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Research on Automotive Manufacturing Process Optimization Methods for Multi-Supplier Collaboration

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Abstract: This study aims to optimize the automotive manufacturing process for multi supplier collaboration, and proposes a systematic solution based on the integration of blockchain and cloud platform technology to address the core challenges faced by the automotive supply chain in the context of Industry 4.0, such as multi-level supplier cross regional distribution, rapid increase in component types (such as the number of electric vehicle parts growing more than 100 times), and severe information silos. Research and innovate the construction of BaaS architecture to integrate cloud resources, quantify enterprise information contribution using entropy method, and design smart contracts based on Gale Shapley algorithm to achieve supply-demand bilateral matching; We constructed a decentralized application prototype using the Truffle framework and Ganache testing network, and verified the actual effectiveness of three smart contracts: information sharing incentives, supply and demand matching, and privacy protection. The results indicate that this solution effectively addresses the three key challenges of insufficient implementation of cross level information sharing functions in blockchain, weak incentive mechanisms for information sharing, and lack of quantitative models for supply and demand matching. It provides a reusable technical path for optimizing the automotive manufacturing process through multi supplier collaboration, and promotes the digital upgrading of the supply chain and sustainable development of the industry.

1 Introduction

As the core pillar of the global manufacturing industry, the synergy efficiency of the automotive supply chain directly determines the competitiveness and sustainable development level of the industry. With the advancement of Industry 4.0 and digital transformation, the automotive supply chain presents typical characteristics such as multi-level supplier cross regional distribution, a surge in component types (such as an increase of over 100 times in the number of electric vehicle parts compared to traditional models), and severe information silos [1]. These factors collectively lead to low efficiency in supply demand matching, rising management costs, and intensified bullwhip effects[2]. Taking a certain year's data as an example, the global automobile production in a certain region reached 26.0822 million units, accounting for more than 30% of the global production. The complexity of its supply chain is more representative - the multi architecture integration from traditional mechanical components to intelligent networked systems has made information sharing and collaborative decision-making a key bottleneck for industrial upgrading. The current field faces three challenges in the integration of blockchain and supply chain, as well as supply-demand matching. Firstly, blockchain applications mostly remain at the macro architecture design level, and specific functional implementations for cross level information sharing in the supply chain (such as decentralized trust mechanisms and transparent data storage) have not been fully explored; Secondly, the research on incentive mechanisms for information sharing is weak, and enterprises have insufficient willingness to participate due to issues such as uneven distribution of shared benefits and privacy leakage risks, resulting in widespread free riding behavior; Thirdly, supply-demand matching relies heavily on qualitative strategy analysis and lacks a quantitative evaluation model based on information contribution, making it difficult to achieve efficient and transparent bilateral matching. The goal of this project is to optimize the automotive manufacturing process for multi supplier collaboration, focusing on the integration of blockchain and cloud platforms to build a supply chain information sharing cloud platform based on information contribution. At the theoretical level, the innovative BaaS architecture [3] integrates cloud platform resources, quantifies enterprise information contribution using entropy method, and designs smart contracts based on Gale Shapley algorithm[4] to achieve supply and demand bilateral matching, forming a systematic solution from architecture design to algorithm embedding; At the practical level, a decentralized application prototype was constructed using the Truffle framework and Ganache testing network to verify the actual effectiveness of three smart contracts: information sharing incentives, supply and demand matching, and privacy protection. This provides a reusable technical path for the digital upgrade of the supply chain.

2. Correlation theory

2.1 Blockchain technology and its core mechanisms and applications

Since the birth of Bitcoin in 2008, blockchain technology [5]has undergone iterative development from 1.0 to 3.0. 1.0 era focuses on digital currency transactions and decentralized payments; In the 2.0 era, Ethereum introduces smart contracts and expands into the financial sector (such as DeFi, DAO, NFT, etc.); In the 3.0 era, a multi chain network ecosystem will be built, with applications extending to multiple industries such as agriculture, logistics, healthcare, identity verification, and energy distribution, becoming a key technology to promote decentralized innovation in various fields. Its core is distributed ledger technology - composed of data blocks containing transaction information and previous block hash values concatenated in chronological order, which achieves secure storage and tamper proof data in decentralized networks through cryptography and consensus mechanisms. The main features include decentralization (nodes jointly maintain the ledger), security (digital signature and consensus mechanism tamper proof), transparency (publicly verifiable transaction data), immutability (hash chain structure ensures traceability of modifications), and anonymity (anonymous addresses protect privacy). The consensus mechanism is the core of blockchain operation, and common types include Proof of Work (PoW), which competes for accounting rights through computationally intensive challenges but consumes high energy; Proof of Stake (PoS) allocates accounting rights based on token holdings, reducing resource consumption but potentially leading to wealth concentration; Delegated Proof of Stakes (DPoS) improves efficiency by electing representative nodes through voting, but there is a risk of centralization; Practical Byzantine Fault Tolerance (PBFT) adopts Byzantine Fault Tolerance algorithm to achieve high transaction capacity, low latency, and dynamic accounting node selection in medium-sized systems, suitable for scenarios such as automotive supply chain. Smart contracts, as a key feature of blockchain, are a "self executing" program proposed by cryptographer Szasbo. Based on If Then logic, transactions and protocols can be automatically executed in a decentralized environment without the need for intermediaries. Its execution requires users to trigger transactions, which are verified by blockchain network consensus, executed according to preset logic, and the results are recorded. It has the characteristics of automation, irreversibility, trustworthiness, transparency, and immutability.Figure 1 Smart Contract Execution Process

