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The Optimization of Digital Currency Electronic Payment in RMB Based on Big Data and Fuzzy Theory

Luo Yuan, University of Southampton, UK
Chang Su, Nuffield College, University of Oxford, UK*
Bo Fang, School of Economics and Management, Changchun University of Science and Technology, China
Yunfan Meng, Wenzhou-Kean University, China
Xinyang Wang, International Development College, London School of Economics and Political Science, UK
Wenyou Gao, School of Economics and Management, Changchun University of Science and Technology, China

ABSTRACT

Supply chain management is a key component of the Electronic-China Yuan (e-CNY) infrastructure and is crucial to developing and using e-CNY. This paper first provides an overview of the features of e-CNY and the idea of incorporating supply chain management into the creation of e-CNY software to better meet user payment requirements. This will help to reinforce the CNY's dominant position in the global monetary system. Meanwhile, this paper uses the fuzzy theory evaluation method to assess the software supply chain management informatization level. More broadly, this paper discusses the development level of digital enterprise supply chain management informatization to understand the current situation of e-CNY software supply chain management. The network's energy usage will increase when e-CNY software is developed. This research suggests a routing protocol based on the combination of chaotic particle swarm optimization (CPSO) and ant colony algorithm (ACA). It employs a new CPSO algorithm to optimize the cluster head selection.

KEYWORDS

Chaos Particle Ant Colony Algorithm, Digital Currency Electronic Payment, Electronic-China Yuan, Fuzzy Theory, Simulation Optimization, Supply Chain Management

INTRODUCTION

As an essential innovation in financial science and technology, electronic payment in digital currency is gradually changing the traditional payment and financial system pattern, which has a far-reaching impact on economic and social development. Electronic payment in digital currency has spread rapidly worldwide because of its convenience, high efficiency, and security. Especially in China, electronic payment in digital currency has developed rapidly, with electronic-China yuan (e-CNY) as the representative, leading the wave of innovation in financial technology. From a historical perspective,

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*Corresponding Author

the development of digital currency has experienced a gradual evolution. From the earliest bitcoin to the digital legal tender issued by central banks, digital currency has gradually become an essential topic in the financial field. The introduction of e-CNY will have a far-reaching impact on payment and financial systems and bring new challenges and opportunities for supply chain management. e-CNY is a China yuan digital currency directly issued by the People's Bank of China. Currently, the electronic version has the function of consumption just like paper money (Ren, et al., 2023). In 2021, the Boao Forum for Asia (BFA) saw a spike in e-CNY discussion. Researchers such as He et al. (2023) believe e-CNY, a high-tech product launched by the central bank, will become a powerful tool to significantly promote the financial service economy and effectively manage financial risks. e-CNY has become more ingrained in everyday life for regular people through the development of digital government affairs. In addition to making scene development straightforward, this makes consumer acquisition clear and persistent, bringing it closer to the actual economy. Without a doubt, introducing e-CNY will fundamentally alter the ecosystem of currency operation. Meanwhile, supply chain finance management benefits significantly from the traceability of e-CNY since it can be used to manage the confirmation of various assets in supply chain finance and achieve supply chain finance business verification (Ta et al., 2018).

Under the rapid global economic growth trend, supply chain managers are facing significant pressure. Therefore, their goal is continuously optimizing the supply chain to improve efficiency and reduce costs (Uddin et al., 2023). As an essential part of modern economies, the supply chain management of software industry is facing increasing complexity and challenges. The research, development, production, and sales of software products involve multiple participants and complex processes, thus information interaction, cooperation, and coordination become vital issues. The introduction of e-CNY will bring new payment and settlement methods for software supply chain management. It will also impact the existing supply chain management model. It is necessary to take the essential preventive measures to predict and control the risks of supply chain operation in a timely and effective manner to ensure the healthy and sustainable operation of the supply chain to reduce the risks faced by e-CNY software development enterprises in supply chain management (Marak & Pillai, 2018). Big data technology can efficiently process massive supply chain data and provide real-time data analysis and decision support, thus helping enterprises to better cope with market changes. The model based on fuzzy theory is adopted to track and manage the risks in the supply chain effectively. Subsequently, the model can be verified by Matlab software, and the risk assessment results can be provided to managers as the basis for decision-making (Pham et al., 2023; Feng & Chen, 2022).

The energy usage of network connection has always been an issue in the development of software for e-CNY (Yuan et al., 2019). This paper introduces a routing protocol based on chaos particle swarm optimization (CPSO) and the ant colony algorithm (ACA) to lower the network energy consumption and extend the life cycle of wireless sensor network (WSN). Fuzzy theory and the combination of CPSO and ACA are essential research directions in modern intelligent algorithms, and they offer the potential advantages of solving and optimizing complex problems. Combined with the research on software supply chain management of e-CNY, applying these emerging algorithms can help optimize the decision-making processes in the supply chain, improve management efficiency, and reduce costs. The cluster head selection approach is enhanced by utilizing the CPSO algorithm, considering nodes' residual energy, and clusters' compactness. Meanwhile, multi-hop routing is optimized using ACA's optimization capabilities, allowing the combination of these two techniques to significantly lengthen the life cycle of the software development network (Chen et al., 2019; Ye & Zhao, 2023).

The introduction of e-CNY, the complexity of software supply chain management, and the application requirements of emerging algorithms provide strong support and motivation for the research of software supply chain management combined with e-CNY under the application of fuzzy theory and the combination of CPSO and ACA. Based on these issues, the research is conducted with the goal of better fulfilling users' payment needs. The characteristics of e-CNY and the theory behind applying supply chain management to e-CNY software development are first analyzed and summarized. Next, by using fuzzy theory evaluation method, the progress of supply chain management information software construction and the overall cognition of digital enterprises on the development of supply chain management information are evaluated. The study then suggests a routing protocol based on the union of the CPSO and ACA algorithms and employs a novel CPSO algorithm to improve the choice of the cluster head. The research in this paper provides the theoretical value for implementing and developing e-CNY in the future.

