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Evaluation of SongketChain: A Framework to Protect Unique Cultural Product using Blockchain Technology

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ABSTRACT

The traditional art of Songket weaving in Sarawak, Malaysia, embodies a rich cultural heritage that has faced threats from counterfeit practices, undermining the authenticity and economic value of this artisan craft. In response, this research introduces SongketChain, a blockchain-based framework aimed at preserving the originality and enhancing the traceability and transparency of Songket production. By leveraging both public and private blockchain technologies, SongketChain offers a novel approach to securing pattern rights and supply chain logistics, ensuring that each Songket product's journey from weaver to consumer is documented and verifiable. This study evaluates the effectiveness of SongketChain through a comparative analysis of blockchain platforms and consensus algorithms, highlighting the framework's potential to mitigate counterfeit issues and support the sustainable development of the Songket market. The findings demonstrate that blockchain technology can play a crucial role in protecting cultural heritage, offering a replicable model for other traditional crafts facing similar challenges. This research contributes to the discourse on the application of blockchain in cultural preservation and supply chain management, laying the groundwork for future explorations into its broader implications for the artisan sector. Quantitatively, the study showcases a 100% improvement in transparency and traceability across the Songket supply chain, effectively integrating over 12 unique data points per product to authenticate and secure the Songket production process from inception to customer delivery.

1. Introduction

Industries are facing significant pressure from customers and governments to adopt sustainable manufacturing methods due to prominent illicit trades, unethical production techniques, and fragile supply networks [1]. It is anticipated that industries would operate with transparency and improve visibility at both the operational and organisational levels [2]. An illustrative instance can be observed in the textile and apparel sector, wherein significant challenges arise as a result of variations in

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consumer demand, intensifying competition, product recalls, and the proliferation of counterfeit goods [3]. Songket is a type of fabric that is classified within the textile and garment sectors, known for its luxurious and intricate designs traditionally woven with gold or silver threads, making it a symbol of prestige and cultural heritage in various Southeast Asian countries [4].

The production of Songket, a traditional fabric, has been observed in the Malay Archipelago since the 9th century [5]. The item is an exquisite traditional Malay textile meticulously crafted using silk or cotton threads, adorned with vibrant metallic threads to create the Songket patterns. The Songket motifs are produced by the extra weft technique called *menyongket*, which involves the insertion and weaving of metallic threads into the fabric. Songket weaving is a meticulous, arduous, and monotonous procedure that demands a significant amount of focus from the weaver [4]. Hence, Songket holds significant value as a cultural heritage and historical treasure. Songket has distinct characteristics that set them apart from other commodities, as each Songket manufactured embodies a unique heritage and cultural heritage. Songket symbolises an individual's social standing and holds significance in customary occasions including wedding ceremonies, the festive period, and the portrayal of the community.

Nevertheless, the industry encounters specific problems. According to a report by Isa [5], counterfeit Songket is being imported from India at a more affordable price. Specifically, grade A Songket is priced at MYR 900 each pair, while grade B Songket is priced at MYR 500 per pair. Local vendors typically increase the price of counterfeit Songket by between MYR 3000–MYR 7000, so negatively impacting the local Songket community and the economy. Songket made by hand in Kampung Rajang, Sarawak, range in price from MYR 900 to MYR 10000, depending on their quality and pattern. These Songket are considered to be among the finest manufactured, as their production is not commercialised. In order to enhance the existing productivity of the Songket market in Sarawak, it is imperative to implement a more intelligent solution for pattern rights as the market continues to expand. One potential solution involves the utilisation of blockchain technology for the purpose of managing Songket patterns.

The objectives of this research are as follows:

i. To formulate a framework for providing traceability and transparency for *the Songket* supply chain
ii. To study a list of blockchain technologies (public blockchain such as Ethereum and private blockchain such as Hyperledger) and determine which is most suitable to apply to the solution
iii. To evaluate the transparency and traceability of blockchain technologies using the proposed framework

This study aims to bridge this gap by proposing SongketChain, a pioneering blockchain-based framework designed to protect the unique patterns of Songket and enhance its supply chain's transparency and traceability. The contribution of this research is twofold. Firstly, it introduces an innovative application of blockchain technology tailored to the unique needs of the traditional textile industry, offering a blueprint for safeguarding cultural heritage against counterfeiting. Secondly, by evaluating the effectiveness of SongketChain using a variety of blockchain platforms and consensus algorithms, this study sheds light on the potential of blockchain technology to revolutionize supply chain management for traditional crafts, setting a precedent for future research in this domain. Through SongketChain, this research not only addresses the pressing need for a solution to the counterfeit crisis but also contributes to the broader discourse on leveraging technology to preserve and empower cultural heritage in the digital era.

In order to apply blockchain to business processes efficiently, blockchain and business process characteristics must be identified. Inconsistency in confirmation settlement that heavily relies on the implementation of consensus protocols poses a major challenge in business process operations, especially those that are time-critical [6]. This study will focus on traceability and transparency.

Blockchain consists of private and public blockchains. The availability of the blockchain is one of the main purposes of this study. The difference between the public and private blockchains is that they both use different consensus algorithms to approve the creation of transactions, and the difference in algorithms on both blockchains would affect traceability and immutability. This study will adopt two blockchain frameworks to compare each of the blockchain properties and how they will affect traceability and immutability, which will fulfil the purpose.

According to [7], the name blockchain stems from its technical structure: a chain of blocks. Each block is linked to the previous block with a cryptographic hash. A block is a data structure that allows for the storage of a list of transactions. Transactions are created and exchanged by peers of the blockchain network and modify the state of the blockchain. As such, transactions can exchange monetary amounts but are not restricted to financial transactions only and, for example, allow for the execution of arbitrary code within so-called smart contracts. At their basic level, they enable a community if users record transactions in a shared ledger within that community, such that under normal operation of the blockchain network, no transaction can be changed once published [8]. There are two types of blockchain: the public blockchain and the private blockchain. Different types of blockchains have different types of consensus algorithms for different purposes.

1.1 Background on Songket Production Supply Chain

The textile and clothing supply chain is a network with numerous materials many possible permutations and complicated processes. Due to dynamic customer preferences and volatile trends, textile and clothing products have a short shelf-life with multiple styles and collections every season [6]. Songket is one of the textiles that continuously produced with less security and documentation.

Songket manufacturing process is a complex process that consumes a lot of time and energy. One single Songket can take up to five months to be complete because the process to produce one Songket requires a lot of attention and detail. Songket manufacturing process will be explained briefly in this section which will justify why blockchain technology will be implemented for the framework.

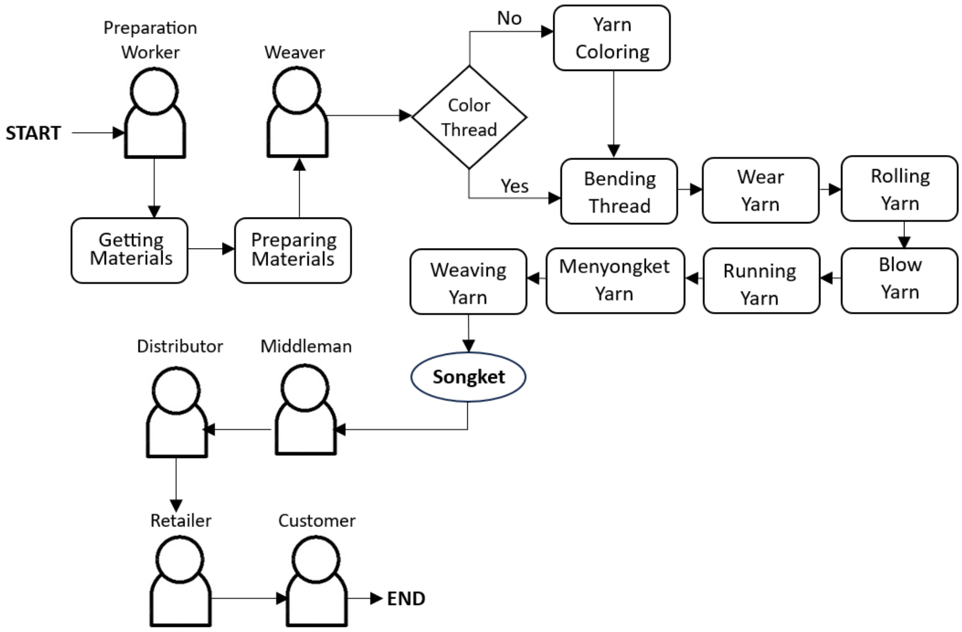

Fig. 1. Songket Manufacturing Process Flowchart

Based on Figure 1, the Songket manufacturing process starts with the preparation worker getting materials and preparing them for Songket making. The weaver will determine whether the thread needs to be coloured or not, and the thread will undergo a bending process. After the bending process, the length of the thread will be determined through the wear yarn process, and the moulded yarn will be rolled on the roll board according to the width of the gear tooth and long loser. Loose threads are inserted into the gear to be trimmed in the blow-yarn process. Next, the foreign threads will be stripped to prevent interruptions for the next process of running the yarn. Then, in the *menyongket* yarn process, Songket cloth is woven with a three-point or five-point technique. The final process for the Songket manufacturing process is weaving yarn, where loose yarn will be stepped by feed yarn to be fabricated. For full-patterned Songket fabrics, golden threads are stretched through a gold thread piston to produce flower pattern embroidery or full-pattern design decoration. For a patterned Songket pattern or scattered flower pattern, gold threads are stretched through attempts to obtain the desired motifs. Usually, after a thread of gold is ripped, it is beaten (beat) and then followed by two threads of feed. Weavers will convert button threads through rotation and predefined patterns. This process is repeated to produce a Songket cloth.

