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EDITED BY
Roman Vitenberg,
University of Oslo, Norway

REVIEWED BY
Milan Cabarkapa,
University of Kragujevac, Serbia
Polinpapilinho F. Katina,
University of South Carolina Upstate,
United States

*CORRESPONDENCE
Osama Ahmed,
osama.ahmed.v2@s.gifu-u.ac.jp

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# Proposing blockchain based framework to mitigate VUCA realm problems for automobile life cycle

Osama Ahmed* and Hiroshi Kamabe

Department of Electrical, Electronic and Computer Engineering, Gifu University, Gifu, Japan

In today's automotive industry, characterized by demand volatility, process uncertainty, supply chain complexity, and information ambiguity, achieving operational excellence has become increasingly challenging. To address these issues, we propose a novel framework that integrates blockchain technology into the life cycle of an automobile. Specifically, our solution employs Delegated Proof of Stake (DPoS) as a consensus mechanism and utilizes a Private Interplanetary File System (IPFS) for data storage and retrieval. This framework aims to enhance transparency, traceability, and data integrity across all stages of an automobile's life cycle. We provide a detailed delegate's election process in DPoS and data storage and retrieval on Private IPFS through sequence diagrams. By mitigating vulnerabilities and reducing uncertainties, our approach improves operational efficiency and stakeholder satisfaction, offering a robust solution to the challenges within the VUCA (volatility, uncertainty, complexity, ambiguity) realm in the automotive industry.

KEYWORDS

**delegated proof of stake (DPoS), volatility, uncertainty, complexity, ambiguity (VUCA), InterPlanetary file system (IPFS), sequence diagram and blockchain**

## 1 Introduction

In the 21$^{st}$ century, technological advancements have resulted in a resurgence, marking the onset of the 4$^{th}$ industrial revolution. Emerging concepts such as quantum manufacturing, neuromorphic computing, digital twins powered by AI, biohybrid robotics, autonomous supply chains, edge AI integration, swarm robotics, and programmable matter are beginning to influence the next wave of production innovations. Building on established predictive maintenance, new trends now focus on autonomous and AI driven maintenance systems that go beyond fault prediction to enable real time decision making and adaptive repairs. Leveraging these technologies enables streamlined production processes and cost optimization. It is crucial to recognize that the fourth industrial revolution has impacted all aspects of manufacturing enterprises, including manufacturing, logistics, management, and marketing Popkova et al. (2019). Human involvement in production processes can be supplanted by intelligent devices that communicate autonomously. To thrive in today's landscape, automotive companies must harness a spectrum of advanced technologies. These transformative technologies, collectively known as CASE (connectivity, autonomy, shared mobility, and electrification), are transforming the global automotive sector Dutt et al. (2020).

The automotive industry faces multifaceted challenges that span design, manufacturing, promotion, sales, insurance, and the historical documentation of automobiles and their components throughout their life cycle. To maintain a competitive edge, the automotive sector must continuously evolve by integrating advanced technologies such as robotics, artificial intelligence (AI), the Internet of Things (IoT), and machine learning (ML). These technologies, now widely adopted across the industry, are reshaping how vehicles are designed, manufactured, and operated. Blockchain, meanwhile, has emerged as a transformative force, addressing longstanding challenges such as assembly line delays, just in time delivery, ownership verification, and counterfeit prevention. It offers a secure and transparent platform for collecting, storing, managing, and leveraging automotive data throughout the vehicle lifecycle. Furthermore, the convergence of AI, ML, and blockchain represents a synergistic approach that enhances automation, decision making, and data integrity. In modern vehicles, AI improves user experience, safety, and operational intelligence, paving the way toward fully connected and autonomous transportation systems.

The fundamental structure of the blockchain is based on data blocks and facilitates the recording of distributed transactions with efficiency, verifiability, and permanence. Consequently, this reduces the complexity of the process and associated costs by eliminating intermediaries. Users of blockchain enabled applications can access comprehensive vehicle histories, assured of their authenticity and integrity Moosavi et al. (2021).

In the aftermath of the Cold War, military strategists sought new ways to describe the unpredictable and rapidly changing global landscape. This led to the emergence of the acronym VUCA, which stands for Volatility, Uncertainty, Complexity, and Ambiguity. Originally coined by the U.S. Army War College, the concept has since gained prominence across disciplines to frame the challenges faced in dynamic and unstable environments. In organizational and technological contexts, VUCA highlights the need for adaptive, resilient and forward looking strategies to navigate uncertainty and interconnected risks. Horney et al. (2010).

Seizing opportunities requires a thorough understanding of them; however, a review of the actions and statements of organizational leaders reveals a notable lack of understanding. Three primary issues arise from how few terms are employed by organizational leaders. Firstly, they tend to be used casually, with VUCA (volatility, uncertainty, complexity, ambiguity) often reduced to a mere synonym for "unpredictable change" Johansen and Euchner (2013). A cursory web search of the individual components of VUCA typically reveals that they are frequently employed together as industry buzz in executive discussions, consultant blogs, and business publications, often treated interchangeably. Although these terms share related meanings, their nuances are crucial for leaders to grasp. Indiscriminate use of the VUCA acronym can lead to potentially hazardous consequences, as it overlooks the distinct meanings of its four components, which could otherwise offer valuable insights to leaders.

Secondly, even when individuals acknowledge the distinctions in meaning, there is a notable absence of guidance on how to effectively address each of these conditions. Although executives may recognize the challenges of operating in a VUCA realm in interviews and press releases, they often fail to delve into specifics on how firms can navigate such an environment. Those who do address the issue typically offer overly simplistic solutions that apply broadly across all four components, such as "innovate", "be creative", "remain flexible" or "listen more". History shows that such generic advice rarely produces exceptional leaders, meaningful change, or resilient organizations. Ultimately, a notable number of organizational leaders, perhaps due to the lack of available practical guidance and lack of technological knowledge, are responding to the challenges of the VUCA world by adopting a traditional attitude Meyers and Bull (2002). An emerging narrative of organizational leadership of thought suggests that traditional concepts such as strategy and marketing are considered obsolete and defunct in the face of perceived chaos and uncontrollability inherent in the VUCA realm. The challenges faced by the automotive industry and its stakeholders in the VUCA realm along with possible solutions are explained in Table 1.

VUCA dynamics also significantly impact higher education, particularly in preparing students for the challenges of volatile and complex environments Green et al. (2019). In the context of design and engineering education, these dynamics requires fostering adaptability, critical thinking, and interdisciplinary collaboration among design and engineering students. Moreover, the development of innovative educational frameworks equip future engineers with the competencies required to address rapidly evolving problem spaces. Engineering education must evolve to ensure that graduates are equipped with the resilience and adaptability necessary for success Rouvrais et al. (2023). Integration of VUCA and resilience training across various levels of the engineering curriculum, from freshman courses to professional engineering programs. By exploring and comparing existing teaching and learning activities, key insights emerge about the importance of a progressive approach in embedding such critical skills.

The automobile industry stands as a prime example of a VUCA environment due to its exposure to rapidly shifting technologies, global supply chain disruptions, and evolving regulatory frameworks. The sector faces volatility through unpredictable demand shifts and raw material price fluctuations, uncertainty from emerging electric and autonomous vehicle technologies, complexity arising from the integration of IoT devices, cloud platforms, and software defined vehicles, and ambiguity in navigating inconsistent global emissions and data privacy regulations Company (2020); Johansen and Euchner (2013); Johansen (2012). These interconnected challenges justify the application of the VUCA lens and call for resilient, transparent, and adaptive systems. As such, the integration of blockchain and decentralized storage frameworks offers promising pathways to address these multifaceted disruptions, particularly in enabling traceability, compliance, and stakeholder trust across the vehicle lifecycle.