The innovation of this paper is to combine the application of e-CNY with software supply chain management and use fuzzy theory and the combination of CPSO and ACA. This paper combines e-CNY with software supply chain management for the first time and discusses the influence and challenge of digital currency on supply chain management. Additionally, combining fuzzy theory with CPSO and ACA provides a new solution to the decision-making problem in software supply chains and breaks through the limitations of traditional algorithms with theoretical innovation.

The overall organizational structure of this paper is as follows. Section 1 expounds on the importance, development history, present situation, and trend of electronic payment in digital currency and puts forward the innovation and contribution of this paper. Section 2 (literature review) presents the research of scholars in related fields and discusses the advantages and disadvantages, emphasizing the value of this research. Section 3 introduces e-CNY's characteristics, and an innovative method based on CPSO and ACA is proposed. Section 4 (results) evaluates the model's performance and compares it with different schemes. Section 5 is the discussion that explores the results obtained and analyzes them with previous studies. Section 6 (conclusion) briefly reviews the results and explains the limitations and prospects of this paper.

LITERATURE REVIEW

At present, digital money has expanded the meaning of existing monetary and financial systems, and the e-CNY has become more crucial to financial transactions. From the perspectives of technical security, economic governance, infrastructure, and laws and regulations, Radic et al. analyze the features, effects, and issues associated with the internationalization of e-CNY and proposes solutions to address these issues and adhere to the development trend of the global digital currency (2022). According to Kshetri, the "local" digital currency should establish its legal characteristics before being further improved by dividing it into payment and stable types (2023). Xia et al. (2023) studied the adoption background of electronic payment in e-CNY. Mehlkop et al. focused on digital currency's privacy and acceptance in the United States, India, and Germany, and the research explored the attitudes of different countries towards the privacy and acceptance of centralized digital currency (2023). Chiu et al. (2023) analyzed the influence of bank market power on central bank digital currency and put forward a theoretical framework based on quantitative evaluation.

In contrast with traditional transnational credit transactions mediated by physical currency, which need third parties' involvement and raise the cost of bank financing, e-CNY provides a lower cost means for financial exchange; however, it carries significant risks in international credit transactions. E-CNY can successfully resolve the credit issues conventional international banks face based on supply chain technology (Xu, 2022). Li and others think supply chain technology has increased the privacy and secrecy of digital currency users, which benefits information security. Still, its concealment and encryption simplify criminals' efforts to carry out illicit activities and re-inject money into the market (Wu et al., 2021). The intelligent coding of digital currency requires a more ideal trade platform, Muegge & Sandstrom noted, and only in this way can people support the coordinated development of trading and financial services in digital currency (2021). These technologies include supply chain, big data, and cloud computing. In fact, intelligent supply chain technology can provide real-time tracking of the entire business process and decrease system latency (Muegge & Sandstrom, 2021). Thangavel et al. used dynamic analysis of a T-S fuzzy financial system with a sampling data control method, and their research results highlighted the practicability in financial system modeling (2022). Deng and Zhang proposed an improved cumulative prospect theory-interactive multi-attribute decision making (CPT-TODIM) method, which was used to evaluate the development of digital inclusive finance in uncertain probability. The research emphasized financial evaluation in an uncertain environment (2023). Zhou et al. designed and implemented the enterprise financial decision support system based on business intelligence, and their study emphasized supporting and implementing enterprise financial decisions based on business intelligence (2023). Di Caprio et al. proposed a novel ant colony algorithm to solve the shortest path problem with fuzzy arc weight; their results showed the method performed well and produced good effects in dealing with the shortest path problem under fuzzy arc weight (2022).

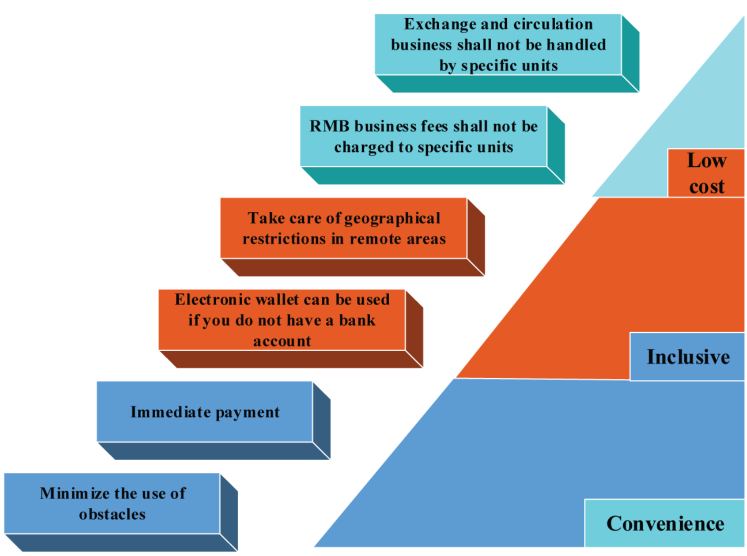
Relevant academics have conducted many studies of e-CNY, described and addressed its current issues, and provided remedies. Still, a systematic algorithm is needed to ensure the long-term implementation of the strategy. This paper proposes using particle chaotic ACA and fuzzy theory to optimize the software supply chain management of e-CNY and fully exploit its primary technical function, building on the theoretical foundation already in place. By utilizing e-CNY technology, e-CNY can enjoy internationalization by improving the handling of security concerns, economic management, while maintaining the stability of the RMB exchange rate and necessary supporting systems.