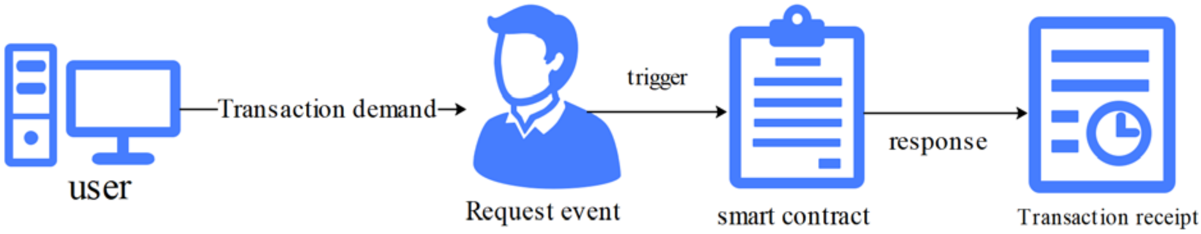

Figure 1. Smart Contract Execution Process

Smart contracts can be applied in scenarios such as digital currency settlement, IoT device management, intellectual property protection, and supply chain management, effectively reducing transaction costs and time, enhancing execution security and credibility, and providing important support for the implementation and application of blockchain technology.

2.2 The role and key influencing factors of blockchain technology in supply chain information sharing

Information sharing is the core way to improve the overall efficiency of the supply chain and the credit level of node enterprises. For example, Hyundai Motor Company achieved transparency in manufacturer and supplier information through the VAATZ system, which promoted a 2.23-fold increase in profits from 2000 to 2012. With the development of emerging technologies such as artificial intelligence and 5G, information sharing methods and platforms continue to innovate. Due to its decentralized, tamper proof, transparent and traceable characteristics, blockchain technology has shown significant advantages in supply chain information sharing - by automatically executing transactions and protocols through smart contracts, reducing information asymmetry and transaction costs, while improving data sharing security and regulatory strength, effectively solving reliability, privacy protection and trust mechanism issues, and reducing information sharing costs and operational risks. However, the promotion of information sharing still faces multiple challenges: there are differences in information sharing capabilities among enterprises, and technological maturity and resource richness directly affect the efficiency of screening and sharing key information; Mutual trust between enterprises is the cornerstone of information sharing, but the pursuit of maximizing benefits and security risk concerns often make it difficult to establish trust; The risk of information leakage is high, and if sensitive information is maliciously leaked or tampered with, it will cause incalculable losses and reduce the willingness of enterprises to share; The cost of information sharing includes investment in manpower, material resources, and technical facilities. Enterprises need to balance costs and benefits to achieve maximum economic benefits. These factors collectively affect the frequency, value, and optimal timing of information sharing, and need to be optimized through technological integration and mechanism design to promote high-quality development of the supply chain.