In addressing the challenges posed by the VUCA realm in automobile industry, our proposed solution involves adaptation of a blockchain framework to mitigate vulnerabilities and overheads throughout the life cycle of an automobile. These vulnerabilities and overheads manifest themselves at various stages, beginning with the initial conceptualization of a new automobile variant, which may entail complexities in design. Subsequent stages, including manufacturing and assembly, are susceptible to issues related to the supply chain of parts and raw

**TABLE 1** Comprehending the VUCA realm.

| Elements | Definition | Challenges | Solution |
|---|---|---|---|
| Volatility | Unpredictable, Unstable | Customer demands change abruptly. Wars and pandemics cause supply chain issues. Keeping all stakeholders onboard is difficult | Adaptability. After consensus, all stakeholders must agree |
| Uncertainty | Risk can never be fully mitigated | Natural calamities, terrorism | Access to timely and transparent information |
| Complexity | Different types of processes generate multiple types of data | Human error, delays in meeting deadlines | Aligning internal company operations with external complexity is the most effective and efficient approach |
| Ambiguity | Cause and effect are not well understood. Lack of knowledge | Transition to new technology and procedures | Every node knows its responsibilities, and the data is distributed securely |

materials. Ensuring the quality and functionality of the finalized product through rigorous testing is imperative. Furthermore, meeting market demands and ensuring to meet the customer needs, keeping up with the advanced trends and technologies and timely availability to customers pose additional challenges. Post sales processes, such as insurance claim processing and maintenance further add to the complexity. Additionally, communication within smart cities and eventual recycling at the end of the automobile's life cycle are integral considerations. Using blockchain technology in all stages, our objective is to improve efficiency, transparency, and resilience within the automotive industry, ultimately contributing to mitigate challenges in the VUCA realm.

To cope with all those issues and problems that we acronymize as VUCA in the automobile industry, a huge amount of data is also generated in the complete life cycle of an automobile resulting in the endless requirement of storage. This data generation is periodic and frequent and contains text files, images, and videos of various aspects of the automobile life cycle. Several file systems are already implemented across various networks in the world, among these, the Private InterPlanetary File System (IPFS) best suits our infrastructure requirements.

To address the challenges posed by the VUCA realm in the automotive industry, we propose using the Delegated Proof of Stake (DPoS) consensus mechanism, integrated with an overlay IPFS network. This framework ensures that stakeholder requirements are continuously prioritized and revisited throughout the vehicle's lifecycle. Moreover, to understand system behavior, we use sequence diagrams to provide more clarity on our system. Once the vehicle enters the post production phase, this system continues to support ongoing adaptation, enabling real time updates and modifications based on immutable blockchain records. This seamless integration not only ensures stakeholder satisfaction but also enhances market competitiveness through efficient, data driven decision making by stakeholders.

Our review of the literature identified a significant research gap while many articles focus on specific genres of the auto industry, none comprehensively describe the overall life cycle of automobiles integrating blockchain and IPFS. This paper aims to fill this gap by presenting a new framework that encompasses all aspects of an automobile's life cycle and involves all stakeholders. Furthermore, we have analyzed the VUCA realm as a challenging environment that affects automobiles and their stakeholders, as detailed in Table 1. The existing literature from various researchers in the VUCA realm fails to adequately address the challenges, opportunities, and emerging trends in the automotive life cycle. Our paper seeks to address these gaps and contribute to the existing knowledge base in this field.

## 2 Related work

This section reviews the related works on AVs/EVs, the VUCA realm, the Blockchain consensus mechanism DPoS, the auto industry (especially manufacturing, logistics and supply chain), and file systems (particularly Private IPFS).

Elliptic Curve Cryptography (ECC) has emerged as a crucial component in blockchain and IoT security. ECC offers advantages over RSA in terms of smaller key sizes and faster computations, making it more suitable for resource constrained environments Yadav (2021); Chandel et al. (2020). When combined with blockchain technology, ECC enhances data security in cloud storage by providing resistance to man in the middle and replay attacks Benmenzer and Beghdad (2022). The integration of ECC in blockchain applications extends to various fields, including IoT, cloud computing, and image security Vijay Nikhil et al. (2024). ECC's efficiency in transaction size and speed makes it particularly valuable for blockchain implementations, where these factors are essential for optimal performance Chandel et al. (2020). As blockchain technology continues to evolve, ECC plays a vital role in ensuring data integrity, confidentiality, and privacy across decentralized systems Yadav (2021); Benmenzer and Beghdad (2022).

Numerous studies have explored the application of blockchain technology in the realm of autonomous vehicles (AV). Initially, a straightforward approach involved the storage of data parameters representing the current state, sourced either directly from the vehicle's operating system or neighboring vehicles Narbayeva et al. (2020). Subsequently, researchers have addressed the challenge of determining liability in unforeseen events, particularly accidents, given the complete autonomy of control. In Oham et al. (2018), an encompassing framework is proposed to navigate this issue, offering potential solutions for stakeholders including car owners, insurance companies, and automotive manufacturers. Furthermore, forensic data storage emerges as a focal point, as demonstrated in Guo et al. (2020), where the feasibility of such a system is demonstrated using the Hyperledger Fabric network.

The security vulnerabilities inherent in AVs have garnered significant attention in various studies, underscoring the importance of protecting these vehicles against potential threats. Researchers are increasingly exploring the potential of blockchain technology to address a range of security challenges, including denial of service attacks, GPS spoofing, timing manipulation, and man in the middle attacks Gupta et al. (2021). The field of blockchain security and privacy is rapidly evolving, with a focus on enhancing data control, traceability, accountability, fault tolerance, and scalability Gupta et al. (2020). Refueling infrastructure is also poised for transformation, particularly in light of the European Union's mandate for all new vehicles, including future autonomous vehicles (AVs), to be electric within a few decades. Consequently, efforts are underway to improve electric refueling processes, leveraging Ethereum Virtual Machine based smart contracts to streamline this activity Pedrosa and Pau (2018). Furthermore, blockchain technology holds promise for improving the resilience of firmware update mechanisms Baza et al. (2019b).

Another area of interest lies in the management of AV traffic, where blockchain enabled smart contracts could facilitate dynamic congestion management in urban environments, allowing vehicles to autonomously adjust speeds based on a fee based algorithm. Currently, electric vehicles (EVs) are garnering significant attention due to advances in battery technology and emissions reduction. However, challenges persist in their widespread adoption, especially in the domain of charging infrastructure Florea and Taralunga (2020). The limited availability of charging stations poses obstacles for both home and public charging facilities, necessitating drivers to seek out charging facilities, contributing to range anxiety Pevec et al. (2019). Blockchain based solutions offer promising avenues to address these challenges by enabling drivers to share private charging resources, as exemplified in Fu et al. (2021), which introduces a peer to peer (P2P) framework for private charging pile sharing systems. Furthermore, Okwuibe et al. (2020) proposes a smart charging system leveraging blockchain to alleviate load congestion on the electric power grid. In addition to improving the charging infrastructure, blockchain technology facilitates real time payments with cryptocurrencies and increases security Foti and Vavalis (2021), as evidenced in Lasla et al. (2020), which explores how blockchain incentivizes EV users to share energy surplus, thus improving clean energy availability and alleviating range anxiety. Additionally, technology offers opportunities for enhancing energy trading security, online EV monitoring, charging infrastructure management, and fostering the concept of the Internet of EVs, while promoting shared energy resources.

The forthcoming generation of vehicles demands novel production methodologies rooted in the integration of Industry 4.0 smart principles Jadoon et al. (2020); Gîrbacia et al. (2022). Smart manufacturing poses a challenge with its heightened interaction among manufacturing entities. Blockchain technology emerges as a solution to streamline vehicle manufacturing processes by improving the integration of shared systems and components managed by various entities. The blockchain ensures increased security, traceability, and immutability of shared data within smart manufacturing frameworks. This technology fosters a seamless exchange of information across various stakeholders, bolstering efficiency and transparency throughout the manufacturing life cycle. Thus, leveraging blockchain in smart manufacturing holds promise for optimizing the production of next-generation vehicles, paving the way for improved collaboration and innovation within the automotive industry.

