A Blockchain-Based Secure Model for Automobile Supply Chain with IoT

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A Thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering

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Candidate's Declaration

This is to certify that the work presented in this thesis, titled, "A secure model for Blockchain-Based Automobile Supply chain with IoT", is the outcome of the investigation and research carried out by me under the supervision of Prof. Dr. ARM Harunur Rashid, Professor, MPE Dept., IUT, Board Bazar, Gazipur-1704, Bangladesh.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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The thesis titled "A secure model for Blockchain-Based Automobile Supply Chain with Iot " submitted by Ekra Binta Noor, Student No: 180011209 Tawsif Zaman Arnob, Student No: 18001117 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of B Sc. in Mechanical Engineering **on 7th December 2022.**

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Abstract

"AutoChain," a blockchain-based solution designed to enhance transparency and trust within the global automotive supply chain. Traditional supply chains often face challenges such as disruptions and difficulties in identifying reliable partners. AutoChain addresses these issues by leveraging decentralized record-keeping of manufacturers, suppliers, and customers. By utilizing blockchain technology, AutoChain ensures the security, tamper-proofing, and traceability of transactions, with Layer 1 of the Ethereum Blockchain recording supply chain transactions among key stakeholders and Layer 2 capturing real-time data from IoT devices.

To promote trust among participants, AutoChain implements an authentication system to validate the authenticity of stakeholders. Additionally, a reputation management system is incorporated, enabling the rating of end users based on the services provided. In cases of disruptions within the supply chain, AutoChain utilizes a game theory algorithm to identify the most suitable replacement participant. This novel approach separates the blockchain for global automobile supply chain transactions, offering a dedicated layer for addressing disruptions through game theory-based participant selection.

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Nomenclatures and Symbol

Abbreviation	**Meaning**
BC	Blockchain
R	Regulator
S	Supplier
C	Customer
M	Manufacturer
RMS	Reputation Management System
SCM	Supply Chain Management
EVM	Ethereum Virtual Machine
ERP	Enterprise Resource Planning
SC	Supply Chain

List of symbols:

ETH	Ethereum Currency

Chapter 1: Introduction

Chapter 1.1: Background

In today's globalized business world, supply chains have become increasingly complex and dispersed (Longo, F et al2019; Ma, F at al 2020; Brody, P. et al 2017;). Despite significant investments in improving tracking mechanisms for parts and values, many companies still have limited ability to do so (Pirola, F. et al 2020; Litke, A et al 2019; Westerkamp, M 2020;). There is often a disconnect between systems used within a single company and those used across different companies. Implementing a traceability system can help reduce costs, and waiting time, and improve quality and customer service, thereby giving organizations a competitive edge (Khan, S et al 2018; Sarkar, M et al 2021;). Additionally, consumers are increasingly interested in determining the ethical origins of the products they purchase. The importance of automation in the supply chain has also risen in recent times (Casino, F et al 2021). Automation requires the integration of multiple systems which generates a large amount of data that is crucial for monitoring and ensuring the quality of products at every stage of the supply chain (Casino, F et al 2021).

The automotive industry can be a key sector in running the economy of a nation (Fan, Y et al 2019). However, businesses in this industry face a variety of difficulties, including the inability to trace in-transit components, internal production, and items that are intended for delivery. (Ning, F et al 2020; Hasan, et al 2020;). The entire supply chain is facing a sizable hurdle because of this. Furthermore, excess capacity increases spending and reduces the effectiveness of supply chain activities.(Shao, L et al 2020). Consumers are also concerned about the origin of the parts used in a specific vehicle or product category as well as their sustainability. (Cognex, Dai, B et al 2021;). Real-time tracking and communication are challenging to implement because supply chain participants lack a consistent information access strategy.(Alfian, G et al 2020; Dallasega, P.; et al 2018;). Additionally, maintaining the proper Inventory Quality Ratio (IQR) across many nodes is a challenge for supply chain businesses, which causes traceability problems. Additionally, unscheduled operational interruption brought on by raw stockouts and equipment malfunctions affects lead times and lengthens client wait times, which has a detrimental effect on the effectiveness of the supply chain. (Abu Zwaida et al 2020; Pourhejazy et al 2020).

Blockchain is a new technology that has been made possible by Industry 4.0. By enhancing security and enabling information sharing across networked supply chains, it has the potential to address some of the issues the automobile sector is now facing.(Kamble, S.S et al 2020). The waiting time, cost, risk reduction, speed, quality, dependability, and flexibility of the supply chain may be impacted.(. Korpela, K et al 2017; Pan, X et al 2020;). Blockchain technology can create an immutable ledger/database system that is shared, secured, and provides permission accessibility, which facilitates increased transparency and improved visibility (Di Vaio et al 2018). The automobile sector can benefit from blockchain technology in many ways, including enhanced incoming facility logistics, object tracking, and traceability of component origin. (Petri, I. et al 2020). However, the adoption of blockchain in the supply chain is still in its early stages. Blockchain functions as a decentralized database with a collaborative network that maintains secured transactional data (Tandon, A et al 2020). The automotive industry has only recently started to investigate the uses of blockchain in its operations, despite the fact that it has a significant potential to alter a variety of aspects of how the sector functions. Figure 1 depicts a straightforward automotive supply chain that demonstrates the movement of goods between suppliers to consumers. Blockchain can help manage the automobile supply chain because of the vast number of components involved. Businesses are still looking for solutions to enhance their supply networks and accept the transformations driven by blockchain technology.

In order to enhance supply chain operations in the automotive sector, this study will integrate blockchain technology. Even if information systems are used in the present supply chain, partners are reported to lack trust. In order to increase trust, organizations put a lot of effort on sustaining positive relationships with other team members, but there is no assurance that the information supplied is true. This problem may be solved by "AutoChain", which offers a safe and open mechanism for information sharing. According to the literature, the application of blockchain technology in the automotive supply chain is still in its infancy, and there is a need for more study and investigation in this field but we were unable to find any sort of Blockchain being utilized for a decentralized automotive supply chain that AutoChain provides.

The study will identify traceability problems in different supply chain nodes, and create a novel IoT- enabled double layered blockchain called "AutoChain" for global automobile supply chain enhancement and tackling disruption.

We discussed what we are going to do and why in section 2 of this study. The earlier works that we discovered to be related to our issue are covered in section 3 of this report. We covered our work process in section 4 of the study. We have covered our computational work in section 5. We went into great detail about the result and performance of our model and the entire structure in section 6. We reviewed our conclusion in part 7 before talking about our future goals in the section.

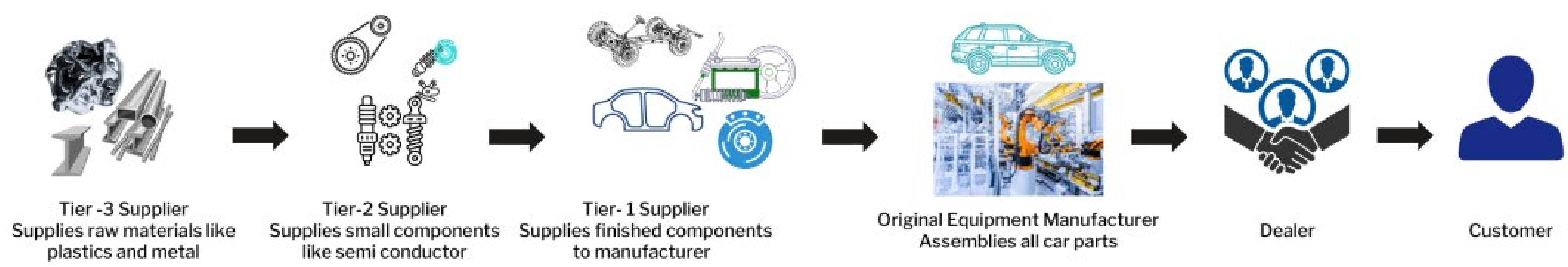

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Fig-1: Traditional Supply Chain

Chapter 1.2: Objectives of the Study

- To make a Blockchain-based Automobile Supply Chain having two Layers.
- Introduce IoT devices in Layer 2 of the Blockchain.
- Removing complexity in Automobile Supply Chain.
- Securing Data and improving management in Automobile Supply Chain.
- Blockchain was made efficient by improving scalability with two layers.
- Reputation-based management system for selecting participants of the game.
- Implementing game theory for the selection of a new participant instead of a disrupted participant.

1.3 Blockchain

Blockchain technology has been widely recognized as the future of secure currency management, as it provides a range of services such as security, integrity, global accessibility, privacy preservation, immutability, and transparency. (Akhter, A.S et al 2021) Additionally, its decentralized and distributed storage system is considered an added advantage. The use of blockchain technology is also known to provide protection against various types of attacks.Typical assaults including Sybil attacks, unknown source attacks, man-in-the-middle (MITM) attacks, illegal entry, and DDoS (distributed denial-of-service) attacks are difficult to carry out because of its decentralized and distributed storage system. Furthermore, the consensus protocols in place provide an added layer of security and ensure the integrity and stability of the information.

1.4 Supply Chain and IoT

The adoption of blockchain technology in supply chain management (SCM) has the potential to bring about disruptive changes in various industries, leading to the reconfiguration of traditional relationship models due to the disintermediation of transactions. As an example, Figure 2 illustrates the use of a smart contract in a trade between a producer (A) and a supermarket (B). After the terms of the trade have been fulfilled by both parties, a contract is written, coded, and stored in a blockchain structure. The contract is triggered when it meets the negotiated conditions, at which point the money and goods are transferred according to the contract, without the need for an intermediary. This process not only speeds up the transaction but also reduces costs and improves trust, as all participants in the network have a copy of the ledger.

In SCM, it is important to coordinate various parties, processes, and resources, and the permissioned nature of blockchain provides security, authenticity, and ownership to save time.

(Malik et al 2019) The Internet of Things (IoT) refers to a network of interconnected devices that share data, such as for automation or monitoring, either privately or publicly. The IoT can assist in detecting malware and DDoS attacks in the network. (Awan et al 2021).