Due to the complex process of the manufacturing side, adopting a blockchain-based traceability system is one of the possible solutions to address these challenges and ensure a seamless exchange of information between supply chain partners. This system can track and record all the information related to each stage of product transformation while safeguarding crucial and sensitive data throughout the supply chain [7,8].

1.2 Blockchain Technology

There are two different types of blockchain that are available for the current research which are public blockchain and private blockchain [9].

1.2.1 Public blockchain

One of the popular alternatives for Bitcoin is Ethereum which borrows heavily from Bitcoin architecture. It is a public blockchain with a built-in cryptocurrency called Ether [10]. Ethereum enables decentralized execution of the “world computer” by providing a platform for blockchain-based smart contracts, which are programs that other Ethereum addresses/actors can audit and participate in. For instance, a contract can encode a fair lottery that is auditable by anyone on the network [11]. Furthermore, Ethereum has rules and penalties that based on smart contracts to come to an agreement while enforcing the obligations. Developers can create various applications on Ethereum by constructing and developing smart contracts, which will be executed in the Ethereum virtual machine (EVM). Normal users can transfer Ether to others and use those applications by invoking smart contracts. Ethereum requires users to pay transaction fees for protecting it from frivolous or malicious tasks that will exhaust the resources [12]. Ethereum currently uses a proof of work (PoW) protocol, but the plan is to update its network to proof of stake (PoS). There are other emerging public blockchain such as Ripple, Stellar and many more but what makes Ethereum stand out from the crowd is its design of purpose [13]. Ethereum serves more like a general blockchain for a variety of purposes by supporting creation of dApps and smart contracts is EVM infrastructure [14].

1.2.2 Private blockchain

A private blockchain is a permissioned blockchain**.** Private blockchains work based on access controls which restrict the people who can participate in the network. There are one or more entities which control the network, and this leads to reliance on third parties to transact. In a private blockchain, only the entities participating in a transaction will have knowledge about it, whereas the others will not be able to access it. Hyperledger Fabric is a permissioned blockchain infrastructure providing a modular architecture with a delineation of roles between the nodes in the infrastructure, execution of Smart Contracts and configurable consensus and membership services [15]. Consensus is pluggable for Hyperledger Fabric depending on application specific requirements, various algorithms can be used hence no mining is required. Table 1 shows the comparison between the characteristics between Ethereum and Hyperledger Fabric.

Table 1
Comparison Between Ethereum and Hyperledger Fabric

Characteristics	Ethereum	Hyperledger Fabric
Founded Date	July 2015	July 2017
Currency	Ether	None
Governance	Ethereum Developers, Enterprise Ethereum Alliance	Linux Foundation, IBM
Consensus	PoW (Proof of Work)	PBFT (Practical Byzantine Fault Tolerance)
Network	Permissionless, Public	Permissioned, Private

1.2.3 Consensus algorithms

A consensus mechanism in blockchain plays a crucial role on generating and validating a transaction. Consensus algorithm can be categorized according to the type of network of blockchain, either public or private [16]. Cryptocurrency is one of the main factors that determine what kind of consensus applicable for public blockchain as some mining process is required. On the other hand, consensus in private blockchain has more conserved approach on involving the nodes for validation of transactions.

Two major cryptocurrencies, Bitcoin and Ethereum use Proof of Work (PoW) consensus algorithm to achieve consensus on new block creation. The basic idea of PoW is to let all members compete to solve a CPU-bound puzzle and whomever solves the puzzle first gets to create the next new block, which is later verified by all other members [17]. Public blockchain usually has their own cryptocurrency, such as bitcoin and ether. These cryptocurrencies will be rewarded to a miner whoever solved complex computational puzzle that led to creation of new block in the blockchain network. However, PoW faces criticism, whereby [18] mentioned that it consumes a lot of energy given the computationally heavy algorithm. Furthermore, PoW is unsustainable in long run because it has a high latency of transaction validation which use a lot of electricity for concentrated mining power.

This issue is a major concern for Bitcoin and Ethereum, thus they proposed another consensus algorithm which are Proof of Stake (PoS) for their system. Under this algorithm there are no more miner involved in the creation of new block, but they are known as “validator”. Rather than mining the blockchain, they validate the transactions to earn a transaction fee and no mining is required, the creator of a new block is chosen in random, depending on the validator’s wealth which is also defined as stake [18]. However, this algorithm comes with another problem which is known as “Nothing at Stake”.

Voting consensus algorithm are preferable in private blockchain, where the nodes are known. This is the fundamental distinction contrasted with Proof based consensus calculations, where nodes are regularly allowed to join and pull back from the checking system. In vote base consensus it requires to exchange the results in the network before appending the block to the blockchain. If a peer wants to append a block to its chain, a check is to be made that at least x (x is the threshold set) peers agree on it. If there are f failed nodes, then for a decision f plus one should be operable. There are two types voting consensus which are Byzantine Fault Tolerance (BFT) and Crash Fault Tolerance (CFT).

On the other hand, there are Crash Fault Tolerant (CFT) and Byzantine Fault Tolerant (BFT) that many algorithms inherit from, both are different but relatable. According to [19], the definition of CFT can be understood as a system that is tolerant to component (software or hardware) malfunctioning. Kafka and Solo are instances of CFT which both serves as consensus algorithm in Hyperledger Fabric platform. In a blockchain network, Kafka, and SOLO works as ordered that determine which transactions to add into the blockchain in what order, and due to it is a CFT based solution it will still allow transactions happened when some of the nodes in the blockchain is down. For instances of BFT, there are Practical Byzantine Fault Tolerant (PBFT) and Simplified Byzantine Fault Tolerant (SBFT).

The Practical Byzantine Fault Tolerant (PBFT) first assumes that there are independent node failures and manipulated messages propagated by specific, independent nodes [20] in a blockchain network. All the nodes in the PBFT are ordered in a sequence with one node being the primary node (leader) and the others referred to as the backup nodes. For the PBFT model to work, the assumption is that the number of malicious nodes in the network cannot simultaneously equal or exceed 1/3 of the overall nodes in the system. PBFT works effectively and safety as long as at most (n-1)/3 nodes, where n represents total nodes, are malicious or faulty at the same time. Coyler PBFT consensus (called views) consists of 4 phases as below [20]:

i. A client sends a request to the leader node to invoke a service operation.
ii. The leader node multicasts the request to the backup nodes.
iii. The nodes execute the request and then send a reply to the client.

iv. The client awaits f + 1 (f represents the maximum number of nodes that may be faulty) replies from different nodes with the same result. This result is the result of the operation.

The Simplified Byzantine Fault Tolerant (SBFT) is an improved consensus algorithm over PoW for permissioned network blockchain. SBFT involves a validator who bundles proposed transactions and forms a new block. Unlike the Bitcoin blockchain, the validator is a known party, given the permissioned nature of the ledger, consensus is achieved as a result of a minimum number of other nodes in the network ratifying the new block. In order to be tolerant of a Byzantine fault, the number of nodes that must reach consensus is 2f+1 in a system containing 3f+1 node, where f is the number of faults in the system. For example, if we have 7 nodes in the system, then 5 of those nodes must agree if 2 of the nodes are acting in a faulty manner [21].