METHODS AND MATERIALS

Characteristics of E-CNY and Its Application in Supply Chain Management

An electronic currency built on internet technologies, e-CNY is legal tender issued by the People's Bank of China, and, along with China Yuan, it serves as the country's official legal tender (Shen, 2022). Supply chain-based internationalization of e-CNY has become unavoidable in response to the national initiative to promote international trade and investment facilitation and reinforce the leading position of e-CNY in the global monetary system. With the rapid expansion of the internet and the digital economy as an essential driving force for technological progress and industrial transformation, the supply chain integration has become increasingly important (Hou et al., 2023). As indicated in Figure 1, the characteristics of e-CNY can be distilled into three categories.

Figure 1. Characteristics of e-CNY

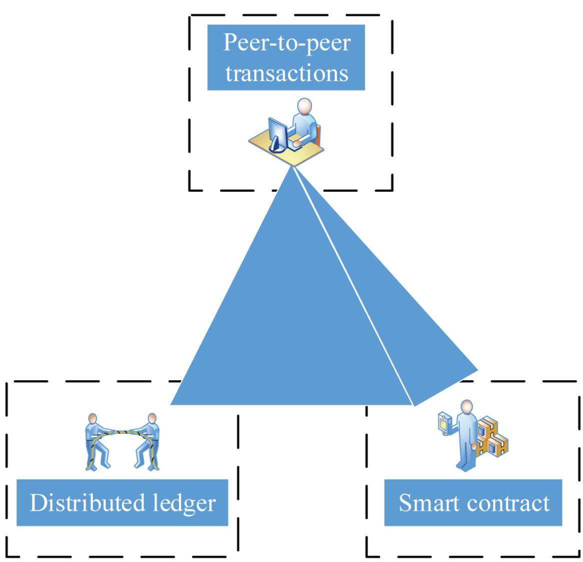


e-CNY has three characteristics: (1) low cost, which ensures low transaction costs and no RMB business fees; (2) inclusivity based on trading and circulation that are not restricted by specific units, encouraging many parties to participate in and promote currency circulation; (3) convenience in its consideration of geographical restrictions through the use of e-wallets that allow convenient payments without a bank account, the provision of instant payments, the reduction of obstacles, and improved user experience. The People's Bank of China has always followed the "one currency, two banks, and three centers" development paradigm, requiring a great deal of time and effort to give holders a fair and efficient trading platform, even though it can satisfy the trading needs of many holders. Supply chain is a new technology to promote the technical progress of business management (Duensing et al., 2023). The elements in Figure 2 depict the application of supply chain principles to e-CNY.

Applying the supply chain to e-CNY includes three parts: distributed ledger, peer-to-peer transmission, and smart contract. Distributed ledger is a database stored in multiple nodes, sharing account book data with the data kept in the same account book (Diallo, 2022). In addition to digital currency's identity authentication, data security, system security and other functions, electronic money and supply chain technology can also record account book transaction information on multiple servers and build an independent, decentralized, and open network for merchants, thereby ensuring the accuracy and transparency of transaction data (Tsolakis et al., 2023; Meng et al., 2022).

Given the decentralized nature of the supply chain, there is no longer the control of a single server, and the nodes have equal status, so that the nodes on the whole network can share data (Bechtsis et al., 2022). Additionally, each node follows the encryption technique independently, independent of a third party or trustor. This feature allows digital currency to carry out point-to-point transactions and real-time transaction data transmission (Wang et al., 2019). Smart contracts can be traded automatically using algorithms and according to the rules in the supply chain (Sanjaya & Akhyar, 2022). The developer begins "payment settlement" on the blockchain in issuing "digital wages," uploads the developer's salary and other information to the bank account, and ensures the security of the transaction through smart contracts under open and transparent conditions. The e-CNY can be moved from the developer's account to the company's account after the transaction and smart contract are finished. The supply chain avoids the cost of intermediate links and realizes "point-to-point" real-time settlement, because both parties can directly conduct e-CNY transactions in this program (Yang & Zhou, 2022).

Figure 2. Applying supply chain principles to e-CNY



In the age of the digital economy, government regulation of currency issuance is the best means to carry out the right to issue money. The development of world currencies is in line with the supply chain-based e-CNY, and the new development model also aligns with the supply chain's promotion of electronic internationalization. e-CNY should fully appreciate the advantages and technical characteristics of e-CNY as it develops and is promoted, adheres to its core technical responsibilities, and pushes e-CNY toward internationalization by implementing e-CNY technology, improving the way security risks are managed, enhancing economic management, preserving the stability of the e-CNY exchange rate, and establishing and enhancing pertinent supporting systems (Cheng, 2023).

Information Construction of Supply Chain Based on Fuzzy Theory

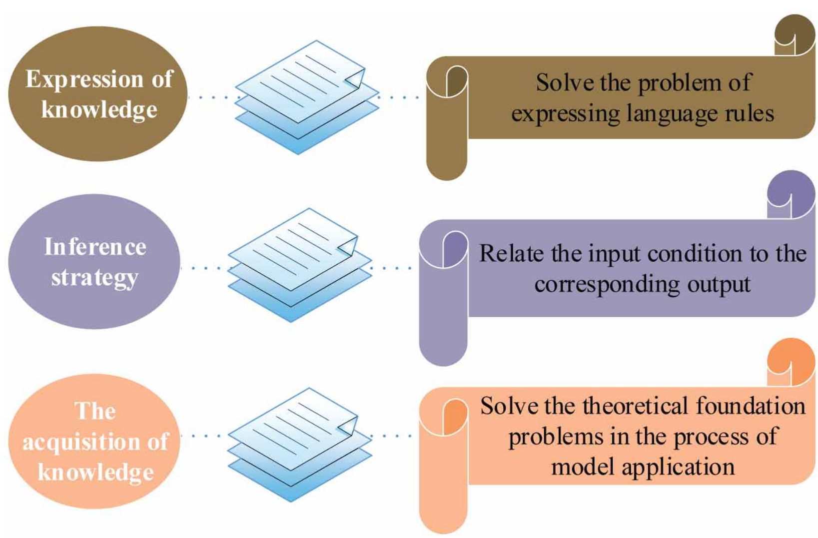
Fuzzy theory studies and deals with fuzzy phenomena, and the concept of things it deals with is fuzzy. It is difficult to determine whether an object conforms to this theory, that is, the uncertainty brought about by the ambiguity of extension. This is called uncertainty fuzziness. From a mathematical point of view, the degree of consistency between elements in the universe and their concepts is not expressed by absolute 0 or 1, but by real numbers between 0 and 1 (Gupta & Lee, 2023). Any mapping μ_A from a given domain U, U to a closed interval [0,1] is expressed as:

$$\mu_A : U \rightarrow [0,1] \tag{1}$$

Fuzzy set A is defined where μ_A is the degree to which the elements in fuzzy set A belong to the set, $\mu_A(x)$ is the degree to which the elements in fuzzy set A belong to fuzzy set A (membership), μ_A is called membership function, and $\mu_A(x) \in [0,1]$. Membership function is the basis of fuzzy mathematics theory, generally obtained according to experts' experience. Still, in practical application, because different people have different understandings of fuzzy concepts, it is often subjective and therefore difficult to determine membership value.

Fuzzy control system is based on regular expert system, fuzzy theory, and control theory. When establishing a complex mathematical model of controlled process, one should try to express expert behavior and experience simply (Nasrollahi et al., 2021). To establish a successful fuzzy control system, three fundamental problems need to be solved, as shown in Figure 3.

Figure 3. Establishment conditions of fuzzy control system



A fuzzy control system needs to effectively express fuzzy knowledge, establish reasoning strategies to deal with the relationship between input and output, and ensure that the acquisition and application of knowledge have practical significance, so that the system can be applied to complex real-world problems.

The supply chain risk monitoring and early warning system incorporates fuzzy theory in combination with the features of supply chain risk. To build a monitoring and early warning system, fuzzy logic must first analyze a massive amount of collected risk data. Figure 4 depicts the steps involved in creating the supply chain management monitoring and early warning system.

In the process of building this mechanism, a great deal of risk data related to the supply chain must be collected, including information on suppliers, transportation, inventory and market. These data may come from various sources, such as sensors, supply chain software, and market reports. The collected data may have problems such as noise and missing values, so it is necessary to clean, transform, and normalize the data to ensure the quality and consistency of the data for subsequent analysis. Then, the fuzzy logic analysis is carried out, and the fuzzy rule base is established. Finally, the corresponding risk early warning information is generated through fuzzy logic reasoning to realize more effective risk management. The relevant data of risk indicators can be obtained by analyzing the actual operation results of supply chain enterprises. In the process of data processing, it is necessary to limit the data within the range of [0,1]; that is, the following equation generally carries out the normalization of data:

$$y = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{2}$$

Figure 4. Construction of monitoring and early warning mechanism of supply chain management

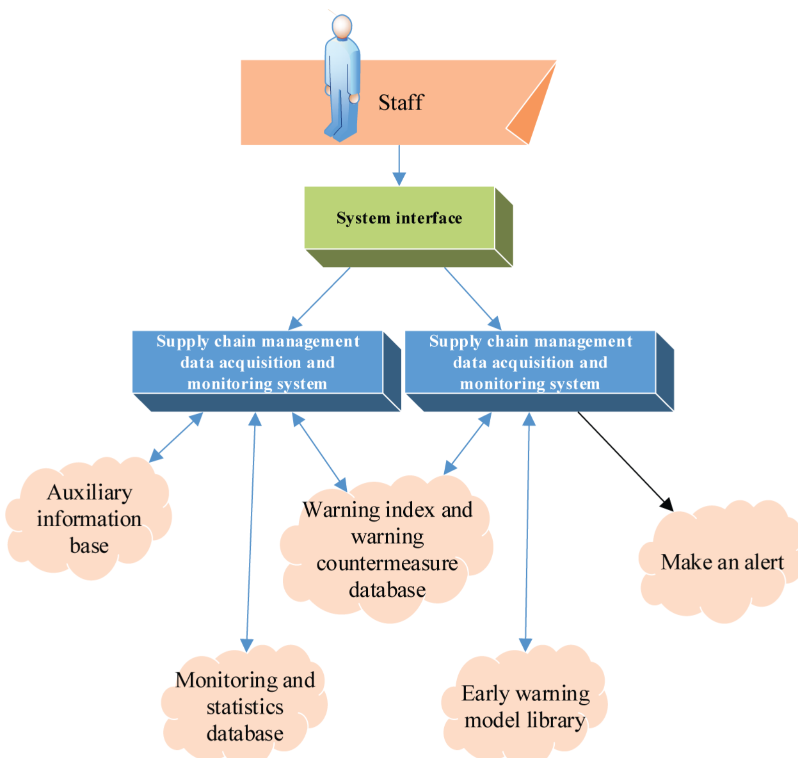


Table 1. Evaluation scale of supply chain management informatization

Opinion Rating	Very Good	Good	General	Poor	Very Poor
Fuzzy value	1.0	0.8	0.6	0.4	0.2
	0.9	0.7	0.5	0.3	0.1
	0.8	0.6	0.4	0.2	0

In (2), x represents the actual system data, x_{max} represents the maximum value of x in actual data. x_{min} represents the minimum value of x in actual data, and Y represents the normalized value of x.

This paper uses triangular fuzzy numbers to fuzzily semantic variables, and fuzzy values can be obtained through triangular fuzzy numbers, which provide data sources for evaluating supply chain management indicators. The principle of triangular fuzzy number is shown in the following equation:

$$u_n\left(x\right)=\begin{cases} 0, & x<n_1 \\ \dfrac{x-n_2}{n_2-n_3}, & n_2\le x\le n_3 \\ 0, & x>n_3 \end{cases} \tag{3}$$

In (3), n represents a positive trapezoidal fuzzy number, and n∈(n_1,n_2,n_3). Among them, 0 $\le n_1 \le n_2 \le n_3$.