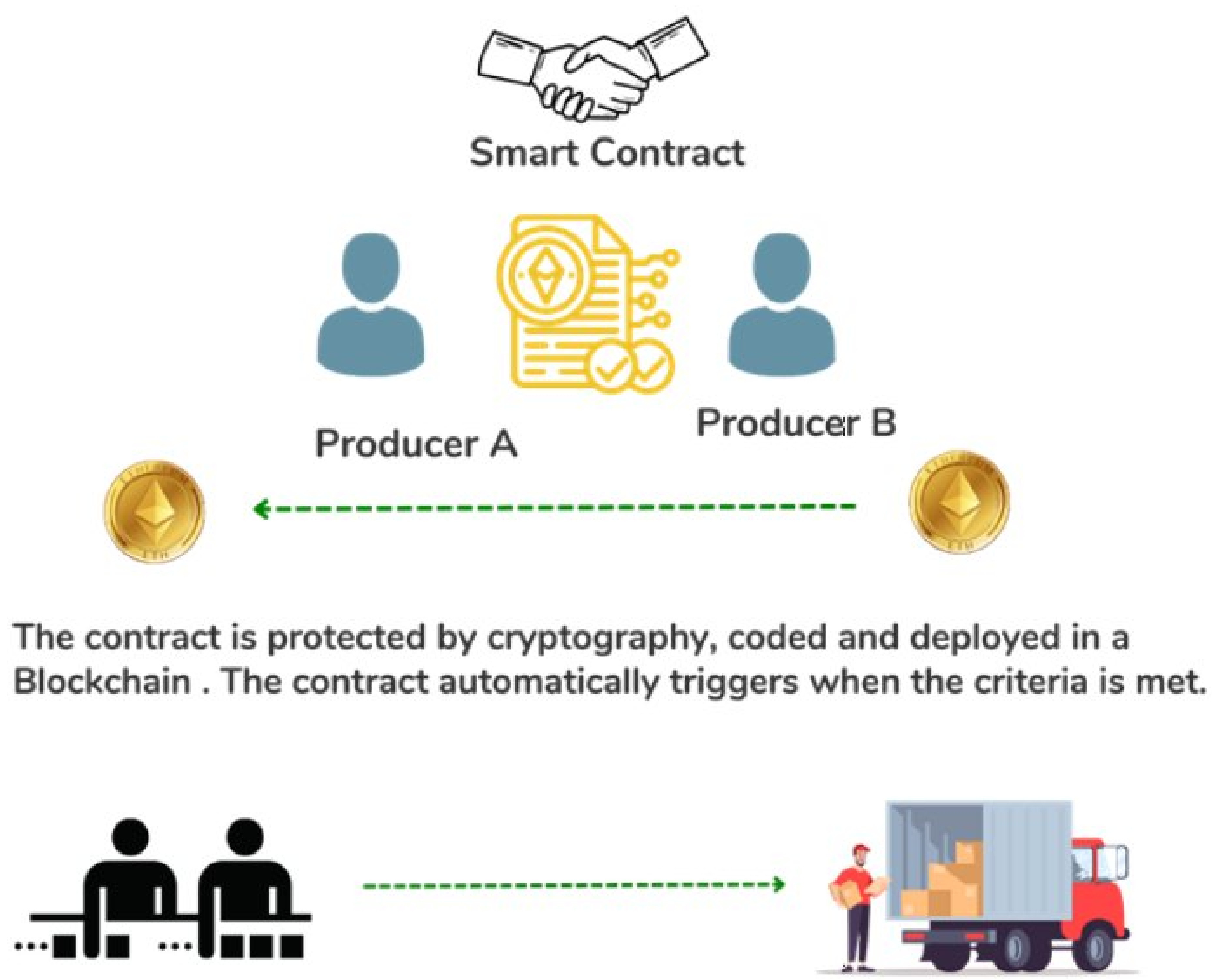


Fig-2: Blockchain-enabled Supply Chain

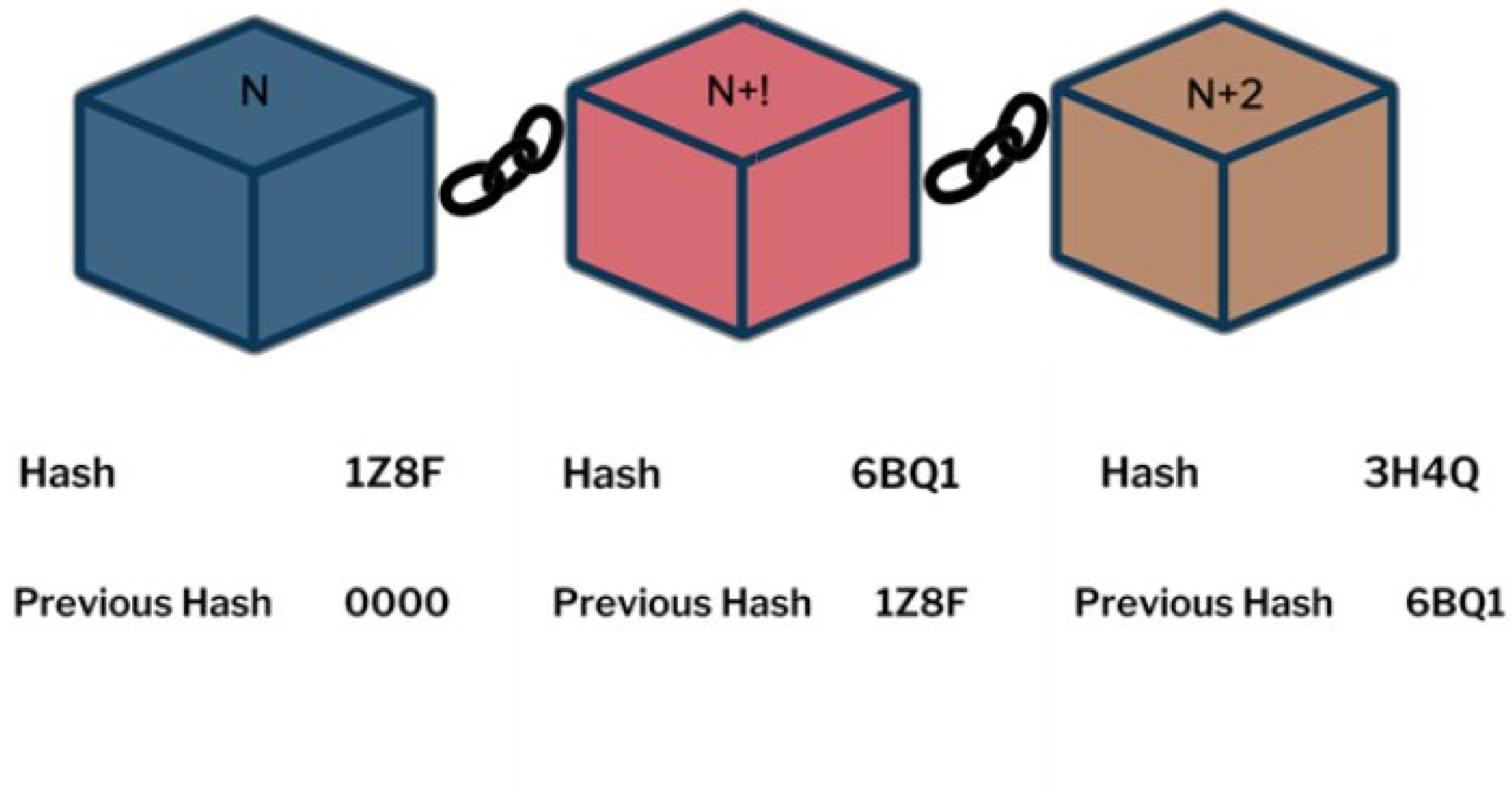


Fig-3: How Blockchain works

1.5 IoT And Blockchain

Blockchain and Internet of Things collaboration creates a setting for secure, effective transactions with lower prices and reusable components. Machine-learning techniques have been utilized in the medical industry to diagnose various disorders. Security is a major problem for any industrial application (Uddin et al, 2021). By merging enterprise resource planning and supply chain solutions, these methods can also be used for ongoing temperature and moisture monitoring and alarms in supply chain management, particularly for medicines and food. Machine learning and blockchain are used to address security attacks in industrial IoT (Vargas et. al). Machine learning techniques have been effectively utilized in the medical field to identify a variety of illnesses. (Ali et al 2019; Awan et al 2021;Javed et al 2021; Nabeel et al2021;Gupta et al; Nagi et al 2021).Blockchain-based IoT offers several benefits for the supply chain, including improved information flow and traceability, increased information accessibility, the ability to link information flow with material flow, and reduced risks of rule violations and fraud.(Frikha et al 2021; Kouhizadeh et al 2020;) In order to employ blockchain-based IoT for supply chain management systems, this article aims to highlight existing technological research subjects, intelligent devices, and future research paths. To the best of our knowledge, no comparable research on the application of blockchain IoT in the supply chain has been done.

1.6 Reputation Management System in Blockchain

A reputation management system in the blockchain is a decentralized approach that uses blockchain technology to ensure transparent and trustworthy management of reputation information. Participants are assigned verified digital identities, and reputation-related transactions are recorded on an immutable blockchain ledger. Based on collected comments, reputation scores are produced, and consensus procedures verify the validity of transactions. Using a novel strategy to increase ETS effectiveness, Khamila et al. (2018) presented an Emission Trading Scheme (ETS) that makes use of blockchain technology to address the management and fraud problems now present in ETS. A new block is generated by the leader node with the most reputation, and it is certified and confirmed by reputation-based voting, according to a technique presented by (Zhuang et al. in 2019) (2022 Dharma et al).

1.8 Game Theory-based participant selection in Blockchain

In a blockchain-based supply chain, game theory can be used to optimize participant selection and incentivize cooperation among participants. Game theory is a mathematical framework that analyzes strategic decision-making in competitive situations. Participating parties act selfishly in their interest resulting in a sub-optimal output for transactions. This makes it difficult for trust to be established and an effective equilibrium to be reached among parties. Therefore, it is essential to ensure coordination among all parties and for all parties to collaborate effectively to avoid this problem. Using game theory models, we can develop novel approaches and prove mathematically that the blockchain is more efficient in establishing a supply chain equilibrium among parties, ensuring fairness among various parties (Gao et al 2022). Game theory techniques can be adopted in order to understand and model competitive

or cooperative scenarios between rational decision-makers. (Ramona et al 2011) proposed a theoretical framework for combining reputation-based systems, game theory, and network selection mechanisms. Pietro et al 2020 proposed A game theoretic model for Blockchain and smart contracts in supply chain management. This proves the usefulness of game theory in blockchain-based supply chains. But we could not find any work which used game theory based on the automobile supply chain with blockchain. Burhan et al 2020 proposed a game theory-based data transaction for a MANET system where they allocate reputation value for every transaction based on the assessment of the trustworthiness of adjacent nodes towards cooperation in forwarding the respective data packets.

1.9 Motivation & Scope

In this thesis work, we are trying to make a blockchain-based supply chain for the automobile industry with the Internet of Things(IoT). The world is catching up with new technology very quickly as it transitions from Industry 4.0 to Industry 5.0. The technology of the future is blockchain, where everything has been shown to be transparent and unchangeable. Researchers and businesses alike are working to implement blockchain in every industry they can. It has already been used in many fields, including banking, voting, medical data storage, etc., but because of its complexity and high computing demands, it has been challenging to use in so many fields. We intend to use blockchain technology and distribute workload as a result. We are attempting to implement Internet of Things (IoT) devices that will reduce supply chain gaps, collect data, and store it.

To reduce inconveniences such as the payment system's platform dependence, unregulated pricing, delays caused by payment confirmation, etc. All of those problems are resolved in the suggested way by utilizing cryptocurrency that is blockchain-based.

The suggested approach includes a reputation management system where manufacturers can give feedback on the service they received, more especially regarding the suppliers and their goods. As soon as a review is received, the server will average all of the ratings for each Supplier, and when the manufacturers are given a list of suppliers to choose from, Suppliers with relatively higher rating points will be given preference. Additionally, because suppliers can set their own prices, they can strike a balance between ratings and pricing.