Proof-of-Authority (PoA) is a consensus algorithm which can be used for permissioned network blockchain. It uses a set of 'authorities', which are designated nodes that can create new blocks and secure the ledger. Ledgers using PoA require sign-off by majority of authorities for a block to be created [21].

Torneo consensus algorithm are one of the private blockchain consensus. When a node wants to join the blockchain it asks the right for this by sending a request to every node. If the node is confirmed as authorized, it will receive the blockchain, the right to create a transaction and the right to try to add the next blocks. Every 15 seconds (this time can be changed), a request is sent to every connected node to pick randomly a number between 0 and 1. Every node will broadcast this number and wait to receive every random number. When a node has received every random number, it selects the biggest one and sends it to the node which had selected this number a "winner vote". When a node has received as many "winner votes" as the number of connected nodes, it means that it is the winner, and it has the right to add the next block. Then the node has to mine the block in the same way as a proof of work consensus algorithm but with a very low difficulty allowing a normal computer to find the nonce value in less than a second. In this way the loss of time and the energy waste are avoided [22].

It is important to verify which consensus algorithm that are suitable for the solution. Some consensus algorithms are made for different application. For instance, CFT, BFT and PoA might be more suitable than to implement in the solution compared to PoW and PoS as it does not require mining process that consume heavy computational power which is not needed in a supply chain transaction when creating new block.

3. Methodology

3.1 Framework for Transparency and Traceability

This section addresses the research methodology that will be implemented based on the literature review, utilizing blockchain technology discussed in previous section. The main contribution of this paper is a novel framework which provides a generic implementation of *Songket* supply chain. To our knowledge, no such attempt has been made to design and develop such framework to protect unique pattern of *Songket*. The value of such framework is to provide an implementation blueprint for system designers and system developers as a guideline to design and develop a *Songket* supply chain system. The *Songket* supply chain will be addressed as SongketChain.

3.2 Assumptions

Figure 2 shows the weaver actors in the Songket Retail chain. The *Songket* supply chain generic framework presented in this paper is based on the following key assumptions:

i. Preparation worker(A,B,C) and Weaver(A,B,C) all have transaction with Merchant.
ii. Preparation worker(B,C) and Weaver(B,C) have a transaction with Merchant.
iii. Preparation worker C and Weaver C have a transaction with Merchant.

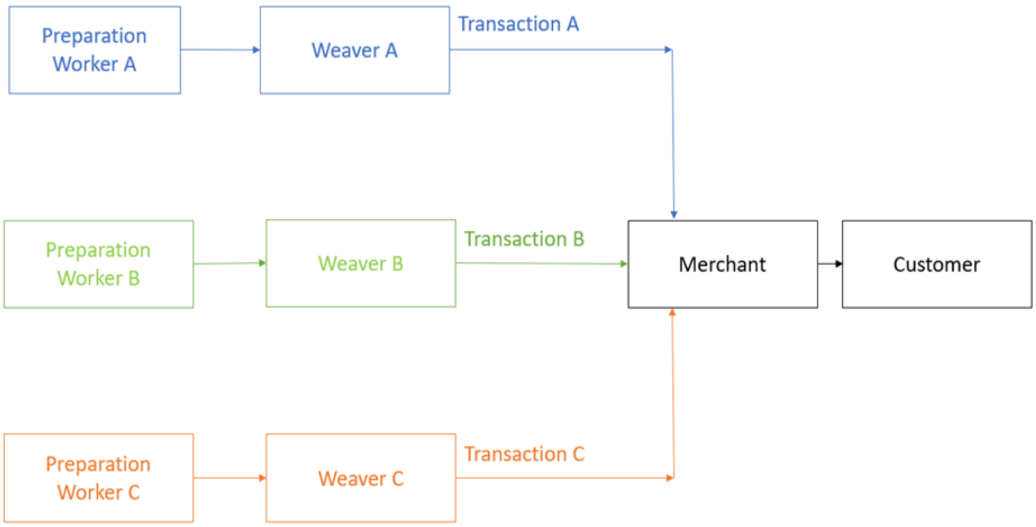

Fig. 2. Weaver Actors in the Songket Retail Chain

The term framework refers to an application-level development blueprint which provides two important information. Firstly, the framework shows component required for the Songket supply chain to function, plus the logic behind of each of the sub-components. Secondly, it provides the logical flow of the Songket supply chain process based on blockchain technology. Beside the term framework, there are several other terms used throughout this chapter that need explanation and definition. An entity in the framework refers to the parties involved in the Songket supply chain, namely the producer, supplicant, and customer. Each entity contains an agent and each entity's action is conducted through the agent. In the context of the framework, an agent is defined as a computer program that acts on behalf of an entity (x). An engine in the framework is a conceptual term that implies a set of processes to achieve and outcome.

3.3 Transparency and Traceability

Retail chain transparency is about providing information about the supply chain parties, thereby mapping the entire supply chain network. Retail chain traceability is about providing information about the product level and mapping the product flow from the source. The relationship between retail chain transparency and traceability can be described as traceability depends on transparency, and higher transparency will provide higher traceability strength, as shown in Figure 3.

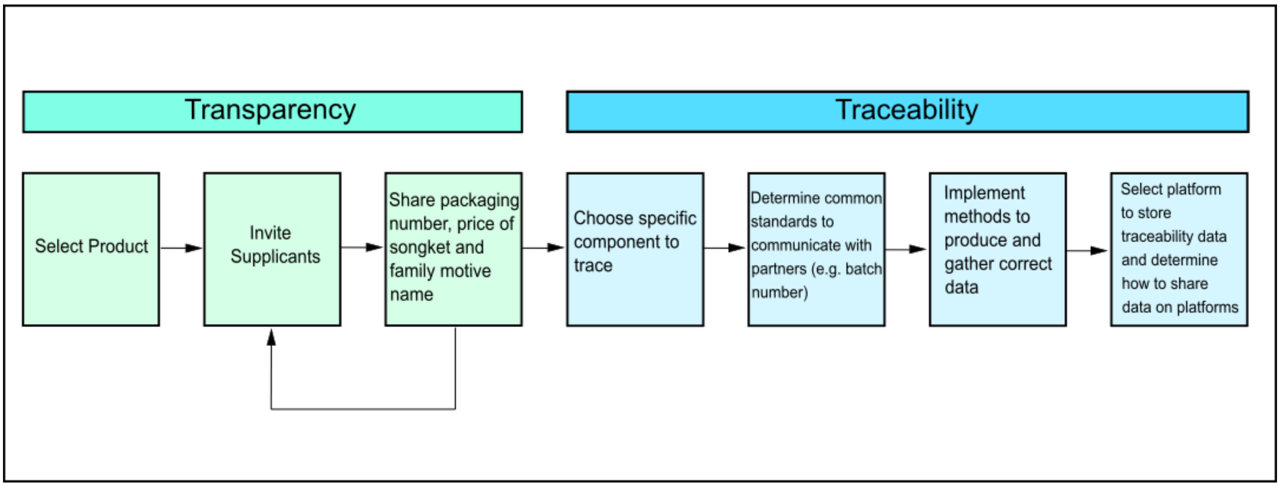

Fig. 3. Transparency and Traceability mechanism

To produce authentic product and minimize counterfeit issue, transparency and traceability can be used as a functional requirement that contribute to product authenticity. Transparency consists of two quality factors which are to provide information and to provide mechanisms. To achieve transparency, the system must fundamentally provide information about data, processes, and events (in the form of evidence).

i. Data: Refers to information that are crucial in the system
ii. Processes: Refers to what happening when data are stored in the system
iii. Events: Refers to situation that happens after one process is complete

3.4 Generic System Architecture

A *system* is defined as a group of entities that interact with each other. In the context of *Songket* supply chain, we have defined three type of entities that make up the system, which are producer, supplicant, and customers. In the following section, the supplicant will be known as distributor, middleman, and retailer that work together before sending the product to the customers. Figure 4. illustrates the generic system architecture for Songket supply chain.