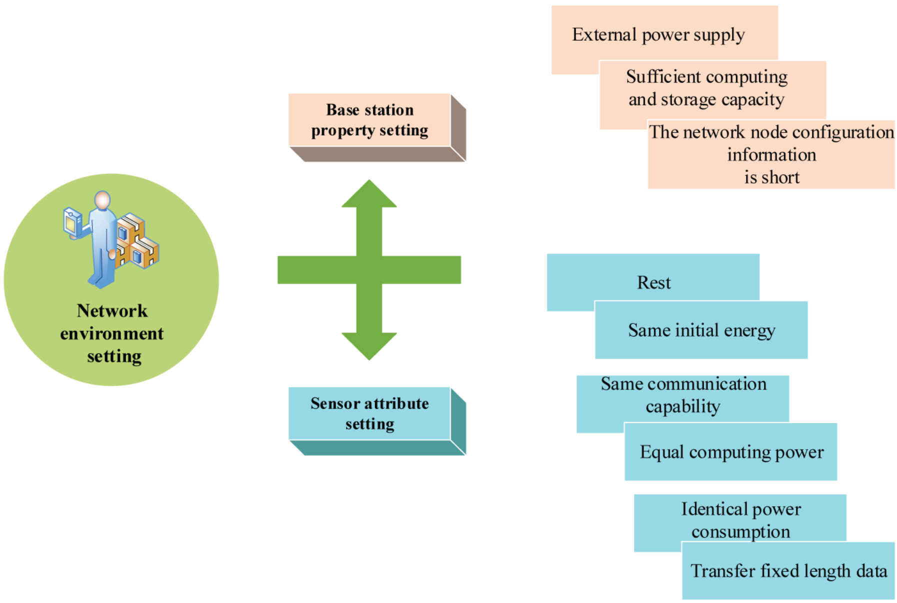
The semantic factors in this paper's evaluation of supply chain management information technology are graded on a scale of very poor, poor, general, reasonable, and very good to provide a collection of remarks. The fuzzy values of the semantic variables in the evaluation index of supply chain management informatization can be adjusted as shown in Table 1 below, following the triangular fuzzy number principle.

This paper proposes the following index evaluation principles: simplicity principle, comprehensiveness principle, easy implementation principle, strategic principle, synergy principle, emphasis principle, dynamic principle, practical principle, and balance principle, based on the analysis methods of index evaluation principles combined with the traits of supply chain collaborative management. The use of relevant measurement indicators to assess and determine the efficacy or efficiency of supply chain management is a crucial component of the design and analysis of the evaluation of supply chain management.

Routing Protocol Based on CPSO and ACA

Based on an analysis of traditional clustering strategies and routing protocols, this paper introduces two swarm intelligence algorithms, CPSO and ACA. It suggests a clustering routing protocol to balance the energy consumption of WSN, improve the expansibility of the network, and extend the life cycle of the network (Banyal et al., 2021). First, the clustering stage improves the fitness function of the particle swarm; the cluster head configuration is optimized by taking into account the residual energy, the Euclidean distance between clusters, the Euclidean distance from cluster heads to base station nodes, and the Euclidean distance from cluster members to cluster heads. The data gathered by the cluster head is then relayed along the optimal path found during the routing stage, which uses the basic ACA to determine the optimum route from the cluster head to the base station (Majdi, 2022). Figure 5 below depicts the software network setup created for this study.

Figure 5. Software supply chain management network environment



The network environment setting includes the base station attribute and the sensor attribute. Among the properties of base stations, stable power supply is needed to ensure the long-term operation of the system. Secondly, it needs enough computing and storage capacity to process and store extensive data. Finally, the configuration information between the base station and the network node should be brief to reduce the communication overhead. In the sensor attribute setting, the sensor should have a sleep mechanism to save energy. The initial energy of sensors should be the same to ensure fairness. The communication ability between sensors is the same to keep balance. Additionally, the sensors have equal computing power to ensure uniform task sharing.

The sensor needs to transmit fixed-length data for processing and transmission efficiency to improve the reliability and stability of the system. In the CPSO algorithm, each particle has a position vector and a velocity vector, and its number of bits represents the number of bits in the problem's solution space, which are recorded as X_i and V, respectively. The position vector and velocity vector of particles are expressed as:

$$X_i = \left[x_{i1}, x_{i2}, \ldots, x_{id}\right] \tag{4}$$

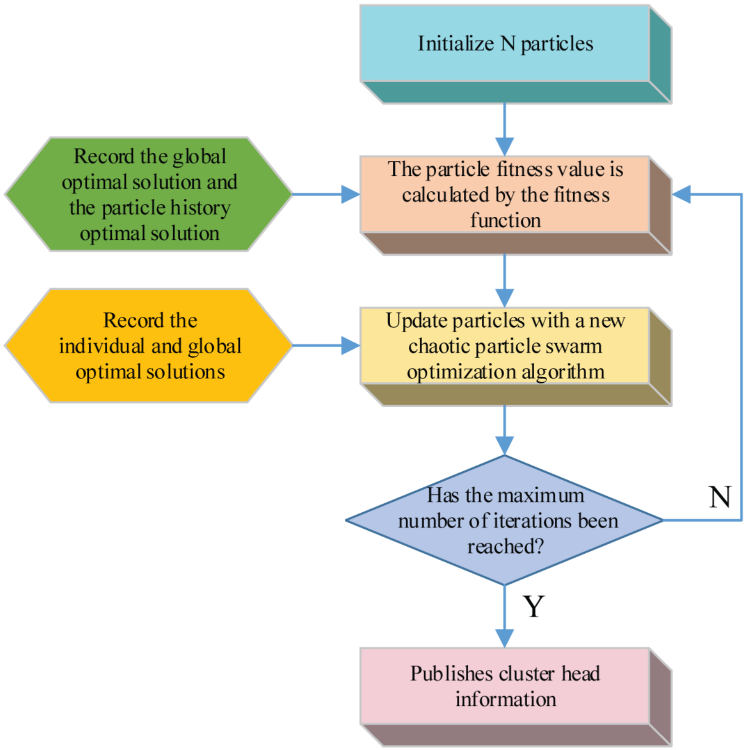
$$V_i = \left[v_{i1}, v_{i2}, \ldots, v_{id}\right] \tag{5}$$

In the above equations, x_{id} represents the d-dimensional position component of the position vector X_i, and v_{id} represents the d-th velocity component in the velocity vector V_i.