Chapter 2 Methodology

In our research on blockchain, automobile supply chain, and IoT, we first conducted a thorough literature review to gain a deeper understanding of the subject matter. We also familiarize ourselves with the Solidity programming language and various tools such as Truffle Suite, Ganache, and Meta Mask Wallet, which are essential for writing and deploying smart contracts.

Next, we wrote and deployed a smart contract in Solidity, which served as the foundation for our blockchain-based supply chain model. This smart contract outlined the various transactions that would take place within the supply chain and how they would be recorded on the blockchain.

Later we will collect real-time data from the automobile industry and analyze it using the AnyLogic software. This data was compared with our blockchain-based supply chain model to determine its effectiveness and efficiency. The results of this comparison helped us to identify areas of improvement and make necessary adjustments to our model.

Overall, this research project required a significant amount of time and effort to complete. However, the end result was a comprehensive and functional blockchain-based supply chain model that can be used to improve the efficiency and traceability of the automobile industry's supply chain operations.

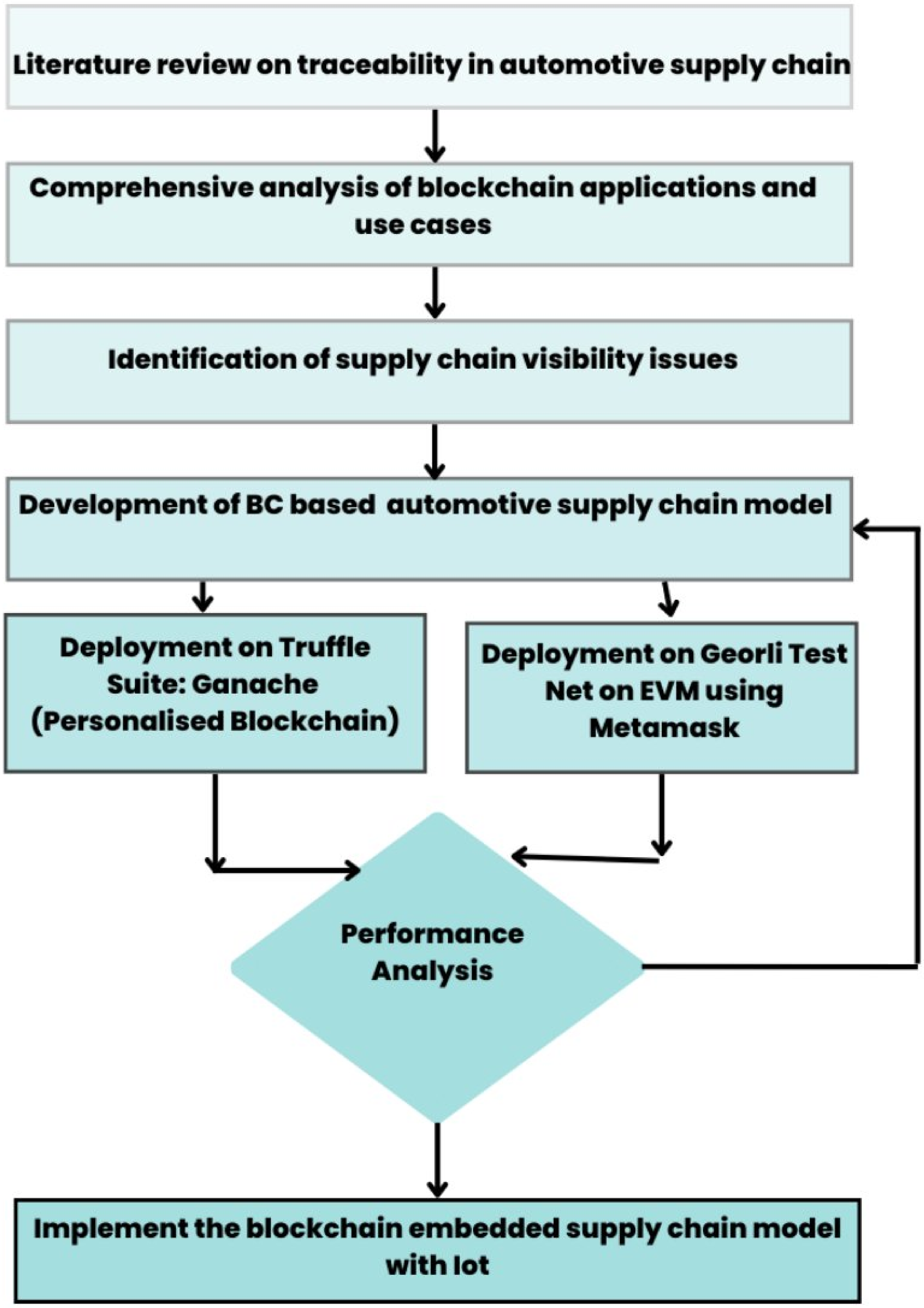


Fig 4: Methodology Workflow

Chapter 3: Literature Review

Chapter 3.1 Blockchain

Blockchain is undoubtedly the technology of the future for managing safe monetary transactions. The fundamental features offered by blockchains are security, authenticity, availability everywhere, privacy protection, data integrity, transparency, etc. (Ahmed, M et al 2021). Additional benefits include distributed storage and a decentralized storing mechanism. A unique characteristic of blockchains is their defense against many forms of attacks. Numerous common assaults, such as Sybil attacks, unidentified origin attacks, man-in-the-middle attacks, illegal access, and distributed denial-of-service, cannot be carried out on a blockchain due to its decentralized and distributed storage approach. Consensus mechanisms also add an additional layer of protection to this, ensuring the accuracy and stability of the data.

Chapter 3.2: Supply Chain Applications of Blockchain

Several studies have been conducted on the application of blockchain technology in supply chain management, with a focus on transparency and traceability. (Weng Chun Tan et al 2021) conducted a bibliometric and network analysis of research on blockchain management, and found that it is conducted across various platforms and countries. (M. Hussain et al 2021) examined the use of blockchain-enabled IoT devices in supply chain management, while (D. M. Vistro and M Faooq 2021) looked at the challenges and opportunities presented by blockchain in food supply chain management. (Sohail Jabbar 2021) conducted an analysis of blockchain-based supply chain management, and (Justin Sunny Et.al 2020) argued that firms are incorporating blockchain into their supply chain activities to improve transparency through tracking and tracing events. The impact of the SARS-CoV-2 pandemic on supply chain failures and how blockchain technology can address these issues is also examined by (A. S. Sangeetha 2020). Other studies, such as those by (A. S. Sangeetha 2020) and (S. Madumidha 2019) discuss the opportunities and challenges presented by blockchain technology in the context of open manufacturing and the Industrial Internet of Things (IIoT). (Y. Tsang 2019) proposed a blockchain-driven IoT solution for food traceability, while (A. Alahmadi 2019) investigated the use of blockchain-based smart contracts for secure and fair IIoT-enabled supply chain management. (S. J. Divey 2019) argued that the supply chain and logistics industry is considered to be the next promising use case for blockchain technology. The table includes the authors, publication year, outcomes measured, and key findings of each study.

Table-1: Paper 1-17 Previous works and Key findings

NO	Authors	Key Findings	Topic
1	Mehrdokht Pournader, Yangyan Shi, Stefan	Blockchain applications in supply chains, transport and logistics	LR, BC, SC
2	Andreas Kamilarisa,b,* , Agusti Fontsa , Francesc	rise of blockchain technology in agriculture and food supply chains	BC, Agri, SC
3	Saikat Mondal, Kanishka Wijewardena, Saranraj	RFID based Information Architecture for Food Supply Chain	FSC, BC, RFID
4	Neje Rozman, Rok Vrabic, Marko corn	Distributed logistics platform based on Blockchain and IoT	BC, IoT, SC
5	Randhir Kumar, Rakesh Tripathi	counterfeit medicine supply chain through Blockchain	BC, SC
6	Faisal Jamil 1 , Lei Hang 1 , KyuHyung Kim	Medical Blockchain Model for Drug Supply Chain	BC, SC
7	PRATYUSH KUMAR PATRO 1 , RAJA WASIM AHMAD 2 , IBRAR YAQOOB	Blockchain-Based Solution for Product Recall Management	BC, SC
8	Yu Xia and Thomas Li-Ping Tang	Sustainability in supply chain management for the auto industry	BC, SC, AM
9	Marco Conoscenti, Antonio Vetro`	Blockchain for the Internet of Things	BC, IoT
10	Aditya Prakasha , Arpit Agarwala , Aditya Kumar	Risk Assessment in Automobile Supply Chain	SC, AM
11	Bjørn Jæger 1 and Alok Mishra 1	IoT Platform for Seafood Farmers and Consumers	IoT, SC
12	Jingjing Chen 1,2, Tiefeng Cai 1 , Wenxiu He 1	Blockchain-Driven Supply Chain Finance Application for Auto Retail Industry	BC, SC, Auto, Fin
13	Behzad Esmaeiliana , Joe Sarkisb , Kemper Lewis	Blockchain for the future of sustainable supply chain in Industry 4.0	BC, SC, 4IR
14	1 N. Nasurudeen Ahamed, 2 Karthikeyan P,	Sea Food Supply Chain Management Using Blockchain	SC, BC
15	Sohail Jabbar1,2 · Mohammad Hammoudeh1	Blockchain supply chain: analysis, challenges, and future directions	SC, BC
16	Amine Belhadi a , Sachin Kamble	Manufacturing and service supply chain resilience	Sc, Manufacturing
17	G. Zyskind, O. Nathan	Management of access policies and references to users' data	Bc, Data Security

Table-2: Paper 18-34 And Key Findings

NO	Authors	Key Findings	Topics
18	D. Vorick and L. Champine	Management of data storage contracts	BC, Data Storage
19	C. Bocovich, J. A. Doucette	Management of document storage contracts	BC, Contract Storage
20	G. Zyskind, O. Nathan	Tamper-proof log of events and management of access control to data	BC, Control data
21	S. Wilkinson	Management of metadata of data kept in a storage system	BC, storage
22	G. Ateniese, M. T. Goodrich,	Automatic compensation of clients of in case stored data are lost	BC, Data store
23	M. Bartoletti, D. Gessa, and A. S. Podda,	Immutable log where storing metadata of messages of decentralized applications	BC, security
24	Y. Zhang and J. Wen	Purchase by devices or human beings of assets such as sensors data or goods	BC, sensor, Iot
25	D. Worner and T. von Bomhard	Purchase of sensors data in IoT	BC, sensor, IoT
26	D. Wilson and G. Ateniese,	Management of identity verification and certificate revocation of PGP certificates	Security, Iot
27	L. Axon C. Fromknecth, D. Velicanu	Public Key Infrastructure (PKI). Management of update, registration and revocation of keys	Security
28	L. Matteis	Tracking of users and contents points in a social voting system	Traceability
29	D. Vandervort	Rating system where customers can give feedbacks about a purchase	Reputation
30	J. Herbert and A. Litchfield	Management of software license validation	Authorization
31	B. Gipp, N. Meuschke,	Timestamping service, in order to prove a content has been produced before a specific date	Data Store
32	P. Bylica, L. Glen, P. Janiuk	Implementation of a lottery	Traceability
33	G. W. Peters and E. Panayi	Banking applications such as automated and distributed bank ledgers	ledger
34	L. Ren	Implementation of a social cryptocurrency, to quantify social influence	Cryptocurrency

3.3 Ethereum

The proposed technique uses Ethereum as the blockchain, which has various benefits for the system. While Ethereum trails behind Bitcoin in terms of popularity, it still has several highly unique qualities that make it a popular choice for companies. The smart contract (Ahmed, M et al 2021), which transforms Ethereum into a system for managing digital assets rather than just transferring money, is its most essential characteristic. Unlike other types of blockchain, like Bitcoin, Zcash, Dash, Peercoin, Ripple, Monero, and Multichain, smart contracts allow for the management of the entire system from a single platform. Since there is no coin cap, Ethereum can support more transactions per second than the majority of other blockchain systems.