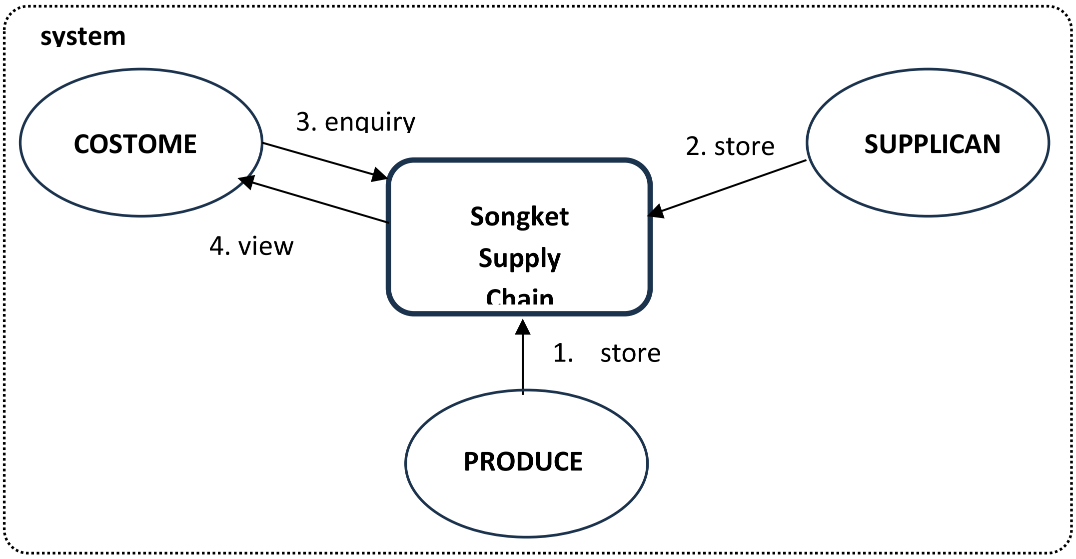

Fig. 4. General architecture of the system

A relationship in the system is defined as a connection between two entities in the system which is represented by an arc connected between those two entities, as shown in Figure 4. The connection represents the action or process between the entities. Store process in the system is the process of registering the product in the system through producer and supplicant. Enquiry is the process of requesting information from the system and view is the process gaining information after the enquiry process.

3.5 General View of the Framework

Figure 5 shows the general view of the framework for Songket supply chain. The framework consists of various module located in different entities. One property of the framework is that it should be as transparent as possible so that it is possible to implement the framework in the Songket market. For example, the storage of data module uses the accuracy as the metric validated by the module, but the storage of data module can also cater for other metrics such as currentness and availability. One limitation is that, in its current implementation, the module (and subsequently the framework) is unable to cater for composite metric (combination of several metrics) and can be addressed in future works.

Several processes such as the register, search, and buy are not discussed form the implementation from the point of view since those processes are part of underlying specific service provisioning system implementation, such as web services.

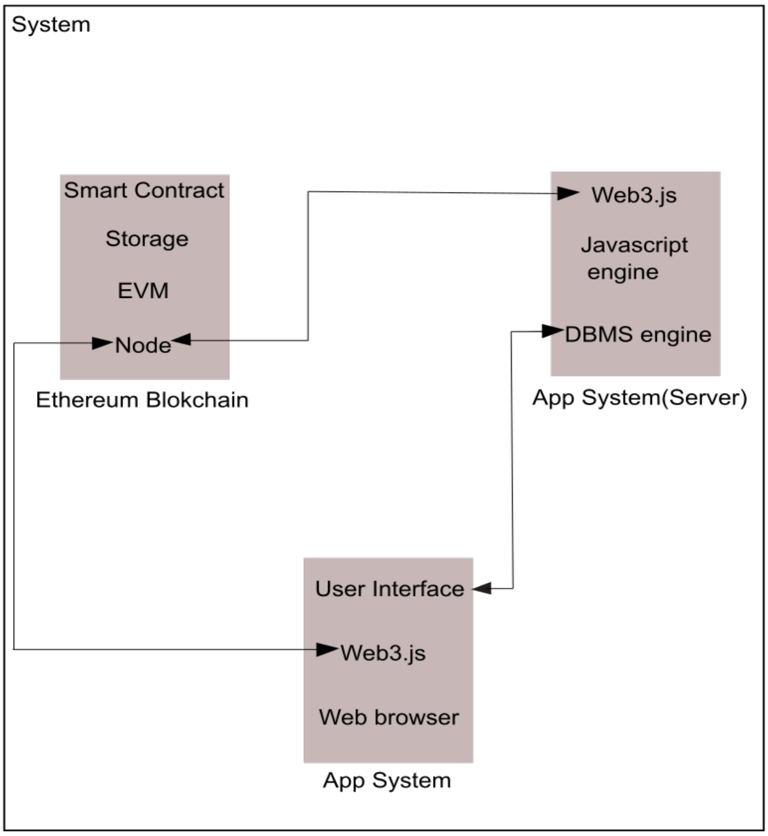

Fig. 5. General View of the Songket Supply Chain Framework

3.6 Store Process (Data Input)

Figure 6 illustrates a simplified representation of the Songket supply system and its main phases. As the flow of product went further, more and more ledgers will be appended to the blockchain system as there will be new information generated every time the product is transfer to a new owner.

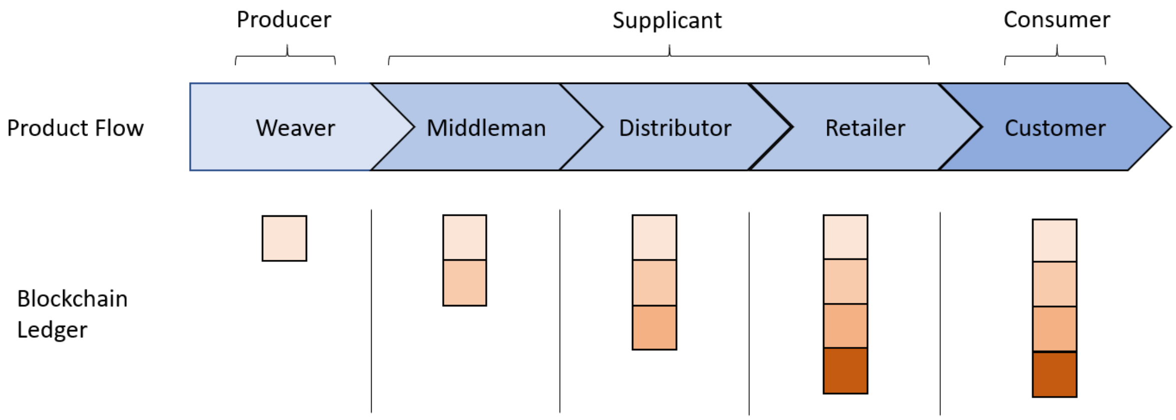

Fig. 6. Flow of Product on Blockchain Ledger

The backbone of decentralized applications is the creation of smart contracts. It is the foundation of every decentralized application. Once created and started, even the creator cannot change it. This application "smart contract" is like a voting system. Weavers need to put their products into the app, just like entering the date. Then, customers need to choose their products. During the voting process, the "voting" of the event is initiated by calling the "votedEvent" function. Some metadata are passed so that we can view all activities on the blockchain. We can then "watch" this event. Inside the pseudo code, if the "votedEvent" is triggered, the suggested system log will be logged to the console. We will also re-render everything on the page. This is one of the voting systems of the process, After the voting is over, the decided product will reach the customer, and the farmer repeats the process. Figure 7 shows the Ethereum pseudo-code involved in the smart contract, which shows the creation of a constructor when product 1 and product 2 are called.

```
create contract;
    constructor weaver1 = product 1
        credentials;
        add id
        add name
        add qCount

If credentials not available
    repeat credentials;
Else
    mapping;
    map weaver qCount
    add WeaversCount

        function addWeaver
        WeaversCount++

    constructor addWeaver(product 1)

end
```

Fig. 7. Pseudo-code of the Framework

3.7 Data Dictionary for Blockchain Ledger

Table 2 provides insights into the data used for experimental research in the framework. The data is populated to the stage before the customer. The customer is assigned read access in the retail chain network. Please note that in actual implementation, the system will generate more technical data and metadata. This table provides an overview of the data related to the retail chain. This is when creating a new transaction or product from one owner to another. Required when transferring. Some data such as location and date and time seems to be duplicated, but this is necessary in the process, because at each stage of supply changes, these data need to be updated accordingly instead of overwriting previous data values. It is required as part of the backtracking process.

Table 2
Data Dictionary for Blockchain Ledger

Weaver	Middleman	Distributor	Retailer
Family Motive Name	Family Motive Name	Family Motive Name	Family Motive Name
Location	Location	Location	Location
Created DateTime	Created DateTime	Created DateTime	Created DateTime
Songket No	Songket No	Songket No	Songket No
Material	Packaging No	Packaging No	Packaging No
Price	Price per Songket	Price per Songket	Price per Songket
Technique	Quantity	Quantity	Quantity

If each table contains at least four transparency data. This information is defined as transparency data and consists of the Family Motive name, Location, Created DateTime, and Songket No. The name represents the family motive of an entity, by creating a family heritage that currently owns the current ledger and is transferred to another party by itself or with it. The location and creation date and time of this ledger when it was created or transferred.