3. Research method

3.1 Bilateral Matching Theory and Its Application in Supply Chain

Bilateral matching [7] is a mechanism that pairs members of two different groups based on their respective preferences, and determines the optimal matching object for both parties through a matching strategy to form the optimal matching result. The core algorithm Gale Shapley is widely adopted due to its simplicity and effectiveness. This algorithm is based on clear preference ranking rules of participants and ensures fairness and efficiency of matching through stability principles (i.e., any participant is most inclined towards the current matching result). According to the difference in the number of participants, bilateral matching can be divided into three categories: one-to-one bilateral matching (each participant can only match with a single member of the other party), one to many bilateral matching (one participant can match with multiple members of the other party), and many to many bilateral matching (both participants can match with multiple members of the other party). In the automotive supply chain, the matching between supply and demand presents a typical "many to many" characteristic - suppliers usually serve multiple manufacturers, and manufacturers also accept supply from multiple suppliers, and there are differences in the products supplied. The Gale Shapley algorithm, as a delay matching algorithm, can quickly solve stable matching solutions through the mechanism of "the selector initiates and the receiver retains the selection until the end of the matching", and can ensure the stability of the results regardless of the quantity relationship or preference order between the two parties. In addition, the bilateral matching theory can overcome the failure of traditional methods in scarce resource allocation due to ethical, legal constraints, or price factors, and prevent speculative behavior of market entities from disrupting supply chain coordination. This algorithm is widely used in fields such as recycling and remanufacturing, government enterprise cooperation, cloud manufacturing task matching, and agricultural supply and demand information matching. By customizing preference rules or combining with technologies such as intelligent Internet of Things, it can improve the accuracy and efficiency of matching decisions, reduce information communication costs, and promote the informationization development of related industries.

3.2 he Development and Application of Blockchain as a Service (BaaS)

The concept of Blockchain-as-a-Service (BaaS) was jointly proposed by technology giants Microsoft and IBM. Microsoft was the first to launch BaaS services based on the Azure cloud platform at the end of 2015, providing maintenance and deployment support for open source community distributed ledger networks in a fully hosted mode; IBM followed suit in February 2016 by releasing a BaaS service based on the Bluemix platform, providing a lightweight blockchain solution that complies with the Hyperledger standard; In May of the same year, Amazon partnered with DCG, a digital currency group in the financial industry, to launch a dedicated BaaS environment, marking the potential of BaaS in enterprise level applications and driving cloud service giants to compete in laying out blockchain open source communities. BaaS integrates blockchain technology into cloud platforms to solve the technical accessibility challenges for small and medium-sized enterprises - reducing development and deployment complexity, providing features such as pluggable consensus and on chain and off chain data synchronization, supporting supply chain finance, electronic bills, and other scenarios. Enterprises can choose basic resource specifications as needed, achieve low-cost, customized blockchain solution deployment, and eliminate subsequent maintenance costs, saving manpower and time. With the development of edge computing, Kubernetes, Serverless and other technologies, BaaS is transforming from "one to many" to "many to many" and becoming a new type of digital economic infrastructure. After overcoming technological barriers, the service quality, security, business maturity, and customization capabilities of service providers have become key influencing factors for enterprises to adopt blockchain technology, accelerating its widespread application in the industry.support and technical path for privacy protection in high-dimensional commercial data publishing.

3.3 Analysis of Operation Mode and Technical Architecture of BaaS Platform in Automotive Supply Chain

The evaluation of the contribution of automotive supply chain information and the construction of a bilateral matching model are based on two core assumptions: firstly, blockchain technology ensures that enterprises share complete and effective information through decentralization and immutability, reduces fraud costs, and identifies fraud nodes in real time; The second is that the benefits of information sharing are positively correlated with contribution, and high-quality information can improve the efficiency of supply and demand matching and reduce matching costs. The evaluation of information contribution adopts a four-dimensional indicator system - enterprise operating status (weight 0.5664, including asset size 0.1304, market share 0.0968, goodwill 0.3392, all positive indicators), sharing tendency (measured by social responsibility investment 0.1914, positive indicators), innovation capability (weight 0.1666, including internal R&D funds 0.0999, patent authorization quantity 0.0667, all positive indicators), credit evaluation (weight 0.0756, including legal litigation quantity 0.0258, negative indicator, enterprise credit rating 0.0498, all positive indicators), and uses entropy method to calculate indicator weights. The core steps include standardization processing as shown in the formula

$$y_{jk}^{'} = \frac{y_{jk} - y_{jmin}}{y_{jmax} - y_{jmin}} \tag{1}$$

($y_{jk}$is the original value of the kth indicator for the jth enterprise) Shift to eliminate negative values

$$y_{jk}^{''} = y_{jk}^{'} + \xi \tag{2}$$

Proportion of indicators

$$P_{jk} = \frac{y_{jk}^{''}}{\sum^{R} \sum_{k=1}^{K} y_{jk}^{''}} \tag{3}$$

Entropy value

$$e_k = -\frac{1}{\ln R} \sum_{j=1}^{R} P_{jk} \ln P_{jk} \tag{4}$$

The coefficient of difference$g_k = 1 - e_k$, the weight$w_k = \frac{g_k}{\sum_{k=1}^{K} g_k}$ and the final comprehensive evaluation index 'are obtained. The dynamic calculation rule for the contribution of enterprise information is: if information has not been shared in a certain year but has been shared in history, the weighted sum of the previous three years shall be used

