make prudent decisions. The other important measure, which is critical in nature, is traceability; which dwells on the capability of tracing a full lifecycle of a product, beginning at the point of origin to the end consumer. The implementation of IoT devices and blockchain allows tracking the history, location, and condition of goods at each stage of the supply chain, thus being able to track the history, location, and condition of goods at any time. This is mostly required in sectors like food, pharmaceuticals and logistics which require the authenticity and safety of the products. Increased traceability also enables faster detection of problems, i.e., contamination, delays, etc., and facilitates prompt corrective measures. Efficiency is used to determine how the system utilizes resources coupled with minimization of delays as well as general operational performance. Minimized manual interventions and more time-saving processes are the result of automated processes, real-time data monitoring, and smart contracts. This promotes quicker transactions, reduced operation and coordination of the supply chain participants. The proposed system makes use of transparency, traceability and efficiency that will predetermine the safer,istable and leaner supply chain that will improve productivity and satisfaction of the stakeholders.

4.2. Comparative Analysis

Table 1: Comparative Analysis

Parameter	Traditional System	Blockchain-IoT System
Transparency	45	90
Traceability	50	92
Security	55	95
Efficiency	60	88

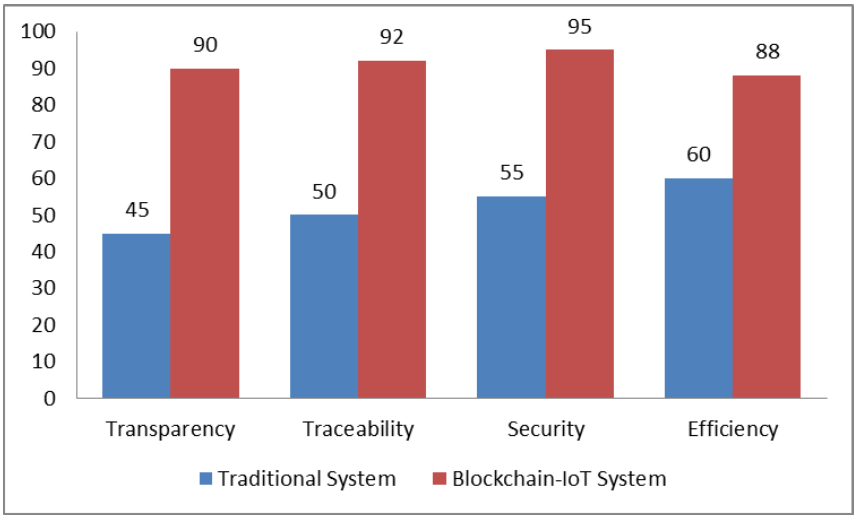

Fig 5 - Comparative Analysis

4.2.1. Transparency

Traditional supply chain system has relatively low levels of transparency with performance level of approximately 45%. This is largely attributed to centralized data storage and little flow of information among the stakeholders which can normally contribute to information gaps and lack of trust. Conversely, the Blockchain-IoT software greatly enhances transparency to the range of 90 percent with a decentralized and immutable ledger. Any entity can see real-time data that is verified, which guarantees transparency and eliminates the risk of fraud or manipulation of data.

4.2.2. Traceability

Tracing in the old system is at around 50 percent; because the process of tracing products on various stages is usually divided into parts, and is mostly subject to manual records keeping. This complicates the tracking of the origin or movement of goods without complications. Nevertheless, with the combination of IoT sensors and blockchain technology, the system based on the Blockchain-IoT system improves the traceability to approximately 92%. This enables constant track and recording of product data, they can have an end-to-end visibility and easily detect problems within the supply chain.

4.2.3. Security

In the traditional supply chains, the security stands at moderate, as half of it is around 55, because of factors including centralized databases and absence of good encryption systems. These systems tend to be susceptible to cyber attacks, information breach, and unauthorized access. Conversely, Blockchain-IoT system has a high level of security of around 95 percent. The reason is that blockchain employs cryptography and decentralized validation systems so that data is not vulnerable and can be secure, tamper-resistant, and cannot be changed by unauthorized agents.

4.2.4. Efficiency

Conventional systems have efficiency rate of about 60 since in most cases, the system is manual, paperwork and there is usually a delay in sharing of data. The inefficiencies may result in rising operation expenses and anti-timely decision-making. Compared to this, the Blockchain-IoT system is even more efficient, approximately at 88% because it automates business operations using smart contracts and allows real-time information exchange. This saves on time, minimizes human mistakes and improves the level of coordination among the stakeholders hence a streamlined supply chain that is also fast.

5. CONCLUSION

To sum it up, the convergence of the Blockchain and Internet of Things (IoT) technologies can be considered a radical method of bringing supply chain management systems to the age of modernization. The given system illustrates the possibility of this system to be used to considerably improve the visibility of the entire supply chain and efficiency of its work. Using IoT devices, it is possible to collect real-time data and monitor goods at all points in their supply chain related to their place, state, and treatment. When safely stored on a blockchain network, this real-time data will make sure that all information is correct, cannot be changed, and can be available to all authorized parties in a convenient way.

Transparency is one of the significant gains that have been realized in the proposed system. In contrast to the conventional centralized systems, in which information is many times disaggregated, and limited, the blockchain-based solution allows a common and non-amenable ledger. This will give each party, such as suppliers, manufacturers, distributors and consumers access to same and validated data. Consequently, there is a great improvement in trust of the stakeholders, and the possibilities of fraud or manipulation of the data are minimized. On the same note, traceability is enhanced since all the transactions and movements of goods are documented with time-stamp records and this means product movements are tracked end to end. This is more useful in the areas of the industry where authenticity and safety of products are paramount.

The other important benefit of the integrated system is security. Blockchain provides security against data hackage and cyber attacks through recognized cryptographic methods and decentralized authentication procedures. Also, the introduction of smart contracts standardizes most processes, including verification and the execution of payments, hence the reduced involvement of manual intervention and the elimination of human error. This would have a direct impact towards better efficiency, because operations will be quicker, more dependable and less expensive.

In spite of all these benefits, challenges still exist that should be solved. The questions of scalability, in terms of managing high data rates produced by Internet of Things devices, and in interoperability among the various blockchain platforms and the existing systems are only subjects of

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further study. The next-generation effort is to build more scalable architecture as well as standardized frameworks so as to have seamless integration of all this technology and also to make it used extensively. On the whole, the postulated Blockchain-IoT solution is powerful, safe, and efficient in the next-generation supply chain management.

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