The potential applications of blockchain in manufacturing services are diverse and promising. A notable example is Man4Ware, a middleware solution that uses blockchain features for smart manufacturing Mohamed and Al-Jaroodi (2019). By incorporating blockchain services, this platform enhances the security, traceability, and immutability of shared manufacturing data. Furthermore, Lee et al. (2020) introduces a blockchain based conceptual framework designed for smart manufacturing systems that use blockchain to facilitate the transmission of device data and manufacturing services. Quality assurance in manufacturing is bolstered through blockchain services, as demonstrated in Zhang et al. (2019), where transparent and secure data on material provenance and production equipment management are provided. Moreover, Shahbazi and Byun (2021) presents a platform that integrates IoT, ML, and blockchain technology to monitor manufacturing systems. Blockchain's role in this context includes preventing the dissemination of fraudulent data and enhancing data transmission security, thereby optimizing costs and ensuring data integrity throughout the manufacturing process.

Recent research has focused on developing decentralized, privacy preserving ride sharing systems using blockchain technology. These systems aim to address issues associated with centralized services, such as single points of failure, privacy concerns, and vulnerability to attacks Baza et al. (2020); Badr et al. (2021); Mahmoud et al. (2024); Baza et al. (2019a). Proposed solutions incorporate various privacy preserving techniques, including spatial cloaking, encryption, and pseudonyms Baza et al. (2020); Badr et al. (2021); Mahmoud et al. (2024). To improve matching accuracy while maintaining privacy, some approaches use multiple overlapping grids or semantic matching models Badr et al. (2021); Mahmoud et al. (2024). Integration of blockchain with IPFS has been suggested to address scalability challenges Mahmoud et al. (2024). Additionally, smart contracts and time locked deposits have been proposed to ensure trust, fair payment, and commitment from users Baza et al. (2019a). These blockchain based systems aim to provide transparent, secure, and efficient ride sharing services without relying on centralized third parties.

Cloak is a privacy preserving query framework for blockchain systems that leverages the distributed and independent nature of blockchain ledgers to protect the privacy of client query requests Xiao et al. (2024). Cloak improves query performance by up to 4x compared to the state of the art Spiral and reduces storage overhead by 50% compared to Spiral. It decomposes client requests into multiple subrequests and sends them to independent full nodes, then aggregates the results to serve privacy preserving queries. Gai et al. Gai et al. (2022) propose a blockchain based digital twin solution to redesign supply chain management systems and improve their efficiency.

The automotive industry is poised for significant growth, with projections that estimate an annual expansion of $8\% - 10\%$, underscoring its crucial role in national economies Gîrbacia et al. (2022). Consequently, automotive manufacturers are under increasing pressure to fortify their defenses against supply chain counterfeiting and enhance security measures against malicious attacks Oham et al. (2021). One potential solution to address counterfeiting threats involves leveraging permissioned blockchains, such as Hyperledger Sukhwani et al. (2018), which employs a distributed consensus algorithm. Through this approach, manufacturers can establish a transparent and secure framework for verifying the authenticity of components and tracking their journey through the supply chain. By adopting permissioned blockchains, automotive companies can strengthen the integrity of the supply chain, mitigate the risks associated with counterfeiting, and maintain stringent security standards in the face of evolving threats.

The automotive industry faces mounting pressure to innovate rapidly, delivering competitive, eco-friendly products at reasonable prices. Central to this challenge is the complexity inherent in supply chains and logistics Viriyasitavat et al. (2020). Emerging technologies such as blockchain, IoT, Big Data, and AI hold immense potential to revolutionize these aspects Pournader et al. (2020). For instance, the integration of tracking tools and blockchain, along with smart contracts, can automate payments to suppliers upon successful delivery of goods Viriyasitavat et al. (2020). By seamlessly integrating blockchain with other advanced technologies such as cloud computing, IoT, big data analytics, and cyber security, supply chain networks can achieve heightened trust, transparency, immutability, and reliability Kamble et al. (2023).

An efficient survey of various file systems is presented in Macko and Hennessey (2022), drawing the reader's attention to different genres of file systems implemented worldwide. The survey discusses their advantages and disadvantages based on network type, latency, geography, and partition tolerance. In contrast, Shi et al. (2024) sheds light on the types of files stored in IPFS, their accessibility, and the content providers within the IPFS network. Moreover, Abdullah Lajam and Ahmed Helmy (2021) integrates the file system with the blockchain and evaluates the performance of the system.

Various studies have proposed blockchain based solutions to improve logistics and traceability. For instance, a blockchain based logistics monitoring system was developed and tested on Ethereum, primarily aimed at enabling parcel tracking Helo and Hao (2019). Similarly, TokenTrail, a decentralized blockchain application utilizing semi fungible ERC 1155 tokens, addresses traceability concerns Kuhn et al. (2021). Moreover, the use of smart contracts can establish hyperconnected logistics networks using blockchain and (Betti et al., 2019). Although blockchain technology holds promise for improving vehicle tracking and freight management, widespread deployment remains a prospect rather than a current reality. These studies collectively underscore the potential for blockchain to revolutionize the automotive industry, improving efficiency, transparency, and security.

# 3 Life phases of an automobile

The life cycle of an automobile involves a complex and interconnected series of stages, each vital to the production, distribution, utilization, and eventual disposal of an automobile. It all begins with meticulous design and planning at the automobile manufacturer, where teams of engineers, designers, and planners collaborate to conceptualize and develop new vehicle models. Once the design is finalized, the process moves to parts manufacturing, where specialized suppliers produce various components according to the manufacturer's specifications. These components, ranging from engines to interiors, are then supplied to the assembly plant. Here, skilled workers meticulously assemble parts into complete vehicles on the assembly line, adhering to strict quality control standards to ensure safety and performance.

In all these processes, stakeholder's requirements are prioritized and addressed at every stage. The automobile is designed and manufactured according to stakeholder's satisfaction and needs. Even after the automobile passes the production stage and enters commercial or practical usage, there is still a need for adaptation. Changes are made accordingly in the upcoming automobiles on the assembly line. If an automobile is not adapted to meet evolving requirements, stakeholder's satisfaction cannot be achieved. Moreover, in a competitive market, continual adaptation and improvement are necessary.

After assembly, automobiles are distributed to dealerships and distributors, who manage sales and marketing efforts to attract potential buyers. Upon purchase, ownership of the automobile is transferred to the customer. Auto owners then enter the stage of vehicle usage, where they rely on their automobiles for transportation needs. Throughout this stage, automobile manufacturers and maintenance workers play a crucial role in ensuring ongoing maintenance, repair, and upkeep of the vehicles, addressing wear and tear, and ensuring continued performance and safety on the road.

Finally, as an automobile reaches the end of its usable life, it undergoes the end of life stage. Here, they are recycled or disposed of in an environmentally responsible manner. Recycling centers play a key role in dismantling and recycling vehicle components, salvaging materials for reuse and minimizing environmental impact. Through these stages, from initial design and manufacturing to usage and eventual disposal, the life cycle of an automobile involves a coordinated effort between stakeholders to provide safe, reliable, and sustainable transportation solutions. The depiction of the life cycle of an automobile is illustrated in Figure 1.

# 4 Proposed framework of blockchain in auto mobile life cycle

Our proposed infrastructure utilizes the blockchain consensus mechanism, DPoS, chosen for its efficiency and suitability for systems with limited resources, along with the use of IPFS network. The life cycle management of an automobile within this framework begins with identifying the demand for a new vehicle. Then it moves through the design and planning phases, where detailed engineering and resource allocation occur. Following this, the production phase involves manufacturing the automobile according to the finalized designs. Once the vehicle is in use, it undergoes regular operation and maintenance to ensure optimal performance. Finally, at the end of its life cycle, the vehicle is responsibly disposed of or recycled. This structured approach ensures a comprehensive and sustainable management of the automobile from inception to end of life.