3.8 System Architecture for SongketChain Framework

Objective of this system architecture is to illustrate how the SongketChain framework can be realized through software system. This system will be used as validation platform in the next section. The following Figure 8. shows the system architecture.

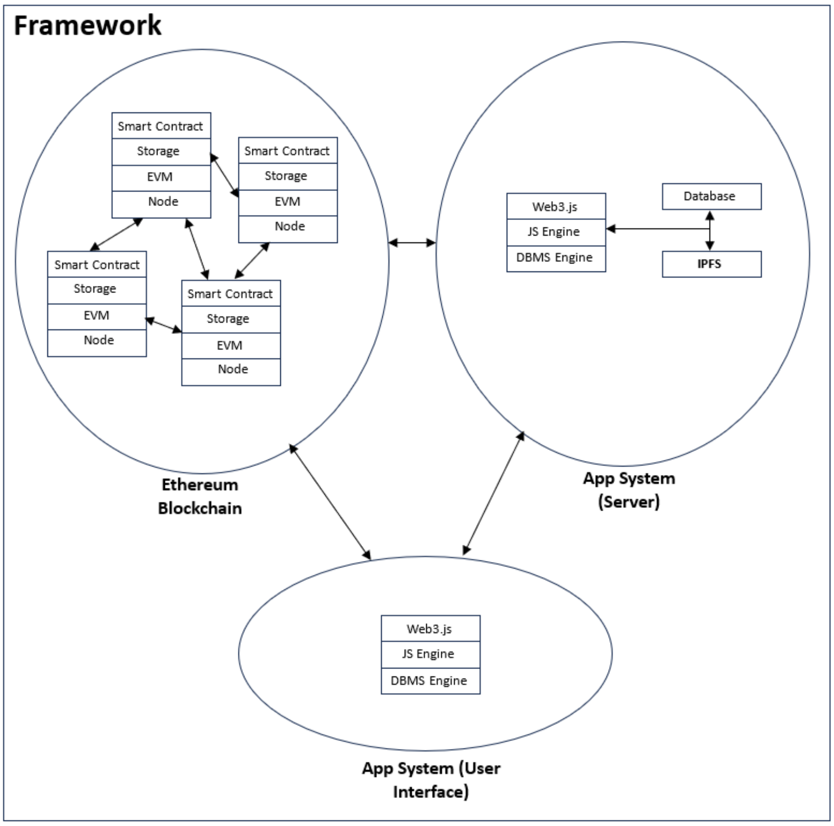

Fig. 8. System Architecture

3.8.1 General sequence of interactions

Customers will get transparent information about the product from the initial level of the product and get detailed information about the weaver. If the customer is satisfied, he will get more products from weaver. Moreover, weaver get the best prices for their products, and intermediaries will not make more profits. The whole activity is divided into multiple phases, such as login phase, execution phase, verification phase, order phase and payment phase. Figure 9 shows a use case diagram that describes the various stages and the stakeholders involved in these stages. During the login phase, every stakeholder involved in this system should log in to the online portal. Weavers can add new products to the portal during the execution phase.

During this execution phase, all other stakeholders can access the product. Before obtaining the product in the verification phase, stakeholders should obtain the consensus of all other stakeholders. All other stakeholders can access the product during this execution phase. A stakeholder should get a consensus from all other stakeholders before obtaining the product in the validation phase. At this stage, customers will obtain products based on the consensus given by farmers and retailers. After successfully accepting his payment request, the product will be delivered to him at the payment stage.

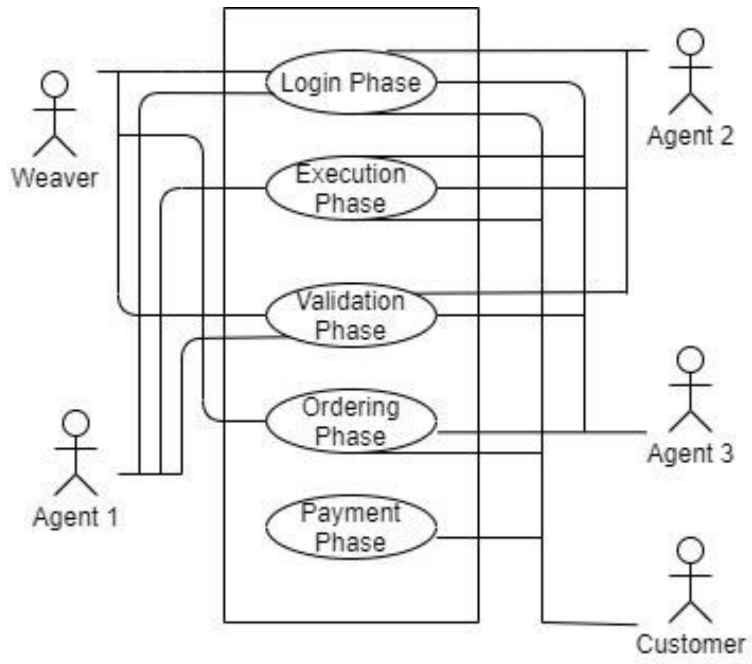

Fig. 9. Use Case Diagram

Figure 9 shows the sequence diagram among the various stakeholders in the proposed system F2C. The various activities of multiple stakeholders are shown in Figure 10. These activities are arranged by numerical representation. The first activity is the process of logging into the online portal. All stakeholders should carry out this activity. Every stakeholder who wants to participate in the supply chain process should log in to the portal. Through the username and password, all stakeholders can enter the login portal. After successfully completing the login process (Activity 2), the product that the weaver will add is the third activity. In this way, the genesis block of the product can be created in the necessary fields.

