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Blockchain based Wine Supply Chain Traceability System

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***Abstract*—The necessity of wine supply chain traceability system is inevitable due to increase in counterfeiting, adulteration, and use of excessive preservatives and hazardous chemicals. To overcome these issues, wine industry is in need of a traceability system which enables a consumer to verify the composition of each batch of wines from the grape growers to the retailers. However, most of the current systems are RFID and web based and thus it is possible to counterfeit stored information as required. This study proposes a blockchain based wine supply chain traceability system where every transaction is recorded as a block in the chain and is visible to the relevant participants. These blocks of information is immutable since any change to the recorded information will break the chain. In addition to providing quality information management framework, the proposed traceability system enables transparency, safety, and security in the overall process from the grape to the bottle.**

***Keywords*—Supply chain traceability; blockchain; consensus; miner; transparency**

I. Introduction

Wine counterfeiting has increased rapidly since the early 1990's and fraud wines accounted almost 5% of the current secondary market worldwide that would amount to $15bn [1]. Among wide varieties of wine frauds, counterfeiting and relabelling of cheaper wines to expensive and highly collectable wines are the most prevalent type of fraud. In recent times, wine industry is paying more attention to prevent fake wines by enabling traceability in the wine supply chain. Traceability is a method through which anyone would be able to verify the overall process including raw materials, transport and storage conditions, processing, distribution, and sales in the wine supply chain.

A number of traceability systems and standards have been developed to automate the supply chain activities. In particular, barcode, radio frequency identification (RFID), Quick Response (QR) code, Electronic Product Code (EPC), EPCglobal, wireless sensors are most appealing technologies and paradigms for supply chain traceability. The Global Standard One (GS1) system provides a global and generic standard to facilitate the identification of companies and their products as well as to exchange information about them [2]. GS1 implements a numbering or coding scheme at every stage of production and distribution to uniquely identify products and services. A machine readable representation of a number or barcode is used to specify the item to which it is assigned. Recent GS1 standardization developments also provide industry-standards for the use of RFID supported EPC. Isabel et. al. proposed a wine supply chain traceability system that uses both RFID and Wireless Sensor Networks [3]. A wireless sensor network was deployed in the vineyard to collect meteorological data and plant heath information, whereas RFID tags are used to record data of harvesting, decantation, fermentation, and conservation processes. Another RFID based traceability system is proposed in [4] which relies on a pervasive and mobile architecture. The proposed system provides a transactional view of process tracking which illustrates generation and management of data records in the system. In addition, an architectural view of the system is also presented to enable tracing procedure to remotely retrieve recorded information. Kreshnik et al. proposed a data model and system prototype to support mobile access to the wine information through encrypted barcode technology [5]. The data model is an adaptation of the GS1 standards which represents the participating entities and their activities such as irrigation management, grape monitoring in vineyards, process monitoring and steering in wine cellars. To defend against counterfeit products, the identities of the participating entities are initially encrypted, coded and printed on the bottle label known as QR code image. Only authorised entities can retrieve the global traceability identifier through a web/mobile application and a decryption key. A recent IBM Institute for Business Value study on blockchain based food supply chain management system shows that safety and authenticity of products from suppliers to consumers can be ensured by tracking provenance and movement of food in the supply chain. The study focused on three key aspects where blockcahin can achieve significant breakthrough: extended visibility, dynamic optimization, and open forecasting [6].

Most of the wine supply chain traceability systems use barcode and/or RFID tags to store information in different phases of the supply chain. This information is retrieved manually and stored in a central database. Finally, a web or mobile interface is developed to display the information to the end users. One of the major concerns in the existing traceability system is authenticity of the source information since it is easy to reproduce or forge the information at any time. Further, there is no efficient way to identify counterfeit bottles in most of the cases since those bottles are always accompanied by fake provenance histories. Thus, wine industry needs a solution to ensure authenticity and provenance of every bottle of wine it produces. This paper proposes a blockchain based wine supply chain traceability system that records detailed information of all processes in an immutable and incorruptible database. The rest of the paper is organized as follows: Section II describes the wine supply chain entities. Section III briefly explains the blokchain technology. Section IV presents the proposed blockchain based traceability system. Section V

provides implementation details and outcomes. Finally, Section VI discusses and concludes the paper.