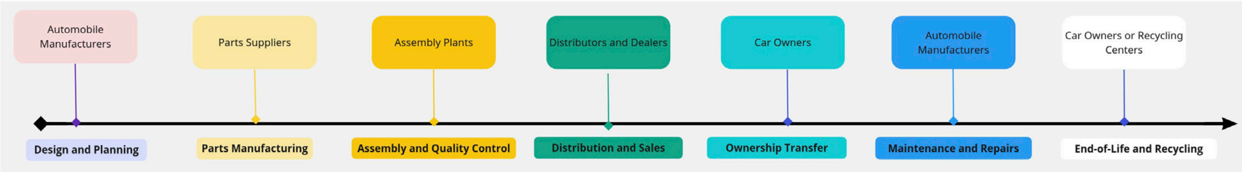


FIGURE 1
Life cycle of an automobile.


FIGURE 2
Workflow of DPoS.

## 4.1 Preliminary knowledge

Before understanding the framework, a few basic concepts are used in our framework which need to be addressed.

### 4.1.1 Blockchain basics

Smart contracts are self executing digital agreements stored on a blockchain. It automatically enforces the contract terms and conditions (T&C) once they are met, ensuring that all parties involved can immediately trust the outcome. Smart contracts are particularly useful for automating transactions and agreements, reducing the need for intermediaries, and increasing the efficiency and reliability of contract execution. In addition, our proposed scheme leverages the benefits of DPoS in a permissioned blockchain environment by initially selecting delegated nodes through a controlled and governance driven, democratic process. Within our framework, participants, who are pre-approved stakeholders as determined by access control policies enforced through smart contracts, elect delegated nodes, ensuring that all token holders have a say in governance. These smart contracts automatically verify whether a node meets the eligibility criteria, such as identity, role, or compliance parameters, thereby eliminating the need for a centralized governing body. At the onset of the blockchain network, every node, that inherently holds tokens participates in this election. The nodes that receive the most votes are elected as delegates. These delegates are granted special privileges and responsibilities, including validating transactions, setting protocol rules, proposing changes to block size, adjusting witness reward shares, creating new blocks, and maintaining the integrity of the blockchain. This structure enhances the efficiency and democratic nature of our blockchain network. The general workflow of DPoS is illustrated in Figure 2.

While the oligarchic nature of DPoS, where a limited set of delegates hold decision making power, is often seen as a drawback in public blockchains, it is a deliberate design choice in our permissioned framework. This structure enables faster consensus and efficient network management, critical for automotive industry applications that demand high throughput and reliability. Since pre-approved stakeholders elect all delegates through a democratic voting process, and can be removed if they act dishonestly or fail to perform, the system ensures accountability and maintains decentralization within the permissioned environment. This balance between efficiency and governance makes DPoS well suited for our use case.

### 4.1.2 Delegate nodes

In the automotive industry, numerous participants contribute to different domains. Among them, delegates hold a pivotal role in validating transactions and producing new blocks in a blockchain network. Delegates are elected by stakeholders through a process determined by their stakes within the network. Figure 3 illustrates election process for delegate selection. The process begins with nodes being installed and synchronized with the blockchain. Nodes acquire and stake tokens to register as candidates. Once registered, nodes campaign for votes and participate in an election. Stakeholders cast their votes, and the election results are provided by the blockchain.

Based on the election outcome, nodes can either accept the delegate role or continue as regular nodes. Delegates are required to submit their consent and are subsequently updated in the blockchain as active delegates.

### 4.1.3 Incentive and reward mechanism

In our proposed permissioned DPoS blockchain framework, rewards play a central role in motivating participation and maintaining the integrity of the network. Stakeholders engage in passive stacking by delegating their tokens to trusted delegates, who are responsible for validating transactions, proposing updates, and maintaining the blockchain. Once a block is validated or transactions are processed, rewards, such as transaction fees or predefined incentives, are distributed according to a fixed

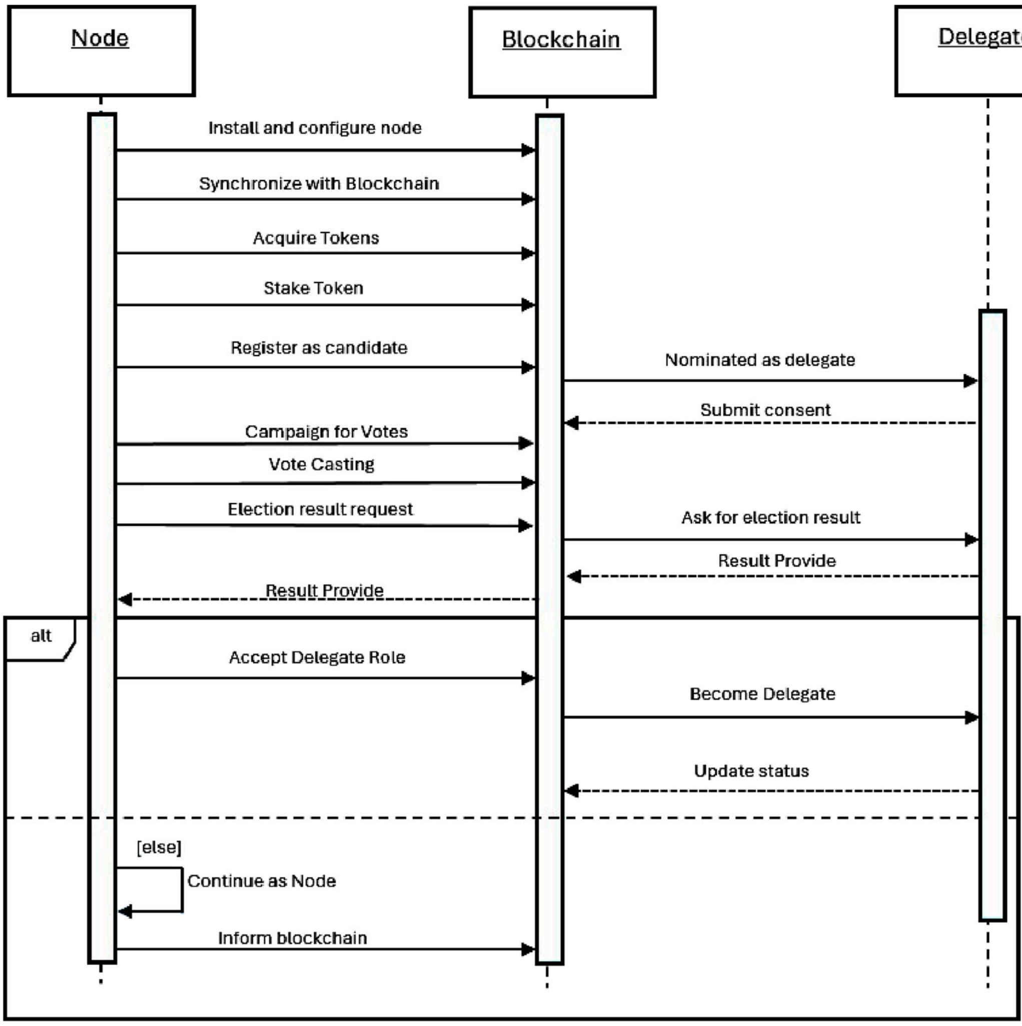


FIGURE 3
Stages when a node becomes Delegate.

scheme. A portion of the reward is allocated to the delegate for their active participation, while the remainder is proportionally distributed among stakeholders based on their contributed stake. This ensures that both parties are fairly compensated and have a vested interest in the network's performance. Misbehaving or underperforming delegates can be replaced through a voting process, preserving accountability. Furthermore, rewards are not limited to cryptocurrencies; they can also include digital certificates, credits, or access privileges depending on the application domain, such as in automotive systems, where compliance and priority processing may serve as additional incentives.

