Research Article

A Regulated Anticounterfeiting Traceability Metamodel Based on Blockchain in Supply Chain in the Era of IR 4.0

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Received 24 April 2022; Revised 12 May 2022; Accepted 16 May 2022; Published 8 June 2022

In order to solve the problems of information island, information tampering and forgery, and information asymmetry between enterprises and consumers in the supply chain and to improve the efficiency of the whole system and realize the interconnection and effective supervision of supply chain information, the typical links of supply chain supervision system based on blockchain are abstracted through the comprehensive analysis of supply chain business processes and data characteristics. A regulatory anticounterfeiting traceability metamodel based on blockchain in the supply chain is constructed. Combined with the data of the supply chain system of a rice processing enterprise, a case study is carried out. The anticounterfeiting and traceability supervision metamodel based on the blockchain can be well applied to the rice supply chain system; solve the problems of data privacy encryption, secure storage, and authority management in the rice supply chain; and realize the interconnection and effective supervision of supply chain information. For enterprises in different positions in the supply chain, a unified anticounterfeiting traceability platform is established through the model, which can provide security and privacy protection for all kinds of enterprise data at the same time; for consumers, the model meets the security and traceability of each data of purchasing goods and ensures the integrity and authenticity of the data. The research content of this paper can provide a practical application solution for supply chain security supervision.

1. Introduction

Blockchain technology has the feature of automatically executing agreed code according to business rules through a trust mechanism and can clearly record the entire process data on the chain and then truly and reliably transmit the flow of funds, logistics, and information [1]. In recent years, researchers have conducted research and exploration in the supervision and management of the blockchain combined with the supply chain and traceability links, established product identification through various identification technologies, applied sensors to detect the supply chain and traceability links, formulated corresponding management system, established a management system to deal with all aspects of product production and carry out data upload, real-time monitoring, risk warning, and information traceability [2–5]. Through the supervision and traceability of the various management systems of the supply chain and traceability links, an anticounterfeiting traceability supervision system driven by blockchain technology is finally formed [6]. The anticounterfeiting and traceability system based on blockchain technology can ensure the accuracy and consistency of the data stored by each participating node [7], protect the legitimacy of the data, ensure the quality of products, improve the credibility of enterprises, and enhance consumers’ confidence in products. In blockchain-based security and traceability systems, consumers, intermediaries, and businesses share a distributed ledger through consensus algorithms. The research results of many researchers show that this method can eliminate the behavior of counterfeiting and high imitation in the process of commodity sales and effectively avoid the merchants’ behavior of using second-hand goods as shoddy goods. Such a process does not need to be
stored in the enterprise database, ensuring the security of the data. However, blockchain is characterized by low system throughput, low consensus efficiency, high energy consumption, and poor data availability, which makes it challenging to combine with traditional anticounterfeiting and traceability models.

It can be seen from Table 1 that after years of development, blockchain technology has expanded beyond the financial fields such as e-money, forming a new enterprise-level application based on distributed applications, smart contracts, and other technologies and providing decentralized solutions for all walks of life.

In order to solve the problems of supply chain data privacy encryption, secure storage, and authority management and realize the interconnection and effective supervision of supply chain information, this paper will conduct a comprehensive analysis of the supply chain business process and its data flow characteristics, sort out and refine the public and encrypted information of each business link of the supply chain, and build a supply chain supervision metamodel that can be applied to any industry in combination with blockchain technology, taking rice processing enterprises as an example.

2. Background

2.1 Challenges of Anticounterfeiting Traceability System in Supply Chain. During the operation of the supply chain, due to the authenticity, the complexity of key data and information in the supply chain, and the traceability of various products, some challenges will inevitably be encountered [8, 9]. The current challenges faced by the anticounterfeiting traceability system in the supply chain are as follows.

2.1.1 Information Island. Due to the need for anticounterfeiting, the supply chain is usually supervised by regulators, and the upstream and downstream enterprises are connected in series [10]. The data of the enterprises in the supply chain are maintained by the enterprises themselves, which easily causes an information island in the supply chain [11, 12]. Information island affects the real time and consistency of information and the smooth implementation of enterprise business [13].