3.4 Blockchain & IoT for Traceability and Transparency in SC

Recent studies have investigated the application of blockchain technology in supply chain management, with a particular focus on transparency and traceability. A bibliometric and network analysis by (Weng Chun Tan et al 2021). found that research on blockchain management is conducted among various research platforms and countries. In a study by (M. Hussain et al 2021), the authors examine the use of blockchain-enabled IoT devices in supply chain management.

Similarly, (D. M. Vistro and M Faooq 2021) explored the challenges and opportunities presented by blockchain in food supply chain management. Another study by Sohail Jabbar (2021) conducted an analysis of blockchain-based supply chain management. Justin Sunny et al. (2020) argue that firms are increasingly incorporating blockchain into their supply chain activities to improve transparency through tracking and tracing events.

The impact of the SARS-CoV-2 pandemic on supply chain failures and how blockchain technology can address these issues is also examined by (A. S. Sangeetha 2020). P. Wan (2020) highlights the potential of blockchain-enabled information sharing in enhancing collaborative work across different types of supply chains. Other studies, such as those (by A. S. Sangeetha 2020) and (S. Madumidha 2019) discuss the opportunities and challenges presented by blockchain technology in the context of open manufacturing and the Industrial Internet of Things (IIoT).

(Y. Tsang 2019) proposes a blockchain-driven IoT solution for food traceability, while (A. Alahmadi 2019) investigates the use of blockchain-based smart contracts for secure and fair IIoT-enabled supply chain management. (S. J. Divey 2019) argues that the supply chain and logistics industry is considered to be the next promising use case for blockchain technology. (Sidra Malik et al 2019) introduced TrustChain, a consortium blockchain to track interactions among supply chain participants and to dynamically assign trust and reputation scores based on these interactions. (Francesco Longo 2019) conducted an experimental study on blockchain-enabled supply chains. A summary of the studies conducted on blockchain-based supply chain management with IoT from 2019 onwards is presented in the table below. The table includes the authors, publication year, outcomes measured, and key findings of each study.

Table 3: A list of Papers containing Blockchain and IoT applications in the supply chain from 2019 onwards

	Year	Published Channel	Author	Intervention	Outcomes Measured
	2021	Journal	Weng Chun Tan Et.al	Management of supply chains, blockchain co-citation, and networking study.	Identify the major publications, organizations, nations, and research organizations.

	2021	Journal	Nesrin Ada , et al	Blockchain Technology for Enhancing Traceability and Efficiency in Automobile Supply Chain	Showed better outcome with blockchain implementation in the automobile supply chain than traditional
	2021	Journal	M. Hussain et al	A Comprehensive Review of the Literature on Blockchain-Based IoT Devices for Supply Chain Management	
	2021	Conference	D. M. Vistro, M. Farooq	A Study of Blockchain and IoT Applications and Limitations in the Food Supply Chain	Having a thorough understanding of blockchain and any potential repercussions will not just be helpful for new professionals in critical fields.

	2021	Journal	Sohail Jabbar	Supply chain with blockchain technology: analyses, issues, and future prospects	• Obstacles to the adoption of blockchain for supply chain applications, both technological and non-technical • The suitability of different consensus methods for use in supply chain applications • The ecosystem's tools and technology for blockchain • A few crucial areas as potential future study areas

	2020	Journal	Justin Sunny Et.al	Businesses have begun integrating blockchain technology throughout existing supply chain operations to increase transparency by identifying and monitoring events.	Gaining knowledge of the possibilities of blockchain-enabled traceability systems by reading the literature that is currently accessible
	2020	Conference	A. S. Sangeetha	Blockchain technology has the potential to address the supply chain issues that the SARS-CoV-2 outbreak uncovered.	Blockchain will improve the efficiency and transparency of supply networks and have a beneficial impact on everything from payments to delivery to storage.

	2020	Journal	P. Wan	It can be beneficial to improve collaborative work in many kinds of supply chains to implement blockchain-based information exchange inside them.	Sharing of information on the blockchain can improve teamwork in various supply chains, including those for construction, healthcare, and smart cities.
	2020	Journal	Jinying Li	Opportunities and obstacles related to transparent production and the industrial IOT	
	2020	Journal	V. G. Venkatesh	Blockchain-enabled supply chain transparency and social sustainability framework	This study includes a number of constraints, including the system design it established for observing social sustainability compliance difficulties.

	2020	Journal	Jacopo Grecuccio	Food-Chain Traceability and Beyond Using Blockchain and IoT	Modeled a software framework that enables IoT devices to communicate with a blockchain that is built on Ethereum.
	2020	Conference	Shubham Sahai	Blockchain and 0 Knowledge Proofs for Supply Chain Privacy and Traceability	The approach is a blockchain-enabled sc that offers privacy, traceability, and effective contaminant tracing.
	2019	Conference	S. Madumidha	Utilising the IoT and blockchain technology in the food supply chain	
	2019	Journal	Y. Tsang	IoT for Food Traceability Powered by Blockchain with Integrated Consensus Protocol	A proposed system for a blockchain IoT-based food traceability system

	2019	Conference	A. Alahmadi	Secure & Fair IIoT-based SCM Supply through BC Smart Contracts is a suggested method for a blockchain-based IoT-enabled food traceability.	A BC-enabled SCM system in the IIoT
	2019	Conference	S. J. Divey	The field of supply chains and logistics is seen as the most potential application for this rapid technological advancement.	
	2019	Conference	Sidra Malik	SC Assisted by Blockchain and IoT: Trust Management	TrustChain concept tracks interactions between supply chain actors and uses a consortium blockchain to dynamically give

					trust and reputation scores based on these interactions.
	2019	Journal	Francesco Longo	An experimental supply chain research using blockchain	• The prospective use of a BC in SC; • The effectiveness of a supply network overall; • The drawbacks of asymmetric information between supply chain tiers.

Chapter 4: Description of the Model/System

In this paper, an Ethereum blockchain is set up for complete transactions of an automotive supply chain. The system consists of three main protocols, which are: (1) The authentication protocol, (2) the transaction storage system, (3) the reputation management system (RMS), and (4) Blockchain Layer 1 and Layer 2. In this section, the elements of the system are briefly described primarily, followed by authentication and reputation management systems are thoroughly explained.

4.1. Components

This system is composed of key stakeholders, primarily entailing: –

- Customer(C).
- Manufacturer(M).
- Supplier(S).
- Regulator(R).
- IoT
- Reputation Management System (RMS)
- Ethereum Blockchain Layer 1. (BC1)
- Ethereum Blockchain Layer 2. (BC2)

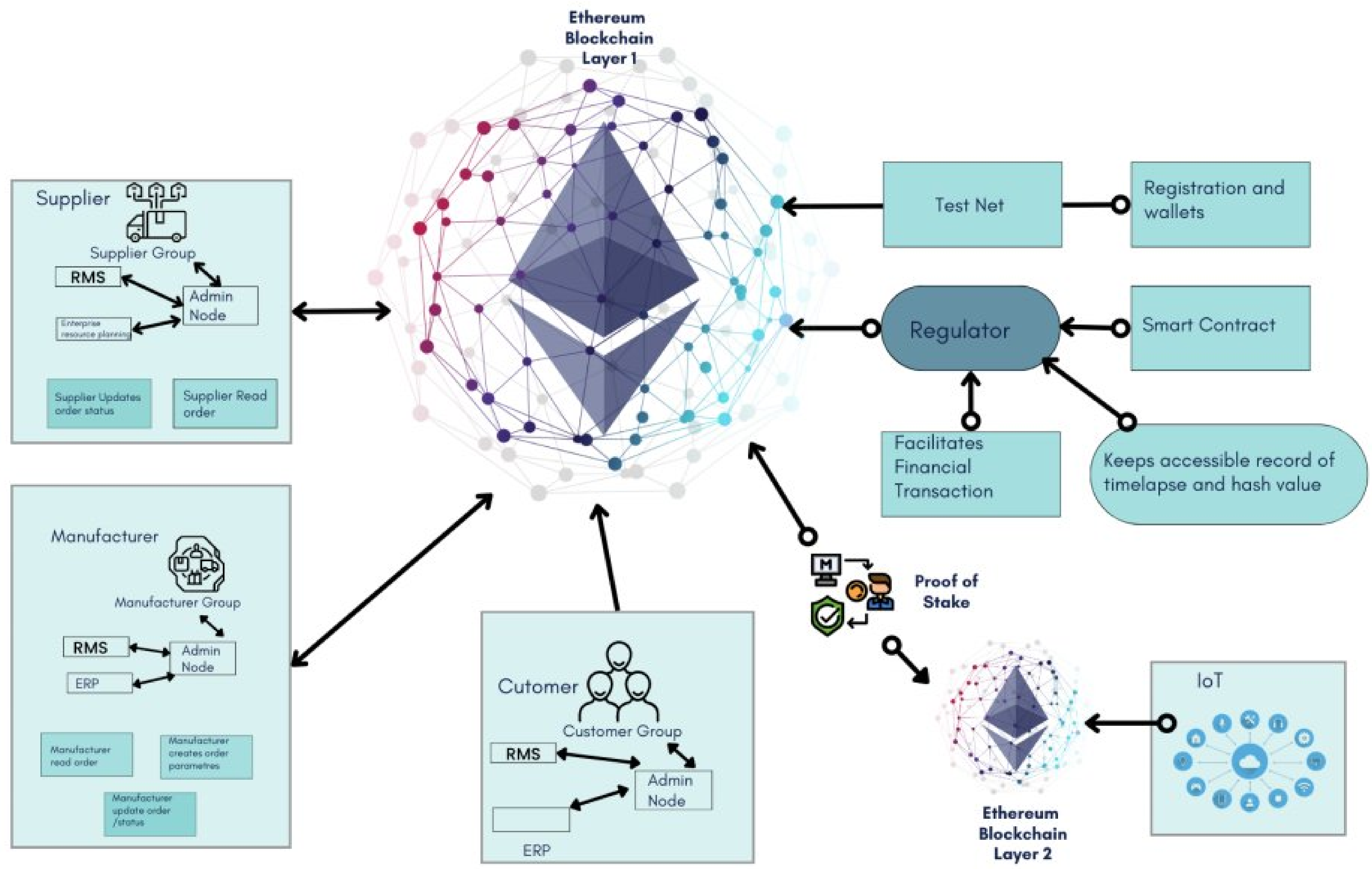


Fig 5: System Structure for the supply chain

4.2 AutoChain

AutoChain employs a two-layer architecture, with Layer 1 serving as the primary layer for handling key stakeholder transactions within the system. In order to enhance the scalability of the blockchain, we have introduced Layer 2, which is specifically designed to handle real-time data generated by IoT devices. This strategic division of functionality allows for improved scalability by reducing the storage burden on the main Layer 1.