### 4.1.4 InterPlanetary file system network

Managing and storing voluminous data generated at high rates in blockchain networks is a significant challenge. Storing all this data directly on the blockchain is impractical due to the extensive communication and computational costs. Our proposed framework integrates Private IPFS with DPoS consensus mechanism to address this issue. Unlike centralized systems, blockchain and Private IPFS offer decentralized solutions that mitigate risks such as single point of failure, enhancing security and scalability. Private IPFS enables efficient decentralized storage and retrieval of large datasets, significantly reducing the on chain storage burden. This is achieved by offloading bulk data to Private IPFS while keeping essential metadata on the blockchain. Private IPFS supports content versioning, allowing for the tracking of changes over time and providing access to previous versions of files, which is vital for ensuring data integrity. Additionally, using Private IPFS ensures data privacy by restricting access to authorized participants within a permissioned environment, which contrasts with the open access model of public IPFS. By combining Private IPFS with the DPoS consensus mechanism, the framework maintains access control and ensures secure and efficient data management. The interaction between the node and Private IPFS is shown in Figure 4. This integrated approach enhances the scalability and security of the system, making it well suited for environments with high data generation rates, offering a robust and decentralized alternative to centralized solutions.

Running a Private IPFS network, however, demands custom infrastructure and operational coordination, particularly for ensuring high availability and fault tolerance. Our framework addresses this by

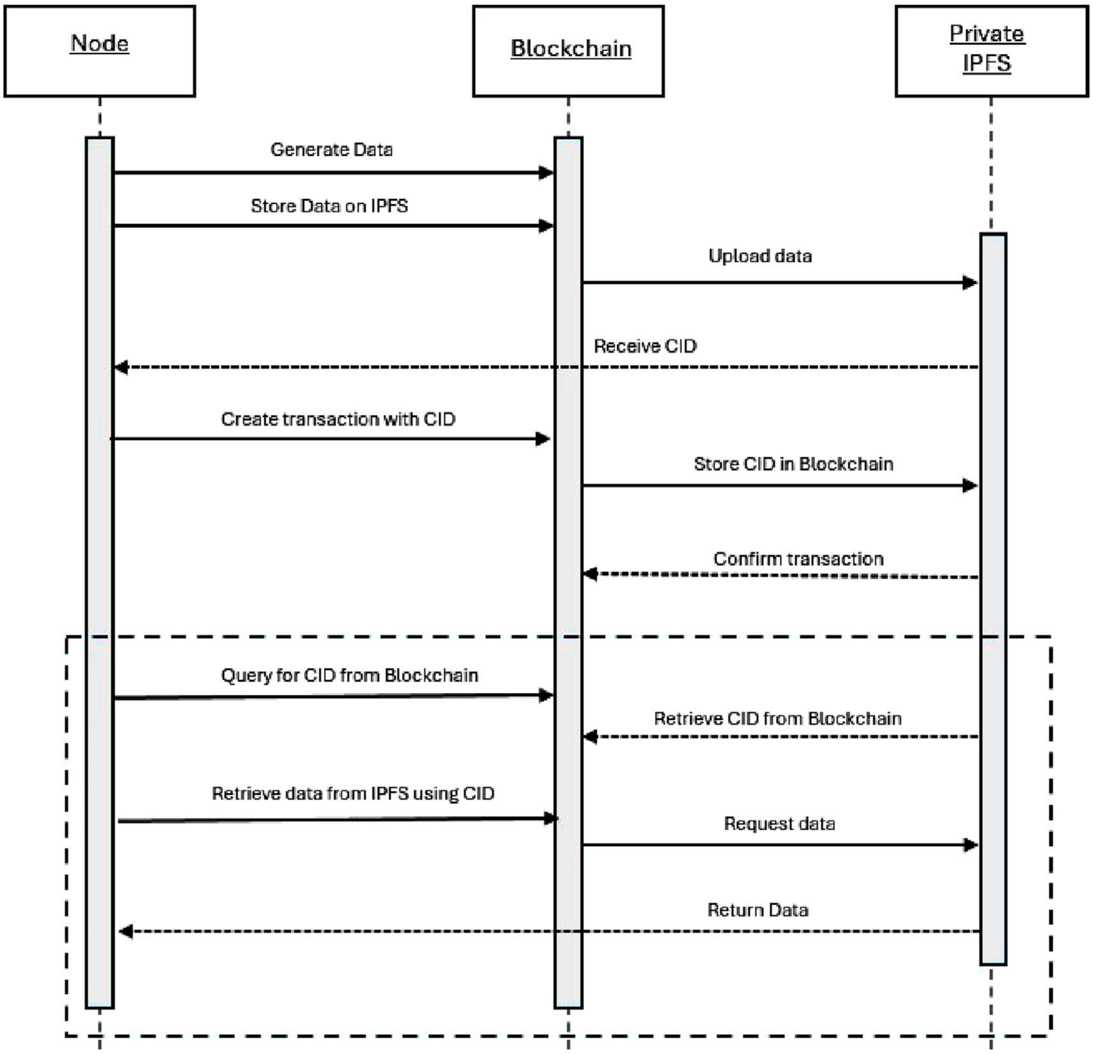


FIGURE 4
Storage and retrieval of data from node and Private IPFS.

organizing nodes into domain specific clusters (e.g., insurance, registration, servicing), where nodes within a cluster redundantly pin only the data relevant to their assigned responsibilities. This targeted replication ensures that critical data remains available even if some nodes go offline. Coordination among these nodes is governed by smart contracts on the DPoS blockchain, which enforce rules regarding data publication, access control, and replication responsibilities. Such orchestration guarantees high availability while avoiding the inefficiencies of global replication. To reduce storage overhead, the framework employs IPFS's inherent content addressing and deduplication through hashing, which prevents redundant storage of identical data across nodes. By leveraging role based node segmentation and Content Identifier (CID) managed access, the system adheres to the principle of least privilege, ensuring nodes access only the data they are authorized to handle, thereby enhancing privacy and compliance.

In our proposed framework, Private IPFS operates alongside DPoS. To understand its functionality, consider a node that generates a significant amount of data, such as images and videos. Storing this vast amount of data directly on a blockchain network is impractical. Instead, this data can be stored off chain on a Private IPFS network. When a node needs to store data, it sends the data to the Private IPFS network, which returns a CID that uniquely identifies the data. The node then creates a transaction containing the CID and submits it to the blockchain. The blockchain confirms the transaction and stores the CID. This CID, which includes version, codec, and multi hash information, allows all nodes to access the data from the Private IPFS. In addition, the CID facilitates data retrieval when needed. For example, if a node, such as a "Body and interior" which is responsible for the body and interior related issues of an automobile, requires data, the CID stored in the blockchain enables the node to retrieve the data from the Private IPFS.