2.1.2 Tampering and Falsifying Information. Due to business competition, it is very common for upstream and downstream enterprises to tamper with and forge information [14]. At the same time, enterprises participating in the supply chain will more or less have some product privacy information that cannot be disclosed to the public, such as the poison information of food processing raw materials [15, 16]. This information needs to be regulated, but it cannot be mastered by competitors.

2.1.3 Information Asymmetry between Enterprises and Consumers. In the process of enterprise marketing and consumer purchase, the information obtained by enterprises and consumers is inconsistent. When collecting information, consumers often cannot fully understand the quality, performance, purpose, and price of relevant products in the market, and enterprises cannot fully understand the preferences, needs, and other information of consumers. Usually, consumers are at a disadvantage [17].

2.1.4 The Traditional Supervision System Is Inefficient. The traditional supply chain supervision mode needs a lot of repeated verification and inspection of the data in each link of the supply chain, which makes the time cost high and the information redundant [18]. At the same time, all links of the traditional supervision system may have problems such as dishonest enterprises tampering with the detection data, which reduces the credibility of the supervision results, so the supervision department has to spend more time and resources to confirm the accuracy of the supervision data [19]. Finally, it leads to low regulatory efficiency and poor data traceability.

2.2 Blockchain Opportunities for Anticounterfeiting Traceability System in Supply Chain

2.2.1 Breaking the Information Island. Blockchain is the key technology to breaking the information island [20]. For enterprises, the construction of a supply chain system based on the blockchain can be planned uniformly, and each supply chain link can be directly added or adopted to eliminate the generation of “isolated islands” from the source [21].

2.2.2 Ensure the Authenticity of Information. The blockchain uses encryption algorithms to ensure the correctness of data (hash) and the validity of identity (signature) and uses consensus algorithms to ensure the decentralization and nontamperability of data [22].

2.2.3 Break the Barriers of Information Asymmetry. The advantage of blockchain is that it can lead to consumption and drive the economy [23]. Because the rules of the smart contract are transparent, fair, and matchable, they can combat the information asymmetry between enterprises and consumers [24]. First, find the precise demand from the information source of consumers, and then, the enterprise digests the production capacity by allocating the means of production, so as to maintain the balance of goods and materials and help the enterprise and consumers match the information source. This can not only avoid the waste of enterprise means of production but also meet the consumer demand of users in the market economy.

2.2.4 Improve the Efficiency of the Regulatory System. Blockchain technology can aim at the disadvantages of the traditional single-center service system and establish a decentralized or multcenter crossplatform credit system, so as to reduce costs, improve regulatory efficiency and regulatory capacity, and alleviate the problems of regulatory information asymmetry, regulatory lag, regulatory gap, and so on [25, 26]. For regulated supply chain participants, blockchain technology helps to reduce labor workload and reduce enterprise compliance costs [27].

2.3 Existing Business Entities of Anticounterfeiting Traceability System in Supply Chain

2.3.1 Problems with Existing Systems. The anticounterfeiting traceability system has many participating enterprises in each link [28], including raw material producers, suppliers,
warehousing enterprises, processing enterprises, logistics enterprises, and distributors; in the supply chain and traceability links, various enterprise entities generally have data standard differences and inconsistent storage format problem [29]. At the same time, the current lack of a unified supervision and management system in the market has led to small relevance between nonadjacent business entities, poor information circulation, and long circulation, and the privacy and security of some key data cannot be guaranteed, and there is a risk of loss or tampering [30]. It is not conducive to the information transmission between the supply chain and traceability nodes and the supervision of related departments. In addition, due to the long circulation cycle of the anticounterfeiting traceability system and the asymmetry of information among the various links, it is difficult for regulators to determine the main link in which the problematic product reaching the consumer is caused, and the problem is not easy to remedy, and it is urgent to build a safe and efficient supervision and management system [31].

2.3.2. Existing Supply Chain Supervision Traceability Process.
The process of the supply chain supervision system is divided into three parts from the perspective of information transmission, as shown in Figure 1(a). The participants of information circulation are mainly various parts of the supply chain and consumers. The raw material supplier sends the raw materials to the storage department of the manufacturer through logistics. The storage department transports the raw materials to the production line, and the products produced are finally sold to consumers by the seller. Information traceability participants are also all parts of the supply chain and consumers. The consumer sends a traceability request, which can be sent to each part of the supply chain step by step through the information chain. The participants of information supervision are all parts of the supply chain and supervision departments, including government supervision departments and enterprise supervision departments. The supervision department shall supervise and manage all links of information circulation and information traceability.

