Mathematical Problems in Engineering

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Lead Guest Editor: Fuli Zhou
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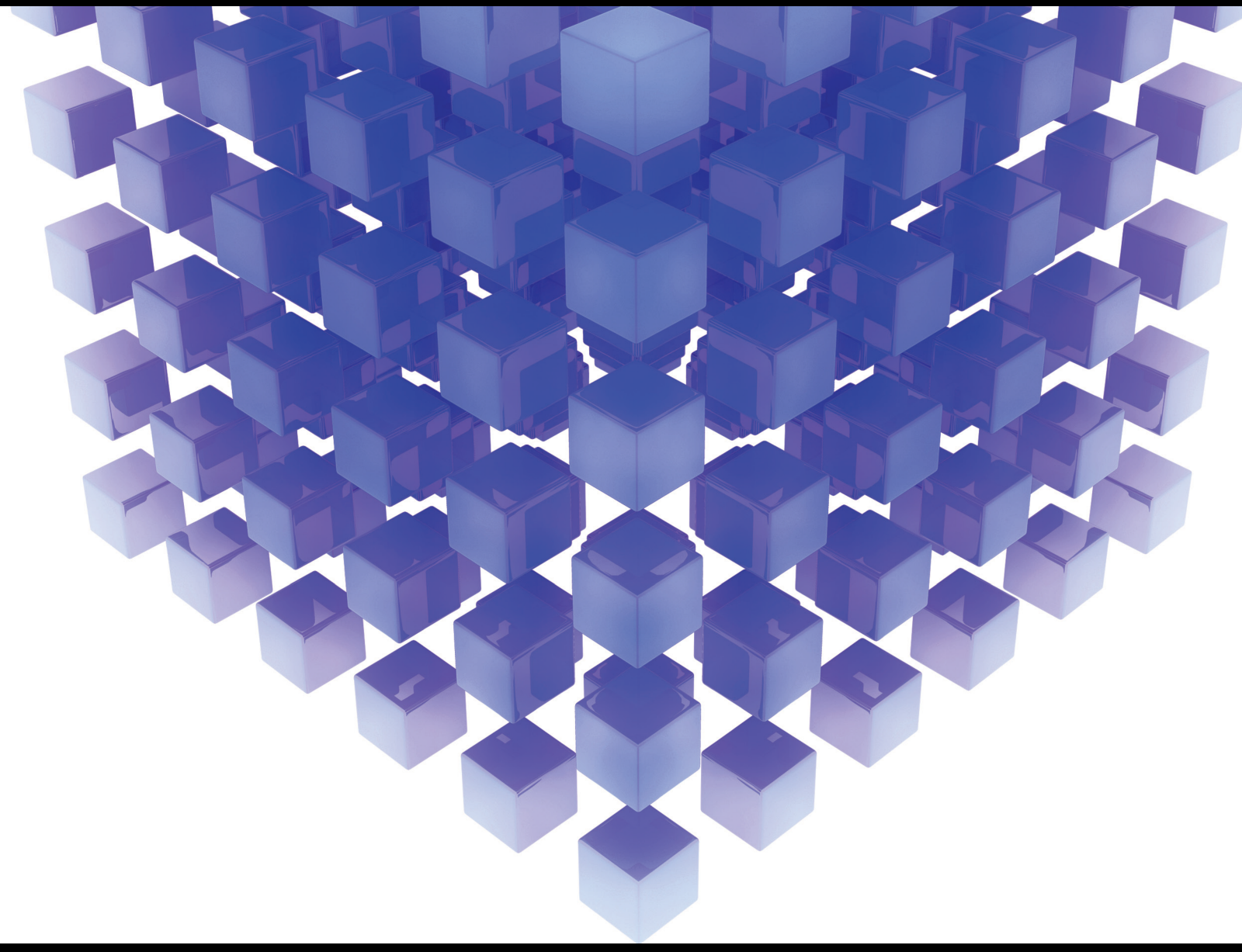

End-of-life Vehicle Recycling Management: Initiatives, Models and Industrial Applications

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Chief Editor

Academic Editors

Contents

Hindawi
Mathematical Problems in Engineering
Volume 2023, Article ID 9872695, 1 page
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Retraction

Retracted: Exploring the Influence of Local Government Debt on Enterprise Investment through the Empirical Evidence at the Municipal Level

Mathematical Problems in Engineering

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] M. Cao, K. Duan, and H. Ibrahim, "Exploring the Influence of Local Government Debt on Enterprise Investment through the Empirical Evidence at the Municipal Level," *Mathematical Problems in Engineering*, vol. 2022, Article ID 2531808, 18 pages, 2022.

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Research Article

Two-Layer Location-Routing Problem Based on Heuristic Hybrid Algorithm

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Location-routing problem (LRP) thoroughly considers location allocation problem (LAP) and vehicle routing problem (VRP) which has been an integral part applied in modern logistics. A number of researchers at home and aboard have put forward their views by establishing fine models. On the basis of studying the previous research results by classification, summary, and comparative analysis, this study hence proposes a new solution-fuzzy clustering model and algorithm to resolve two-layer location-routing problem based on a heuristic hybrid algorithm: Designing a hybrid genetic and simulated annealing algorithm (GASA) to optimize the initial value of the fuzzy C-means clustering algorithm (FCM); considering the roving visit characteristics of vehicles to design the path by employing a special VRP problem—the multiple traveling salesman problem (MTSP). Theoretical analysis and experimental results show that the algorithm used in this study has the advantages of fast convergence speed and less iterations, which significantly improve the quality of the initial solution of FCM in LAP, shorten the vehicle patrol cycle in VRP to a great extent, improve the vehicle utilization, and save the vehicle patrol costs. A specific example is programmed by MATLAB to verify the feasibility of this method.

1. Introduction

Location allocation problem (LAP) and vehicle routing problem (VRP) are two essential parts in logistics which are widely used in life and engineering. On the one hand, LAP strategically considers the location of the distribution center, but it fails to include the characteristics of vehicle tours from a tactical aspect, which may easily lead to a larger actual distribution distance. On the other hand, VRP takes the characteristics of vehicle tours into account; however, it does not consider whether the location of the distribution center is reasonable from a strategic view, which will easily result in a high total cost of the entire logistics system [1]. To address both disadvantages arising from LAP and VRP, some scholars have put forward the location-routing solution from the strategic and tactical aspects which comprehensively considers problems of the site selection of distribution center, coverage of distribution services, and vehicle routing optimization, aiming to seek the optimal solution of the entire logistics system by integrating both merits of LAP and VRP. The LRP is an NP-complete problem, and a series of related approximation algorithms have emerged in recent years, so we hope to obtain a satisfactory solution (may not be the optimal solution) with high quality through the approximation algorithm.

In practice, the site selection of the distribution center and the path design of the distribution service are two vital aspects. The site selection is related to the strategic decision made by the logistics enterprises, while the path design concerns their tactical decision. In order to better serve the needs of economic and societal developments, a number of experts and scholars at home and abroad have actively explored the field of LRP and achieved enormous results.

A large number of studies have shown that the overall optimization of positioning, allocation, and path holds the key to solving LRP. Previously, scholars were limited to the

study of a single distribution center, employing the total cost function to describe the path cost [2]. By comparing the total cost function and the potential location path cost, Webb pointed out that the path cost cannot be represented by the approximate total cost function at a certain moment [3]. Wang dan et al. also made similar findings in their research [4]. Later on, scholars realized the importance of site decision-making and path coordination. Therefore, many scholars have renewed their research on this matter: Cooper believes that the appropriate location of the distribution center directly affects future transportation costs, so the site selection and the path problem should be integrated for study [5]. Bookbinder seeks to solve LRP by building a nonlinear mixed integer programming model [6]. There are also extensive research studies on LRP in China. Some scholars have established a two-stage planning model to determine the site selection plan [7], customer division, and logistics distribution in terms of recycling and transportation path design [8]; studied multiobjective random LRP in the context of considering a variety of uncertainties [9]; established a three-layer LRP model on the basis of introducing the important parameter of storage cost to the traditional two-layer LRP model; and applied the genetic algorithm to seek a solution [10, 11].

In addition, the study by Tang et al. is noteworthy, who solved the TSP with the asymptotic formulation. The result was approximately equal to the path length in the distribution system, while the time cost was much shorter [12, 13].

For LRP research, there are various common solutions:

The traditional fuzzy C-means clustering algorithm (FCM) is essentially a local optimization algorithm, which is very sensitive to the selection of the initial value and is easy to converge to the local extreme point.

The present single heuristic algorithm also has its shortcomings. For example, genetic algorithms are susceptible to fall into local optimum; simulated annealing algorithm is lacking incomprehensive search ability, etc [14].

The tour feature of vehicles has not been fully utilized.

With regard to the shortcomings of previous studies in these aspects, this study proposes a new solution, namely, the fuzzy clustering model and algorithm to resolve a two-layer location-routing problem based on heuristic hybrid algorithm:

In the first-layer mathematical model (LAP model), the initial value of FCM is optimized by using the genetic simulated annealing algorithm (GASA) [15].

In the second-layer mathematical model (VRP model), the genetic algorithm is used to solve a special VRP problem—the multiple traveling salesman (MTSP) problem [16].

Therefore, this study aims to solve the LRP more effectively by using the above methods.

2. Problem Statement and Model Building

LRP can be defined as follows: a distribution network plans to set up m distribution centers, with available vehicles and n customers. The set of the distribution center is defined as $M = \{M|M = 1, 2, \ldots, m\}$. The set of the available vehicles is defined as $S = \{S|S = 1, 2, \ldots, s\}$. The set of the customers is defined as $N = \{N|N = 1, 2, \ldots, n\}$.

The set of points composed by the distribution center and customers is defined as $V = M \cup N = \{V|V = 1, 2, \ldots, m + n\}$.

The set of edges is defined as $E = \{(m, n)|m, n \in V\}$. Let the distance (Euclidean distance) corresponding to each edge be D_{mn}, and let the distribution cost be C_{mn}. There is no capacity limitation for vehicles and distribution centers.

Each vehicle has only one service path, and the start and end points must be at the same distribution center. Each distribution center can have multiple vehicles to provide service for multiple customers while each customer can only be served once by one vehicle at the same distribution center. The decision variable x_{mns} represents whether the vehicle S accesses the edge (m, n) (yes = 1, no = 0). The decision variable y_{mn} represents whether customer N is within the service range of distribution center M (yes = 1, no = 0).

Fuzzy C-Means (FCM) can be defined as follows: selecting $m\,(2 \le m \le n)$ locations for a distribution center and let n data samples be $X = \{\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_N\}$. The set of served customers is defined as $\{P_1, P_2, \ldots, P_m\}$. The location of the distribution center is $\{P_1, P_2, \ldots, P_m\}$ Let the similarity classification matrix be U, and let the degree of membership of the n customer to the m distribution center be μ_{mn}.

The dissimilarity between $\mathbf{x}_i$ and e_j is defined as $d(\mathbf{x}_i, e_j)$. Let the characteristic of the sample be p.

Since this paper focuses on shortening the solution time on the basis of optimizing the solution method, only the situation where distance cost is the core factor of site selection will be considered.

2.1. The First Layer of the Mathematical Model. Let the objective function be $J_q(U, e)$, and the maximum value of U is as follows:

$$\min \quad J_q(U, e) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\mu_{ij}\right)^q \left(D_{ij}\right)^2. \tag{1}$$

To divide X into m clusters, the following three conditions should be satisfied:

$$\begin{gathered} \mu_{mn}\colon X \longrightarrow [0, 1], \forall m \in M, \forall n \in N, \\ \sum_{i=1}^{m} \sum_{j=1}^{n} \mu_{mn}\left(\mathbf{x}_k\right) = 1, k = 1, 2, \ldots N, \\ 0 < \sum_{k=1}^{N} \mu_{mn}\left(\mathbf{x}_k\right) < N, \forall m \in M, \forall n \in N. \end{gathered} \tag{2}$$

The minimized constraints of $J(U, e)$ is (4). This leads to the following Lagrange function:

$$J(U, e) = \sum_{i=1}^{m} \sum_{j=1}^{N} \left(\mu_{ij}\right)^q \left(D_{ij}\right)^2 - \sum_{j=1}^{N} \lambda_j \left(\mu_{ij} - 1\right). \tag{3}$$

The membership μ_{mn} is calculated as follows:

$$\mu_{mn} = \frac{1}{\sum_{i=1}^{m}\left(D_{ji}/D_{li}\right)^{2/q-1}}. \tag{4}$$

The center (distribution center) $\{e_i\}$ of each cluster can be written as follows:

$$e_{ij} = \frac{\sum_{i=1}^{m}\left(\mu_{ij}\right)^{q}\mathbf{x}_{ij}}{\sum_{i=1}^{m}\left(\mu_{ij}\right)^{q}}. \tag{5}$$

These functions are called membership functions. The fuzzy membership function value has the mathematical characteristics of a set. In other words, each vector $\mathbf{x}$ belongs to multiple clusters at the same time but with a different degree of membership. The corresponding value μ_{mn} in the interval $[0, 1]$ quantifies the degree of membership. A value close to 1 indicates a high degree of membership to the cluster while a value close to 0 indicates a low degree of membership to the cluster.