The steps of cluster head election based on the CPSO algorithm are shown in Figure 6.

Figure 6 shows the application of the CPSO algorithm to the cluster head election process. First, an initial particle swarm is created, containing n particles, representing a possible cluster

Figure 6. Cluster head election steps based on CPSO algorithm

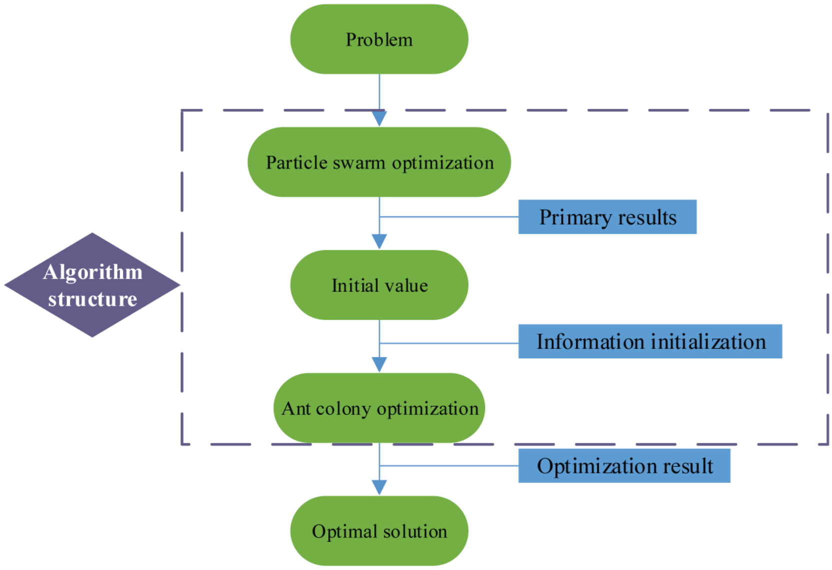


head. For each particle, the fitness function calculates the fitness value to measure its advantages and disadvantages in cluster head election. Each particle's historical optimal solution, global optimal solution, and corresponding fitness value are recorded. The chaotic particle swarm optimization algorithm is used to update the position and speed of each particle in order to find a better solution for cluster head election in the search space. The optimal solution is then recorded, and the updated particle position and velocity may lead to new historical and global optimal solutions, which are recorded. Whether the predetermined maximum number of iterations has been reached is checked. If it has not, the above process continues. Finally, the global optimal solution is selected to determine the cluster head node and its information is published to the network to complete the cluster head election process.

Although ACA has a significant ability to look for a better solution when applied to the partner selection problem, there are numerous issues like blindness and a slow convergence rate in the first search because of insufficient data. Particle swarm optimization (PSO) has an excellent global search capability in practice. However, its local optimization capability is subpar, the late convergence speed is poor, and it easily stagnates due to the system's inadequate utilization of feedback information (Hadi & Makki, 2023). Combining the two approaches to obtain complimentary benefits is considered based on these limitations. Figure 7 displays the suggested algorithm structure.

The new algorithm solves the shortcomings and combines the advantages of ACA and PSO. The fundamental concept is as follows: the initial pheromone matrix of ACA is constructed following the primary results, the initial solution set of the problem is generated using randomness and global solid search capabilities of PSO, and the optimal solution to the problem is then obtained using the benefits of positive feedback and strong optimization capabilities of ACA.

Figure 7. Algorithm structure design



RESULTS

Experimental Evaluation

The algorithms' performance is evaluated using Matlab software, and the performance variances of algorithms in various ranges are compared. The parameters for the simulation experiment are shown in Table 2.

In order to determine the performance of the fuzzy supply chain management monitoring and early warning mechanism, it is evaluated from three aspects: transaction qualification rate, satisfaction degree, and expert rating. The data source of this study is a questionnaire to determine the risk level of fuzzy supply chain management monitoring and an early warning mechanism – 231 questionnaires were distributed, 225 questionnaires were recovered, and 217 valid questionnaires were obtained by eliminating invalid questionnaires. For this study, the five risk levels are set as low, lower, medium, higher and high; the evaluation results are divided into very poor, poor, average, good, and very good according to the evaluation scale shown in Table 1. Using the CPSO coding program, the model's single objective function and multi-objective scheme are calculated, and the algorithm is further

Table 2. Parameter settings

Parameter	Initial energy (J)	Base station location	Packet size (bit)	Energy consumption of transmitting and receiving circuit (nJ/bit)
Value	1	(0,0)	4000	50
Parameter	Energy consumption of free space model (pJ/bit/m^2)	Energy consumption of data fusion (nJ/bit)	Energy consumption of multipath attenuation model (pJ/bit/m^4)	Probability of a node becoming a cluster head
Value	10	5	0.0013	0.1

compared with PSO and Di Caprio et al. (2022) from the perspective of average optimal fitness. Finally, the CPSO algorithm is combined with the ACA, and the effectiveness of CPSO, ACA, and CPSO+ ACA are compared from the perspective of solution accuracy and convergence speed.

Results Analysis

Matlab simulates the supply chain risk of the e-CNY software's fuzzy theory reasoning. When combined with the scale for evaluating supply chain management information technology, three tests are run: the transaction qualification rate, the satisfaction level, and the expert score. Figure 8 below displays the test outcomes.