The processing link is the core link of the anticounterfeiting traceability system, which can not only guide and restrict the quality of raw material suppliers and the information of the storage department but also provide means of production for the sales link and uniformly distribute and manage the logistics, business flow, information flow, and capital flow with the help of logistics enterprises, storage enterprises, and financial institutions. Therefore, it is very necessary to strengthen the supervision of processing enterprises [32].

2.4. Research Objectives. In order to solve the problems of data privacy encryption, secure storage, and authority management in the supply chain, especially the problems of information island, information tampering and forgery, and information asymmetry between enterprises and consumers in processing enterprises, and improve the efficiency of the whole system and realize the interconnection and effective supervision of supply chain information, this paper constructs the metamodel of anticounterfeiting traceability system based on the blockchain through the analysis of traditional anticounterfeiting traceability system, as the first basis for possible blockchain implementation. By constructing key traceability data (public information and encrypted information), track the cycle of product supply chain and traceability links, and each link of product production is associated with its affiliated enterprises and owners. The model takes a rice processing company as an example to conduct a comprehensive design, sort out and refine the public and encrypted information of each business link of its supply chain, and build a supply chain supervision metamodel that can be applied to any industry in combination with blockchain technology.

3. A Regulated Anticounterfeiting Traceability Metamodel Based on Blockchain

3.1. The Architecture of Supply Chain Supervision System Based on Blockchain and IoT (Internet of Things). A complete supply chain system based on blockchain and IoT is divided into two levels: data collection and data processing. Among them, the data in the supply chain is collected through video, audio, and production line coding or scanning. Smart contract plays a vital role in data collection. The smart contract needs to ensure that the data uploaded and operation results of each node in the blockchain network are exactly the same so that each node and participant of the supply chain can verify whether the execution results of the smart contract are correct in the blocks generated by the data uploaded to the blockchain. The process of data transmission also needs to ensure the integrity and correctness of smart contract execution. At the same time, data collection, device access, device control, and data transmission need the support of IoT. The collected data will be encrypted and distributed stored on the ECS. These data will be used for AI training, data comparison, intelligent analysis, and data mining. In this system, there should also be data supervision levels. This hierarchy consists of government, business, and consumer roles. The government and enterprises will ensure that the data collection results are consistent with
the actual situation, and consumers unknowingly help enterprises complete anticounterfeiting and traceability by means of anticounterfeiting code scanning and raw material traceability. The complete system architecture is shown in Figure 2.

3.2. Supply Chain Supervision System Model Based on Blockchain. A complete supervision model should not only include the supervision of government agencies on the supply chain and traceability links but also cover the data upload and query of enterprise entities and the traceability of consumer goods in the supply chain and traceability links, so as to realize the integration of supervision. In this way, on the one hand, it can supervise and manage all aspects of information in the product production process in the supply chain and traceability link, so as to ensure the security and authenticity of information when data flows in the product supply chain and traceability link. On the other hand, it can also reduce the information gap between enterprise owners in the supply chain and traceability link and between regulators and enterprise entities in the supply chain and traceability link, avoiding information islands.

3.3. Metamodel Information Flow Analysis. The metamodel is the generalization and abstraction of a specific situation, which is called a model. As a modeling language, it provides syntax rules and highlights the relationship with common terms. In fact, a model is an application of a metamodel with specific values. In the anticounterfeiting traceability product supply chain process method with supervision as the core, we propose a data element model to cover the useful

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**Figure 1:** Model details of supply chain supervision system based on blockchain.
information of managing product traceability in the whole supply chain and life cycle. This method can be adopted regardless of the nature of the product and the organization of the supply chain.

In the anticounterfeiting traceability supervision system, each step of the production process is connected with each other in a logistics manner. The data includes different products, semifinished products, and raw materials, as well as containers, pallets, and packaging boxes (large, medium, and small) required for logistics. In the circulation process of the product in the supply chain, the data collected should include the data exchange between the participants in the supply chain and the traceability link or indicate the status of the activity.