2.2. The Second Layer of the Mathematical Model. The objective function can be written as follows:

$$\min \quad G_d = \sum_{m\in M}\sum_{n\in N}\sum_{s\in S} C_{mn} * x_{mns}, \tag{6}$$

C_{mn} depends on the distance from the distribution center m to the customer n:

$$C_{ij} = K * D_{ij} = K * D\left(\mathbf{x}_i - e_j\right) = K * \sqrt{\sum_{j=1}^{p}\left(\mathbf{x}_{ij} - e_{ij}\right)^2}, \tag{7}$$

here K represents the freight cost per unit, namely the freight rate.

A customer can only be served by one car:

$$\sum_{m\in V}\sum_{s\in S} x_{mns} = 1, \forall n \in N. \tag{8}$$

A customer can only be served by one distribution center:

$$\sum_{m\in M} y_{mn} = 1, \forall n \in N. \tag{9}$$

Each vehicle can be dispatched to finish the delivery tasks only on one route:

$$\sum_{m\in M}\sum_{n\in N} x_{mns} \le 1, \forall s \in S. \tag{10}$$

Neither the customer nor the distribution center is allowed to ship to itself, which means there is no route between them:

$$x_{mms} = 0, \forall m \in V, \forall s \in K. \tag{11}$$

Distribution centers are not allowed to ship between each other:

$$\sum_{m\in M}\sum_{n\in M} x_{mns} = 0, \forall s \in S. \tag{12}$$

The number of vehicles departing to and returning from the customers should be equal:

$$\sum_{m\in V} x_{mns} - \sum_{m\in V} x_{nms} = 0, \forall n \in V, \forall s \in S. \tag{13}$$

The total number of vehicles in the entire distribution system should not exceed the total number of existing vehicles S:

$$\sum_{m\in M}\sum_{n\in N}\sum_{s\in S} x_{mns} \le s. \tag{14}$$

Suppose each distribution center has the same number of vehicles mean_V:

$$\begin{aligned} \text{mean\_}V &= \frac{S}{cn}, \\ \text{mean\_}V &= 1, 2, \ldots. \end{aligned} \tag{15}$$

In addition, x_{mns} and y_{mn} are 0–1 decision variables, the properties of which are as follows:

$$\begin{aligned} x_{mns} &\in \{0, 1\}, \forall m, n \in V, \forall s \in S, \\ y_{mn} &\in \{0, 1\}, \forall m \in M, \forall n \in N. \end{aligned} \tag{16}$$

3. Algorithm Design

3.1. Implementation of the Fuzzy C-Means Clustering Algorithm. In the fuzzy C-means clustering method, each data point belongs to a certain cluster center according to a certain fuzzy membership degree [17]. Jim Bezdek proposed the clustering technology as an improvement to the traditional clustering technology in 1981 [18]. Firstly, a number of cluster centers are randomly selected, and all data points are given a certain fuzzy membership degree to the cluster center [19]. Then, the iterative method is used to continuously modify the cluster center, and the iterative process minimizes the distance from all data points to each cluster center as well as the weighting and optimization objectives of the membership value [20]. The output of fuzzy C-means clustering is a list of cluster centers and the membership value of each data point for each cluster center [21].

3.2. Genetic Algorithm. The genetic algorithm (GA) is a probabilistic optimization algorithm that is based on natural selection and genetic theory and uses the combination of evolutionary survival of the fittest and the random exchange of chromosome information in a population to search for global solutions. It was first put forward by Professor J. Holland of the University of Michigan in 1975 [22].

The genetic algorithm is composed of three modules: encoding and decoding, individual fitness evaluation, and genetic operation. In the genetic algorithm, we define a population or group as the set of encoded chromosomes,

and each individual is the phenotype of its corresponding chromosome [23].

3.2.1. Encoding and Decoding. The encoding and decoding of genetic algorithms correspond to the genotype and phenotype of organism at the macro level and correspond to the transcription and translation of DNA at the micro level [24]. The operation object of the genetic algorithm is a point set (string), the mapping from the solution space of the problem to the genetic algorithm space is called encoding, and the mapping from the genetic algorithm space to the solution space of the problem is called decoding [25].

Binary coding is adopted for the two-layer model in this study. In the first layer of the model, each chromosome is composed of m cluster centers. For the p-dimension sample vector, the number of variables to be optimized is $m^* p^*$. If each variable uses k-bit binary coding, the length of the chromosome is a binary code string of $\mathrm{m}^* p^* k$. In the second layer of the model, each chromosome is composed of n nodes (including customers and distribution centers). For the q-dimension sample vector, the number of variables to be optimized is $n^* q$. If each variable uses l-bit binary coding, the length of the chromosome is a binary code string of $n^* q^* l$.

3.2.2. Individual Fitness Evaluation. The fitness function is a measure of individual fitness. In this study, the first layer of the model takes (1) as the objective function and its reciprocal $1/J_q$ as the fitness function, the value of J_q is smaller, the value of its reciprocal $1/J_q$ is higher, the individual fitness value is higher, and it can satisfy two conditions that is the customer is more intensive, the establishment of distribution center is more economical and the fitness is higher. The chance of genetic inheritance to progeny individuals is higher. Similarly, the second layer of the model takes Equation [26]. (6) as the objective function and its reciprocal $1/G_d$ as the fitness function. The value of $1/G_d$ is smaller, the value of reciprocal $1/G_d$ is higher, the individual fitness value is higher, and it can satisfy two conditions: the total distance of distribution is shorter, the cost is lower, and the probability of the gene with the highest fitness being passed on to the progeny individuals is higher [27].

3.2.3. Genetic Operation. Selection Operator: In this study, the individual fitness of the parent population is evaluated and sorted according to the size of the fitness value, and then a random traversal sampling strategy is used to generate the progeny population.

Crossover Operator: Considering that the number of effective genes on each chromosome may not be the same, the single point crossover operator is used in this study.

Mutation Operator: The mutation operator refers to the generation of mutation genes with a certain probability and the selection of mutation genes by a random method. In this study, two individuals are randomly selected, and then two genes of the selected individuals are randomly exchanged to achieve mutation operation [28].

3.3. Simulated Annealing Algorithm. Although the parallel search pattern of the genetic algorithm has a strong search capability in the whole solution space, it has a slow convergence and poor local search capability. The probabilistic abrupt jump nature of the simulated annealing algorithm is an effective way to find the optimal solution to the problem in the search space. However, the serial search approach of the simulated annealing algorithm leads to less than comprehensive results for the search space and does not facilitate running the search process in the most promising search regions [29]. Thus making itself inefficient in terms of operations. Therefore, we combine the advantages of the genetic algorithm and simulated annealing algorithm to optimize the initial clustering centers of the fuzzy C-mean clustering algorithm.

Lombard et al. mentioned in their paper that the simulated annealing algorithm originated from the findings of statistical mechanics of materials and was originally proposed by Metropolis et al. In 1983, Kivkpatrick et al. proposed to apply the simulated annealing algorithm to solve combinatorial optimization problems, and their starting point was based on the similarity between the annealing process of physical solids and combinatorial optimization problems in general [30].

The simulated annealing algorithm is a kind of stochastic search algorithm. Theoretically, it is a globally optimal algorithm. Its core is composed of "Three Functions" and "Two Criteria." The former refers to the state generation function, state acceptance function, and temperature update function, and the latter refers to the sampling stability criterion (inner loop termination criterion) and the annealing termination criterion (outer loop termination criterion) [10].

3.3.1. State Generation and Acceptance Functions. The state generation function, also known as the neighborhood function, is a function that ensures that the generated candidate solutions are spread throughout the solution space as much as possible. In this study, the genetic algorithm is embedded in the simulated annealing algorithm as its inner loop structure. In other words, the state generation function corresponds to the genetic operator in the genetic algorithm, and the state acceptance function in the simulated annealing algorithm corresponds to the population iteration operation in the genetic algorithm [10].

3.3.2. Temperature Update Function. The temperature update function can have various forms. In this study, it is given as follows [29]:

$$T_{i+1} = T_i * k_q \quad i = 0, 1, 2, \ldots, \tag{17}$$

here k_q is the cooling coefficient, and its value determines how fast the temperature drops.

3.3.3. Sampling Stability Criterion. The Metropolis sampling stability criterion, also known as the inner loop termination criterion, is used to reach thermal equilibrium at any constant temperature. Its role in the algorithm is to define

Table 1: Client coordinates.

Nos.	Coordinates
1	(0.2266, 0.0658)
2	(0.9020, 0.6752)
3	(0.6990, 0.6662)
4	(0.8107, 0.7774)
5	(0.3453, 0.3365)
6	(0.2889, 0.2624)
7	(0.5827, 0.3995)
8	(0.5572, 0.7973)
9	(0.1611, 0.1290)
10	(0.0525, 0.3003)
11	(0.1226, 0.0865)
12	(0.6464, 0.4419)
13	(0.3726, 0.4734)
14	(0.8218, 0.6348)
15	(0.5215, 0.2849)
16	(0.5307, 0.2081)
17	(0.5215, 0.7569)
18	(0.6243, 0.3511)
19	(0.7841, 0.6275)
20	(0.8483, 0.0178)
21	(0.0616, 0.3822)
22	(0.1692, 0.8558)
23	(0.3142, 0.3240)
24	(0.3095, 0.6284)
25	(0.5163, 0.1034)
26	(0.3364, 0.9960)
27	(0.9675, 0.4120)
28	(0.0251, 0.6994)
29	(0.5178, 0.8281)
30	(0.2201, 0.9690)
31	(0.5455, 0.7088)
32	(0.9107, 0.0855)
33	(0.5668, 0.7064)
34	(0.0494, 0.7305)
35	(0.4789, 0.7273)
36	(0.2233, 0.5032)
37	(0.8480, 0.2040)
38	(0.4529, 0.9115)
39	(0.4823, 0.3539)
40	(0.6527, 0.9238)
41	(0.9248, 0.3725)
42	(0.5147, 0.0494)
43	(0.0617, 0.3826)
44	(0.7940, 0.2926)
45	(0.7414, 0.5063)
46	(0.5395, 0.1430)
47	(0.8302, 0.7108)
48	(0.1240, 0.2596)
49	(0.5330, 0.2463)
50	(0.3668, 0.1719)
51	(0.0403, 0.0030)
52	(0.1390, 0.8815)
53	(0.1311, 0.9338)
54	(0.1679, 0.9176)
55	(0.8107, 0.2406)
56	(0.8808, 0.2671)
57	(0.1797, 0.3355)
58	(0.3126, 0.0158)
59	(0.3268, 0.5915)
60	(0.1077, 0.9922)
61	(0.0449, 0.8286)
62	(0.5965, 0.2003)
63	(0.1101, 0.9886)
64	(0.2517, 0.1577)
65	(0.3456, 0.6481)
66	(0.5236, 0.5425)
67	(0.1704, 0.6832)
68	(0.9218, 0.4146)
69	(0.0745, 0.3948)
70	(0.4568, 0.6939)
71	(0.9960, 0.1876)
72	(0.7049, 0.8491)
73	(0.2948, 0.0159)
74	(0.6819, 0.7943)
75	(0.4643, 0.4818)
76	(0.1130, 0.8745)
77	(0.7603, 0.5215)
78	(0.7316, 0.1828)
79	(0.2154, 0.2482)
80	(0.6186, 0.6382)

the acceptance probability in terms of the difference between the objective function of the new solution and the current solution, i.e.,

$$P = \begin{cases} 1, & \text{if } E(x_{\text{new}}) < E(x_{\text{old}}), \\ \exp\left(\dfrac{E(x_{\text{new}}) - E(x_{\text{old}})}{K * T}\right), & \text{if } E(x_{\text{new}}) \geq E(x_{\text{old}}), \end{cases} \tag{18}$$

here K is the Boltzmann constant.

In order to better integrate the genetic algorithm and simulated annealing algorithm, the genetic generation in the genetic algorithm is set to the length of the Markov chain in the simulated annealing algorithm as the inner loop termination criterion in this study [16].

3.3.4. Annealing Termination Criterion. The annealing termination criterion, also known as the outer loop termination criterion, is used in this study to determine whether the program is terminated or not. If it holds, the program terminates; otherwise, the program proceeds to the next iteration.

4. Algorithm and Its Example Verification

4.1. Algorithm Flow of the First Layer Mathematical Model

(1) Initializing control parameters: simulate initial annealing temperature T_0, cooling coefficient k_q, end temperature T_{end}, individual size of population sizepop, maximum generation MAXGEN, crossover probability p_c , and mutation probability P_m, etc.