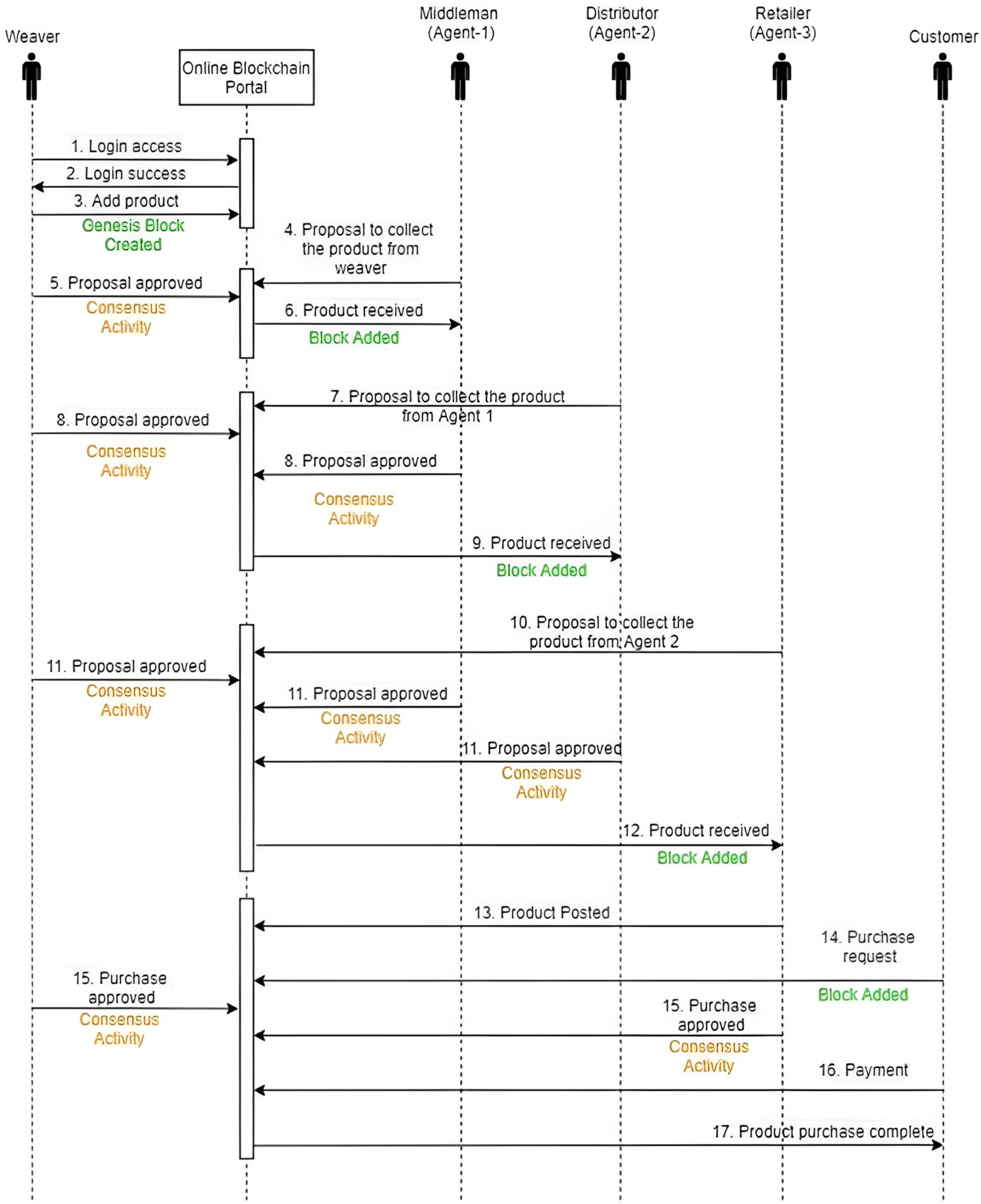

Fig. 10. Sequence Diagram among Stakeholders

The fourth action involves the stakeholders who act as agents or processors demonstrating an elevated level of interest in procuring items from the weaver. Following the acquisition of consent from the weavers (activity 5), Agent 1 will proceed to acquire the product (activity 6). The inclusion of his data regarding the acquisition of products from weavers is appended as a single unit alongside the initial genesis block. The process of creating the blockchain for this product has commenced.

Agent 2/distributor will subsequently demonstrate interest in providing shipping assistance to facilitate the transportation of the product from its current location to another destination. another (activity 7). His proposal will be approved by the stakeholders' weavers and agent 1 (activity 8). After successful approval, the product will be transferred from Agent 1 to Agent 2 for transportation (Activity 9). His information about the product received from agent1 is added as a block in the blockchain. Similarly, the Agent 3/retailer shows his proposal to collect products from the distributor (activity 10).

After obtaining the consensus approval of the stakeholder weaver, Agent 1 and Agent 2 (Activity 11), he will receive the product (Activity 12). His information about receiving products from Agent 3 is added as a block in the blockchain. Then, Agent 2 will publish the product to be sold on the online portal (Activity 13). Then, the customer will send a request to purchase the product (activity 14). After the farmer and Agent 3/retailer approve, his request will be approved (activity 15). Next, the customer will go through the payment process (activity 16). Finally, after successful payment, he will receive the product (activity 17).

4. Result and Discussion

The application of the proposed framework is demonstrated through an example blockchain program written in Solidity, HTML and JavaScript on Ryzen 5 3600 CPU 3.59 GHz with 16 GB memory running on Windows 10. This program also uses Ganache Ethereum Blockchain, InterPlanetary File System (IPFS) and Metamask. The blockchain is designed for one channel connecting supply chain partners that involved in the production of Songket. The supply chain starts with Songket manufacturer and passes through different supply chain partners until the customer get the final product. The example demonstrates the application of the blockchain-based framework in tracking and tracing transactions and collect traceability information. The follow section explains the main components of the example blockchain.

4.1 Main Components

4.1.1 SongketChain stakeholders

i. <u>Weaver:</u> Weaver represents a group of individuals that weave Songket with the raw materials they get from the preparation worker and produce the Songket within the time frame of three to six months. Completed Songket will be transferred to the next partner(distributor) while the location of the Songket is being updated into the blockchain. Each batch is assigned with a unique IPFS link provided by IPFS.
ii. <u>Distributor:</u> Distributor is a group of logistic service provider that receive Songket from weaver. Distributor transports produced Songket to respective the respective partner(retailer). Distributor will update the location of the product and it will add the data in the blockchain.
iii. <u>Retailer:</u> Retailer receives the finished and ready-to-sell Songket product from distributor. Retailer will update the location of the product and data will be updated in the blockchain ledger. Retailers are the last partner that can update the location in the blockchain ledger.

4.1.2 Smart contract

A smart contract is a self-executing contract in which the terms of an agreement between a buyer and a seller are written directly in lines of code. The code and protocols exist on a distributed, decentralized blockchain network. Code controls execution, and transactions are traceable and irreversible. Smart contracts enable trusted transactions and agreements between different anonymous parties without the need for a central authority, legal system, or external enforcement mechanisms.

In this blockchain application, data of the Songket is embedded in the smart contracts. The smart contract will be compiled (after logging in with Metamask) in Remix Ethereum IDE and the contract ABI with the contract address will be copied and pasted in the JavaScript file. Data of the produced Songket will be gained through a user interface.

4.1.3 Permission

Each partner in the blockchain would have to register in the system in order to use the system. User data will be stored in the local database. Each partner will be assigned according to their role in the system. Only weaver can add the Songket data and information in the system. Each partner can update the location of the product in the system except for customer since customer can only read the details of the product.

4.1.4 Consensus

The blockchain system run on a single computer system. The first peer generates all transactions; Metamask will link the blockchain with SongketChain. After verification, the transaction is written into a block containing the block ID, the hash of the previous block, the transaction (and traceability information), and the address of the verifying peer. For demonstration purposes, random numbers are generated for each block following a proof-of-work consensus mechanism.

4.1.5 Transactions

The blockchain system demonstrates a simple scenario of trading and transfer of Songket product from weaver to retailer in sequential order by simulating the material flow in a typical supply chain. In practice, there may exist multiple partners at each supply chain stage that are connected on the blockchain network over different channels. Similarly, a supply chain actor may procure assets from multiple weavers, and subsequently transfer these assets to multiple customers.

4.2 Implementation of SongketChain Framework

SongketChain users need to login into the system in order to use the blockchain system as shown in Figure 11. If the user is not registered, user need to register their account as shown in Figure 12. For the demonstrative purpose, first a transaction is performed by weaver uploading the image to IPFS using the “Upload Image” (as shown in Figure 13) page and get the link given by the IPFS.