Table 2 is showing key information like public data: static data, dynamic data, and encrypted data for classification of supply chain and traceability.

The supply chain is connected with multiple entities in multiple links such as product supply, manufacturing, distribution, and retail. More participants and more complex business forms bring more massive and rich data, many of which are business-sensitive privacy data. It is these business-sensitive privacy data that enable the modern supply chain system to operate efficiently and respond quickly to the changes in product demand. If these business-sensitive privacy data are not properly protected and rashly linked, it is bound to bring significant privacy risks and cause all kinds of business risks that may cause actual economic losses.

In data flow analysis, data is divided into public data and encrypted data. Public data can be open to all participants in the supply chain and blockchain, including static data and dynamic data. Static data is the data that will not change for a long time in the production process, such as supplier information (name, ID, etc.), customer information (name, ID, etc.), and raw material information (name, origin, batch, etc.), while dynamic data is the data that will change frequently in the production process, such as product specification, production time, quantity, real-time data of commodity sales, product authenticity feedback information, and product sales positioning information. The encrypted data can only be accessed and supervised by enterprise regulators and regulators through the key. Encrypted data includes toxic information of raw materials, internal price, output, logistics situation, real-time inventory information, market supply and demand, and credit situation. It is the combination of these three data types (static data, dynamic data, and encrypted data) that can summarize, classify, and describe the whole process of the supply chain. This data can participate in all steps of the supply chain process, manage participants, and connect production information to physical elements to trace the journey of products from “farm to dining table.”

The goal of anticounterfeiting traceability is to be able to quickly find information related to batches or products. It is the combined blocks of these data that provide a complete description of the supply chain and traceability links. At the same time, for data privacy, a key is required for identification at any stage. In fact, the model can limit participants in various steps and connect the information to the traceability chain to trace the process of products from raw materials to consumers.

3.4. Construction of Data Model in the Metamodel. In the supply chain, the data owned by each participant contains many important components, but these components can basically be divided into public data and encrypted data. To establish a system that can be used by every participant in the whole supply chain, the data uploaded by participants need to be standardized, managed, and supervised.

According to the current situation of anticounterfeiting and traceability supply chain, we set four different types of users: complete users, lightweight users, supervisors, and consumers:
Table 2: Key information classification of supply chain and traceability chain.

<table>
<thead>
<tr>
<th>Supply chain and traceability</th>
<th>Public data</th>
<th>Dynamic data</th>
<th>Encrypted data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Name, place of origin, batch, other information…</td>
<td>Specification, quantity…</td>
<td>Toxicity, internal price…</td>
</tr>
<tr>
<td>Production process</td>
<td>Production list, production type, production line…</td>
<td>Production, time…</td>
<td>Production proportion, yield…</td>
</tr>
<tr>
<td>Product</td>
<td>Name, place of origin, batch, production information, other information…</td>
<td>Specification, quantity, time…</td>
<td>Output…</td>
</tr>
<tr>
<td>Logistics</td>
<td>Means of transport, mode of transport, pallets/boxes/boxes…</td>
<td>Location, transportation time…</td>
<td>Logistics situation analysis…</td>
</tr>
<tr>
<td>Storage</td>
<td>Product ownership, storage specifications…</td>
<td>Inventory, location, commodity specification, commodity source, time…</td>
<td>Inventory…</td>
</tr>
<tr>
<td>Sale</td>
<td>Sales mode, sales qualification…</td>
<td>Detailed sales data, business information, time…</td>
<td>Payment records, sales analysis, market supply and demand…</td>
</tr>
<tr>
<td>Enterprise</td>
<td>Basic information of enterprises…</td>
<td>Information of the person in charge of the relevant link…</td>
<td>Core supply and marketing objects, capital status, credit status…</td>
</tr>
<tr>
<td>Feedback</td>
<td>Commodity basic information, batch</td>
<td>Authenticity, product positioning, dealers…</td>
<td>Defective rate, fleeing situation…</td>
</tr>
</tbody>
</table>

![Diagram](image)

Figure 3: Data model and data hierarchy in metamodel.
(1) Complete user: it needs to store all data, including raw materials, production, logistics, and sales; at the same time, it also needs to upload, download, delete, modify, and query data.