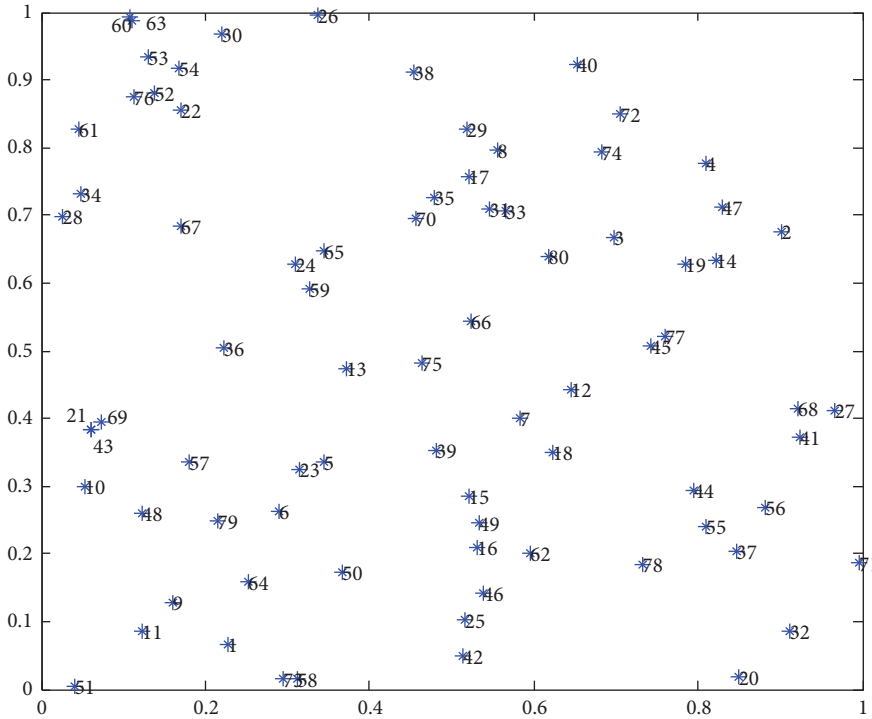

Figure 1: Client distribution map of the distribution network.

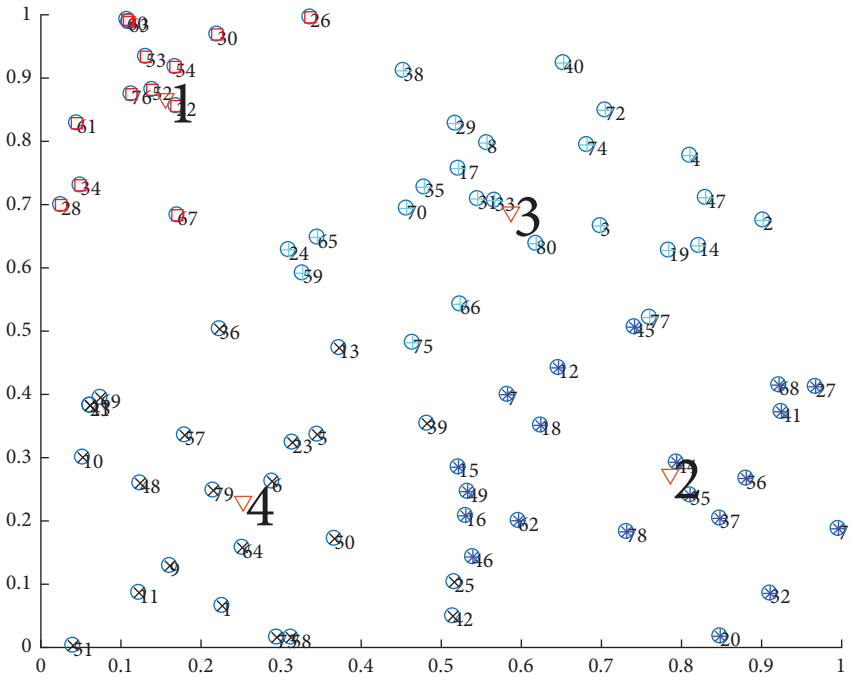

Figure 2: Location-distribution map.

(2) Randomly initializing cn cluster center generates the initial population $Chrom$. Then, formula (4) is used to calculate degree of membership μ_{mn} of each node to the cluster center, and formula (1) is used to calculate the fitness value of each individual f_i, $i = 1, 2, \ldots,$ sizepop.

(3) Setting iteration counter gen←0.

(4) The selection operator, crossover operator, mutation operator, and other genetic operations of population Chrom are performed to generate the progeny population. For the individuals in the progeny population, the formula (4) is used to calculate the

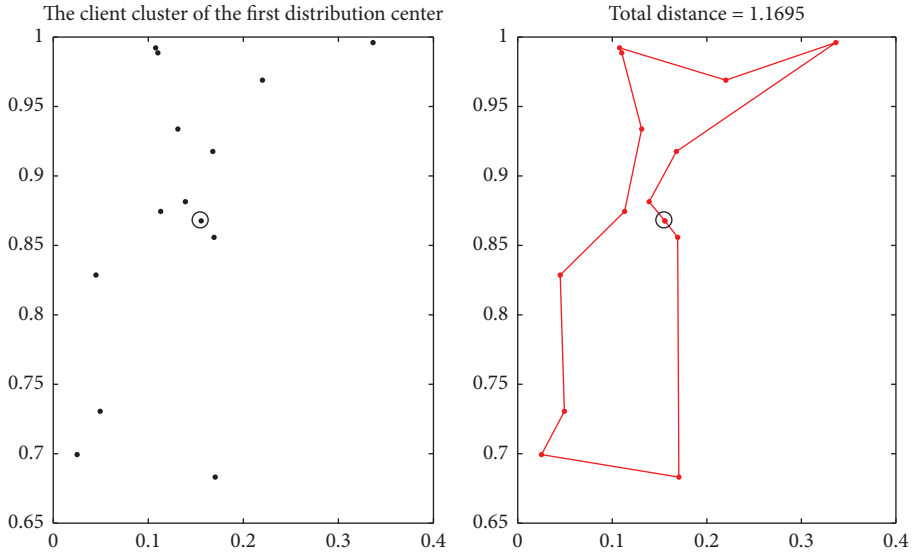

Figure 3: The client cluster and the distribution route of the first distribution center.

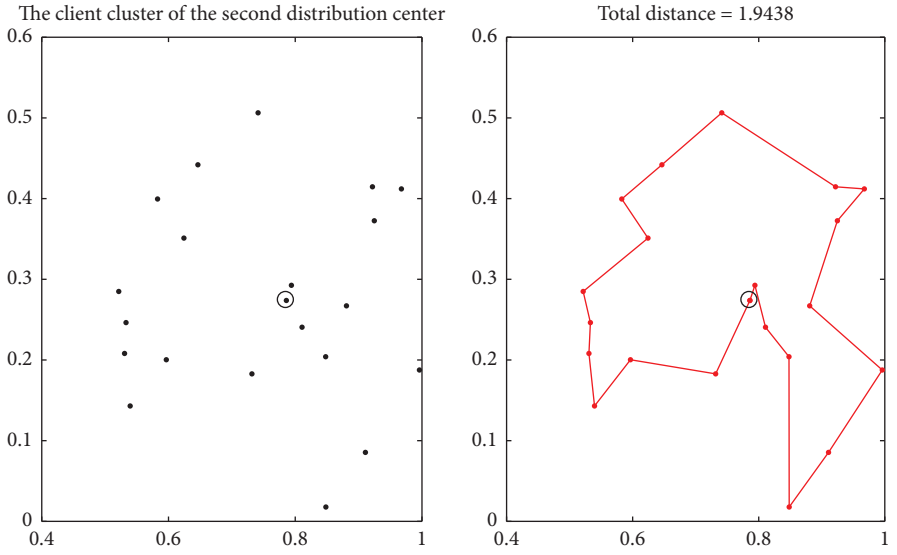

Figure 4: The client cluster and the distribution route of the second distribution center.

degree of membership of each node to cn cluster center, and the formula (1) is used to calculate the fitness value of each progeny individual. The metropolis algorithm is used to determine whether or not to accept the progeny individuals. If $f_i' > f_i$, then the progeny individuals replace the parent individuals; otherwise, the progeny individual is $P = \exp(f_i - f_i'/T)$.

(5) Determining whether or not out of the inner loop. If gen < MAXGEN, then gen ⟵ gen + 1, turn to Step4; otherwise, go to Step6.

(6) Determining whether or not out of the outer loop. If $T_i < T_{\text{end}}$, then producing the cluster result, the first layer model program ends, and the second layer model program starts.

4.2. Algorithm Flow of the Second Layer Mathematical Model

(1) Initializing control parameters: population size pop_size, maximum number of iterations MAX_num_iter, coordinate matrix xy of each node, distance matrix $dmat$ of each node, maximum number of vehicles MAX_V that can be dispatched by each distribution center, etc.

(2) Importing the location distribution results of the first layer model. If $fenzu \longleftarrow 1$, then $fenzu = 1, 2, \ldots, cn$.

(3) Initializing the population generates the initial population tmp_pop_rte and formula (6) is used to calculate the fitness value of each individual, $i = 1, 2, \ldots,$ pop_size.

(4) Setting iteration counter num_iter ⟵ 0.

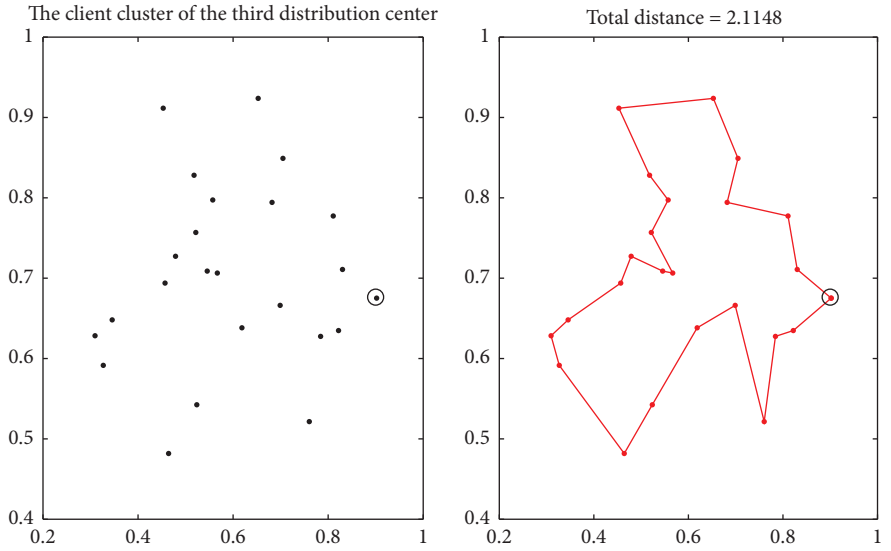

Figure 5: The client cluster and the distribution route of the third distribution center.

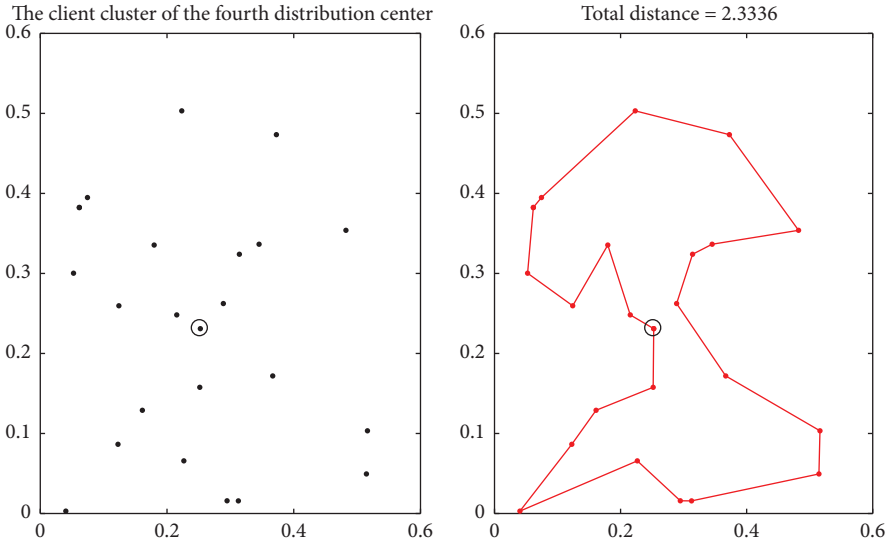

Figure 6: The client cluster and the distribution route of the fourth distribution center.

Table 2: The client distribution served by each distribution center (mean_V = 1).