By offloading real-time data processing to Layer 2, AutoChain achieves a more streamlined and efficient blockchain operation. Layer 1 can focus on managing essential transactions involving key stakeholders, while Layer 2 handles high-volume, real-time data transactions. This separation optimizes the overall performance of the blockchain, enabling it to accommodate a larger number of transactions and scale more effectively.

The introduction of Layer 2 with IoT integration not only enhances the scalability of AutoChain but also ensures that the main Layer 1 remains less storage heavy. This architecture aligns with the objective of maintaining an efficient and robust blockchain infrastructure while effectively managing the increasing volume of data generated by IoT devices.

Interested parties (supply chain stakeholders) must register by supplying the essential information and papers in order to participate in the proposed system, AutoChain. Each participant will be given a set of keys (public and private). All communications will be conducted via the public key, which will serve as the member's identification. In addition time, the public key would conceal the member's true identity, so preserving privacy. Nevertheless, the block production and validation processes in a typical blockchain involve a lot of intricate computations, necessitating the usage of computationally intensive servers. To reduce transactional latency, certain calculations are therefore carried out via an edge server. The blockchain is in charge of keeping all transaction results and reputation management systems inside a transaction in order to maintain its security, data integrity, availability, transparency, etc., along with the authenticator. Any link in the supply chain can simply register for the system by submitting the necessary data and paperwork. It joins the blockchain after registering and can conduct transactions at any time via Internet access. Customers will place orders, and the manufacturer and supplier will update the order status in accordance with their inventory and production in response to demand. The EVM verifies each order as well as any modifications to an order. The management of inventories is done by the regulator. Through the virtual machine for Ethereum, all of this data is exchanged.

4.3. Authentication Protocol

The validity of the members, or Supply Chain stakeholders, is verified in the proposed system using blockchain. Before using any of the system's services, each of them must personally register. Following registration, they are given a set of keys, and all subsequent conversations will be conducted using their public keys. The system verifies the orders' membership status before to producing any transactions from the customer (C), and it also verifies the manufacturer's or supplier's legitimacy prior to advancing any transactions. (S). Additionally, any member can use the reqAInfo function to send a message to the server asking for the authentication details of another component in order to confirm the legitimacy of a specific C, M, or S. ().

4.4 Reputation Management System

A reputation management system was introduced to the system in order to ensure the quality of service. The end user may provide feedback regarding the obtained service following each transaction (order and change order) with the billing service. A rating of one to five can be given, with five (5) denoting the best service and one (1) denoting the worst service imaginable. A stakeholder with relatively higher ratings will be given priority on the list when the server suggests it. The server will determine the mean of the total ratings for each stakeholder. All of the fields in the transaction have been filled up following the end user's feedback, and the server will produce the block based on the transaction.

In this case, after the manufacturer selects their suppliers, they can make deals of a certain duration which will be renewed after that. And there will be a smart contract for the deal. This way we can ensure a good environment and dealership between suppliers and manufacturers.

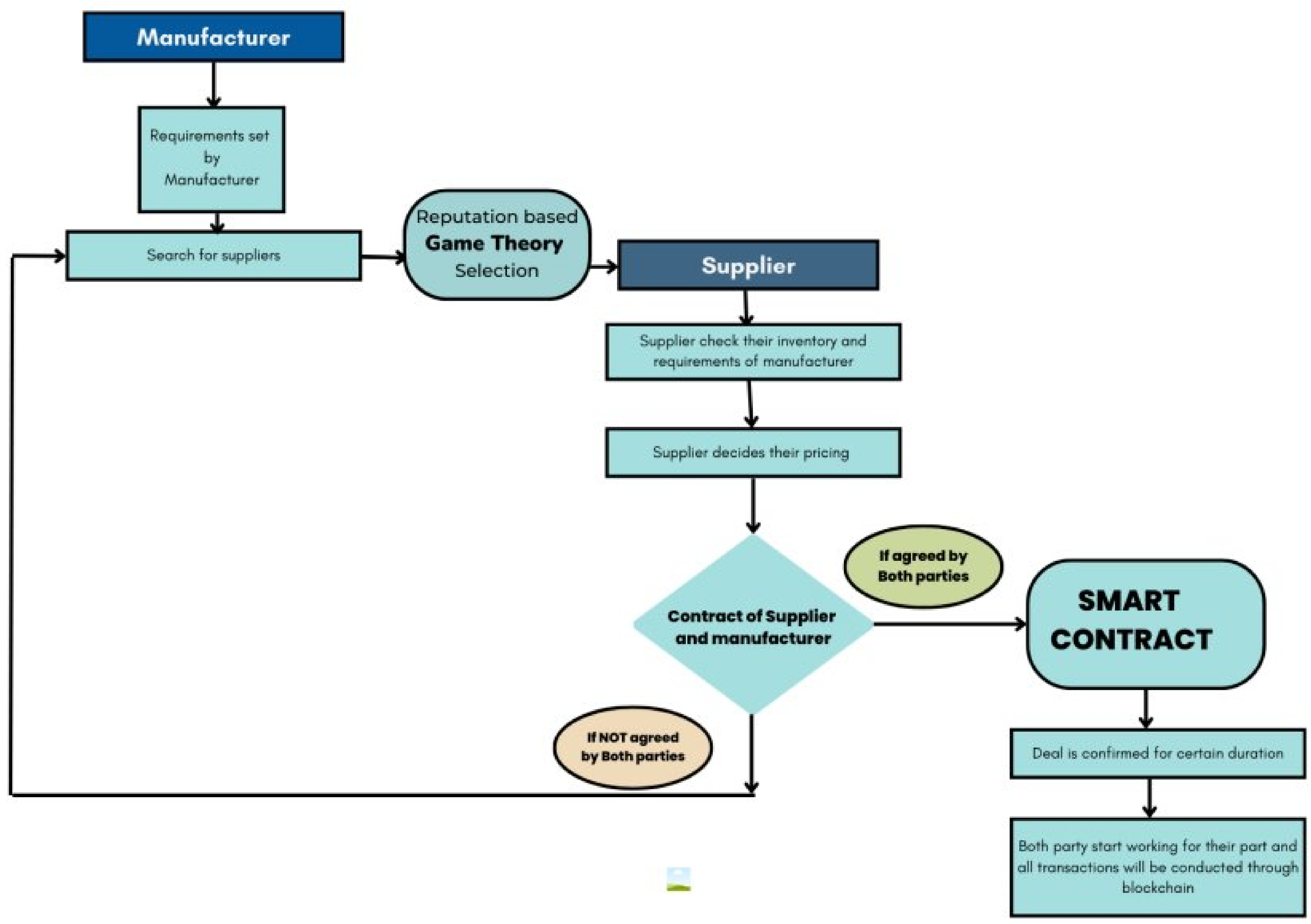


Fig 6: Workflow of AutoChain

In this flowchart we have shown how the whole reputation and authentication system will work and how the deals will be confirmed between the manufacturer and dealers.

4.5 Game theory-based electing new participants in case of disruption

To address disruptions in the supply chain, we have devised a novel game theory-based system for electing new participants, valuing them based on reputation. This system incorporates a reputation management system that assigns reputation values to transactions, enhancing transparency and trustworthiness. By applying game theory models, we have developed innovative approaches and mathematically demonstrated that the blockchain promotes efficiency in establishing an equilibrium within the automotive supply chain, ensuring fairness among all parties involved. Participants in the network utilize game theory to make decisions based on the reputation of a participant facing a disruption.

The algorithm for this game can be as follows:

Algorithm: Reputation-Based Game for Participant Election in Blockchain-Integrated Automotive Supply Chain

Input: Set of participants P, Reputation scores R, Disrupted participant X

Output: Elected participant E

1. *Initialize the network* $N = \{P, R\}$
2. *Calculate the reputation score for each participant* $i \in P$ *using* $R\_i = (\alpha * P\_i) + ((1 - \alpha) * R\_i\text{-}1)$, *where* P_i *is the participation score of the participant i and* $R\_i\text{-}1$ *is the reputation score of participant i-1 and* α *is a weight parameter.*
3. *Calculate the reputation score for the disrupted participant X using* $R\_X = (\alpha * 0) + ((1 - \alpha) * R\_i\text{-}1)$
4. *Let the set of participants with reputation scores greater than or equal to a threshold value T be* $P\_T = \{i \mid R\_i \geq T\}$
5. *If the set* P_T *is not empty, then* $E = \text{argmax\_i } P\_i$ *in* P_T, *where E is the elected participant with the highest participation score in* P_T.
6. *If the set* P_T *is empty, then* $E = \text{argmax\_i } P\_i$ *in P.*
7. *Return the elected participant E.*

In the above algorithm, the participation score P_i represents the level of involvement of the participant i in the supply chain. The reputation score R_i represents the level of trustworthiness of participant i in the supply chain. The weight parameter α determines the balance between the participation and reputation scores in calculating a participant's reputation score. The threshold value T represents the minimum reputation score required for a participant to be considered for election in case of disruption. The elected participant E is the participant with the highest participation score in the set of participants with reputation scores greater than or equal to the threshold value T, or the participant with the highest participation score in the entire network if no such participant exists in the set P_T.