### 4.1.5 Hybrid system interoperability

Integrating blockchain and Private IPFS with legacy automotive systems such as ERP (Enterprise Resource Planning), manufacturing and diagnostic platforms demands substantial IT effort and a well defined interoperability strategy. While our proposed framework is inherently modular and decentralized, its seamless adoption in real

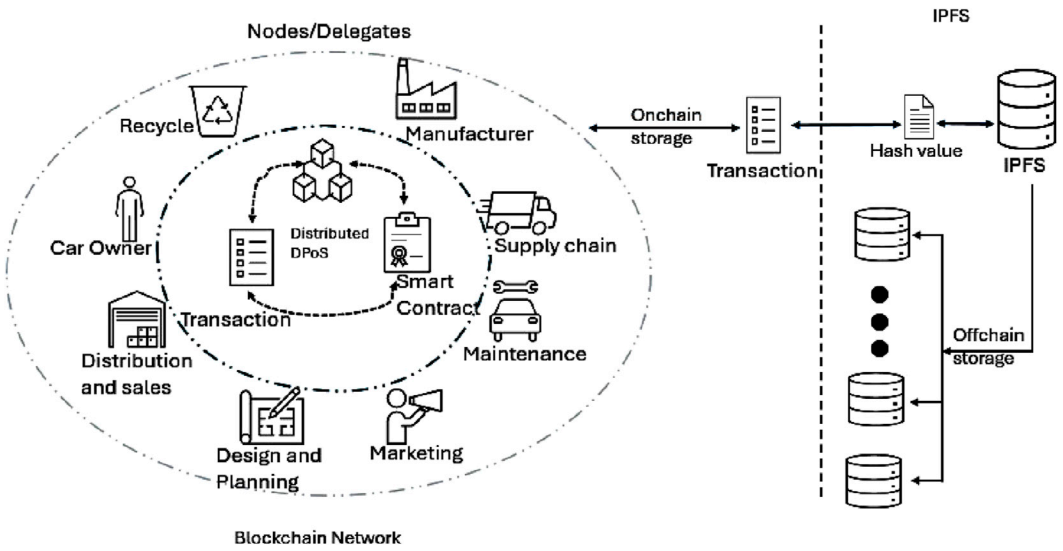


FIGURE 5
Proposed framework.

world automotive environments hinges on the ability to interface with existing digital infrastructure. Legacy systems often rely on proprietary data formats, centralized architectures and tightly coupled workflows, which contrasts with the distributed, content addressed design of blockchain and IPFS. To overcome this gap, middleware APIs and interoperability layers can be introduced to bridge architectural differences and handle protocol translation, map legacy data models to blockchain compatible schemas and enable smooth data flow between on-premise systems and decentralized components. Such middleware also helps in translating service calls, synchronizing state changes and managing access permissions across hybrid environments. However, these integrations are context specific and may require custom adapters, data translators, and governance policies. Therefore, while the framework is technically capable of integration, its full deployment in traditional settings will require phased adoption, collaborative IT design and institutional support to ensure alignment between legacy infrastructure and decentralized technologies.

## 4.2 Description of proposed framework

Our proposed framework integrates several systems to function as a cohesive unit, as seen in Figure 5. This figure maps the relationship between delegates, nodes and an overlay Private IPFS through a blockchain network. The core component of the framework is blockchain technology, which comprises the basic elements of a blockchain. DPoS serves as the consensus mechanism, while the ledger records all transactions after validation by other nodes. Lastly, smart contracts play a pivotal role in automating voting process for delegates, enforcing consensus rules, dispute management and governance of blockchain. Then comes the Private IPFS network, which acts as an overlay network in which data is stored and the corresponding CID of that data is sent to the nodes and stored in a ledger in the form of a transaction.

The following are the key steps involved in establishing our infrastructure.

### 4.2.1 Deployment of nodes

The process begins with deploying nodes and integrating them into a blockchain network. The number of nodes can vary depending on the requirements of the network and the interests of the stakeholders. For our framework, we consider the following tentative nodes:

- Design and Planning
- Manufacturer
- Supply chain
- Automobile Owner
- Insurance
- Logistics
- Marketing
- Climate Control System
- Distribution and Sales
- Recycling
- Maintenance
- Smart Charging
- Exhaust System
- Smart Highways
- Brake System
- Engine and Drivetrain
- Electrical System
- Fluids and Filters
- Tire
- Body and Interior
- Periodic Inspection and Tune-Ups
- Suspension and Steering

### 4.2.2 Blockchain consensus mechanism

The system relies on the DPoS consensus mechanism.

### 4.2.3 Election of delegate nodes

A subset of nodes is elected as delegates based on their reputation within the network. These delegates can be added or removed as needed. Any node in a blockchain network can take part in the election process and become a delegate but for reference, the following nodes can be elected as delegates as per network requirements:

- Design and Planning
- Manufacturer
- Supply chain
- Automobile owner
- Smart charging
- Insurance
- Logistics
- Distribution and Sales
- Recycling
- Smart Highways
- Marketing

### 4.2.4 Delegate selection criteria

Only nodes with satisfactory reputation can become a delegate. Nodes with poor performance or malicious intent are removed from the delegate list.

### 4.2.5 System purpose

The primary goal of this infrastructure is to offer a robust solution for the automobile industry and its stakeholders.

### 4.2.6 Node roles

Nodes are classified as delegates and nodes. The delegate is an elected node responsible for producing and validating new blocks and supervising the governance of the blockchain, whereas nodes cannot validate a block, but can generate a transaction and maintain copies of the blockchain.

### 4.2.7 Data generation and access

Data generation in the automobile industry is sporadic, often linked to specific events such as maintenance or contract renewals. For instance, an insurance delegate requires data when a vehicle undergoes maintenance from nodes like body and interior, Engine and Drivetrain or Fluid and Filters.

### 4.2.8 Data retrieval process

When an automobile node needs data from a body and interior node, it references the CID stored in its block. This CID directs the node to the required data on the Private IPFS network.

### 4.2.9 Off chain storage with IPFS

While most data is stored on chain in the form of transactions within the blockchain ledger, any additional data that exceeds a certain size can be accessed via the off chain Private IPFS network, using a unique CID, as shown in Figure 6.

Nodes and delegates generate various types of data, such as text files, images, and videos. This data is encrypted and validated before being stored in the blockchain ledger as a transaction. Once this transaction is added to the blockchain, all blocks in the network are updated to reflect the new transaction. This ensures the entire blockchain network is synchronized, with each peer node validating and storing a copy of the new data.

However, if the volume of data exceeds a predefined threshold, which means it becomes too large to store directly on the blockchain, this data is offloaded to an overlay IPFS network. In such cases, a CID is generated by the IPFS to uniquely identify the data stored off chain. This CID is then recorded in the blockchain ledger as part of a transaction within a block. After the CID is stored on chain, the blockchain is updated once again, ensuring that all blocks and nodes maintain a consistent copy of the CID linked transaction.

This way, while the bulk of large data remains off chain, its reference is securely preserved within the blockchain, ensuring both efficient storage and data integrity across the entire network.

As automotive ecosystems grow, blockchain networks face increasing transaction loads and data overhead. Our framework mitigates this through the use of domain specific clustering and off chain storage with IPFS, reducing on chain data congestion. Furthermore, the DPoS consensus model with elected delegates ensures that only a limited set of high performance nodes are responsible for block production, enabling faster transaction throughput and lower latency. This design allows the framework to scale horizontally as more stakeholders and services are integrated.

## 4.3 Advantages

Through our proposed framework, we have attempted to address the challenges faced in the VUCA realm.

### 4.3.1 Managing volatility

Identifying and exposing vulnerabilities throughout the vehicle life cycle and providing solutions make it easier to manage volatility when vulnerabilities are discovered. Volatility can be reduced and managed in our proposed framework through key metrics such as Rate of Change, which tracks fluctuations in vehicle conditions or supply chain disruptions, and Crisis Detection, which identifies and alerts stakeholders to potential issues in real time. All data and information are gathered and processed accordingly on the respective nodes or delegates, allowing quick response to any detected volatility.

### 4.3.2 Mitigating uncertainty

Since our framework is configured to interact through nodes or delegates in a blockchain network, each component can communicate and coordinate with the other parts of the ecosystem, providing a seamless experience. This interaction enables time to adapt, allowing the system to quickly adjust to changing circumstances and emerging risks, such as those posed by natural disasters, supply chain problems or disruptions in product distribution and sales. However, risk assessment score helps identify and evaluate potential risks in real time, enabling stakeholders to take informed actions and mitigate risks effectively. This solidarity within the system results in proactive responses and effective risk management, ensuring that uncertainty is adequately managed.