Distribution center Nos.	The number of the clients	Client numbers
1	13	22, 26, 28, 30, 34, 52, 53, 54, 60, 61, 63, 67, 76.
2	20	7, 12, 15, 16, 18, 20, 27, 32, 37, 41, 44, 45, 46, 49, 55, 56, 62, 68, 71, 78.
3	24	2, 3, 4, 8, 14, 17, 19, 24, 29, 31, 33, 35, 38, 40, 47, 59, 65, 66, 70, 72, 74, 75, 77, 80.
4	23	0.1, 5, 6, 9, 10, 11, 13, 21, 23, 25, 36, 39, 42, 43, 48, 50, 51, 57, 58, 64, 69, 73, 79.

(5) According to the genetic operation, three operations of selection, crossover, and mutation are used to make the population *tmp_pop_rte* generate progeny population *new_pop_rte*. For the individuals in the progeny population, formula (7) is used to calculate the cost of the cluster center to each node, and formula (6) is used to calculate the fitness value of the progeny individual to judge whether or not to accept the progeny individuals fitness$_i'$. If fitness$_i'$ > fitness$_i$, the progeny individuals replace the parent and copy

it to the next generation; otherwise, the progeny individuals are not accepted and the parent individuals are copied to the next generation.

(6) Determining whether or not out of the iteration loop. If num_iter < MAX_num_iter, then num_iter ⟵ num_iter + 1 go to Step4; otherwise, go to Step7.

(7) Producing the distribution routes from each distribution center to the customer groups, and the second layer model program ends.

5. Verification of the Algorithm Case and Result Analysis

Assuming that 4 distribution centers which can form a distribution network are going to be built, all 4 available dispatching vehicles will be sent for 80 clients. Client coordinates are shown in Table 1.

According to the designed algorithm, in the first-layer model settings, we set the initial temperature as $T_0 = 100$, the cooling coefficient as $k_q = 0.8$, the final temperature as $T_{\text{end}} = 64$, the population size as sizepop = 20, the genetic maximum as MAXGEN = 30, the crossover probability as $P_c = 0.8$, mutation probability as $P_m = 0.05$. In the second-layer model settings, we set the the population size as $pop\_size = 20$, the genetic maximum as MAX_num_iter = 2000, and the number of the vehicles available in each distribution center as mean_V = 4. MATLAB R2012a is used to write the program for calculation in the experiment, and the program runs on the PC (CPU: Pentium dual-core 1.5 G·Hz; memory: 4 G; operating system: window7 64 bit). By running the program, the client distribution map of the distribution network and the location-distribution map can be obtained, as shown in Figures 1 and 2, respectively:

Every vehicle route map corresponding to each distribution center is shown in Figures 3 to 6, respectively.

The client distribution served by each distribution center is shown in Table 2.

The study shows that the designed two-layer location selection and route model based on the hybrid heuristic algorithm is of high computational efficiency and can deliver a satisfactory solution in a short time.

6. Conclusion

This study has analyzed the advantages and disadvantages of the c-means clustering algorithm, genetic algorithm, and simulated annealing algorithm. The innovations are as follows:

The classical algorithm in the fuzzy c-means clustering algorithm, the original production method of initial value, is improved.

(1) This study has improved the original way of generating initial values based on the synthesis of previous scholars' research. Stimulating the probabilistic jump of the simulated annealing algorithm can make the algorithm jump out of the local minimum and find the optimal solution in a large search space, which effectively makes up for the lack of search ability of the genetic algorithm in the local solution space and can effectively converge to the global optimal solution.

(2) The parallel search ability of genetic algorithm can quickly carry out global search. Making use of the advantages of genetic simulated annealing, a hybrid heuristic algorithm with global search and parallel search is designed to optimize the initial value and improve the convergence speed of the algorithm. This avoids the drawbacks arising from a single algorithm, and at the same time creates the "one plus one greater than two" effect.

The traditional LRP model has also been improved as follows:

(1) Making full use of the tour visit characteristics of vehicles, the multitraveling salesman problem (MTSP) is introduced into the LRP model, which shortens the tour cycle of vehicles, improves the utilization rate of vehicles, and saves the tour cost of vehicles. At the same time, it saves the vehicle's cruising cost and verifies the feasibility of the method in this study by implementing a specific arithmetic example through MATLAB programming.

(2) The complex mathematical model is replaced by a simple mathematical model. Although there is a sacrifice in the accuracy of the model, the solution time of the problem is greatly shortened and the timeliness of the distribution system is ensured with simple solution method. Compared with other methods for LRP solution, the method in this study has a stronger overall solution effect.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request. The questionnaire data was acquired mainly through e-mail and paper filling out.

Conflicts of Interest

The authors declare that there no conflicts of interest.

Acknowledgments

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Research Article

Dynamic Equilibrium Strategy of Power Battery Closed-Loop Supply Chain Based on Stochastic Differential Game

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The industrialization of new energy vehicles has accelerated, and the recycling industry driven by a large number of retired power batteries has exploded rapidly. How to control and deal with decommissioned batteries and balance economic and environmental benefits has become an urgent problem to be solved. Considering the influence of uncertain interference factors, the dynamic equilibrium strategy of power battery closed-loop supply chain members composed of leading manufacturer, recycler, and cascade utilization enterprise was studied. (1) This paper describes the stochastic evolution process of cascade utilization effort level by using Ito process and constructs a stochastic differential game model of closed-loop supply chain dynamic system combined with cost-sharing coordination mechanism. (2) Based on the stochastic differential game theory, the optimal profit function of the participants is given, and the dynamic equilibrium strategy of each participant is obtained. (3) In order to grasp the statistical characteristics of cascade utilization effort level, the random evolution characteristics of cascade utilization effort level are revealed. (4) Combined with numerical example, the influence of relevant parameters on the dynamic system of power battery closed-loop supply chain is analyzed. The results found that with the increase of the proportion of manufacturer sharing the innovation cost of cascade utilization enterprise, the cascade utilization effort level will improve, the profits of cascade utilization enterprise and recycler will increase significantly, the profits of manufacturer will decrease slightly, and the overall profits of the supply chain will increase. The cost-sharing coordination mechanism is conducive to ensuring the steady development of the industry and effectively improving the utilization efficiency of industrial resources.

1. Introduction

At the United Nations General Assembly in 2020, China made a commitment to achieve carbon peak by 2030 and carbon neutralization by 2060. The discussion on the dual-carbon goal is heating up. Under this background, the new energy industry is developing rapidly [1], among which the most representative is the rapid development of new energy vehicles. With the rapid growth of production and sales of new energy vehicles, the output of power batteries has surged, and the earlier batch of power batteries put into use have ushered in the retirement period. According to relevant calculations, the recycling volume of power batteries will reach 120 GWh in 2025 [2]. The decommissioned power batteries are recycled and reused in whole package or disassembled and screened and then reused in other scenarios with low requirements on battery performance, including static scenarios of chemical energy storage such as power generation side, distribution side and power consumption side, and dynamic scenarios such as low-speed scooters and logistics vehicles. This kind of cascade utilization can effectively improve the utilization rate of resources, avoid large-scale idling and abandonment of power batteries before they have exerted their due effect, reduce the harm of harmful metal leakage in batteries to the environment and human body, and effectively protect the ecological environment. At present, due to the various specifications of decommissioned power batteries, the testing standards need

to be clarified, the industry value evaluation has not reached a consensus and for other reasons, the cascade utilization industry is still in the initial stage of extremely unstable development. How to effectively coordinate relevant subjects to balance economic and environmental benefits, and jointly undertake the important responsibility of promoting the improvement of the comprehensive utilization level of industrial resources has become one of the hot problems of common concern of all sectors of society.

At the macro level, in August 2021, the Ministry of Industry and Information Technology issued the "Administrative Measures for the Cascade Utilization of New Energy Vehicle Power Batteries," which put forward relevant requirements for the recycling and processing of cascade utilization enterprises and the design and production of cascade products. "Vehicle Power Battery Recycling and Utilization Cascade Utilization Part 3: Cascade Utilization Requirements," which was implemented in March 2022, regulates the remaining energy requirements, cycle life requirements, safety requirements, and other performance requirements of cascade utilization of retired batteries. It aims to ensure the highest cycle value and safety of cascade utilization products, and lay the foundation for the standardized and low-carbon cascade utilization of waste power batteries in China. In general, the cascade utilization of power batteries is gradually changing from "national recommended standards" to "national mandatory standards," and cascade utilization has become the general trend. At the micro level, there are many demonstration projects of cascade utilization at home and abroad. More than 100 enterprises at home and abroad have carried out application research and business model exploration related to cascade utilization. Domestically, there is a dual-state trend of technological upgrading from the single application of battery disassembly to the application of the whole module and scale expansion from the kilowatt level to the megawatt level. China Southern Power Grid build energy storage power stations, and used local and Beijing-Tianjin-Hebei electric vehicle retired power batteries in a centralized manner; State Grid Corporation of China (SGCC) build a kilowatt-level cascade energy storage project in Daxing, Beijing to cut peak and fill valleys; Jiangsu Nantong "industrial and commercial energy storage system based on cascade utilization of retired power batteries" and related enterprises led by iron tower company and Bi-Ya-Di also actively responded to promote the whole module and large-scale cascade utilization of power batteries. The foreign cascade utilization market mainly focuses on the user side and its economic benefits. For example, 4R Energy Company, General Electric Company, ABB (Asea Brown Boveri) Group, EnerDel Company and Bosch Group use retired power batteries for home energy storage, commercial energy storage or integrated wind and solar energy storage systems. In response to the management problems caused by the classification and parameter differences of batteries in the cascade utilization, new energy vehicle companies such as Fengfan, BAIC New Energy, Chehejia, and Weilai automobile have successively incorporated the "battery swap mode" into their new development strategies to explore opening up the entire value chain of cascade utilization, which has laid the foundation for the development of cascade utilization. With the promotion of the "battery swap mode" and the development of a circular economy, the cascade utilization will show a blowout trend in the future.

This paper takes the power battery closed-loop supply chain members composed of leading manufacturer, recycler, and cascade utilization enterprise as the study objects, aiming at studying the feedback dynamic balance strategy of power battery CLSC members by introducing the cascade utilization market and combining the cost-sharing coordination mechanism, in the case of considering the influence of uncertain factors. The contribution of this paper is to analyze the dynamic equilibrium strategy of members of power battery CLSC system with cascade utilization market by using stochastic differential game theory, in view of uncertain competitive environment and combined with the cost-sharing coordination mechanism, this paper provides a theoretical reference for the behavior decision-making of relevant enterprises, and is also a beneficial supplement and expansion of existing research in relevant fields, so as to help the efficient utilization of power batteries. In addition, at the practice implication level, combined with the actual situation, this paper provides ideas for improving and innovating the operation mechanism of internal coordination and interaction of power battery CLSC. The research results have important guiding significance for improving the utilization efficiency of industrial resources and reducing environmental pollution.

2. Literature Review

The research in related fields of power battery cascade utilization is also carried out with the emergence of practical problems. From the perspective of industry operation, Li et al. sorted out the relevant policies and standards for the cascade utilization of domestic retired power batteries, investigated and analyzed the effects and roles of relevant typical demonstration enterprises and pilot enterprises [2]. Yano pointed out that the recovery of retired power batteries does have great value through the actual investigation of the electric vehicle industry [3]. Heymans et al. adopted the life cycle evaluation system, and further considered the impact of power battery recycling on the manufacturing cost, and the results showed that the cost can be greatly saved [4]. From the perspective of power battery raw material supply, Ahmad et al. analyzed the global output and prices of metals such as nickel, cobalt, and lithium, and further elaborated on the hidden benefits of power battery recycling [5]. Harper et al. combed the current lithium battery recycling methods and policy measures, classified them and made predictions on future recycling trends [6]. Huang et al. first introduced the recycling products of power batteries and the development of recycling technology [7]. Zeng et al. analyzed the opportunities and challenges faced by the power battery recycling process [8]. Dong et al. sorted out the recycling modes of new energy vehicle power batteries at home and abroad, and compared and analyzed the development advantages of independent recycling of production enterprises,

industry alliances, and third-party recycling modes [9]. Mu et al. built a model based on the theory of system dynamics to analyze the recovery and utilization of power batteries of new energy vehicles [10]. Wang and Wu proposed an improvement strategy to optimize the recovery method and improve the recovery rate of scarce metals according to China's actual situation [11]. Under the background of circular economy, Hao et al. put forward countermeasures such as combination of forward and reverse, joint consultation and joint construction for recycling reverse logistics [12].