(2) Lightweight user: store some data. For example, logistics enterprises only need to store logistics-related data in the supply chain. At the same time, they need to upload, download, delete, modify, and query data.

(3) Supervisor: there is no need to store data. There is a need to view all operation records such as upload, download, delete, modify, and query, and view the data uploaded by the enterprise by level.

(4) Consumer: do not store data but need to upload and query data.

The industry background study found that different enterprises in the supply chain have different data centers. According to the size of enterprises, the size of data centers varies. The data centers of small and medium-sized enterprises are not perfect and do not have strong data processing capacity, and even some enterprises do not have data centers. Therefore, two different server clusters are needed in the data model: supply chain alliance servers (SCAS) and supervision alliance servers (SAS). SCAS stores complete and lightweight data, while SAS only stores the operation data of regulators and ordinary users for data circulation. With the use of a consensus mechanism, we can effectively use the current situation of supply chain participating enterprises to realize decentralized, safe, and rapid data sharing. After the data of SCAS and SAS are interconnected, the data can be shunted and sorted out, and enterprises, regulators, and consumers can also easily trace product information for anticounterfeiting verification. In order to ensure that the recorded content is credible and not tampered with, the model records all key data summaries and stores them in a hierarchical mechanism. The hash value of the data is stored in the data unit, and then, the hash value of each data unit is calculated and put into the data unit block structure, which can effectively reduce the search difficulty and speed up the search progress. Since the bitcoin blockchain adopts the proof of work (POW) mechanism and stably generates a block every 10 minutes, in the model, the data is frozen every 10 minutes, and the current bookkeeper in SCAS automatically submits and generates data similar to bitcoin transaction information, which can truly realize that the production data cannot be tampered with. In the data hierarchy,
there are \( n \) pieces of information data in each data unit. \( N \) can be determined by the algorithm to obtain the most suitable amount of data under the current data flow. Each contains three pieces of information: public key, metadata, and data summary. There are two kinds of identifications for the data digest. Those identified as hash values are encrypted data, while those not identified as hash values are public data. Since each data unit block stores the hash value of the data unit and header information, it is not only conducive to the transmission of each block in the point-to-point network but reduces also the cost of data verification, as shown in Figure 3.

3.5. Construction of Metamodel. According to the process characteristics of product supply chain and traceability link and the business logic of each enterprise in the chain, this paper constructs the anticounterfeiting traceability supervision model based on blockchain, as shown in Figure 1.

A complete regulatory model must not only include government agencies’ supervision of the supply chain and traceability links but also cover the data upload, query, and consumer product traceability parts of the supply chain and traceability links to achieve the integration of supervision. This way, on the one hand, it can supervise and manage all aspects of the product production process in the supply chain and traceability links and ensure the security and authenticity of the information when the data circulates in the product supply chain and traceability links. On the other hand, it also makes the supply chain; reduces information gaps between business entities in the traceability link, regulatory agencies and the supply chain, and between business entities in the traceability link; and avoids information islands. Based on the characteristics of the product supply chain and traceability process and the business logic of them in business entities in the chain, this paper constructs a blockchain-based anticounterfeiting traceability supervision metamodel, as shown in Figure 4.

The production process starts from the raw materials and generates products through the production line and production process. Through the logistics system, products can be directly sold or stored in warehouses, and stored products can also be sold to consumers through sales channels. The enterprise is responsible for the production/development of products and also needs to receive feedback from

Figure 5: A regulated anticounterfeiting traceability metamodel based on blockchain in rice supply chain.
the regulatory authorities and consumers. Regulatory agencies need to supervise every stage of product production, including the quality of raw materials, production processes, storage, logistics, and sales, and feed back the information to the company or the government. In the metamodel, the corresponding relationship between warehousing and SCAs, the warehousing class is 0 n. SCAs is 1, which indicates that warehousing and SCAs are many to one relationship; that is, the data of multiple warehousing classes can be stored in SCAs, while the data of warehousing classes can only be saved in one SCA.

4. Experiment

4.1. Case Study: Rice Supply Chain Metamodel Based on Blockchain. The data of a rice processing enterprise were investigated. The enterprise involves all processes of raw material procurement, logistics, storage, processing, and sales in the rice supply chain. It has a supervision department within the enterprise and has data exchange with the government supervision department. However, due to three different enterprises and several different departments in each link of information, there are information islands, and there are many business exchanges between enterprises and departments, which further increases the difficulty of supervision.