$$C_\theta = 0.6C_{\theta-1} + 0.3C_{\theta-2} + 0.1C_{\theta-3} \tag{5}$$

Reflecting the timeliness of information. The contribution rating is divided by group distance into (0), LC2 (0-315), LC3 (315-630), and LC4 (630-945). The bilateral matching model aims to achieve the maximum matching degree LC1 by matching the supply and demand sides with similar information contribution levels in the supply side set W and the demand side set G, avoiding a large contribution gap to reduce free riding behavior, narrowing the matching scope and improving efficiency, and achieving efficient and transparent supply and demand matching.

4. Results and discussion

4.1 Case simulation running environment and analysis of smart contract design

This article verifies the feasibility of a blockchain system through case simulation, configuring an Ethereum testing environment: using Node.js v18.13.0、npm 8.19.3、Truffle v5.7.3、Ganache v7.7.3、Solidity v0.5.16 Using tools such as Web3.js v1.8.1 and Remix IDE for smart contract development, stability testing, and security analysis, the contract was compiled using the Truffle framework and deployed to the Ganache test chain for simulation, avoiding the consumption of main network GAS. Finally, a decentralized application (DApp) based on HTML+JavaScript+CSS was built to achieve user interaction and data on chain. The experimental environment was a 64 bit Ubuntu 22.04.1 operating system. The design of smart contracts includes three core functions: registering a smart contract (RSC) verifies the legitimacy and uniqueness of the sender's address, stores the enterprise name, password, and index on the blockchain, generates a unique Ethereum address as an identity identifier, and ensures that data is tamper proof and traceable; Information Sharing Smart Contract (ISSC) automatically calculates and updates information contribution based on indicators such as sharing score, frequency, and years after enterprises share legitimate information. It records sharing details and operation traceability through a logging system to ensure transparency and fairness; Bilateral Matching Smart Contract (BMSC) comprehensively considers factors such as price, qualification rate, delivery time, and transaction quantity to generate a preference list for both supply and demand sides. Through matching degree calculation and dynamic adjustment logic, efficient and transparent matching is achieved. The algorithm includes matching degree sorting, cyclic matching, and flag position update logic. Case simulation takes 5 demand side enterprises and 5 supply side enterprises as examples, using publicly available information such as annual reports and industry association data (missing data is filled in using the mean method), to verify the rationality and effectiveness of the bilateral matching algorithm. The matching results show that the demand side and supply side enterprises have successfully paired. Although there are limitations such as cloud node performance dependence and differences between simulation data and actual scenarios, it provides practical reference for system function optimization and performance improvement.

4.2 Model experiment

This paragraph proposes three types of smart contracts: Registration Smart Contract (RSC) [8], Information Sharing Smart Contract (ISSC) [9] and Bilateral Matching Smart Contract (BMSC) to achieve information sharing and supply-demand matching functions. RSC verifies the legitimacy of the information sender's address and checks if it has been registered, stores the enterprise name, password, and index on the blockchain, and generates a unique Ethereum address as the identity identifier; After sharing legitimate information with enterprises, ISSC stores it on the chain and records the sharing details. Based on indicators such as information sharing scores, frequency, and years, ISSC automatically calculates and updates the contribution of enterprise information, and achieves transparency and traceability through a logging system; BMSC considers factors such as price, qualification rate, delivery time, and transaction quantity to generate a preference list for both supply and demand sides. It achieves efficient and transparent matching through matching degree calculation and circular matching logic (such as checking enterprise matching flags and object status in the preference list). Its algorithm includes matching degree calculation, preference list sorting, and dynamic adjustment logic. Case simulation takes 5 automobile manufacturing companies (demand side) and 5 component suppliers (supply side) as examples. The simulation data comes from public information such as enterprise annual reports and industry association data (missing data is filled in using the mean method). The comprehensive evaluation index of each enterprise from 2018 to 2022 is shown in Table 1.