From the perspective of micro-operation, the research on the CLSC (closed-loop supply chain) of power batteries should include multi-cycle and multi-level recycling [13, 14], dual-channel recycling [15, 16], and supply chain coordination. Although literature [13, 14] considered multiple uncertain production processes, it did not consider the impact of the internal coordination mechanism of the supply chain. Literature [15, 16] studied the contract coordination under different recovery modes, but they were all based on static vision and did not study the dynamic game process of the supply chain in depth. Natkunarajah et al. first predicted the sales volume of electric vehicles, and analyzed the recovery rate of the power batteries in different scenarios based on the life cycle of the power batteries, laying the foundation for further discussion on the power batteries recovery mode. Although this study explored different recycling modes, it did not include the cascade utilization market in the research process, which has certain limitations [17]. Yang et al. combined the two recycling methods of "cascade utilization" and "regenerative dismantling" into the reverse supply chain of power batteries, built a reverse supply chain model, and studied the recycling mode of used power batteries for new energy vehicles. However, this study did not consider the impact of uncertainty factors on stakeholders' decision-making [18]. Aiming at maximizing the profit of the supply chain, Lin et al. analyzed the influence of different battery quality, processing cost and other factors on the profitability of the supply chain, but the study did not consider the internal coordination of the supply chain [19]. Heydari et al. constructed a secondary reverse supply chain of a single manufacturer and retailer, increased consumers' willingness to recycle through quantity discounts and payment fees, and designed cost contracts to achieve CLSC coordination [20]. Zhang and Chen took the third-party recyclers whose power battery recycling is the core business as the main body of recycling, and combine the characteristics of the remanufacturing, cascade utilization, and dismantling and recycling of waste power batteries to build a CLSC with multiple recycling channels, and studied the strategy and coordination of decision-makers [21]. Both of them deeply studied the internal coordination problem of supply chain, but they both carried out research from static vision, without considering the dynamic decision-making process of supply chain under the influence of random factor disturbance. Han et al. studied the impact of the "trade-in" strategy in the Cournot duopoly competitive secondary CLSC on the competitiveness of enterprises and product market share, but did not consider the coordinated decision-making of internal agents in the supply chain [22]. Hoyer et al. established a linear analysis model for the CLSC of lithium power batteries to optimally select multiple given production and recycling schemes, but did not consider the important role of the cascade utilization market in the entire recycling process [23]. For remanufacturing cost and recovery rate, Wang and Deng used a dynamic game to compare the optimal decision-making of recycling and remanufacturing supply chain members in three situations, but ignored the influence of random factors [24]. Guo et al. introduced the valuable metal recycling station to build a supply chain model and analyzed the effectiveness of the revenue sharing contract, but further research from a dynamic perspective is needed [25]. Based on the third-party remanufacturing model considering outsourcing and authorization, Zhang et al. constructed a competitive CLSC of duopoly manufacturers and remanufacturers, and studied the strategic trends of each subject [26]. Guan and Hou considered the internal and external coordination of the supply chain under a certain environment, and analyzed the equilibrium decision-making problem of enterprises in the power battery CLSC which introduced the cascade utilization market [27]. However, the impact of uncertain factors on the system needs to be further explored.

To sum up, the cascade utilization of power batteries is still in the early stage of development. At present, the research on the power battery CLSC mainly focuses on the interpretation of the cascade utilization policy, the battery recycling mode, the determination of recycling channels, and the discussion of the CLSC coordination mechanism, both are static and deterministic methodological research, all of them belong to the research on the equilibrium strategy of the decision-making subject in a certain environment, without taking into account the influence of various random disturbances on decision-making subjects in the decision-making process. In essence, the operation process of CLSC system will be affected by a large number of uncontrollable factors [28], such as the personality and emotion of decision-makers, the ability to obtain information, the political and cultural environment where the decision-making subject is located, industry background and humanistic factors, and the evolution process of the system state is difficult to predict. Therefore, in view of the uncertainty of internal and external interference factors in the system, studying the internal coordination mechanism of power battery CLSC and the dynamic equilibrium strategy of decision-makers have become an important field of current research, which also has important theoretical and practical guiding significance for improving the efficiency of comprehensive utilization of resources.

Considering the influence of uncertain factors, this paper introduces cascade utilization market and combines the cost-sharing coordination mechanism to study the feedback dynamic equilibrium strategy of the power battery CLSC members. The structure of the study is arranged as follows: first, the Ito process is used to describe the stochastic evolution process of the cascade utilization effort level, and the objective function of each participant's pursuit of profit maximization is constructed, and the stochastic differential

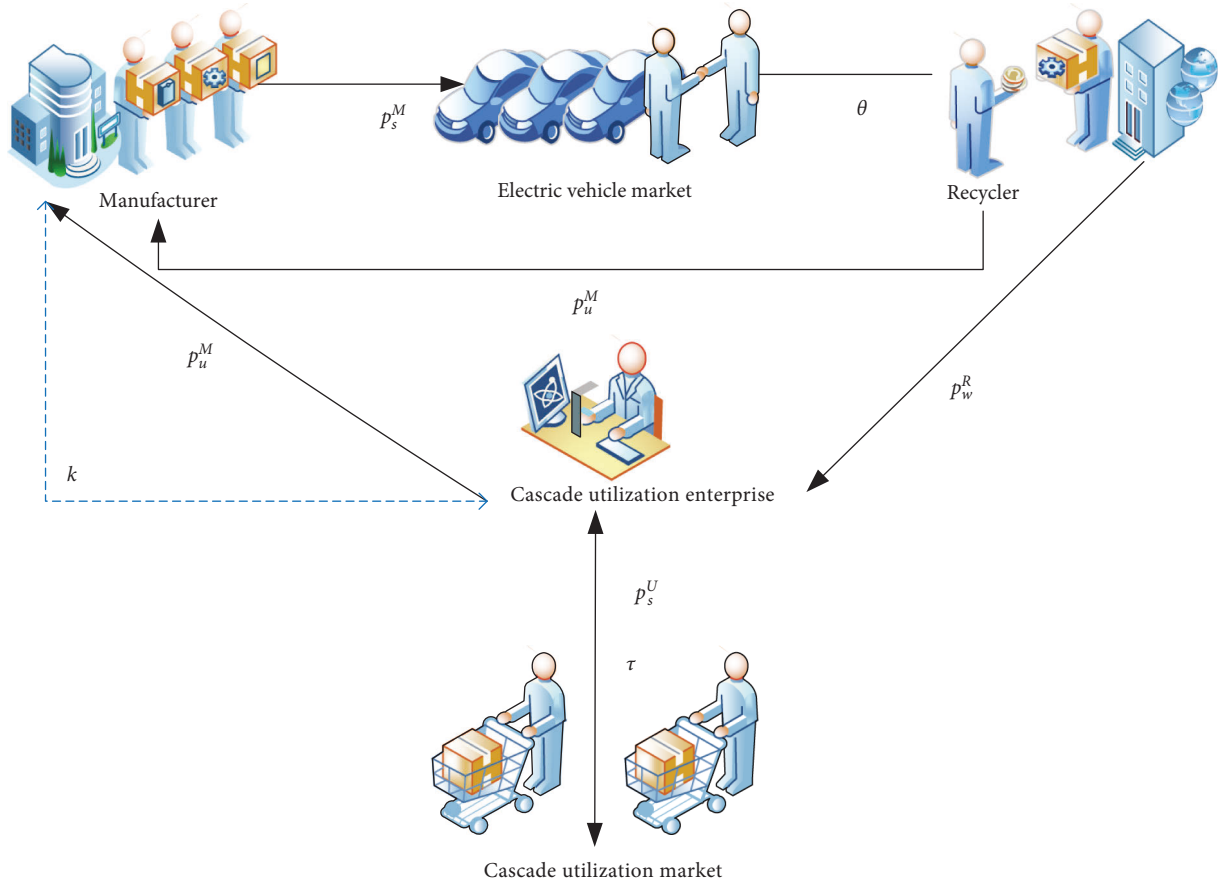

Figure 1: Power battery CLSC model considering cascade utilization.

game model of the CLSC dynamic system is constructed by combining the cost-sharing coordination mechanism; secondly, the stochastic differential game theory and continuous-time dynamic programming theory are used to solve the dynamic equilibrium control strategy of each participant; next, in order to reveal the dynamic evolution characteristics of the random cascade utilization effort level, the stability of the expectation and variance of the random cascade utilization effort level is analyzed; finally, combined with a numerical example, the sensitivity of the relevant parameters is analyzed and verified, and the influence of the relevant parameters on the dynamic system of the power battery CLSC is determined.

3. Stochastic Differential Game Model

3.1. Problem Description. In this paper, a CLSC dynamic system of power battery is constructed, which is composed of manufacturer, recycler, and cascade utilization enterprise. Among them, the manufacturer is in a leading position in the system, responsible for the production and sales (at price p_s^M) of the power battery for electric vehicles, and at the same time, in order to promote the healthy development of the industry and promote the recycling of resources, the manufacturer bears the innovation cost of the cascade utilization of retired batteries (at cost-sharing ratio k). The recycler recycles, sorts, and processes the retired power batteries in the market (at recycling rate θ), and makes profits by selling the waste batteries with high-energy density to the cascade utilization enterprise (at wholesale price p_w^R), and hands over low-energy density waste batteries to manufacturers for remanufacturing (at uniform recycle price p_u^M); Facing the cascade utilization market, cascade utilization enterprise processes and reorganizes the purchased high-energy density batteries into cascade utilization products to sell (at price p_s^U), and is responsible for recycling all the discarded batteries after cascade utilization and handing them over to the manufacturer for remanufacturing (at uniform recycle price p_u^M). Figure 1 describes the basic model of power battery CLSC.

3.2. Variable Description and Model Assumption. In order to simplify the analysis and build the model, the symbols and meanings of variables used in this paper are shown in Table 1.

Based on the product supply chain and resource flow trajectory of the real power battery industry, combined with the basic model and reference to existing studies, the model assumptions are made as follows:

Assumption 1. The demand function of the electric vehicle market for new power batteries [29] is $L(p_s^M(t)) = a - bp_s^M(t)$, and $c_r^M < c_m^M < p_s^M(t)$.

Table 1: Description of variables.

Variable	Description	Variable	Description
$p_s^M(t)$	Unit sales price of new power battery	$\tau(t)$	Cascade utilization effort level
c_m^M	Unit production cost of new power battery	a	Electric vehicle market's market size
c_r^M	Unit reproduction cost of waste power battery	b	Electric vehicle market's price sensitivity coefficient
$\theta(t)$	Recovery rate of waste battery	f	Cascade utilization market's market size
i	Unit price of retired battery recovered by recycler	g	Cascade utilization market's price sensitivity coefficient
$p_w^R(t)$	Unit wholesale price at which recycler sells high-energy density battery	$A(t)$	Cascade utilization effort utility
$p_u^M(t)$	Uniform price for manufacturer to recycle waste battery	δ	Cascade utilization effort utility cost coefficient
$p_s^U(t)$	Unit sales price of cascade utilization battery sold by cascade utilization enterprise	α	Influence coefficient of cascade utilization effort utility on effort level
c_r^U	Unit recovery cost of cascade utilization enterprise	β	Attenuation coefficient of cascade utilization effort level
k	Cascade utilization effort utility cost-sharing coefficient	λ	Discount rate
$\mathrm{d}z(t)$	Standard wiener process	$\sigma(\tau(t))$	Volatility of cascade utilization effort level
$\Delta = c_m^M - c_r^M$	Unit cost-saving of remanufactured products produced by manufacturer	B	Recovery difficulty coefficient

Assumption 2. The number of retired power batteries recovered by recyclers is $\theta(t)L(p_s^M(t)) = \theta(t)(a - bp_s^M(t))$. The recovery fixed cost [30] is $1/2B\theta(t)^2$.

Assumption 3. The demand function for high-energy-density waste batteries in the cascade utilization market [31] is: $L(p_s^U(t), \tau(t)) = (f - gp_s^U(t))\tau(t)$, and $p_w^R(t) < p_s^U(t) < p_s^M(t)$. cascade utilization effort utility cost [32] is $1/2\delta A(t)^2$. The cascade utilization market is different from the ordinary reuse market, and its demand is independent of the demand for new power batteries in the electric vehicle market. The cascade utilization enterprise is responsible for recycling all used batteries after cascade utilization (at unit recovery cost c_r^U).

Assumption 4. As an emerging market, the scale of the cascade utilization market is still small, and the number of high-energy-density waste batteries recovered and sorted by recycler can fully meet the demand of the cascade utilization market.

Assumption 5. Manufacturer with remanufacturing production lines recycle and remanufacture all used batteries at a uniform price $p_u^M(t)$, and $0 < i < p_u^M(t) < p_w^R(t)$, $p_u^M(t) < \Delta$. The power batteries produced with recycled materials and new materials have the same quality and characteristics, that is, there is no difference in sales price and consumer preference.

Assumption 6. In the model, the forward electric vehicle market sales and the reverse decommissioned battery recycling, cascade utilization, and remanufacturing are all completed in one cycle. That is, the model only considers the cycle process of the power battery resource in a single cycle.

Assumption 7. In a single cycle, each game participant discounts its future earnings at a fixed discount rate $\lambda > 0$.