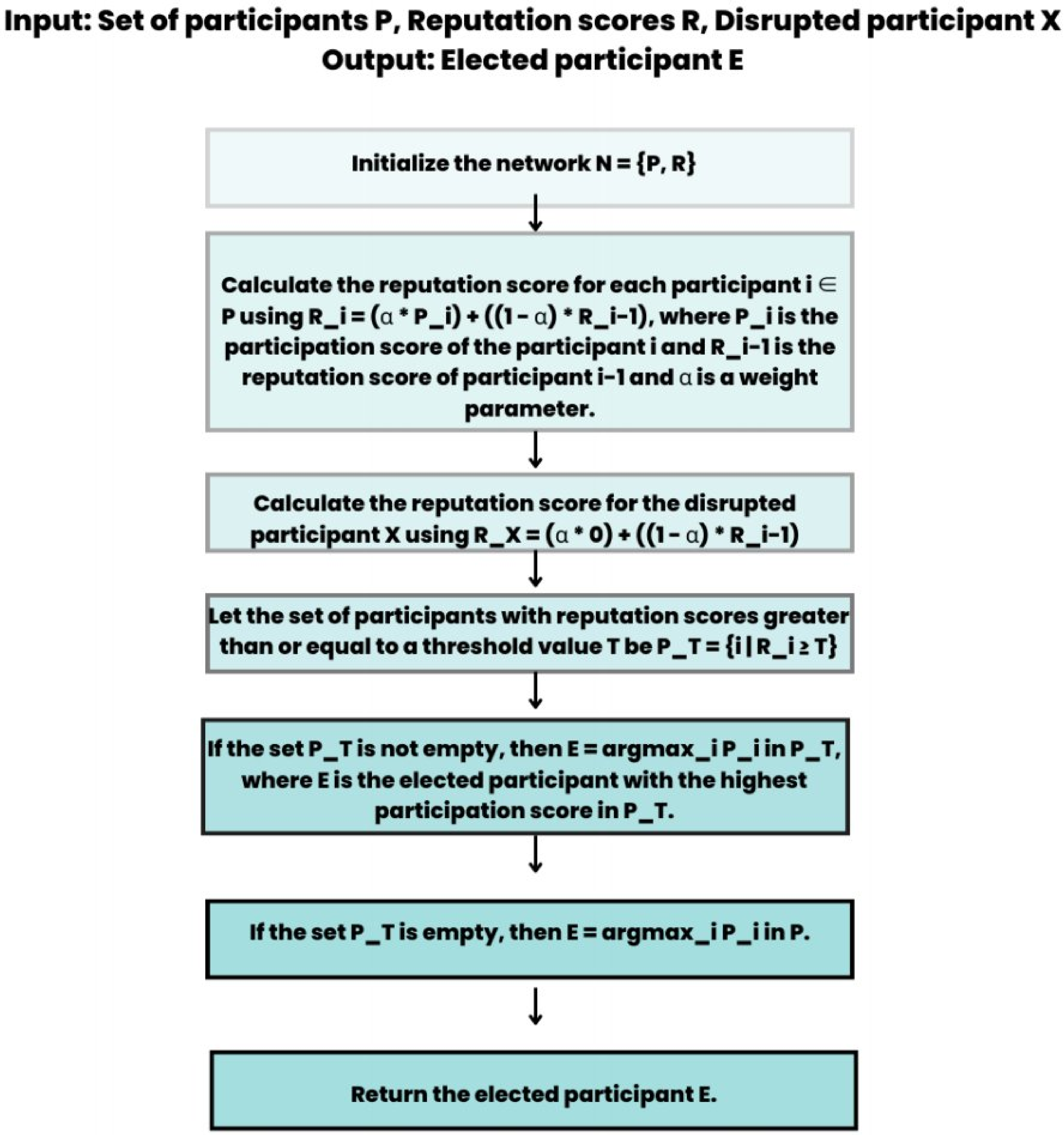


Fig 7: Game Theory-based participant selection

The reputation score calculation R_i = (α * P_i) + ((1 - α) * R_i-1) is a common approach used in the literature for calculating the reputation scores of participants in a network. It is a recursive formula where the reputation score of participant i is calculated as a weighted sum of their current participation score P_i and their previous reputation score R_i-1. The weight parameter α determines the balance between the participation and the reputation score in calculating the reputation score of a participant.

The intuition behind this formula is that the reputation of a participant in a network is influenced not only by their current behavior but also by their past behavior. By using a weighted sum of the participation score and the previous reputation score, the formula gives more weight to the participant's past behavior and provides a more accurate representation of their overall reputation in the network.

This formula is commonly used in reputation-based systems such as online marketplaces, where participants' ratings are based on their past behavior and interactions with other participants. In the context of the blockchain-integrated automotive supply chain, this formula can be used to calculate the reputation scores of the participants based on their previous behavior and, involvement in the supply chain.

The formula and reputation scores in calculating a participant's reputation score* 0) + ((1 - α) * R_i-1) is a variation of the reputation score formula used for the other participants in the network.

The reputation score of the disrupted participant X is calculated as a weighted sum of their previous reputation score R_i-1 and a zero participation score since the participant is currently disrupted and unable to participate in the supply chain. The weight parameter α again determines the balance between the participation score and the reputation score in calculating the reputation score of the disrupted participant X.

This formula allows the reputation score of the disrupted participant X to be updated based on their past behavior in the supply chain, even though they are currently unable to participate due to disruption. By using the same formula as for the other participants but with a zero participation score, the algorithm maintains consistency in the calculation of reputation scores for all participants, including the disrupted participant X.

In the reputation-based game for participant election in the blockchain-integrated automotive supply chain, this formula allows the algorithm to consider the reputation of the disrupted participant X in the decision-making process, even though the participant is currently facing a disruption.

The algorithm for participant election in the blockchain-integrated automotive supply chain uses the reputation scores and participation scores of the participants to select an elected participant that can maintain the supply chain in the event of a disruption.

The set P_T is a subset of the set of all participants P, consisting of participants with reputation scores greater than or equal to a threshold value T. This threshold value T represents a minimum level of trustworthiness required for participants to be eligible for election as the backup participant in the supply chain.

If the set P_T is not empty, then the algorithm selects the elected participant E as the participant with the highest participation score in P_T, denoted by argmax_i P_i in P_T. This means that the participant with the highest participation score among the eligible participants is selected as the backup participant, based on their demonstrated ability to contribute to the supply chain.

If the set P_T is empty, meaning that no participants meet the minimum threshold of trustworthiness, the algorithm selects the elected participant E as the participant with the highest participation score in the entire set of participants P, denoted by argmax_i P_i in P. This means that the participant with the highest participation score, regardless of their reputation score, is selected as the backup participant in the event of a disruption.

This approach allows the algorithm to balance the importance of both participation score and reputation score in selecting the backup participant while ensuring that the supply chain can be maintained even in the absence of highly reputable participants.

Chapter 5: Computational Methodology

Deploying Blockchain, First, the Ganache blockchain was installed in the EVM to execute the experimental configuration. By default, Ganache creates certain public keys for users, and each user gets 100 transactions worth of ether. The public keys obtained by each member VM (Customer, Manufacturer, and Supplier) served as the entity's public identities. The participants then signed up for the blockchain using the Metamask wallet. We left the order/update order amount open during development so that manual entry may be accepted. After setting up the blockchain, we manually requested various orders. The data generated after receiving the entry from the members were then saved as blockchain transactions.Due to the simplification, the suggested system may generate the block practically immediately after receiving a request and can broadcast it to all members. The amount of cryptocurrency, in this case, Ether, is sent from the provider's account to the requesting stakeholder's account during the block generation process (M, C, or S). The stakeholder who receives the service may also offer a rating score (out of 5), and the server will compute the mean of all the reputation scores each stakeholder has received. The rating result will be made publicly accessible. By using the web interface, all the members can check the global (and also own) transaction histories, financial statements, and rating points (provided or received). The system was examined through numerous transactions. Data were manually produced after the simulated system had operated, and information was added to the transaction() method using smart contracts in accordance with the message structure (presented in Figure 4). After those data were inserted, A transaction was carried out in the blockchain. The figure provides specifics of a few of the completed transactions.

Chapter 6: Results & Discussion

6.1 Performance

In this study, we used the Remix IDE and the Geroli Testnet to install a smart contract on the Ethereum test network. The usage of the cypto wallet called MetaMask wallet, which made it possible to connect to the Ethereum network, made the deployment easier. We found that as transactions were manually inputted, the amount of the Ethereum network's currency, Ether, decreased. The speed and efficiency of the Ethereum network were demonstrated by our analysis of the transaction data on Etherscan, which showed that the average transaction time was only 31 seconds. The results we obtained show that the decentralized system of Ethereum enables the quick and secure implementation of cross-border transactions. It should be noted that certain circumstances may still provide problems due to the computational burden and storage cost. The following photos give a visual depiction of how effective and secure the simulation of international transactions is.