### 4.3.3 Reducing complexity

Complexity increases when a system is large and requires substantial effort or involves multiple stakeholders. Satisfying the

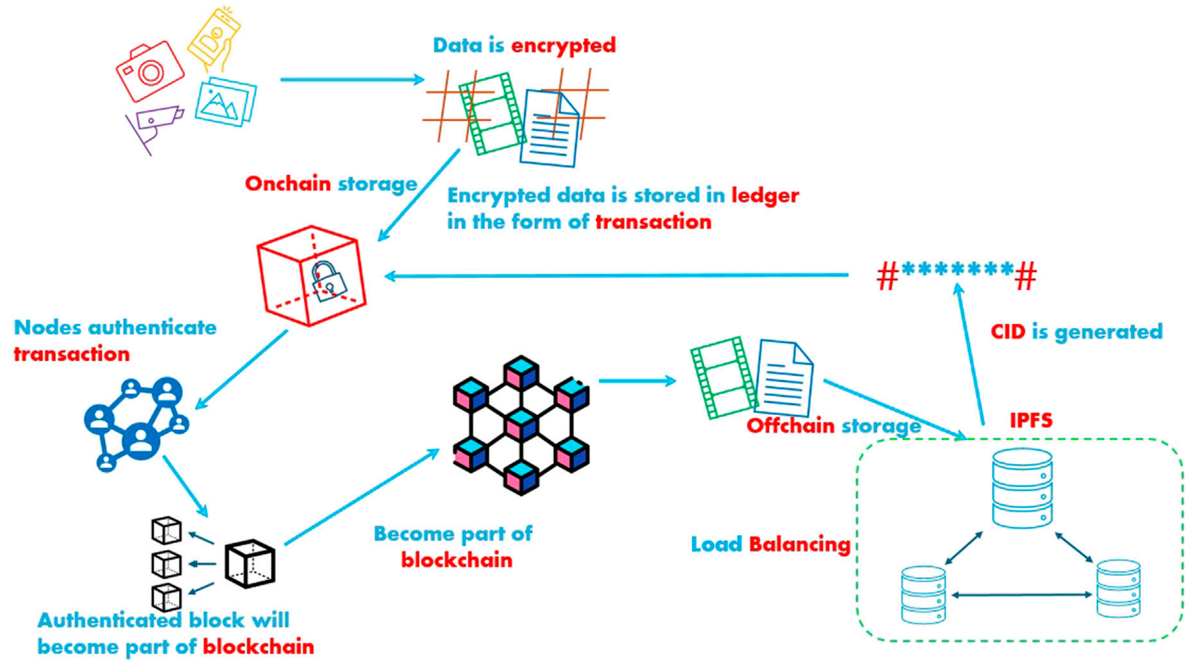


FIGURE 6
Off chain data storage and retrieval.

needs of all stakeholders in such large projects becomes particularly challenging. In the automotive industry, managing the supply chain involves coordinating multiple stakeholders, including parts suppliers, manufacturers, and distributors. Our framework divides the supply chain network into manageable units, represented by nodes (e.g., suppliers, factories, dealerships) and delegates (e.g., regional managers). This modular approach enables efficient tracking of components, production stages, and deliveries, making it easier to manage the larger system by breaking it down into smaller, more manageable components. Additionally, all data are stored in the ledger as transactions, such as part shipments or assembly completions, making it simple to trace the origin and timing of any issues, like delays or defective parts. Deviation analysis allows for real time monitoring of supply chain performance, identifying discrepancies, such as late shipments or inventory shortages, early on and facilitating timely corrective actions. As a key metric, deviation analysis helps manage complexity by enabling real time comparison of operational data with expected norms. By identifying discrepancies and deviations early, the framework facilitates corrective actions, ensuring that the system operates as expected and reducing the complexities of large scale coordination, human resources, supply chain management, production, and regulation.

### 4.3.4 Eliminating ambiguity

In this framework, data transactions are stored on every node, enabling easy traceability and problem resolution. In higher stake scenarios, such as public transport vehicles, compliance and quality are ensured as all relevant data is accessible, and the node responsible can be traced. The Node Credibility Index (NCI) enhances this process by evaluating the trustworthiness of each node based on historical performance and data accuracy. This real time assessment ensures that only reliable nodes handle critical tasks, reducing ambiguity. The public distributed ledger further guarantees clarity, while smart contracts define node roles, ensuring transparency and eliminating uncertainty in the network.

The metrics to evaluate the VUCA elements along with their corresponding reasoning are summarized in Table 2. These metrics provide clear indicators of how the framework addresses each of the VUCA challenges, ensuring that our solution is both adaptable and resilient. By focusing on key performance indicators such as Rate of Change, Crisis Detection Time, Time to Adapt, Risk Assessment Score, Deviation Analysis, and Node Credibility Index, we are able to evaluate and manage each of the VUCA elements effectively.

In addition to the benefits mentioned above, our framework offers several other key advantages. These include enhanced network security, efficient data sharing, and reduced human error. One of the biggest threats to network security is the man in the middle attack. Our proposed system is immune to man in the middle attack because it uses signed contracts. In addition, the distributed nature of blockchain and its immutable ledger help solve the problems of differential pricing because every transaction including pricing details is stored in a block as a transaction that can be verified publicly. This prevents discrepancies and all the nodes and delegates have access to the same pricing details while signed smart contracts can automate pricing agreements, ensuring that the agreed upon prices are applied consistently across all transactions. In addition, smart contracts automate and enforce agreements, reducing the risk of human error and manipulation, thus reducing uncertainty. In all these steps, a track record of the history of all activities performed by any node is created, which also aids in solving maintenance issues. Moreover, signed contracts

TABLE 2 Metrics for VUCA.

| Elements | Metrics | Solution and reasoning |
|---|---|---|
| Volatility | Rate of Change, Crisis Detection, Time | Our proposed framework stabilizes the system by enabling fast, reliable updates and secure data handling. DPoS provides quick validation and adjustment capabilities while Private IPFS ensures data remains decentralized, immutable, and accessible during volatile disruptions |
| Uncertainty | Time to Adapt, Risk Assessment Score | Our proposed framework mitigates uncertainty by ensuring trustworthy data validation, decentralized access, and data integrity. This reduces risks of misinformation and guarantees that stakeholders can make confident decisions based on reliable and accessible information |
| Complexity | Deviation Analysis | In our framework, DPoS addresses this by enabling quick consensus on the state of the system, ensuring discrepancies are detected and corrected faster. In addition, Private IPFS supports this by storing data in a decentralized, immutable manner, ensuring that any detected anomalies are accurate and traceable, reducing structural, organizational, behavioral, and environmental complexity in the system. This combination ensures that data handling and validation processes are efficient and transparent, allowing for better management of complexities in the system |
| Ambiguity | Node Credibility Index | In our proposed framework, DPoS and Private IPFS work together to reduce ambiguity by enhancing trust and clarity in data validation and decision-making. DPoS governs trustworthy validation, while IPFS ensures data transparency and traceability, which eliminates conflicting interpretations and fosters confidence in actions |

TABLE 3 Proposed solution of existing issues.

| Problems | Proposed solution |
|---|---|
| Fraud by man in the middle | By implementing signed smart contracts, the system eliminates the potential for fraud perpetrated by middlemen |
| Tracking the history of each step | Each stakeholder can access real-time updates, allowing them to track the progress of their automobile |
| Differential Pricing | Each block retains its ledger |
| Multiple Stakeholders | Smart Contracts ensure consensus among multiple parties |
| Uncertainty | Ledger is immune to geographical constraints such as natural disasters and socio-economic challenges |
| Quality and Compliance | Through Blockchain smart contracts, only authorized stakeholders can participate |
| Maintenance Issues | Transaction logs help to review the maintenance history of the assembly plant and the automobile |

enable diverse entities to participate in the blockchain, maintaining quality and ensuring compliance through traceability.