3.3. Dynamic Model of Cascade Utilization Effort Level. $\tau(t)$ is the effort made by cascade utilization enterprises to improve the level of cascade utilization, such as developing high-tech and using new media for publicity. In fact, the level of cascade utilization effort is affected by many factors, such as effort effectiveness, consumers' awareness of environmental protection, and other uncontrollable factors. Similar to the advertising capital model [33], it is assumed that the utility of cascade utilization effort affects the evolutionary drift rate of cascade utilization effort level, that is, $\mathrm{d}\tau(t) = \alpha A(t)\mathrm{d}t$. In addition, it is assumed that the decline of consumers' awareness of environmental protection and the aging of relevant facilities affect the cascade utilization effort level, which decreases exponentially at a rate $\dot{\tau}(t)/\tau(t) = -\beta$, that is, $\mathrm{d}\tau(t) = -\beta n(t)\mathrm{d}t$. In addition, similar to Prasad and Sethi [34], it is assumed that the cascade utilization process is influenced by the standard Wiener process, and the volatility of the cascade utilization process is directly proportional to the square root of the cascade utilization effort level, that is, $\mathrm{d}\tau(t) = \sigma\sqrt{\tau(t)}\mathrm{d}z$. Based on the above factors, the evolution process of cascade utilization effort level is described as the Ito process given by

$$\mathrm{d}\tau(t) = [\alpha A(t) - \beta\tau(t)]\mathrm{d}t + \sigma\sqrt{\tau(t)}dz(t). \quad (1)$$

3.4. Fundamental Relation Expression and Stochastic Differential Game Model. Based on the cost-sharing mechanism, the goal of supply chain members is all to maximize profits in the planned period. The manufacturer's income comes from the sales of new power batteries, and its cost comes from the cost of recycling power batteries and sharing part of the utility cost of cascade utilization enterprise. The revenue of the recycler comes from selling recycled power batteries, and its cost is the fixed cost of recycling. The revenue of the cascade utilization enterprise comes from selling cascade utilization products to the cascade utilization market, and its

cost is the effort utility cost of cascade utilization. For the sake of brevity of the model, the time variable t will be omitted in the following statement.

To sum up, the profit target function of the manufacturer is given by

$$\max \pi^M = E\left\{\int_0^\infty e^{-\lambda t}\left[\left(p_s^M - c_m^M\right)\left(a - bp_s^M\right) + \left(\Delta - p_u^M\right)\left(\theta\left(a - bp_s^M\right)\right) - k\frac{1}{2}\delta A^2\right]dt\right\}. \tag{2}$$

The profit target function of the recycler is given by

$$\max \pi^R = E\left\{\int_0^\infty e^{-\lambda t}\left[\left(p_w^R(t) - i\right)\left(f - gp_s^U\right)\tau + \left(p_u^M - i\right)\left(\theta\left(a - bp_s^M\right) - \left(f - gp_s^U\right)\tau\right) - \frac{1}{2}B\theta^2\right]dt\right\}. \tag{3}$$

The profit target function of the cascade utilization enterprise is given by

$$\max \pi^U = E\left\{\int_0^\infty e^{-\lambda t}\left[\left(p_s^U - c_r^U + p_u^M - p_w^R\right)\left(f - gp_s^U\right)\tau - (1-k)\frac{1}{2}\delta A^2\right]dt\right\}. \tag{4}$$

Under the power structure in which the manufacturer is the system leader and the recycler and cascade utilization enterprise are the system followers, the Stackelberg stochastic differential game model of power battery CLSC system equilibrium strategy is summarized as given by

$$\begin{cases} \max\limits_{\left[p_s^M, p_u^M\right]} \pi^M\left[p_s^M, p_u^M, \theta, p_w^R, p_s^U, A\right], \\ \quad \text{s.} \begin{cases} \max\limits_{\left[p_w^R, \theta\right]} \pi^R\left[p_s^M, p_u^M, \theta, p_w^R, p_s^U, A\right], \\ \max\limits_{\left[p_s^U, A\right]} \pi^U\left[p_s^M, p_u^M, \theta, p_w^R, p_s^U, A\right], \end{cases} \\ d\tau(t) = [\alpha A(t) - \beta\tau(t)]dt + \sigma\sqrt{\tau(t)}\,dz. \end{cases} \tag{5}$$

4. Dynamic Equilibrium Strategy

In order to obtain the dynamic equilibrium strategy of power battery CLSC system, first, the reverse induction method was used to obtain the sales price and its own effort utility of cascade utilization enterprise, and then the recovery rate of recycler and the wholesale price of high-energy density waste batteries sold to cascade utilization enterprise are obtained based on the response strategy of cascade utilization enterprise; Finally, based on the response strategies of recycler and cascade utilization enterprise, the manufacturer's sales price of new power batteries and the unified price of recycled waste batteries are obtained.

Proposition 1. *The response strategy of cascade utilization enterprise, sales price and their own effort utility, is given by*

$$p_s^U(t) = \frac{3f + gc_r^U}{4g},$$
$$A = \frac{\alpha V_\tau^U}{\delta(1-k)}. \tag{6}$$

Proof. The HJB (Hamilton-Jacobian-Bellman) partial differential equation that the cascade utilization enterprise equilibrium strategy should satisfy can be obtained by using the continuous dynamic programming theory, as given by

$$\lambda V^U(\tau) - \frac{1}{2}\sigma^2 \tau V^U_{\tau\tau}(\tau) = \max\left\{\left(p_s^U - c_r^U + p_u^M - p_w^R\right)\left(f - g p_s^U\right)\tau - (1-k)\frac{1}{2}\delta A^2 + V^U_\tau(\tau)(\alpha A - \beta\tau)\right\}, \tag{7}$$

where $V^U(\tau)$ is the optimal value function of the cascade utilization enterprise, and $V^U_\tau(\tau), V^U_{\tau\tau}(\tau)$ is the first and second order partial derivatives of the cascade utilization effort level. In order to ensure the existence of the optimal solution of the model, it is assumed that $2B - b(\Delta - i)^2 > 0$.

Solving the optimization of the right-hand side of equation (7), we obtain

$$\begin{cases} \dfrac{\partial \lambda\ V^U(\tau)}{\partial p_s^U(t)} = f\tau - p_u^M g\tau + p_w^R g\tau - 2p_s^U g\tau + g c_r^U \tau, \\ \dfrac{\partial \lambda\ V^U(\tau)}{\partial A} = -A\delta(1-k) + \alpha V^U_\tau(\tau). \end{cases} \tag{8}$$

The response strategy of cascade utilization enterprise is obtained, as given by equation (9), by combining the formulas given in

$$\begin{cases} p_s^U(t) = \dfrac{3f + g c_r^U}{4g}, \\ A = \dfrac{\alpha V^U_\tau}{\delta(1-k)}. \end{cases} \tag{9}$$

□

Proposition 2. *The response strategy of recycler, the recovery rate, and the wholesale price of high-energy density waste batteries sold to cascade utilization enterprise, expression is given by*

$$\begin{cases} \theta = \dfrac{\left(p_u^M(t) - i\right)\left(a - b p_s^M(t)\right)}{A}, \\ p_w^R(t) = \dfrac{f - g c_r^U}{2g} + p_u^M(t). \end{cases} \tag{10}$$

Proof. The HJB partial differential equation that the recycler equilibrium strategy should satisfy can be obtained by using the continuous dynamic programming theory.

$$\lambda V^R(\tau) - \frac{1}{2}\sigma^2 \tau V^R_{\tau\tau}(\tau) = \max\left\{\left(p_w^R - i\right)\left(f - g p_s^U\right)\tau + \left(p_u^M - i\right)\left(\theta\left(a - b p_s^M\right) - \left(f - g p_s^U\right)\tau\right) - \frac{1}{2}B\theta^2 + V^R_\tau(\tau)(\alpha A - \beta\tau)\right\}, \tag{11}$$

where $V^R(\tau)$ is the optimal value function of the recycler, and $V^R_\tau(\tau), V^R_{\tau\tau}(\tau)$ are the first and second order partial derivatives of the cascade utilization effort level.

To obtain the reaction strategy of the recycler, equation (9) is brought into equation (11), and the optimization of its right-hand side is solved, as given by

$$\begin{cases} \dfrac{\partial \lambda V^R(\tau)}{\partial p_w^R(t)} = \left(f - g p_s^U\right)\tau - \dfrac{1}{2}ng\left(p_w^R - p_u^M\right), \\ \dfrac{\partial \lambda V^R(\tau)}{\partial \theta} = \left(p_u^M - i\right)\left(a - b p_s^M\right) - B\theta. \end{cases} \tag{12}$$

The response strategy of recycler, as given by equation (13), is obtained by combining the formulas given in

$$\begin{cases} \theta = \dfrac{\left(p_u^M - i\right)\left(a - b p_s^M\right)}{B}, \\ p_w^R = \dfrac{f - g c_r^U}{2g} + p_u^M. \end{cases} \tag{13}$$

□

Proposition 3. *The optimal strategy of manufacturer, sales price of new power batteries, and the unified price of recycled waste batteries, expression is given by*

$$\begin{cases} p_s^{M*} = \dfrac{2B\left(a + b c_m^M\right) - ab(\Delta - i)^2}{4Bb - b^2(\Delta - i)^2}, \\ p_u^{M*} = \dfrac{(\Delta + i)}{2}. \end{cases} \tag{14}$$

Proof. The HJB partial differential equation that the manufacturer equilibrium strategy should satisfy can be obtained by using the continuous dynamic programming theory, as given by

$$\lambda V^M(\tau) - \frac{1}{2}\sigma^2\tau V^M_{\tau\tau}(\tau) = \max\left\{\begin{array}{c}\left(p_s^M - c_m^M\right)\left(a - bp_s^M\right) + \left(\Delta - p_u^M\right)\left(\theta\left(a - bp_s^M\right)\right) \\ -k\frac{1}{2}\delta A^2 + V^M_\tau(\tau)(\alpha A - \beta\tau)\end{array}\right\}, \tag{15}$$

where $V^M(\tau)$ is the optimal value function of the recycler, and $V^M_\tau(\tau)V^M_{\tau\tau}(\tau)$ are the first and second order partial derivatives of the cascade utilization effort level.

To obtain the optimal strategy of manufacturer, equations (9) and (13) is brought into equation (15), and the optimization of its right-hand side is solved, as given by

$$\begin{cases}\dfrac{\partial\lambda V^M(\tau)}{\partial p_s^M} = \left(a - 2bp_s^M\right) + bc_m^M + \left(\Delta - p_u^M\right)\theta(-b) + \left(\Delta - p_u^M\right)\left(a - bp_s^M\right)\dfrac{\left(p_u^M - i\right)(-b)}{B}, \\ \dfrac{\partial\lambda V^M(\tau)}{\partial p_u^M} = -\theta\left(a - bp_s^M\right) + \left(\Delta - p_u^M\right)\left(a - bp_s^M\right)\dfrac{\left(a - bp_s^M\right)}{B}.\end{cases} \tag{16}$$

The optimal strategy of manufacturer, as given by equation (17), is obtained by combining the formulas given in

$$\begin{cases} p_s^{M*} = \dfrac{2B\left(a + bc_m^M\right) - ab(\Delta - i)^2}{4Bb - b^2(\Delta - i)^2}, \\ p_u^{M*} = \dfrac{(\Delta + i)}{2}. \end{cases} \tag{17}$$

□

Proposition 4. *The dynamic equilibrium strategy of power battery CLSC system is given by*

$$\begin{aligned} p_s^{M*} &= \frac{2B\left(a + bc_m^M\right) - ab(\Delta - i)^2}{4Bb - b^2(\Delta - i)^2}, \\ p_u^{M*} &= \frac{(\Delta + i)}{2}, \\ \theta^* &= \frac{\left(a - bc_m^M\right)(\Delta - i)}{4B - b(\Delta - h)^2}, \\ p_w^{R*} &= \frac{f + g\left(\Delta - c_r^U + i\right)}{2g}, \\ p_s^{U*} &= \frac{3f + gc_r^U}{4g}, \\ A^* &= \frac{\alpha V^U_\tau}{\delta(1 - k)}. \end{aligned} \tag{18}$$

Proof. Taking (18) into the recycler's reaction strategy (13), the optimal strategy of recycler, θ^*, p_w^{R*}, can be obtained. For the sake of completeness, Theorem 1 also lists the optimal strategy of cascade utilization enterprise, p_s^{U*}, A^*.