The rice supply chain process is divided into upper, middle, and lower stages from the perspective of information supervision, as shown in Figure 1. The upstream of the supply chain includes planting links; the midstream includes the links of collection and storage, processing, storage, and transportation, in which the collection and storage also include the links of acquisition, drying, impurity removal, and warehousing, and the processing includes the links of ridge and grain, rice milling, color selection, polishing, and packaging; the downstream is the sales link. Sellers eventually sell rice to consumers, and regulators supervise and manage the supply chain. The processing link is the core link of the rice supply chain, which can not only guide and restrict the upstream rice collection, storage, and planting link but also provide means of production for the downstream sales link and uniformly distribute and manage the logistics, business flow, information flow, and capital flow with the help of logistics enterprises, warehousing enterprises, and financial institutions. Therefore, it is very necessary to strengthen the supervision of grain and oil processing enterprises. In the process of rice supply chain information supervision, some information of enterprises is sensitive and cannot be fully disclosed, such as transaction records, cost information, and hazardous material information. Therefore, it is necessary to classify the information uploaded to the blockchain to distinguish sensitivity and priority, so as to ensure efficient supervision and protect the information from disclosure.

Due to the huge amount of data and various types of data, we selected some representative data and constructed a regulated anticounterfeiting traceability metamodel based on blockchain in rice supply chain, as shown in Figure 5.

In this paper, each link in the rice supply chain is regarded as a node in the blockchain network, and each node corresponds to a cloud database. Each node in the supply chain invokes the smart contract deployed in the blockchain network through the business system. After consensus, most of the data plaintext and ciphertext are recorded in the cloud database, and a small part of the data plaintext, information summary, and the key are saved in the blockchain network. The main node of the rice supply chain enterprise starts from the planting enterprise (grower), flows to the supply chain to the sales enterprise, and finally sells rice to consumers. During the circulation process, each enterprise entity in the supply chain will upload the collected data to the blockchain network and cloud database through the contract. The regulatory authority will send a request to the blockchain network to call the corresponding contract verification authority to realize real-time supervision of the supply chain. Business entities and consumers in the supply chain can also initiate the same information query and traceability request to the blockchain network in different ways to query product information within the scope of authority to verify whether rice meets the required standards or whether the information has been tampered with.

5. Conclusion

This paper studies the digital supply chain combining blockchain and supply chain and finds that the traditional supply chain system has some problems, such as information island, source data fraud, information asymmetry, and low efficiency, which is not conducive to the establishment of an efficient supervision and management system. Through the comprehensive analysis of the business process and data characteristics of the supply chain, the typical links of the supply chain supervision system based on blockchain are abstracted. On this basis, the supervision anticounterfeiting traceability metamodel based on blockchain in the supply chain is constructed, and the model is constructed combined with the data of a rice supply chain system.

In the process of building the metamodel, we found that blockchain has the characteristics of openness, traceability, and non-tampering, which can help the supply chain solve the problems of information island, arbitrary tampering with information, information asymmetry between enterprises and consumers, and so on. Through the analysis and summary of the supply chain, supervision system model, and the abstraction of the metamodel, a flexible and adaptable supply chain anticounterfeiting traceability architecture can be established to provide a guarantee for the establishment of the whole link anticounterfeiting system of the supply chain. Through the case study, the anticounterfeiting and traceability supervision metamodel based on the blockchain can be well applied to the rice supply chain system; solve the problems of data privacy encryption, secure storage, and authority management in the rice supply chain; and realize the interconnection and effective supervision of supply chain information. For enterprises in different positions in the supply chain, a unified anticounterfeiting traceability platform is established through the model, which can provide security and privacy protection for all kinds of enterprise data at the same time; for consumers, the model meets the security and traceability of each data of purchasing goods and ensures the integrity and authenticity of the data.
The constructed supply chain supervision system model and metamodel can solve the problems of supply chain data privacy encryption, secure storage, and authority management and realize the interconnection and effective supervision of supply chain information. The research content of this paper can provide a practical application solution for supply chain security supervision.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References