II. Wine Supply Chain Entities

The main entities of a wine supply chain is identified and a simplified generic model of the system is presented in Fig. 1. The output generated by each entity is also shown in the figure.

A. Grape Growers

Grape growers are one of the key stakeholders in the wine supply chain since the supply chain starts at vineyards. They are taking care of plants and monitoring their growing parameters such as temperature, soil moisture, and fertility. Furthermore, they are also responsible for harvesting the grapes and delivering them to the winery. The records that the grape growers should keep in the chain are location, altitude, types of vines, origin, irrigation, treatments, and pruning or purging date.

B. Wine Producers

Wine producers receive grapes and perform a number of procedures and operations to produce wines from grapes. To ensure traceability, records on the processes and raw materials used to make the wine should be kept on the chain. These includes suppliers' details, receiving date, description of the received products, variety of grapes, records of internal procedures (e.g., decantation, fermentation, and conservation), chemical contents, distributor records, and additives (if any). The finished wine at this stage may be sent to 1) a bulk wine distributor; 2) a filler/packer; or 3) another wine producing cellar for blending.

C. Bulk Distributor

The bulk distributor is responsible for receiving bulk wine from the wine producers and blending and dispatching the batches of wine to the transit cellar or packer. The information that should be recorded in this stage are receiving date, storage details, processing, sampling, analysis of the bulk wine, and dispatch date. If the bulk distributor performs the blending process, the information also must be recorded in the chain.

D. Transit Cellar

The role of the transit cellar is almost similar to bulk distributors as they send batches of bulk wine to the filler or packer. They are responsible for the reception, storage, dispatch, processing, sampling, and analysis of bulk wine.

E. Filler/Packer

The filler or packer receives bulk wine from the transit cellar or bulk distributor and fills into different containers such as bottles, bags, kegs or barrels. Since the identification and labelling of each wine is done at this stage, it is very important to ensure consistency of the labelled information with the record stored on the blockchain. This information include the reception, storage, processing, sampling, analysing, filling, packing, and dispatching of the finished products. Thus, filler or packer needs to maintain consistency of blockchain information and corresponding physical product.

F. Finished Goods Distributor

The pallets and cartons received by the finished good distributor are dispatched to the wholesaler or retailer. The responsibilities of the finished goods distributor are receiving, storing, dispatching, and managing inventory of finished goods. At this stage, if any re-packing or re-labelling is required, the details must be stored in the blockchain.

G. Wholesaler

The wholesaler receives pallets and cartons of wine from the finished goods distributor and dispatches them to the retail stores. They are responsible for the receipt, storage, and delivery of the goods. Thus, they need to maintain consistency of recorded information in the blockchain and corresponding labelled information on physical products.

H. Retailer

The retailer receives finished goods in the form of bottles, cans, and cartons from the wholesaler or the finished goods distributor and sells to the end consumers. When a bottle or carton is sold, the information must be recorded in the blockchain so that it is not possible to use the same label again. The retailers are responsible for keeping details of the received items, storage, and sale information. Upon storing the information on the blockchain, a consumer would be able to see the provenance of the purchased wine by putting the identification number on the website.

I. Other Entities

In addition to the above mentioned entities, there are also a number of other stakeholders in the supply chain that are not directly related to the production or processing of the wine. They are: 1) Raw material suppliers-responsible for providing all the supplies needed for grape growers, wine producers, fillers/packers; 2) Freight operators- responsible for transporting goods from wineries or packers to importers or to other entities (distributor, wholesaler, retailer, etc.); and 3) Importers-responsible for buying goods from the wine producer, selling and delivering finished goods to the wholesaler or distributor of the destination country on the basis of the distribution channel. Fig. 1 presents the transactions among the entities in the wine supply chain.