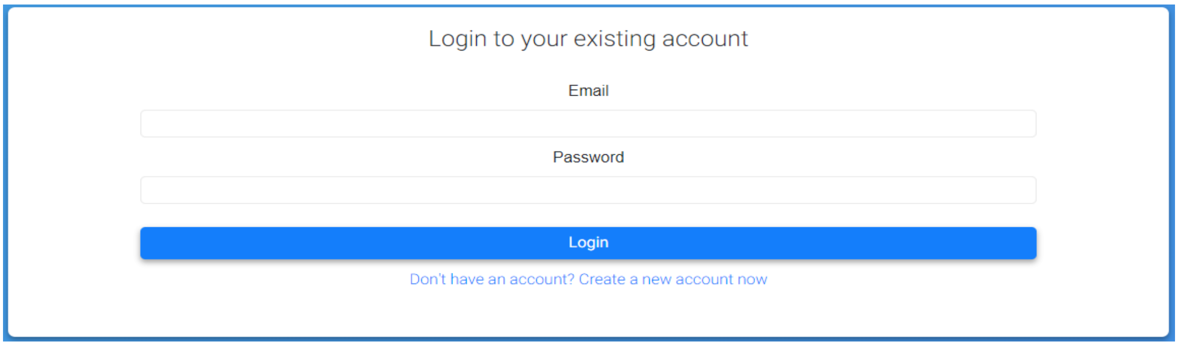

Fig. 11. Login Page for SongketChain

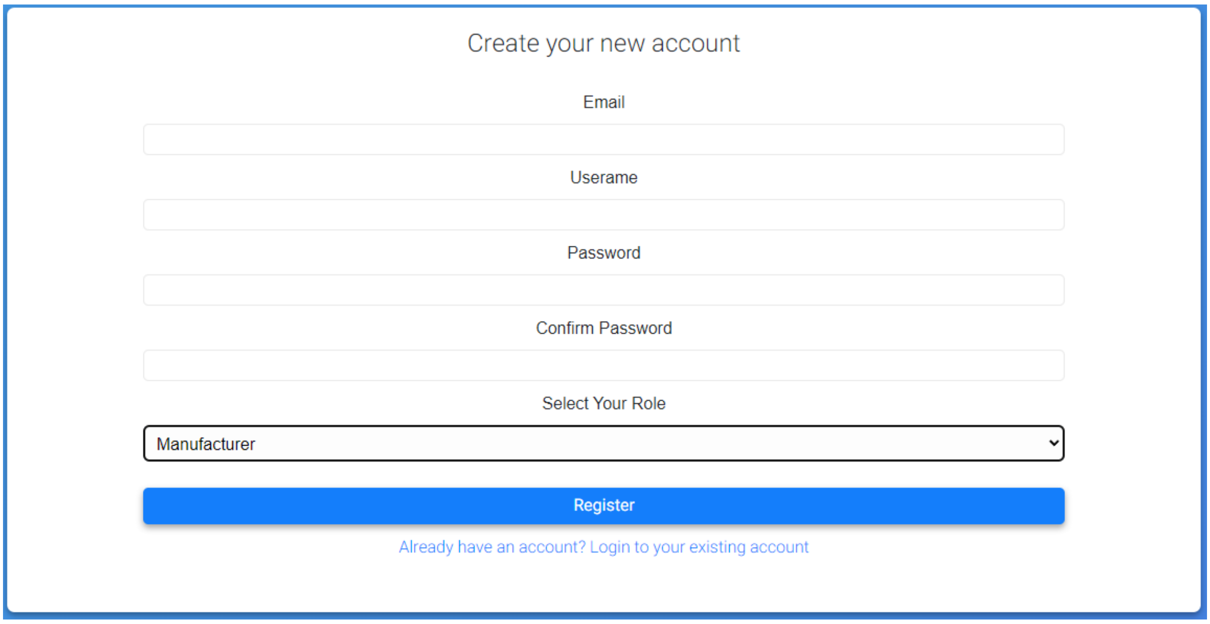

Fig. 12. Register Page for SongketChain

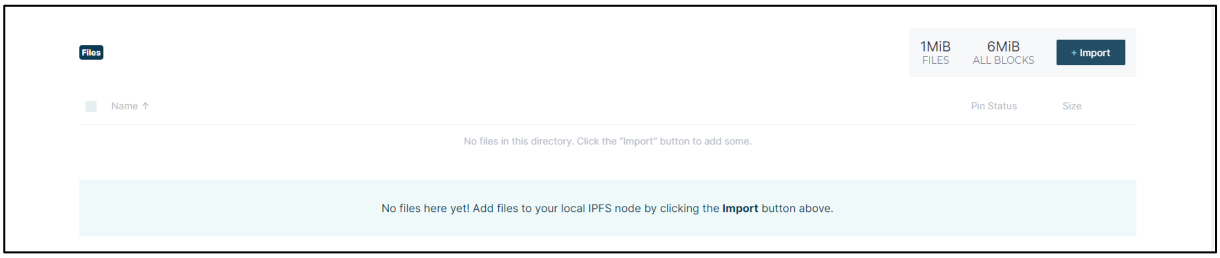

Fig. 13. Upload Image Page for SongketChain

Then, product is created by adding data using the “Add Product” (as shown in Figure 14) and it will be verified and recorded as a block in the blockchain with a QR image.

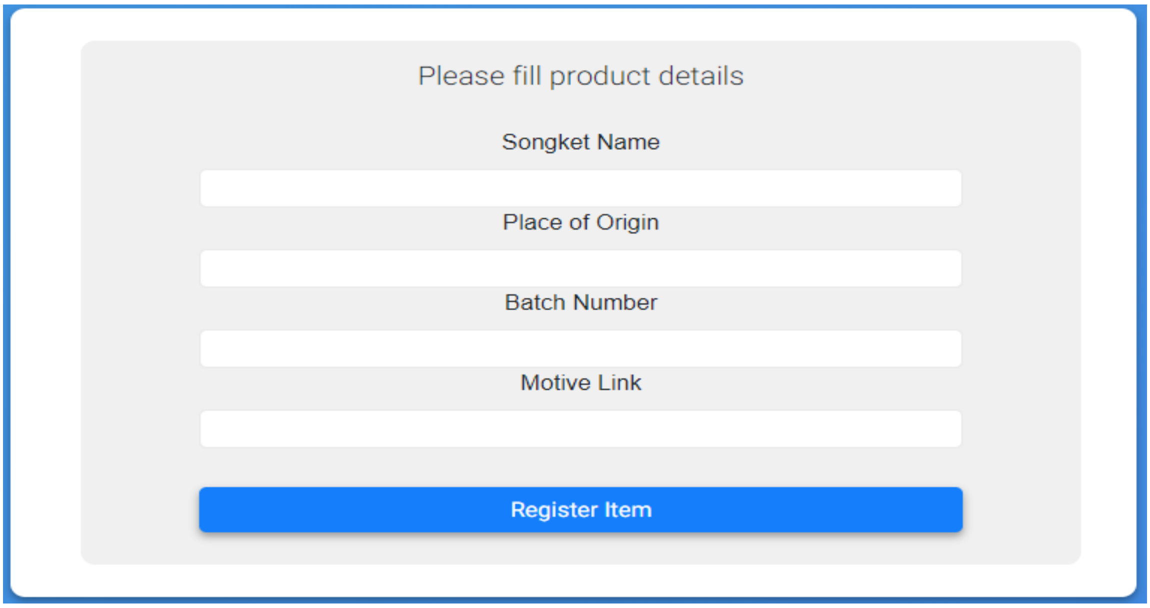

Fig. 14. Add Product Page for SongketChain

Weaver then will update the location of the Songket product by using the QR image as shown in Figure 15, and the data will be store on the block. As previously explained, distributors will log in into the system and update the location of the product by using the QR image once they get the product from the weaver. Data of updated location will be updated to the block.

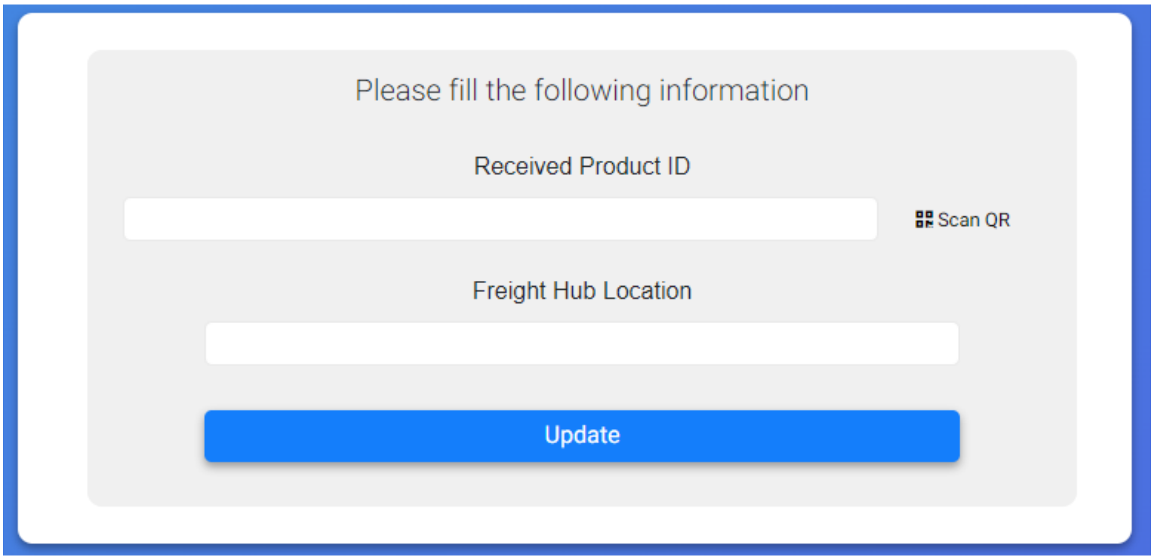

Fig. 15. Update Location Page for SongketChain

Then, retailer will log in into the system and update the location by using QR image once the product is received by distributor. Data of location will be stored in the blockchain. Customers can login into the system to verify the originality of the product by tracing the location updated as shown in Figure 16.