To obtain the dynamic equilibrium strategy of the power battery CLSC system using Proposition 4, it is necessary to determine the specific form of the optimal value function of the manufacturer, cascade utilization enterprise, and recycler in Proposition 4. In fact, this will face the problem of partial differential equation solving. Therefore, the specific solution process of the optimal value function is given by Proposition 5. □

Proposition 5. *The optimal value function of manufacturer, cascade utilization enterprise, and recycler is given by*

$$\begin{cases} V^M(\tau)^* = x_1^*\tau^2 + x_2^*\tau + x_3^*, \\ V^R(\tau)^* = y_1^*\tau^2 + y_2^*\tau + y_3^*, \\ V^U(\tau)^* = j_1^*\tau^2 + j_2^*\tau + j_3^*, \end{cases} \tag{19}$$

where

$$\begin{cases} j_1^* = -\dfrac{\delta(1-k)(\lambda+2\beta)}{2\alpha^2}, \\ j_2^* = \dfrac{\alpha^2\left(f-gc_r^U\right)-8g\delta\sigma^2(\lambda+2\beta)(1-k)}{16g\alpha^2(2\lambda+3\delta)}, \\ j_3^* = \dfrac{\left[\alpha^2(f-gc_1)-8g\delta\sigma^2(\lambda+2\beta)(1-k)\right]^2}{512\delta\lambda g^2\alpha^2(2\lambda+3\beta)^2(1-k)}, \end{cases} \begin{cases} y_1^* = 0, \\ y_2^* = \dfrac{\left(f-gc_r^U\right)^2}{8g(2\lambda+3\beta)}, \\ y_3^* = \dfrac{\left(f-gc_r^U\right)^2\left[\alpha^2\left(f-gc_r^U\right)-8g\delta\sigma^2(\lambda+2\beta)(1-k)\right]}{128\delta\lambda g^2(2\lambda+3\beta)^2(1-k)} + \dfrac{B\left(a-bc_m^M\right)^2(\Delta-i)^2}{2\lambda\left[4B-b(\Delta-i)^2\right]^2}, \end{cases} \begin{cases} x_1^* = -\dfrac{\delta k(\lambda+2\beta)}{6\alpha^2}, \\ x_2^* = \dfrac{2k(\lambda+2\beta)j_2^*}{3(2\lambda+3\beta)(1-\mu_m)} + \dfrac{\sigma^2 x_1^*}{(2\lambda+3\beta)}, \\ x_3^* = \dfrac{B\left(a-bc_m^M\right)^2}{\lambda\left[4Bb-b^2(\Delta-h)^2\right]} + \dfrac{\alpha^2 j_2^* x_2^*}{\delta\lambda(1-k)} - \dfrac{\alpha^2 k j_2^{*2}}{2\delta\lambda(1-k)^2}. \end{cases} \tag{20}$$

Proof. To determine the profit optimal value function of manufacturer, cascade utilization enterprise, and recycler, the system dynamic equilibrium strategy in Proposition 4 is brought into equations (7), (11), and (15), and the partial differential equations that should be satisfied by the optimal value functions of manufacturer, cascade utilization enterprise, and recycler are obtained.

$$\lambda V^M(\tau) = \frac{B\left(a-bc_m^M\right)^2}{\left[4Bb-b^2(\Delta-i)^2\right]} - \frac{\alpha^2 k V_\tau^U(\tau)^2}{2\delta(1-k)^2} + \frac{\alpha^2 V_\tau^U(\tau)V_\tau^M(\tau)}{\delta(1-k)} - \delta V_\tau^M(\tau)\tau + \frac{1}{2}\sigma^2 V_{\tau\tau}^M(\tau)\tau, \tag{21}$$

$$\lambda V^R(\tau) = \frac{\left[f-gc_1\right]^2\tau}{8g} + \frac{B\left(a-bc_m^M\right)^2(\Delta-i)^2}{2\left[4B-b(\Delta-i)^2\right]^2} + \frac{\alpha^2 V_\tau^U(\tau)V_\tau^R(\tau)}{\delta\left(1-\mu_m\right)} - \beta V_\tau^R(\tau)\tau + \frac{1}{2}\sigma^2 V_{\tau\tau}^R(\tau)\tau, \tag{22}$$

$$\lambda V^U(\tau) = \frac{\left[f-gc_1\right]^2\tau}{16g} + \frac{\alpha^2 V_\tau^U(\tau)^2}{2\delta(1-k)} - \beta V_\tau^U(\tau)\tau + \frac{1}{2}\sigma^2 V_{\tau\tau}^U(\tau)\tau. \tag{23}$$

In order to obtain the solutions of the partial differential equations (15) to (17), try the following optimal value function form of manufacturer, cascade utilization enterprise, and recycler with undetermined coefficients.

$$\begin{cases} V^M(\tau) = x_1\tau^2 + x_2\tau + x_3, \\ V^R(\tau) = y_1\tau^2 + y_2\tau + y_3, \\ V^U(\tau) = j_1\tau^2 + j_2\tau + j_3. \end{cases} \tag{24}$$

The first and second derivatives are given by

$$\begin{cases} V_\tau^M(\tau) = 2x_1\tau + x_2 \;\; V_{\tau\tau}^M(\tau) = 2x_1, \\ V_\tau^R(\tau) = 2y_1\tau + y_2 \;\; V_{\tau\tau}^R(\tau) = 2y_1, \\ V_\tau^U(\tau) = 2j_1\tau + j_2 \;\; V_{\tau\tau}^U(\tau) = 2j_1. \end{cases} \tag{25}$$

Substituting equations (24) and (25) into equations (21) to (23), and use the identity relationship to obtain the nonlinear equations that the undetermined coefficient should satisfy

$$\begin{cases} \lambda x_1 = \dfrac{4\alpha^2 j_1 x_1}{o\delta(1-k)} - \dfrac{4\alpha^2 k j_1^2}{2\delta(1-k)^2} - 2\beta x_1, \\ \lambda x_2 = \dfrac{2\alpha^2 j_1 x_2}{\delta(1-k)} + \dfrac{2\alpha^2 j_2 x_1}{\delta(1-k)} - \dfrac{4\alpha^2 k j_1 j_2}{2\delta(1-k)^2} - \beta x_2 + \sigma^2 x_1, \\ \lambda x_3 = \dfrac{B\left(a-bc_m^M\right)^2}{4Bb-b^2(\Delta-h)^2} + \dfrac{\alpha^2 x_2 j_2}{\delta(1-k)} - \dfrac{\alpha^2 k j_2^2}{2\delta(1-k)^2}, \end{cases} \tag{26}$$

$$\begin{cases} \lambda y_1 = \dfrac{4\alpha^2 j_1 y_1}{\delta(1-k)} - 2\beta y_1, \\ \lambda y_2 = \dfrac{\left[f-gc_1\right]^2}{8g} + \dfrac{2\alpha^2 j_1 y_2}{\delta(1-k)} + \dfrac{2\alpha^2 j_2 y_1}{\delta(1-k)} - \beta y_2 + \sigma^2 y_1, \\ \lambda y_3 = \dfrac{B\left(a-bc_m^M\right)^2(\Delta-i)^2}{2\left[4Bb-b^2(\Delta-i)^2\right]^2} + \dfrac{\alpha^2 j_2 y_2}{\delta(1-k)}, \end{cases} \tag{27}$$

$$\begin{cases} \lambda j_1 = -\dfrac{4\alpha^2 j_1^2}{2\delta(1-k)} - 2\beta j_1, \\ \lambda j_2 = \dfrac{[f - gc_1]^2}{16g} + \dfrac{4\alpha^2 j_1 j_2}{2\delta(1-k)} - \beta j_2 + \sigma^2 j_1, \\ \lambda j_3 = \dfrac{\alpha^2 j_2^2}{2\delta(1-k)}. \end{cases} \tag{28}$$

Next, the undetermined coefficients are obtained by solving equations (26) to (28) of the nonlinear equations. The process is: first calculate j_1^*, j_2^*, j_3^*, then calculate y_1^*, y_2^*, y_3^*, and finally determine x_1^*, x_2^*, x_3^*. Hence, Proposition 5 is proved. □

5. Dynamic Evolution Characteristics of Cascade Utilization Effort Level

Since the effort level of cascade utilization is affected by the random disturbance of uncontrollable factors in reality, whether the stochastic evolution characteristics of cascade utilization effort level can be grasped and what kind of evolution characteristics it has. This section discussed the expectation and variance of cascade utilization effort level and the stability of the expectation and variance of cascade utilization effort level.

Proposition 6. *Expectation and variance of random cascade utilization effort level, and when $t \longrightarrow \infty$, the expectation and variance of cascade utilization effort level are given by*

$$\begin{aligned} E(\tau) &= e^{Qt}\left(\tau_0 + NQ^{-1} - NQ^{-1}e^{-Qt}\right), \\ \lim_{t\longrightarrow\infty} E(\tau) &= -NQ^{-1}, \\ D(\tau) &= e^{2Qt}\left(\tau_0 + NQ^{-1} - NQ^{-1}e^{-Qt}\right)^2 - e^{2Qt}\begin{pmatrix} \tau_0^2 + (Q\tau_0 + N)\left(2N + \sigma^2\right)Q^{-2} - \\ N\left(2N + \sigma^2\right)\left(2Q^2\right)^{-1} \end{pmatrix} \\ &\quad - e^{Qt}(Q\tau_0 + N)\left(2N + \sigma^2\right)Q^{-2} + N\left(2N + \sigma^2\right)\left(2Q^2\right)^{-1}, \\ \lim_{t\longrightarrow\infty} D(\tau) &= N\left(2N + \sigma^2\right)\left(2Q^2\right)^{-1} - N^2Q^{-2}, \end{aligned} \tag{29}$$

where $Q = -(3\beta + \lambda)$, $N = \alpha^2 j_2^* [\delta(1-k)]^{-1}$.

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Proof. Bringing the optimal effort utility of the cascade utilization enterprise in Proposition 4 and the optimal value function of the cascade utilization enterprise in Proposition 5 into equation (1), the dynamic model of cascade utilization effort level, and the Ito process of the change of cascade utilization effort level are obtained.

$$\mathrm{d}\tau = \left[\left(\frac{2\alpha^2 j_1^*}{\delta(1-k)} - \beta\right)\tau + \frac{\alpha^2 j_2^*}{\delta(1-k)}\right]\mathrm{d}t + \sigma\sqrt{\tau(t)}dz\ , \tau(0) = \tau_0. \tag{30}$$

Assuming $Q = -(3\beta + \lambda)$, $N = \alpha^2 j_2^* [\delta(1-k)]^{-1}$, equation (30) can be written as

$$\mathrm{d}\tau = [Q\tau + N]\mathrm{d}t + \sigma\sqrt{\tau(t)}\mathrm{d}z, \tau(0) = \tau_0. \tag{31}$$

Solving the differential equation (31), we obtain

$$E(\tau) = e^{Qt}\left(\tau_0 + NQ^{-1} - NQ^{-1}e^{-Qt}\right). \tag{32}$$

Due to $Q < 0$, when $t \longrightarrow \infty$,

$$\lim_{t\longrightarrow\infty} E(\tau) = -NQ^{-1}. \tag{33}$$

The random change process of the square of cascade utilization effort level is obtained by using ITO lemma.

$$\mathrm{d}\tau^2 = \left[2Q\tau^2 + (2N + \sigma)^2\tau\right]\mathrm{d}t + 2\sigma\tau\sqrt{\tau(t)}\mathrm{d}Z(t), \tau^2(0) = \tau_0^2. \tag{34}$$

Integrating both sides of the equation (34) and using the boundary conditions, we obtain

$$\tau^2 = \tau_0^2 + \int_0^t \left(2Q\tau^2 + \left(2N + \sigma^2\right)\tau\right)\mathrm{d}t + \int_0^t 2\tau\sigma\sqrt{\tau(t)}\mathrm{d}Z(t). \tag{35}$$

Taking the expectation on both sides, and using the zero-expectation property of Wiener process, we obtain

$$E\left(\tau^2\right) = \tau_0^2 + \int_0^t \left(2QE\left(\tau^2\right) + \left(2N + \sigma^2\right)E(\tau)\right)\mathrm{d}t. \tag{36}$$

Substituting equation (25) into equation (29), we obtain

$$E\left(\tau^2\right) = e^{2Qt}\left(\tau_0^2 + \frac{\left(Q\tau_0 + N\right)\left(2N + \sigma^2\right)}{Q^2} - \frac{N\left(2N + \delta^2\right)}{2Q^2}\right) - e^{Qt}\frac{\left(Q\tau_0 + N\right)\left(2N + \sigma^2\right)}{Q^2} + \frac{N\left(2N + \sigma^2\right)}{2Q^2}. \tag{37}$$

Then, the variance of cascade utilization effort level is obtained by using the relationship $D(\tau) = E(\tau^2) - [E(\tau)]^2$. Due to $Q < 0$, when $t \longrightarrow \infty$,

$$\lim_{t\longrightarrow\infty} E\left(\tau^2\right) = \frac{N\left(2N + \sigma^2\right)}{\left(2Q^2\right)}. \tag{38}$$

From equations (33) and (38), we obtain $\lim_{t\longrightarrow\infty} D(\tau) = \lim_{t\longrightarrow\infty} E(\tau^2) - \lim_{t\longrightarrow\infty} [E(\tau)]^2 = N(2N + \sigma^2)/(2Q^2) - N^2/Q^2$. In particular, in the absence of random interference ($\sigma = 0$), $\lim_{t\longrightarrow\infty} E(\tau^2) = N^2/Q^2$, therefore $D(\tau) = E(\tau^2) - [E(\tau)]^2 = 0$. Hence, Proposition 6 is proved. □

6. Sensitivity Analysis of Parameters

Analyze the impact of the price sensitivity of the cascade utilization market g, the recycling price of recycler i, and the cost-saving of manufacturer in producing remanufactured products Δ on the sales price p_s^U and effort utility A of cascade utilization enterprise, the wholesale price p_w^R of selling high-energy density batteries and the recovery rate θ of recycler, the sales price of new power batteries p_s^M , and the unified price of repurchasing used batteries p_u^M of manufacturer. Relevant conclusions are summarized in Table 2 and subsequent inferences.