Table 1 Comprehensive scoring table for the contribution of automotive supply chain information

Year	Demand Side 1	Demand Side 2	Demand Side 3	Demand Side 4	Demand Side 5	Supply Side 1	Supply Side 2	Supply Side 3	Supply Side 4	Supply Side 5
2022	0.326881	0.165685	0.222876	0.159432	0.161869	0.121902	0.594065	0.187903	0.069707	0.481963
2021	0.272022	0.470223	0.206965	0.177630	0.233031	0.148693	0.561949	0.213190	0.108200	0.331459
2020	0.235312	0.407018	0.210753	0.136763	0.174755	0.124337	0.576028	0.198287	0.073911	0.284343
2019	0.242784	0.561482	0.117873	0.097827	0.192528	0.104898	0.495147	0.188936	0.080382	0.232414
2018	0.270313	0.480105	0.157092	0.140275	0.213931	0.201031	0.538735	0.252320	0.108762	0.303898

The matching results show that demand side 1 and supply side 5, demand side 2 and supply side 2, demand side 3 and supply side 1, and demand side 4 and supply side 4 have successfully matched. The platform integrates information sharing and supply-demand matching through blockchain technology, reducing usage costs, improving information accuracy and efficiency, supporting full lifecycle information visualization monitoring, ensuring information authenticity and completeness, and building a trusted supply chain ecosystem. Although there are limitations such as cloud node performance dependence and differences between simulation data and actual scenarios, case analysis verifies the rationality and effectiveness of the bilateral matching algorithm, providing practical reference for information sharing and blockchain applications in the automotive supply chain.

4.3 Effect analysis

The blockchain based automotive supply chain information sharing cloud platform integrates information sharing and supply and demand matching through distributed databases, decentralization [10], consensus algorithms, and smart contract technology, effectively alleviating problems such as information silos, bullwhip effects, and difficulty in ensuring information authenticity in traditional supply chains, improving matching efficiency, and ensuring fairness; BaaS services reduce the coupling and usage threshold between business systems and blockchain systems by modularizing commonly used functions such as search queries, transaction submissions, and supply-demand matching. They also reduce investment in technical equipment maintenance and support rapid access and later business expansion; The platform utilizes encryption algorithms and digital signature technology to achieve digital storage and secure transmission of production transaction records and bills, reducing manual review error rates, improving information exchange efficiency, traceability, and security; Blockchain technology has built a new information sharing mechanism that supports transparent, real-time, and tamper proof information exchange between nodes (such as component procurement, production, and delivery data), helping suppliers, manufacturers, and sellers optimize inventory management, production planning, and market response, and alleviate inventory backlog or shortage caused by information asymmetry; By using image technology, RFID, and statistical methods to achieve visual monitoring of the entire lifecycle information, potential value data (such as factors affecting qualification rates and market trends) can be excavated to provide a basis for production optimization, financing decisions, and regulatory accountability; The tamper proof and decentralized nature of blockchain ensures the authenticity and completeness of information. Enterprises can directly cooperate with financial institutions and governments based on the information on the chain, without the need for third-party endorsement, improving the efficiency and convenience of information use; In the long run, platforms promote the deepening of trust between enterprises, form a virtuous cycle of efficient resource allocation, reduce transaction costs, build a stable supply chain trust ecosystem, and lay the foundation for the sustainable development of the industry.

5. Conclusion

In the face of intensified competition in the external market of the automotive supply chain and the demand for internal informatization and digital transformation, traditional supply chains face problems such as difficulty in ensuring information timeliness/authenticity, low degree of sharing, lack of incentive mechanisms, serious "information silos", and low efficiency of supply and demand matching. This article combines blockchain and cloud platforms to construct a BaaS architecture that considers information sharing, enabling enterprises to obtain high-quality traceable information to alleviate the problem of "information silos" and protect information sharing behavior to compensate for the shortcomings of centralized systems. Using the entropy method to construct an indicator system to calculate the level of enterprise information contribution, a bilateral matching model based on information contribution is designed. Transparent and secure matching is achieved through smart contracts, and three smart contracts are developed to achieve supply and demand matching and information sharing functions. The front-end is connected to the Ethernet local testing network Ganache through JavaScript, and a decentralized web interaction page is constructed. Case simulation tests show that the system is feasible. At present, the BaaS architecture and model effectiveness have been preliminarily validated through case analysis. In the future, more real data (not limited to specific regions) needs to be collected to enhance the universal applicability of the framework; It is necessary to be close to real supply chain scenarios and find small enterprises with complete supply chain systems but few levels and small scales to directly use integrated functions without paying attention to underlying logic and maintenance, which is convenient for effect analysis, problem discovery, and solution proposal. At the same time, the differences between the original architecture and BaaS architecture in terms of information sharing degree, supply and demand matching effect, etc. should be compared. The limitations of the model include: the case simulation data is limited to a certain region and needs to be expanded to a wider range to enhance applicability; The research focuses on the role of information sharing among enterprises, but there may be other factors involved in the actual supply-demand matching process that need further exploration.ysis.

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