III. Blockchain Technology

A Blockchain is a distributed, decentralized ledger, or a continually updated list of transactions which records agreements, contracts, and sales [7]. Originally developed to support crypto-currency, this peer-to-peer system can be utilized for any form of transactions without an intermediary. The security of blockchain technology hinges on strong cryptographic schemes that verify and chain together every block of transactions. An attacker would have to compromise 51% of the systems to surpass the hashing power of the target network. Thus, it is computationally impractical to tamper with transactions stored in a blockchain. The following example demonstrates working procedures of the blockchain technology. Let A and B be two participants in a blockchain based payment system and A wants to send money to B. This transaction is represented in

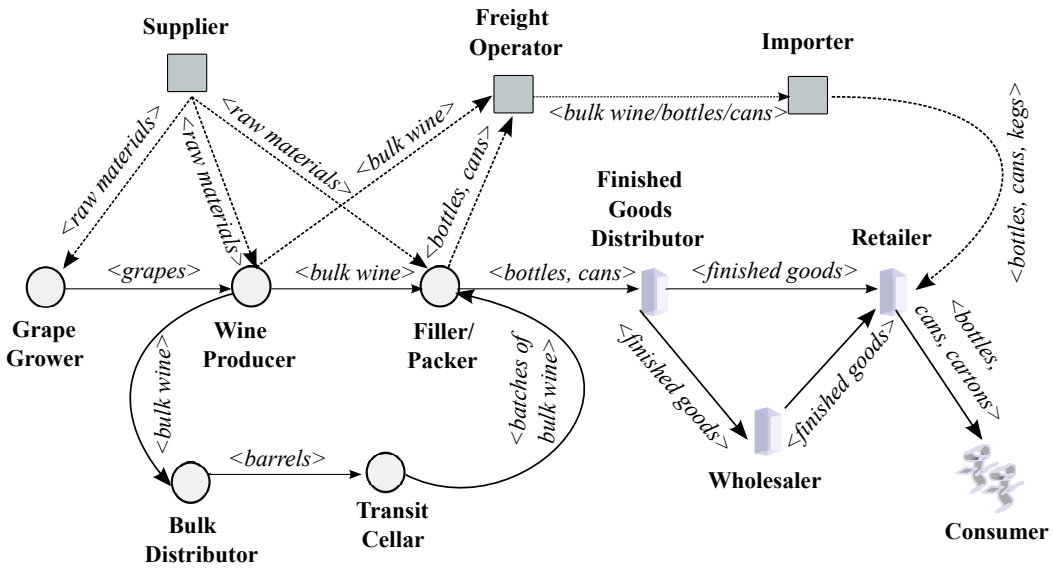

Fig. 1. Entities in the wine supply chain.

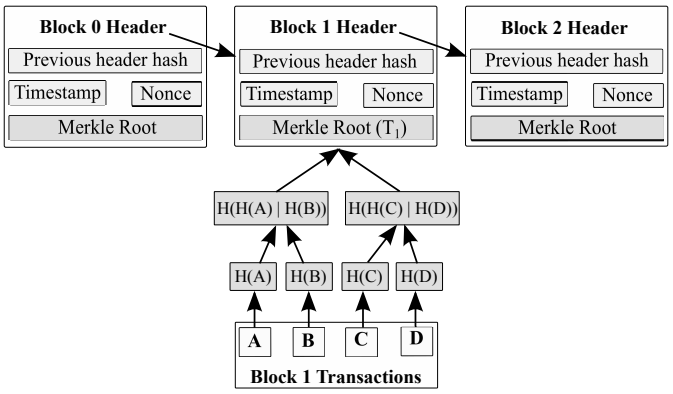

Fig. 2. Simplified blockchain transactions.

the system as a block including information such as a block number, proof of work, previous block, and transaction details and this block is broadcast to every participant in the network. The other participants known as miners verify the block and if more than 50% of the miners validate the block, then the transaction is approved and added to the chain. After that, the money is transferred from participant *A* to participant *B*'s account.

Fig. 2 presents a merkle tree connecting block transactions to the block header merkle root [8]. It can be seen that each transaction in a set is converted to a hash value and the hash values are further combined to obtain the block header merkle root. The final hash value is included into the block's header along with the hash code of the previous block and a timestamp. For public blockchain, the header becomes part of a mathematical problem known as proof of work that can be solved by manipulating numbers. In a private blockchain, proof of work may not be required since the miners need not to be rewarded quickly for verifying a block. More efficient consensus mechanisms such as proof of stake are used in practice. In a merkle tree, any transaction can be verified using the merkle root of that block. To verify an individual transaction *B* in Fig. 2, the sender has to provide *H(A)* and *H(H(C) ‖ H(D))* so that the verifier can compute merkle root T_1: *H(H(H(A) ‖ H(B)) ‖ H(H(C) ‖ H(D)))*. The proposed traceability system uses a private blockchain with pre-selected miners and a block is added to the chain if and only if it is verified by the majority number of miners.