According to the risk test results, 83% of e-CNY trading by software is qualified, which indicates that the trading performance is good and is at an upper-middle level. The satisfaction survey results exhibit a variable pattern that suggests consumers may be unsure about various software platform functions and that further research and improvement are still necessary. According to the experts' scores, often in the upper-middle range, there is much room for improvement in developing the e-CNY software supply chain based on fuzzy theoretical reasoning as described in this paper. The evaluation for supply chain management informatization based on fuzzy theory can thoroughly analyze and rate the management of e-CNY firms, enabling them to master the level of building of supply chain management informatization.

The results listed in Table 3 are obtained through 50 iterations, which well reflects that the multi-objective scheduling problem is a comprehensive optimization, and it is necessary to select

Figure 8. Risk test of e-CNY software supply chain based on fuzzy theory reasoning

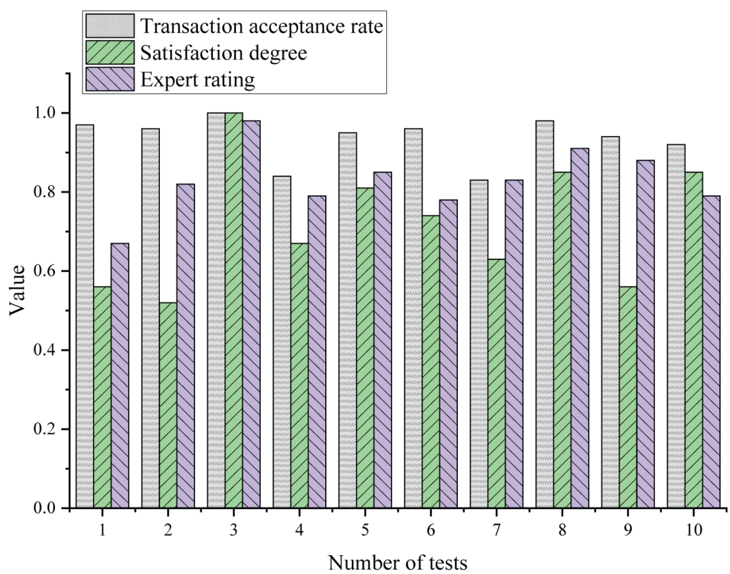


Table 3. Comparison of CPSO single-objective and multi-objective operation results

	CPSO Single Objective	CPSO Multi-Objective
Duration/day	11	13
Quality score/point	89	87
Resource level	108	121
Cost/ten thousand yuan	18.5	19.4

the most balanced point among the objectives, that is, a set of optimal solutions of multi-objective optimization. Therefore, the optimal solutions of each goal may not be obtained by considering only one objective problem.

Figure 9 compares the average optimal fitness curves, that is, convergence charts, obtained by multi-objective examples under the basic PSO algorithm, CPSO algorithm and related scholars Di Caprio et al. (2022). The results show that the PSO algorithm achieves convergence through about 150 evolutionary operations when solving the project scheduling problem. In comparison, the CPSO algorithm needs only about 100 evolutionary operations to achieve convergence, while Di Caprio et al. (2022), a scholar in related fields, needs about 143 evolutionary operations to achieve convergence. The results indicate the CPSO algorithm has higher convergence, faster speed, more minor variance, and relatively stable results.

The solution effect of the algorithm is depicted in Figure 10 below, which compares the effectiveness of CPSO, ACA, and CPSO+ACA in terms of the accuracy of the solution and the algorithm's convergence speed.

The information in Figure 10 demonstrates that when the CPSO algorithm is used to solve the problem alone, the convergence speed of the algorithm is faster in the initial iteration. However, with the increase in the number of iterations, the local search ability needs to be improved later. The convergence curve tends to be horizontal, and the solution is trapped in the local optimum. The first search is blind, slow, and time-consuming when the ACA algorithm is employed to resolve the issue alone, despite the fact that it demonstrates an excellent ability to find a better solution overall. This is because there are not any pheromones present in the early stages. In this study, the algorithm that combines the two approaches effectively overcomes the flaws of each approach while maximizing the benefits of CPSO and ACA. The combined algorithm also significantly increases the speed and accuracy of the problem-solving process through organic combination. The findings demonstrate that the proposed algorithm works better as the number of activities and node businesses in the supply chain increases.