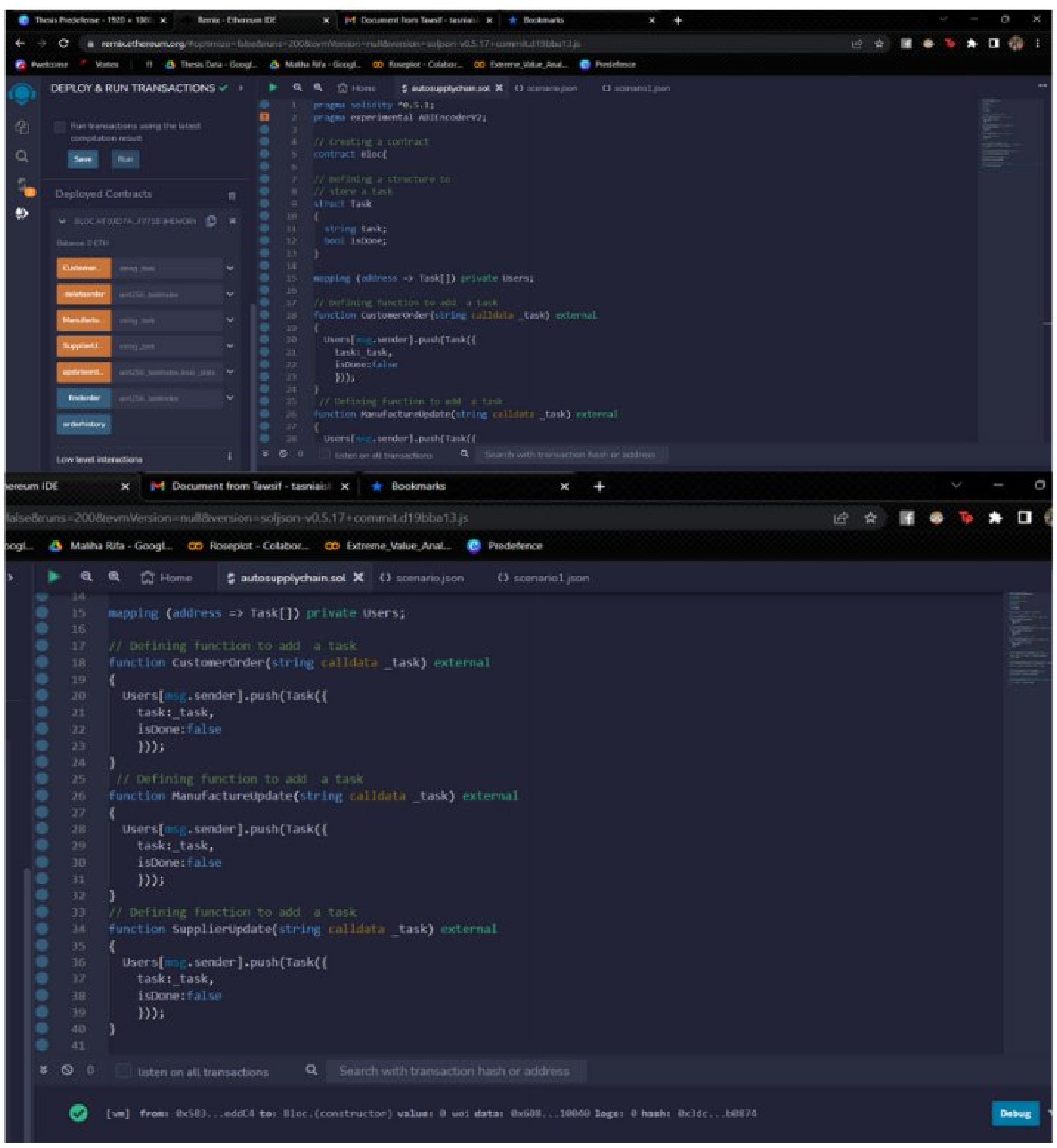
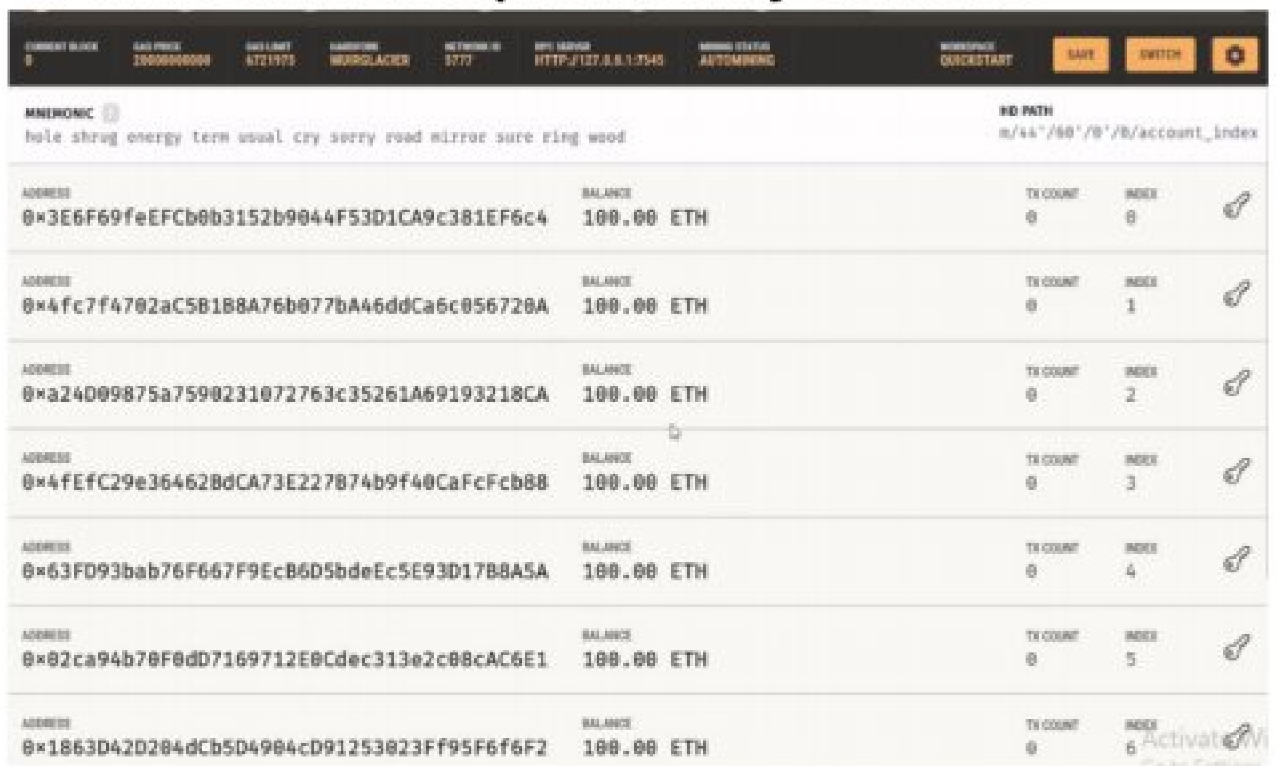
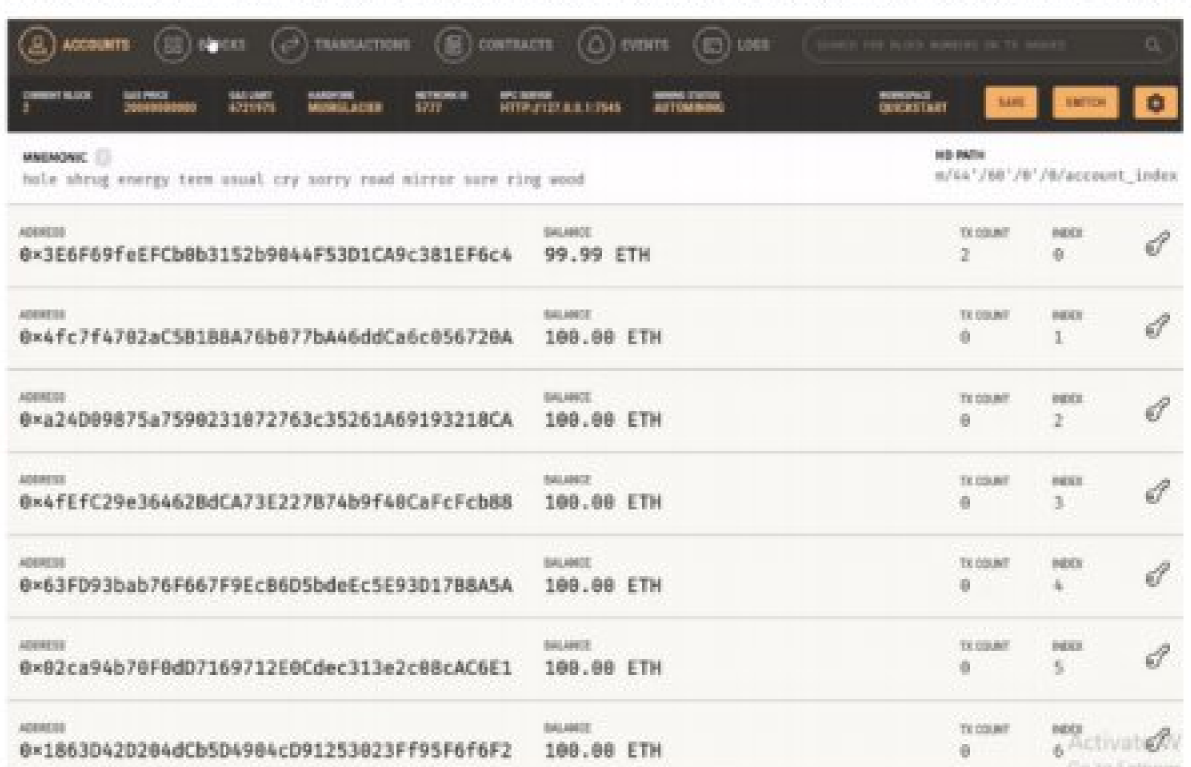