IV. Blockchain based Traceability System

The proposed blockchain based traceability system incorporates the transactions of all primary entities in the chain. For the sake of simplicity, the grape growers, wine producer, bulk distributor, transit cellar, filler/packer, finished goods distributor, wholesaler, and retailer entities are taken in account in the proposed traceability system. Fig. 3 represents the data flow of each entity in the chain. The rectangles with gray colour indicate that the entities are also a part of consensus i.e., a collective decision making process.

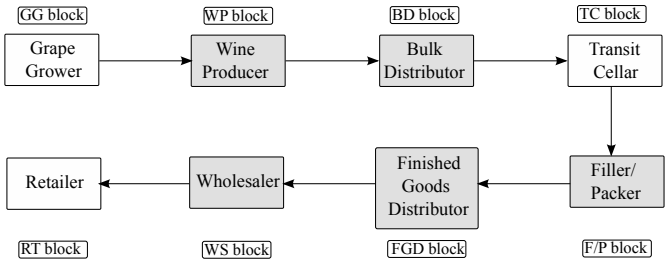

Fig. 3. Data flow among different entities.

A. Key Management

It is assumed that some information is critical in wine supply chain traceability system and must be kept private. To ensure the confidentiality, a common secret key is pre-distributed among all entities in the system. Further, every

participant in the system need to generate a pair of public and private key before starting its operation. The public key must be shared with all other participants so that the originator of a block can be authenticated by the miners using the corresponding public key. Thus, the transaction block may contain information in the form of both plain text and cipher text. Upon receiving a block, the miners have to decrypt the encrypted information as well as check the identity of the requester before validating the block.

B. Building the Blocks

The supply chain starts at vineyards and the grape grower generates the genesis block and adds the required information as described in Section II-A. The block is verified by the majority number of miners in the system before the next block being added to the chain. An ID number is used to uniquely identify each participant in the system, and the batch number indicates the production batch supplied by the wine producer. This is important since there might be more than one grape growers who are supplying grapes to the wine producer. Fig. 4 shows the transaction block generated by the grape grower. Similarly, the wine producer puts all information in a block and share it with all other participants. Eventually, the block is verified and added to the chain. This procedure is followed by the bulk distributor, transit cellar, filler/packer, finished good distributor, wholesaler, and retailer in order to include their transactions in the chain.

ID: GG001
Block# 2 Batch# 1

Origin: ABCD
Type of Vine: XYZ
Treatments: PQRST
.....
.....
Pruning Date: D/M/YY
Delivery Date: D/M/YY
Prev. Hash: abcdef0000a0a0bbcdcdfddfa56781bb
New Hash: 8bc9ef5080a0affbadadfedea56481bc

Fig. 4. A block generated by the grape grower.

C. Trace Back Capability

One of the key features of the proposed traceability system is that the originator of every individual bottle of wine can be traced back. Since every bottle is assigned a unique id, the consumer can see the complete data flow and related information by putting the ID in the system. When the ID is entered, the system first retrieves the retailer transaction. This transaction includes batch id and hash of previous block which are used to trace back all related information and the data flow from the retailer to the grape grower. Since the details of a sold wine is recorded in the blockchain, it is not possible to sell the same item twice. Thus, the proposed system makes wine counterfeiting impossible. Here it is assumed that each crypto-block is always associated with the physical product. The validation of this is provided by the verifiability and immutability properties available in the blockchain mechanism. The following pseudo code presents the steps involved in the trace back procedure.