Figure 9. Comparison of PSO and CPSO operation results

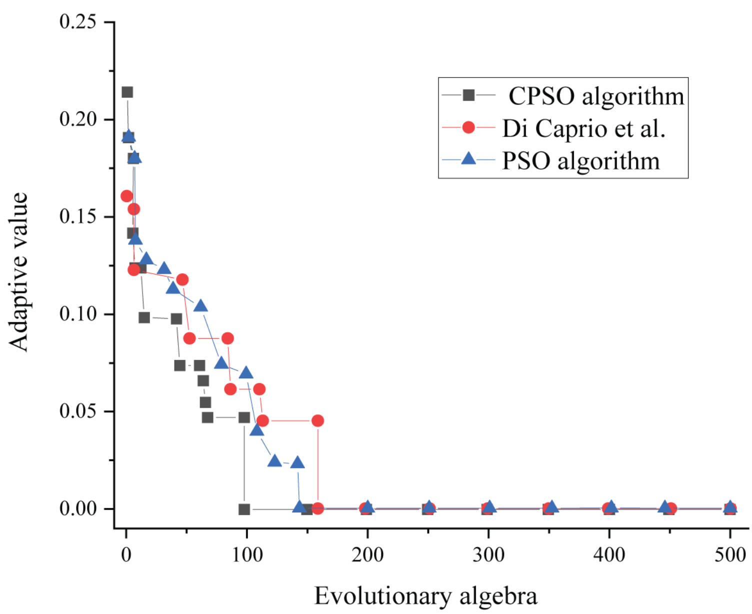
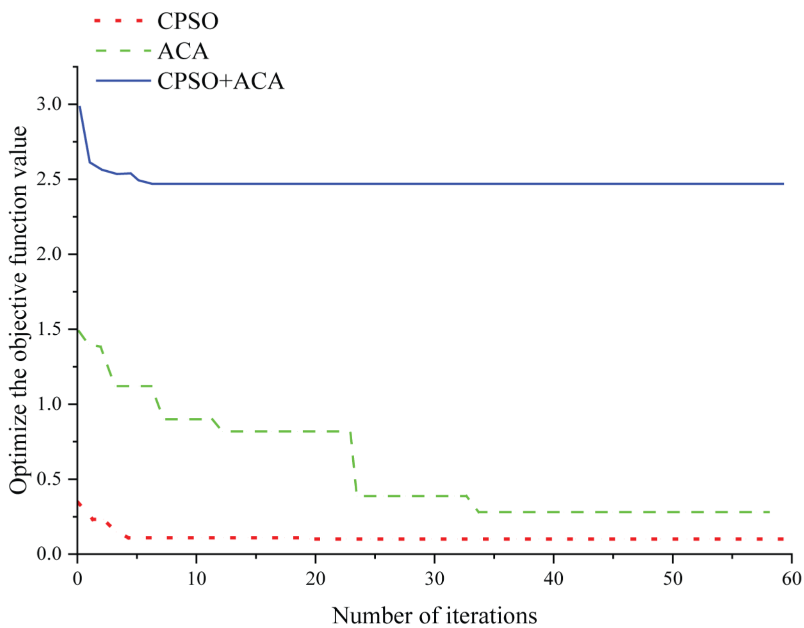


Figure 10. Comparison of solving performance of three algorithms



DISCUSSION

The importance of e-CNY in cross-border payments is emphasized, as Wang et al. (year) note in "Exploring e-CNY payment innovation to support the high-quality development of the real economy." The People's Bank of China, the State Administration of Foreign Exchange, and other departments actively encourage cross-border e-CNY settlement in new foreign trade formats. It promoted the development of e-CNY cross-border investment and financing business, significantly aiding e-CNY's internationalization. Scholars such as Yfanti (2023) believe that cross-border settlement could help e-commerce enterprises reduce risks and losses caused by foreign exchange settlement and promote more standardized operation of enterprises. The research focus of this paper was more inclined to the application and promotion of e-CNY payment in the real economy, and results found that 83% of e-CNY software transactions were qualified, showing that the transaction performance was good and at the upper-middle level. This is consistent with the improvement of supply chain stability and management efficiency studied by Badakhshan & Ball (2023). This study is relatively simple in research background and topic selection, focusing only on the application of e-CNY and software supply chain management, lacking a comprehensive discussion on the whole supply chain finance field.

Additionally, the research methods of the paper are less involved in field research and case analysis, which leads to the need for in-depth understanding of the current situation of e-CNY application and software supply chain management. Furthermore, the application of fuzzy theory and the combination of CPSO and ACA in the field of supply chain finance is relatively new, and greater empirical data and case support are needed. Additional international comparative research is needed, and the development experience in the fields of international digital currency and supply chain management should be explored. This study fully utilizes the advantages of combining the CPSO and ACA algorithms while avoiding drawbacks. The speed and accuracy of the problem optimization process are greatly improved through organic combination. The results show that as the number of active tasks and node enterprises in the supply chain increases, so does the performance of the proposed algorithm. The innovation of this study lies in the combination of e-CNY application and software supply chain management, and the introduction of fuzzy theory and the combination of CPSO and ACA for research. Through investigation and data analysis, this paper discusses the influence and challenge of digital currency on software supply chain management. It puts forward optimization schemes and improvement strategies for critical problems in the supply chain. The research results have practical application value, providing new ideas and solutions for supply chain management practice, helping to improve the efficiency and flexibility of supply chain management, and promoting the deep integration of the application of e-CNY and supply chain finance. Through practical innovation, this paper positively contributes to exploring and developing digital currency and supply chain management.

CONCLUSION

Disclosure of e-CNY transactions to the central bank means that the e-CNY information in the payment and clearing system will be limited to the issuer level, and personal data will be collected by the central bank, thus achieving more accurate monitoring of investment and capital flow. Meanwhile, digital currency can enhance the central bank's ability to implement the central government's monetary policy and make the payment and settlement system intelligently match the policy requirements. This paper primarily summarizes the characteristics of e-CNY and the principle of applying supply chain management to the development of e-CNY software to meet users' payment needs better. The current state of e-CNY software supply chain management is investigated and the degree of software supply chain management informatization construction is assessed using the fuzzy theory evaluation method to determine the overall level of development of digital enterprise supply chain management informatization. To reduce WSN energy consumption, a routing protocol combining CPSO and ACA is used. The results show that the combined algorithm fully utilizes each algorithm's advantages while effectively avoiding its disadvantages, significantly improving the speed and accuracy of the problem optimization process.

The research contribution of this paper is reflected in the following ways. First, through in-depth study of the application of e-CNY in software supply chain management, the influence and opportunities brought by digital currency on supply chain management are revealed. Second, using fuzzy theory and the combination of CPSO and ACA, the critical problems in software supply chain are optimized to improve the efficiency and flexibility of supply chain management. Additionally, this paper provides a new research perspective and method for combining digital currency and supply chain management. It has a specific role in promoting academic research and practical application in related fields. Generally speaking, the research results provide new ideas and direction for the exploration of digital currency application with the supply chain, with both research value and practical significance.

Recommendations for further study include improving upon the current research. Specifically, the CPSO algorithm used in this study needs a faster convergence speed, the energy consumed by nodes is too high, the time is too long, and, as a result, the results may fall into local optimization rather than global optimization. More detailed research and better cluster selection will be required in the future.

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