Fig 8- Deployed Code in Remix IDE

10 different nodes provided by Ganache



Reduction of balance from the node for the transaction



Blocks generated for each transaction

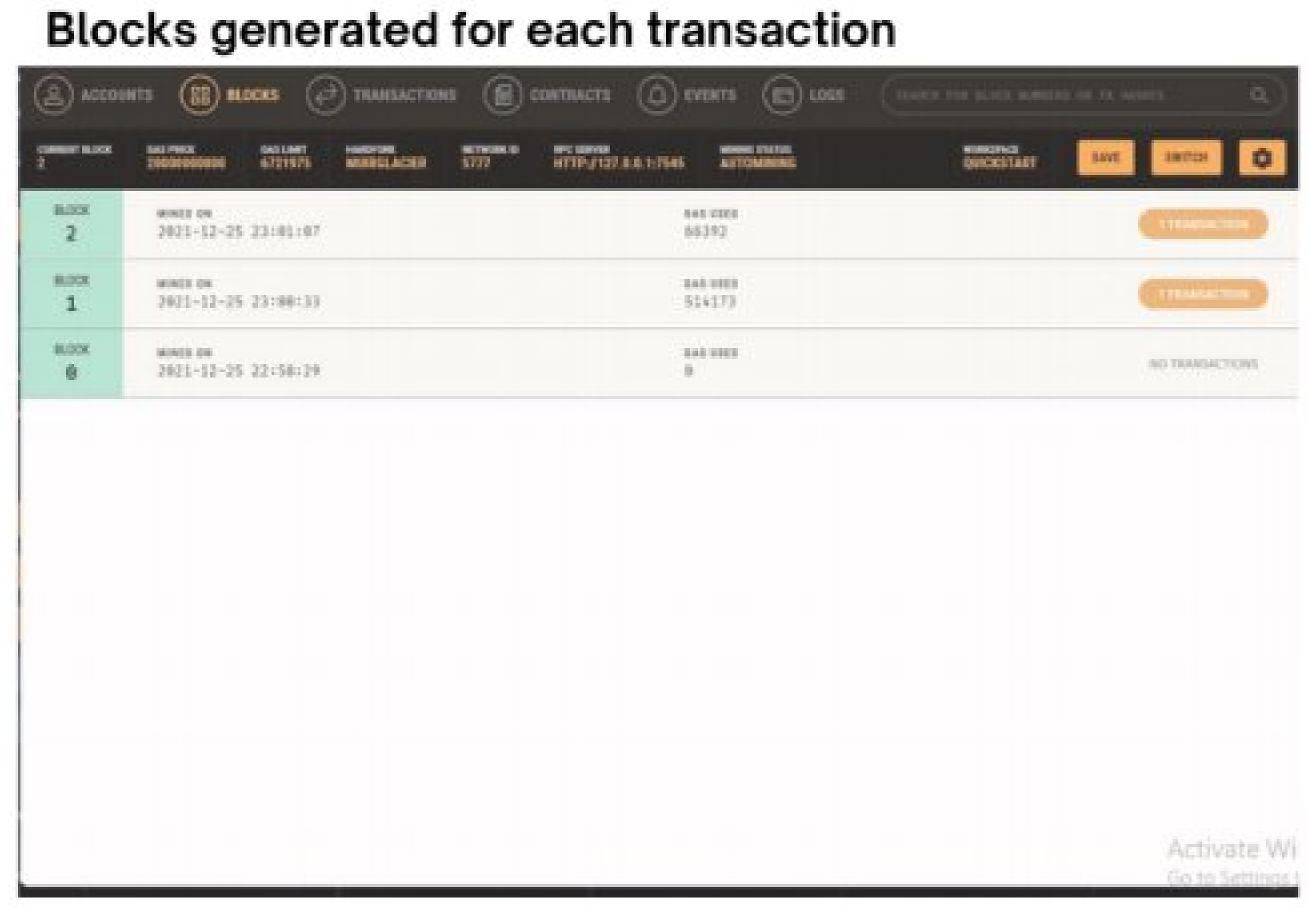


Fig 9-Ganache output of nodes

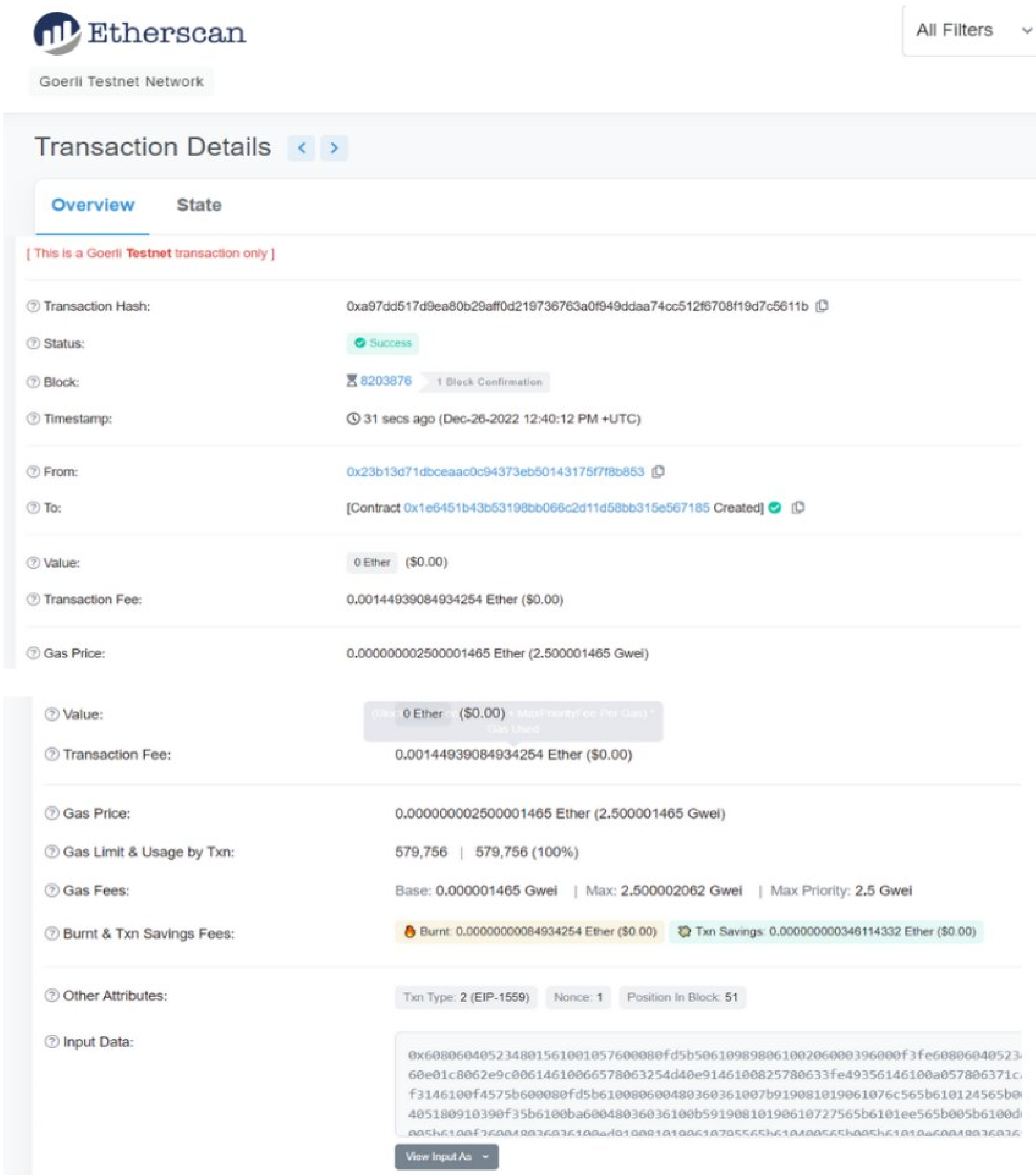


Fig 10: Etherscan Output

In the performance analysis section, we conducted a feasibility analysis and highlighted the advantages that can be achieved through this method.

6.2 Storage Overhead

A single block in a typical Ethereum blockchain can hold up to 512 transactions, and each transaction requires roughly 2KB of storage [Storage Needs for Blockchain Technology]. Ethereum's standard block size is 83.557 KB [Ethereum Average Block Size.]. Consequently, 84KB of storage would be required for each set of 512 charge exchange transactions.

6.3 Computational Time

Elliptic Curve Cryptography (ECC), a technique used by Ethereum, is well known for its resistance to cryptanalysis [Ethereum Glossary]. The consensus procedure is an additional element that influences computation time. Ethereum's primary consensus algorithm is the Proof-of-Work (PoW) technique. 40 blocks with a difficulty level of 32.49 KH may be generated using PoW and ECC in around 4 minutes, according to Kim et al. The consensus protocol's average block generation times for different levels of difficulty are shown in Figure 11 [Kim et al]. (N stands for how challenging the consensus protocol is.)

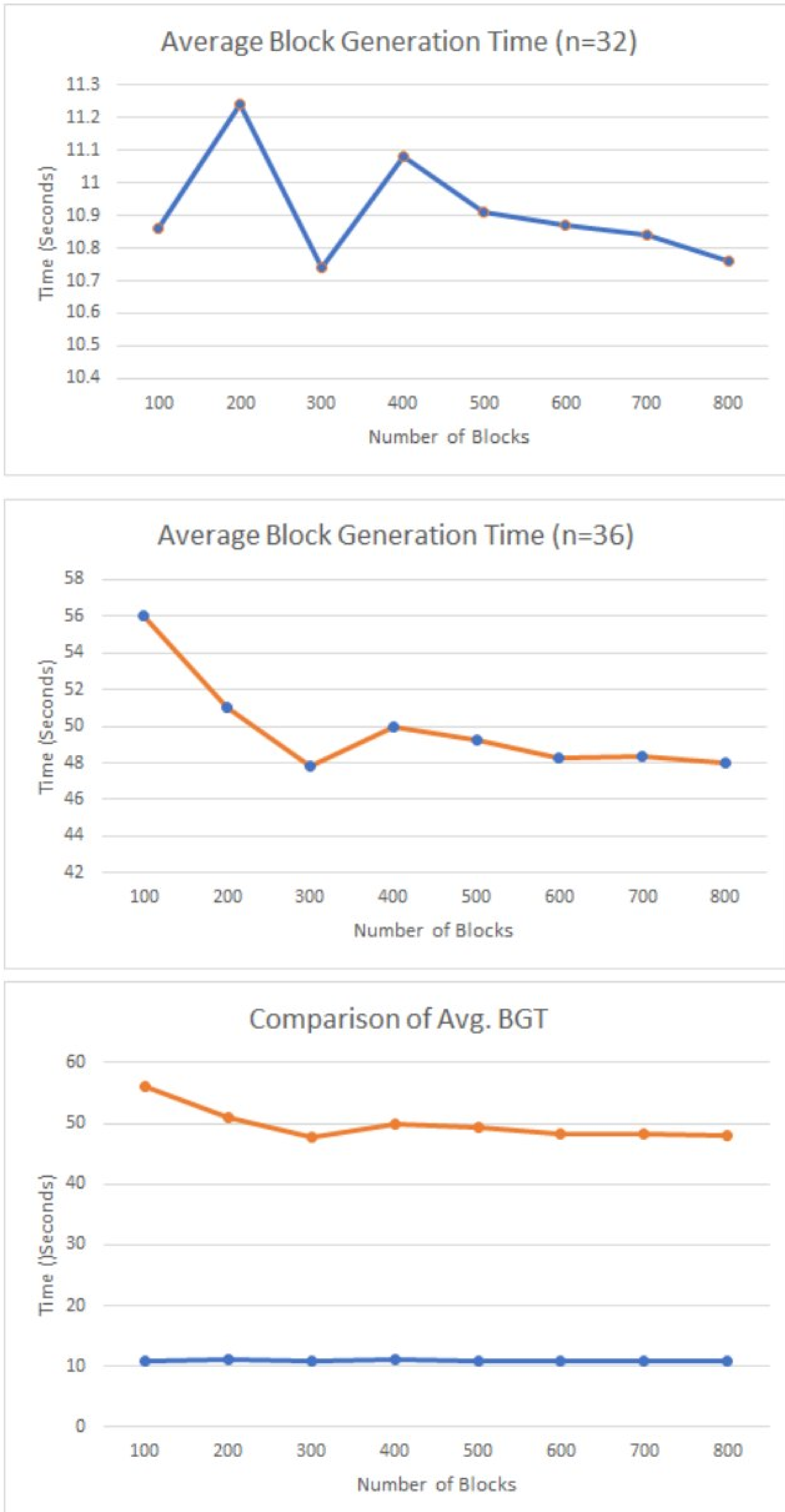


Figure 11 displays the average block generation time (BGT) under two different consensus difficulty levels, namely 32 and 36. The figure also provides a comparison between these two scenarios.

6.4 Propagation Time

Since the system is intended to provide remote help, lowering propagation time is essential to ensuring the suggested method operates efficiently. The good news is that modern high-speed Internet connections can usually supply the necessary services with a respectable propagation time. For instance, whilst future 6G connections are anticipated to be at least 100 times faster than that, current 5G connections can attain transmission speeds of 50 Mbps to 1 Gbps. [What Is the difference between 4G and 5G?].

Consequently, both the Manufacturer and Supplier components of the system are advised to maintain high-speed Internet connections to sustain optimal throughput.

Chapter 7: Conclusion

In this paper, we propose AutoChain, a robust and decentralized blockchain-based infrastructure for the automotive supply chain. Traditional supply chains are often plagued by disruptions, making it difficult to trust new parties and find alternatives in a timely manner. AutoChain addresses these issues by maintaining a decentralized record of manufacturers, suppliers, and customers, which increases the transparency and traceability of transactions.

The system utilizes the Ethereum virtual machine to process transactions, making them secure, tamper-proof, and traceable. The simulation carried out using the Ganache personal blockchain network showed that each transaction took approximately 31 seconds, demonstrating the infrastructure's security and speed. Additionally, the simulation was conducted on an Ethereum test net, allowing stakeholders around the world to participate.

Our added Reputation management system helped the supply chain to tackle disruption due to any reason by utilizing game theory. By using game theory we are able to establish trust and equilibrium between all the participants. This made the supply chain more sustainable and scalable.

In conclusion, AutoChain provides a solution to the challenges faced by the automotive supply chain by increasing transparency, trust, and traceability among the stakeholders such as customers, manufacturers, suppliers, and regulators. The use of Ethereum virtual machines ensures that the transactions are secure and tamper-proof. The simulation results show that the proposed infrastructure is secure, fast, and global in nature.

Chapter 8: Future Scope and Our Next Steps

Two potential future scopes for improvement in the AutoChain system can be:

Optimization of Offload Data to Blockchain Layer 2: Currently, AutoChain employs a two-layer architecture, with Layer 1 handling supply chain transactions and Layer 2 managing real-time IoT data transactions. To further enhance the system's efficiency and scalability, future research can focus on optimizing the offloading of data to Layer 2. This optimization could involve exploring techniques such as data compression, data aggregation, or prioritization algorithms to reduce the data size or improve data processing and transmission efficiency within Layer 2. By optimizing the offload process, AutoChain can achieve faster transaction speeds and improved overall performance.

Optimization of Authentication & Authorization of Member Nodes: As the AutoChain network grows and involves an increasing number of member nodes, optimizing the authentication and authorization processes becomes crucial. Future work can explore advanced authentication mechanisms and authorization protocols to enhance the security and efficiency of member node interactions within the AutoChain system. This optimization could include researching innovative cryptographic techniques, such as zero-knowledge proofs or multi-factor authentication, to strengthen the authentication process while minimizing computational overhead. Additionally, the authorization mechanisms can be optimized to ensure secure and efficient access control to various system resources based on the roles and permissions of member nodes. By optimizing authentication and authorization, AutoChain can enhance the system's overall security and streamline the interaction between participants. As this is a novel work we were unable to compare our model with existing ones which we plan to do in the future.

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