Pseudocode: Trace back procedure

Input: BottleID

Output: Detail_Info of Provenance

Steps:

```
1. WHILE True
2.   Flag ← False
3.    FOR each block in the chain
4.     IF FOUND BottleID
5.       Retrieve BatchID & Retailer Info
6.       Hash_Val ← Prev_Hash
7.        REPEAT
8.              Retrieve Block Using Hash_Val
9.                IF BatchID Matched
10.                 Retrieve Block_Info
11.                 Hash_Val ← Prev_Hash
12.               ELSE
13.                 Hash_Val ← Prev_Hash
14.               End_IF_ELSE
15.       Until Retrieved Packer, Bulk Dist., Wine Prod. &
Grape Grower Info
16.             Display all retrieved info
17.        End_REPEAT
18.       Flag ← True
19.       Break
20.    End_IF
21.   End_FOR
22. End_WHILE
23. IF Flag == True
24.    Display "Not Found!"
25. End_IF
```

V. Implementation Details

A blockchain prototype of the proposed traceability system is implemented on the Multichain platform [9]. Multichain is an open platform for blockchain applications that can be used to design and run a private blockchain. It also offers an important set of functionality called 'streams' which enables the participants to use a blockchain as a distributed database to provide a secured means for data recording and retrieval, timestamping, archiving and traceability. The key benefits of Multichain over other blockchain platforms are: 1) configurable parameters- it allows the user to set all of the blockchain's parameters e.g., chain's protocol, target time, maximum block size etc.; and 2) supports multiple blockchains- unlike Ethereum or Bitcoin, it can create and work with different blockchains at the same time.

For simplicity, a blockchain called 'Multichain WSC' is designed and implemented with five entities, namely, grape grower, wine producer, bulk distributor, filler/packer, and retailer. Among them, wine producer, bulk distributor and filler/packer are designated as the miners. All entities in the

MultiChain WSC

Streams

Stream Name	Stream Items	Anybody Can Publish	Creator	Creation Transaction
root	0	True	1Kje8XUz6UVEE6NC1AD62VP5GaQYSqNsGShX3f	c08340f3f50b32b88977...
GriffithFineWine	5	True	1Kje8XUz6UVEE6NC1AD62VP5GaQYSqNsGShX3f	971f1b3eddcbbe5427d8...

Fig. 5. Multichain WSC streams.

chain generate their own blocks containing transactions which are verified by the miners before being added in the chain. Fig. 5 shows that the 'Multichain WSC' has spawned two streams: *root* and *GriffithFineWine*. Each stream includes a unique transaction id, number of items, and creator address.

Stream: GriffithFineWine

Summary

confirmed	5
createtxid	971f1b3eddcbbe5427d83fc1512328e05cb199d45c46238e60f5e0c5aa2a4d19
creators	1Kje8XUz6UVEE6NC1AD62VP5GaQYSqNsGShX3f
details	{}
items	5
keys	4
name	GriffithFineWine
open	True
publishers	5
streamref	446-266-8087
subscribed	True
synchronized	True

Publishers

Publisher	Items
1Xu7g5MohahCFHaMcismkKNFAC5P5vFGNPxjgE	1
1Kje8XUz6UVEE6NC1AD62VP5GaQYSqNsGShX3f	1
1Yy1kqdze4QWgPi98jawsbPrcuSZ6GtwNbRUY7	1
1FHy38PAbrrVJxG5E3JAUxCZikyhrvAdiqLPzm	1
1MH272bjRNPVyrBxYTiVcV8mHcPSYQ9HTgfafX	1

Fig. 6. GriffithFineWine stream with five participants.

Fig. 6 shows the summary of the *GriffithFineWine* stream as well as unique address of five entities or participants in the supply chain.

Transaction 0017839a4a...6cec

Hash	0017839a4a910f370dbeba9f87ab79076810f4087752e2822bcb9b59af246cec
Appeared in	MultiChain WSC, Block 581 (2017-01-23 17:10:00)
Number of inputs	1 – jump to inputs
Number of outputs	2 – jump to outputs
Size	296 bytes

Fig. 7. Transaction generated by the grape grower.

Once the blockchain stream has been created, the entities can generate and publish blocks of transactions in the chain. Fig. 7 presents the first blockchain transaction of the *GriffithFineWine* stream generated by the grape grower. This transaction appeared in the block 581 and must be verified by the miners before being included in the chain as shown in Fig. 8. The block 581 contains hash of the stream item and miner's signature in addition to miner's address. This address identifies the miner that first verified the block before adding it to the chain. In this way, every participant in the wine supply chain generates their own blocks and eventually the blocks are added sequentially in the stream after being verified by the miners. The purchase information of each and every bottle of wine is recorded in the blockchain by the retailer.