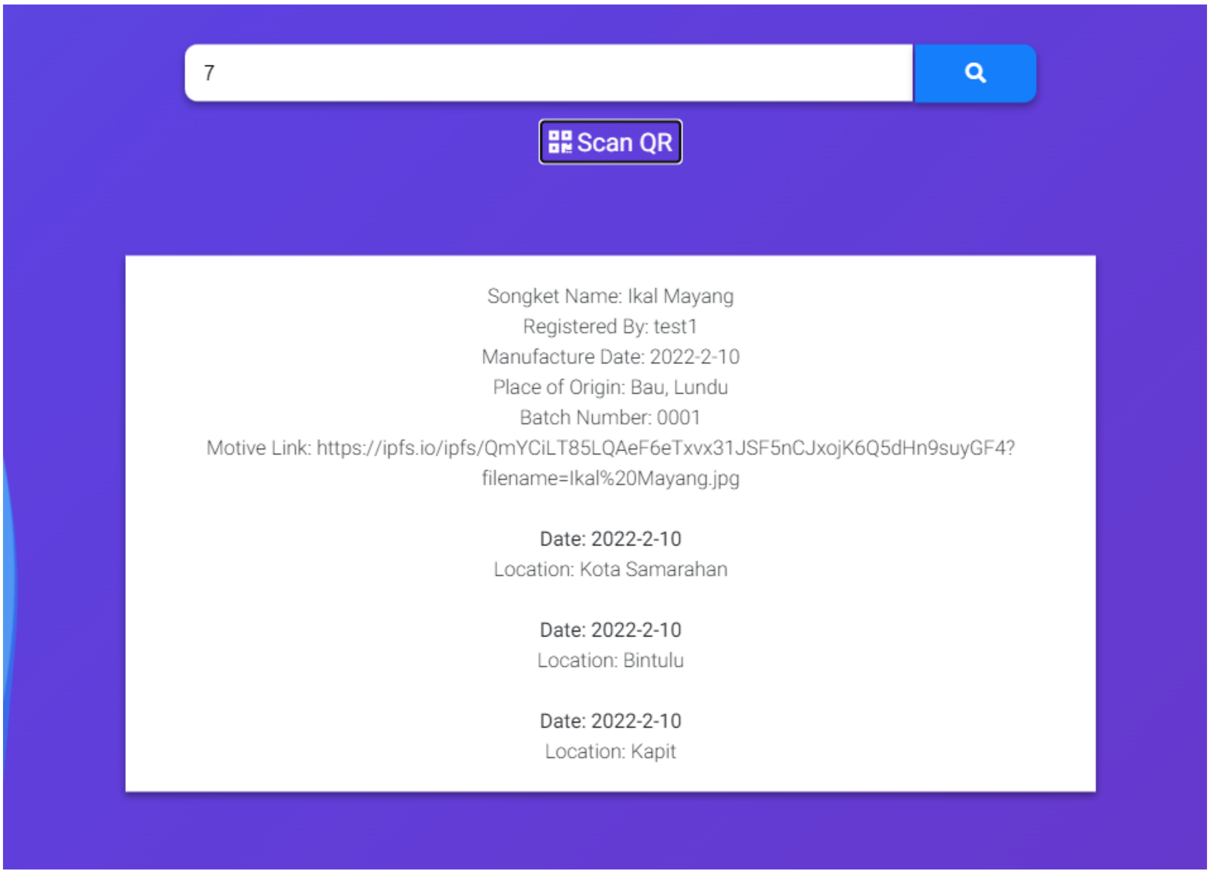

Fig. 16. Check Product Page for SongketChain

4.3 Analysis of Result

To get an insight related to performance and applicability of the proposed framework some simulation runs were performed with the developed blockchain program. To reduce the complexities, the simulation ran on single blockchain node while modifying parameters that could replicate transaction and validation from multiple nodes.

Figure 17 shows the data for each transaction is available to the weaver, distributor, retailer, and customer. A subset of data of supplier (Weaver) and transaction data (Songket) is disclosed as shown in Figure 17. Each transaction will create a new block in the local blockchain (Ganache) and can be traced based on the block hash and parent hash.

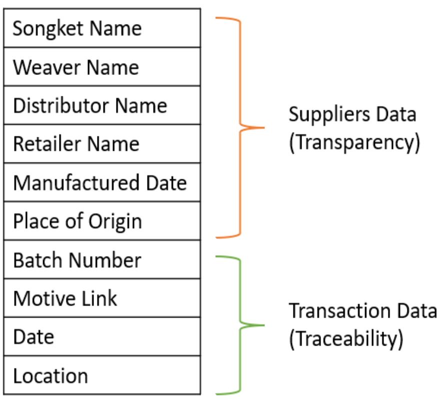

Fig. 17. Suppliers and Transactions data from Weaver to Distributor

4.3.1 Overall supply chain transparency

Figure 18 shows the addition of new data based on Table 4. The number of data obtained from Weaver to Distributor, Distributor to Retailer, and Retailer to Customer is 1. Each added data is the updated location of the Songket product from each party in SongketChain.

	Weaver to Distributor	Distributor to Retailer	Retailer to Customer
	Songket Name	Songket Name	Songket Name
	Weaver Name	Weaver Name	Weaver Name
	Distributor Name	Distributor Name	Distributor Name
	Retailer Name	Retailer Name	Retailer Name
	Manufactured Date	Manufactured Date	Manufactured Date
	Place of Origin	Place of Origin	Place of Origin
	Batch Number	Batch Number	Batch Number
	Motive Link	Motive Link	Motive Link
	Date	Date	Date
	Location 1	Location 1	Location 1
		Location 2	Location 2
			Location 3
Number of Data	10	11	12
Increment of Data	0	1	1
Total Number of Data	10	11	12

Fig. 18. Supply Chain transparency of SongketChain

Table 4 shows the result of overall Supply Chain Transparency. At the first stage (weaver to distributor) of result, there are a total of 10 data. Second stage from distributor to retailer, there an increment of 1 data which consist updated location and date which consist of 11 data. On the last stage of supply chain (retailer to customer), the retailer will update the location and time. Increment of 1 data in the supply chain and present the data updated to the customer which will have 12 data in total by the end of the supply chain.

Table 4
Overall Supply Chain Transparency

SongketChain System	Supply Chain Transparency (%)		
SongketChain	Weaver to Distributor	Distributor to Retailer	Retailer to Customer
	$\frac{8}{8} \times 100\% = 100$	$\frac{9}{9} \times 100\% = 100$	$\frac{10}{10} \times 100\% = 100$

4.3.2 Overall supply chain traceability

Table 5 shows the result of overall Supply Chain Traceability. At the first stage (weaver to distributor) of result, there a total of 2 blocks in the local blockchain (Ganache). At the second stage (distributor to retailer) of result, there are increment of block which is one block added to the local blockchain. At the final stage (retailer to customer) of result, another block is added to the local blockchain. For each transaction in the SongketChain, a new block is created and added to the local blockchain. The main reason of the created block in the first stage is two is because of creation of the Songket product and updated location of the Songket product. Each block is related to the previous block and can be traced by using the block hash and parent hash.

Table 5
Overall Supply Chain Traceability

SongketChain System	Supply Chain Traceability (%)		
SongketChain	Weaver to Distributor	Distributor to Retailer	Retailer to Customer
	$\frac{2}{2} \times 100\% = 100$	$\frac{3}{3} \times 100\% = 100$	$\frac{4}{4} \times 100\% = 100$

4. Conclusions

The textile and apparel industry, including the culturally and historically rich Songket sector, faces a myriad of challenges ranging from counterfeiting to lack of transparency and traceability. These issues not only affect the economic viability of the traditional craft but also pose a risk to the preservation of cultural heritage. As the market for Songket grows, the need for a more secure and transparent supply chain becomes increasingly evident. It is against this backdrop that this research proposes the incorporation of blockchain technology to revolutionize the management of Songket pattern rights and supply chain logistics in Sarawak.

The objectives were threefold: to develop a framework for enhancing transparency and traceability in the Songket supply chain; to assess and compare different blockchain technologies for their suitability in this application; and to evaluate the efficacy of the chosen blockchain technology using the proposed framework. The complex and time-consuming nature of Songket production, which can involve up to five months of intricate weaving, underscores the necessity of implementing a reliable, secure, and efficient system for the betterment of both the producers and customers.

By exploring both public and private blockchain platforms and their corresponding consensus algorithms, this research aims to elucidate the best possible blockchain application for the Songket industry. These technologies have the potential to improve the transparency, immutability, and traceability of the entire Songket production process. Importantly, the implementation of blockchain in the Songket supply chain could serve as a model for other industries, particularly those involving traditional crafts and artisanal goods. The blockchain's decentralized architecture can secure pattern rights, authenticate the origins of the materials, and even provide customers with irrefutable proof of the product's authenticity.

In conclusion, blockchain technology offers a promising avenue to navigate the complex landscape of the Songket industry by promoting transparency, enhancing traceability, and combating counterfeit trade. The successful implementation of a blockchain-based traceability system could not only preserve the cultural integrity of Songket but could also provide a sustainable model for its commercial future. Further research is needed to fine-tune the integration of blockchain into the Songket production process and to quantify the economic and cultural impacts of such an integration.

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