In summary, our proposed system offers solutions to various challenges, as defined in Table 3.

### 4.3.5 Real-world applications

The proposed framework offers a versatile foundation for transforming key operations across the automotive sector and several potential case studies highlight its practical applicability. One compelling use case involves cross-border vehicle history verification, where tamper proof records of ownership, mileage, and service data are stored via IPFS and validated on chain through DPoS, thereby reducing fraud in the used vehicle market. Another scenario focuses on the lifecycle management of electric vehicle batteries, capturing charge/discharge cycles, capacity degradation and ownership transfers using IoT generated data stored in IPFS and immutably referenced on the blockchain. The system also shows promise in autonomous vehicle environments, where sensor logs and driving behavior records are securely stored off chain for auditing in the event of incidents. Additionally, the framework can support secure Vehicle to Infrastructure (V2I) interactions, such as toll payments, traffic signal communications or road condition alerts, ensuring integrity and accountability in real time exchanges between vehicles and public infrastructure.

### 4.3.6 Legal aspects

The proposed framework leverages DPoS and Private IPFS for decentralized management of vehicle lifecycle data, including ownership transfers, servicing logs, and insurance, within the automotive domain. While the system architecture supports cryptographic integrity, role based validation and immutable off chain data referencing, its full practical utility presupposes legal and institutional interoperability. Specifically, jurisdictions operating under smart governance models, where transport authorities, insurers and legal entities can integrate DPoS based trust delegation and accept IPFS hashed records as admissible evidence, offer an ideal deployment environment. In such ecosystems, our framework facilitates real time compliance, automated contract execution and secure auditability without reliance on centralized intermediaries.

However, in traditional regulatory settings, where vehicle registries, courts, or insurers do not formally recognize blockchain authenticated records, the framework's outputs may be constrained to informational or advisory use.

To support broader adoption and compliance, the framework stores records in an auditable, tamper proof and time stamped manner, which aligns with many existing data retention and evidentiary standards. Therefore, while technically agnostic and modular in design, our solution achieves maximal efficacy in digitally unified domains such as smart cities or digital nations,

TABLE 4 Summary of potential disadvantages and mitigation strategies.

| Potential disadvantage | Mitigation strategy in the proposed framework |
|---|---|
| Oligarchy in DPoS (centralization) | In our permissioned blockchain, this is an intentional design trade off for performance. Delegates are democratically elected from pre-approved stakeholders and can be removed if they fail or act dishonestly, ensuring accountability and efficient governance in high throughput environments like automotive systems |
| Private IPFS requires complex infrastructure and lacks built-in access control | The framework addresses this by grouping nodes into domain specific clusters where each cluster pins only relevant data. Smart contracts on the DPoS blockchain enforce access, publication and replication rules. Role based node segmentation and CID managed access follow the least privilege principle, ensuring privacy, fault tolerance, and high availability |
| Lack of default access control in IPFS | Implements smart contract based Role Based Access Control (RBAC) to manage permissions and ensure data confidentiality |
| High storage costs due to duplication in IPFS | Utilizes content addressing and deduplication via hashing to reduce redundant data storage across IPFS nodes |
| Interfacing with legacy automotive systems (ERP, diagnostics, manufacturing) | Middleware APIs are employed to enable protocol translation, data model mapping and state synchronization, facilitating smooth integration with existing enterprise systems |
| Legal recognition of blockchain records may be region-dependent | The system ensures records are tamper proof, auditable and time stamped. It is optimized for smart governance jurisdictions |
| Scalability concerns due to increasing data and node overhead | The framework uses domain specific clustering and off chain storage (IPFS) to limit on chain bloat. Delegated nodes process transactions efficiently and smart contracts streamline verification, enabling the system to scale across distributed automotive environments |

TABLE 5 Comparison of our proposed framework with contemporary systems.

| Stakeholders | Proposed blockchain solution | Contemporary systems without blockchain |
|---|---|---|
| Vehicle Owner | Complete visibility to all the information which takes place in the making, selling, transportation, maintenance, and insurance | Vehicle owner has to take care of all the things individually without any confirmation |
| Dealer/Traders | Easily verify the origin and transformation journey of automobiles. Using sealed IoT devices attached to the automobile, dealers can validate and confirm their provenance and authenticity | Challenges in certifying the origin and journey of automobiles. Koomson (2016) |
| Supplychain | Clients can leverage a distributed and authenticated system to ensure their automobiles are transported under optimal conditions and within the expected time frame | Complex and ambiguous. Warrian and Smitka (2015); Singh et al. (2005) |
| Manufacturer | They benefit from an integrated and distributed ledger, which allows them to manage inputs effectively and track their production processes | Limited control and verification capability over incoming flows from suppliers, such as ensuring compliance with standards and requirements. Rubenstein and Ettlie (1979) |
| Maintenance | The owner has access to all vehicle maintenance records starting from the inception | The owner has to depend on unreliable resources. SELVALAKSHMI (2023) |

where blockchain records possess *de jure recognition* across institutional layers.

## 4.4 Disadvantages

A consolidated overview of the limitations and their corresponding mitigations is presented in Table 4, complementing the detailed discussion in earlier sections.

## 4.5 Comparison of proposed system

Our system provides solutions for VUCA in the automotive industry. It provides an interface for all the stakeholders to communicate, interact and share, thus providing transparency.

From the perspective of a vehicle owner, the system provides visibility into all processes involved in vehicle manufacturing, sales, transportation, maintenance, and insurance. The significance of such a system increases when the automobile has higher stakes or value to the owner. In contrast, in contemporary systems, the owner must rely on information provided by others, which he cannot verify, or the verification process is very difficult. For dealers and traders, it is quite easy to track the vehicle during transportation. Additionally, they can monitor the entire manufacturing process and history, which helps in preventing odometer, wire, bank, title and aggravated identity frauds for older vehicles. The supply chain is the backbone of every economy and company. Our framework tracks the supply chain for manufacturers, dealers, traders, and owners. For a manufacturer, time is critical; if any equipment or parts are delayed, the entire assembly line faces delays, resulting in significant losses and the whole supply chain network faces delays and problems. Our framework not only mitigates supply chain issues but also identifies and addresses problems as they arise. In contrast, contemporary systems make it difficult to hold parties responsible when issues occur Warrian and Smitka (2015); Singh et al. (2005).

Previously, manufacturers faced numerous problems in the manufacturing process, such as assembly line delays and unreliable employees Rubenstein and Ettlie (1979). However, our system allows manufacturers to manage inputs and track the production process more efficiently. Consequently, owners had to rely on unreliable resources when their automobiles were being serviced. With a distributed immutable ledger, owners have access to verified and validated maintenance histories of their vehicles from the beginning. The comparative analysis of our blockchain integrated system *versus* contemporary systems, according to the perspective of various stakeholders, is presented in Table 5:

## 5 Conclusion

In the automotive industry, the landscape of VUCA poses significant challenges, including fluctuating market conditions, unpredictable risks, and complex decision making. Our framework addresses these issues by integrating automobiles into a blockchain network using DPoS for governance and Private IPFS for excessive data storage. DPoS streamlines in decision making by allowing stakeholders to delegate authority, enhancing transparency and accountability while Private IPFS stores the excessive amount of data generated in blockchain and makes it available when needed. This integration ensures increased transparency, vulnerability mitigation, and uncertainty reduction throughout the automobile life cycle, from production to post sales services. By facilitating real time tracking and verification, blockchain integration bolsters operational efficiency and resilience against VUCA related disruptions. In conclusion, our framework offers a robust solution to navigate the complexities of the VUCA realm in the automotive sector, empowering stakeholders to make informed decisions and optimize processes amid dynamic and uncertain environments.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

OA: Writing – original draft, Writing – review and editing. HK: Project administration, Writing – review and editing, Supervision.


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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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