One of the most important features of the proposed wine supply chain traceability system is that anyone in the supply chain can trace the origin, production and purchase history of each individual product if that information is public. Any customer can verify the provenance and authenticity of the purchased wine by inputting the product ID in the system. After receiving the product ID, the system first identifies the batch of wine and then traces back all transactions made by different entities in the supply chain for the corresponding item. The details of each transaction is shown to the consumers as illustrated in Fig. 9. Since the blockchain stream is immutable, counterfeiting and relabelling would not be successful in the proposed system. Thus, the system ensures transparency and security in the overall process of the wine supply chain.

VI. Discussion and Conclusion

This paper proposes a blockchain based traceability system for wine supply chain to provide transparency, provenance, safety and security. Since there has been an increase in counterfeit wines in the global market, blockchain is an effective solution to overcome the problem. One of the drawbacks of blockchain technology is transaction speed for some applications such as bitcoin. For example, it now takes about 43 minutes on average for a bitcoin transaction to be verified [10]. Privacy is another critical issue since neither companies or individuals would like to publish all information onto a public database. However, private blockchains with cryptographic schemes can be used to address these issues efficiently. In private blockchain, sensitive information can be kept secret by encrypting them using a pre-distributed secret key whereas public information can be stored in plain text. To address transaction speed issue, the number of miners can be preselected in a private blockchain based system where all these miners are assumed to have some level of trust.

In the proposed traceability system, a private blockchain

MultiChain WSC 581

← Older Newer→

Block Summary

Hash	000055f096c567627c7fe8ac0922fb28667d1d9a053fd9da22af3edc8a739345
Previous Block	000089195f093d53933b4f50d50754f640971351ebddab3aa70b5ba1f8e94c26
Next Block	00008ed5c8bc2f50bfb753a6607dc56e09c1692de9f16f9d6511ded51266de24
Height	581
Miner	1Kje8XUz6UVEE6NC1AD62VP5GaQYSqNsGShX3f
Version	3
Transaction Merkle Root	07f6ab33a350f7b41eecd3825114e460d11eb8a344fa25f6a597dfd56778322c
Time	1485155400 (2017-01-23 17:10:00)
Nonce	256856
Transactions	2

Transactions

Transaction	Size (kB)
4162f1dce97654c84fc80c15d11c2df784ecbe38ca6d1f62df301c36ecfb3802 Miner Signature	0.185
0017839a4a910f370dbeba9f87ab79076810f4087752e2822bcb9b59af246cec Stream Item	0.296

Fig. 8. Summary of the block 581.

Stream: GriffithFineWine

Stream Items

<< < > >> 20 50 100 500

Time	Key	Value	Raw Data	Publisher	Transaction
2017-01-23 17:32:05	WineBottle001	ID: R001 Wine Bottle ID: WB001 Sold: 01	40 bytes	1MH272bjRNPVyrBxYTiVcV8mHcPSYQ9HTgfafX	5430f1366d...
2017-01-23 17:28:39	WineBottle001	ID: F001 Bulk Dist: BP001	26 bytes	1FHy38PAbrrVJxG5E3JAUxCZikyhrvAdiqLPzm	bfde181595...
2017-01-23 17:26:15	BulkWine001	ID: BD001 Wine Producer: WP001	31 bytes	1Yy1kqdze4QWgPi98jawsbPrcuSZ6GtwNbRUY7	0ea3780dec...
2017-01-23 17:22:27	BatchNum001	ID: WP001 GrapeGrower ID: GG001	32 bytes	1Kje8XUz6UVEE6NC1AD62VP5GaQYSqNsGShX3f	d60a4e3714...
2017-01-23 17:10:00	GG001	ID: G001 Origin: ABCD Type of Vine: XYZ Treatments: PQRST	60 bytes	1Xu7g5MohahCFHaMcismkKNFAC5P5vFGNPxjgE	0017839a4a...

Fig. 9. Tracing back individual wine bottle (WB001).

with five participants has been implemented that allows the participants to encrypt secret information. Thus, the same blockchain stream could be used to record companies critical information as well as public data. However, for simplicity, current implementation only deals with public data. Another limitation is that the current system only provides limited command-line based instructions to store information in the chain. Our future work aims to develop a graphical user interface (GUI) and more advanced application programming interface (API) to easily store and retrieve information in the chain. We also aim to integrate all internal and external entities of the wine supply chain in our future implementation.

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