Inference 1. As the price sensitivity degree of the cascade utilization market g increases, p_s^{M*}, A^* , and p_w^{R*} will decrease. θ^*, p_s^{M*}, and p_u^{M*} remain unchanged.

Proof

$$\frac{\partial A}{\partial g} = -\frac{\alpha\left(f - gc_r^U\right)^2}{16g^2(2\lambda + 3\beta)\delta(1-k)} < 0; \frac{\partial p_s^U}{\partial g} = -\frac{3f}{4g^2} < 0; \frac{\partial p_w^R}{\partial g} = -\frac{f}{2g^2} < 0,$$
$$\frac{\partial \theta}{\partial g} = \frac{\partial p_s^M}{\partial g} = \frac{\partial p_u^M}{\partial g} = 0. \tag{39}$$

□

Inference 2. With the increase in the price of recycler recycling retired batteries i, p_w^{R*} will increase, θ^* will decrease, and the manufacturer's strategy p_s^{M*} and p_u^{M*} will increase. p_s^{U*} and A^* remain unchanged.

Proof

$$\frac{\partial p_w^R}{\partial i} = \frac{1}{2} > 0; \frac{\partial \theta}{\partial i} = -\frac{\left(a - bc_m^M\right)\left[4A + b(\Delta - i)^2\right]}{\left[4A - b(\Delta - i)^2\right]^2} < 0,$$
$$\frac{\partial p_u^M}{\partial i} = \frac{1}{2} > 0; \frac{\partial p_s^M}{\partial i} = \frac{2ab(\Delta - i)\left[4Bb - b^2(\Delta - i)^2\right] - 2b^2(\Delta - i)\left[2B\left(a - bc_m^M\right) - ab(\Delta - i)^2\right]}{\left[4Bb - b^2(\Delta - i)^2\right]^2} > 0,$$
$$\frac{\partial p_s^U}{\partial i} = \frac{\partial A}{\partial i} = 0. \tag{40}$$

□

Inference 3. With the increase in cost-saving of remanufacturing by manufacturer Δ, p_w^{R*} and θ^* will increase, p_s^{M*} will decrease, and p_u^{M*} will increase. p_s^{U*} and A^* remain unchanged.

Table 2: Sensitivity analysis.

	p_s^{U*}	A^*	p_w^{R*}	θ^*	p_s^{M*}	p_u^{M*}
g	↓	↓	↓	⟶	⟶	⟶
i	⟶	⟶	↑	↓	↑	↑
Δ	⟶	⟶	↑	↑	↓	↑

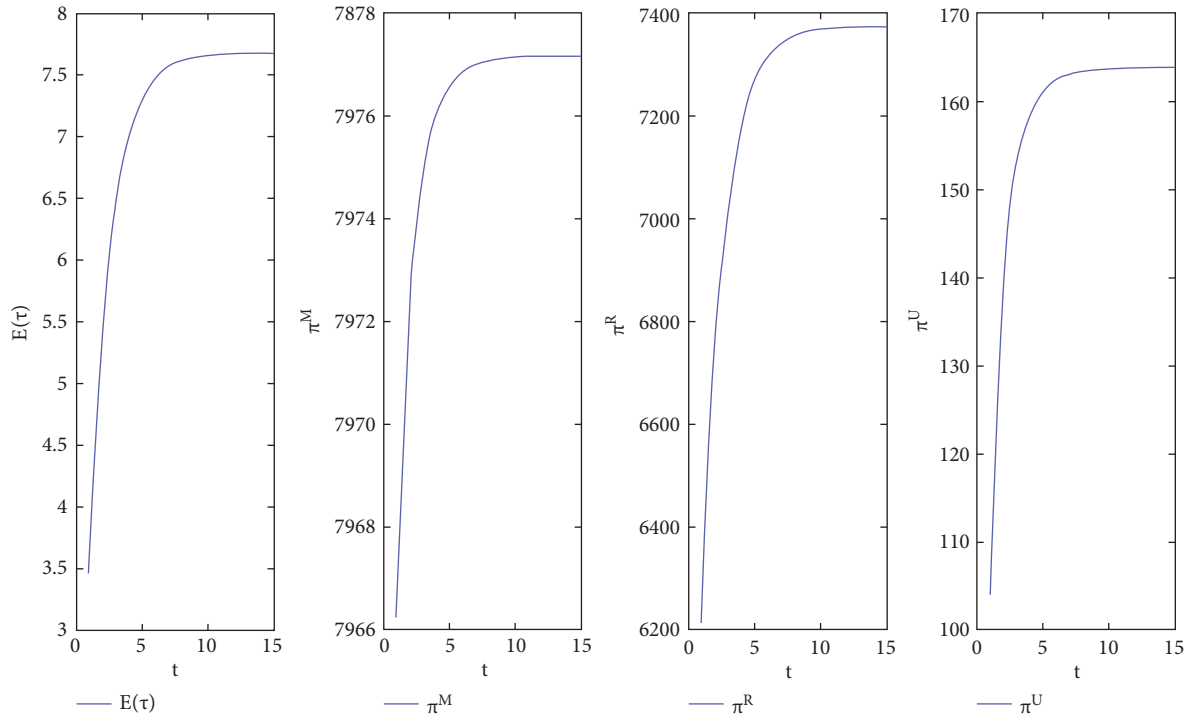

Figure 2: Evolution trajectory of system state variables.

Proof

$$\frac{\partial p_w^R}{\partial \Delta} = \frac{1}{2} > 0; \frac{\partial \theta}{\partial \Delta} = \frac{\left(a - bc_m^M\right)\left[4B + b(\Delta - i)^2\right]}{\left[4B - b(\Delta - i)^2\right]^2} > 0,$$

$$-2ab(\Delta - i)\left[4Bb - b^2(\Delta_r - i)^2\right] +$$

$$\frac{\partial p_u^M}{\partial \Delta} = \frac{1}{2} > 0; \frac{\partial p_s^M}{\partial \Delta} = \frac{2b^2(\Delta - i)\left[2B\left(a - bc_m^M\right) - ab(\Delta - i)^2\right]}{\left[4Bb - b^2(\Delta - i)^2\right]^2} < 0, \tag{41}$$

$$\frac{\partial A}{\partial \Delta} = \frac{\partial p_s^U}{\partial \Delta} = 0.$$

□

7. Numerical Example

In order to describe the model and reveal the law more intuitively, Section (7) analyzes the dynamic equilibrium strategy of the power battery CLSC system under the influence of random disturbance factors. The system parameters are selected as follows: $B = 2$, $\lambda = 0.3$, $a = 70$, $b = 0.5$, $\Delta = 4$, $\beta = 0.3$, $c_r^U = 1$, $\delta = 100$, $\alpha = 3$, $f = 35$, $k = 0.1$, $i = 2$, $g = 0.5$, and $\sigma = 0.01$.

7.1. Evolution Path Analysis. In Figure 2 shows the evolution trajectories of the expectation of cascade utilization effort level, manufacturer, recycler, and cascade utilization enterprise profits under the cost-sharing scenario considering the impact of uncertain factors.

The expectation of cascade utilization effort and the profit trajectory of each participant show a nonlinear upward trend with a gradually decreasing growth rate over time, and will eventually reach a steady state. At the same time, the profit of the manufacturer has always been the highest, and the profit of the cascade utilization enterprise has been in a low state.

7.2. Sensitivity Analysis

7.2.1. Cost-Sharing Ratio. Keeping other parameters unchanged, Figure 3 shows the impact of the change in the cost-sharing ratio, k, on the expectation of cascade utilization effort level and the profit of each participant.

With the increase of k, the cascade utilization effort level, the profits of recycler, and cascade utilization enterprise all show a nonlinear upward trend, while the manufacturer's profit shows a nonlinear downward trend. As manufacturer shares the increase in the innovation cost of cascade utilization enterprise, the overall profits of manufacturer are decline. However, from the perspective of the overall supply chain, manufacturer still occupy a large market share, and

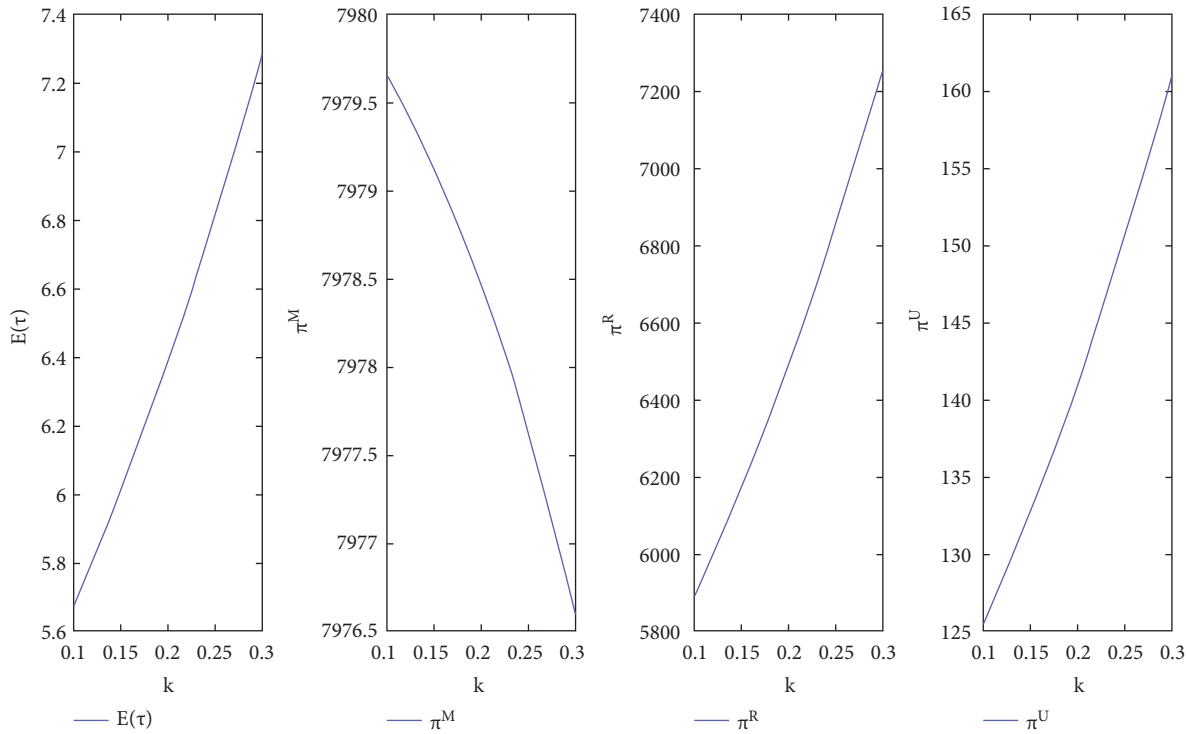

Figure 3: Sensitivity analysis of cost-sharing ratio.

the profit is always higher than that of recycler and cascade utilization enterprises. At the same time, the profits of recycler and cascade utilization enterprises are increasing, which will greatly improve their enthusiasm for recycling resources and effectively promote the steady improvement of cascade utilization levels.

7.2.2. Price Sensitivity Coefficient of Cascade Utilization Market. Keeping other parameters unchanged, Figure 4 shows the impact of the change in the price sensitivity coefficient of the cascade utilization market, g, on the dynamic system of the power battery CLSC.

With the increase of g, A^*, p_s^{U*}, p_w^{R*} π^R, and π^U all show a nonlinear downward trend, and π^R is always greater than π^U, only π^M show a nonlinear upward trend. The increasing sensitivity of consumers to the price of cascade utilization products has a negative impact on both cascade profit and recycling market, and the impact on cascade utilization enterprises is more severe. The demand change of cascade utilization market does not affect the manufacturer's production and recycling decision, but due to the reduction of the cascade utilization effort utility, the cost of cascade utilization effort utility sharing by the manufacturer decreases accordingly. Therefore, when other parameters remain unchanged and g increase, only manufacturers can make more profits.

7.2.3. Recycled Battery Price of Recycler. Keeping other parameters unchanged, Figure 5 shows the impact of changes in the price of recycled batteries by recycler, i, on the dynamic system of the power battery CLSC.

With the increase of i, p_u^{M*}, and p_w^{R*} show a linear upward trend, p_s^{M*} shows a nonlinear upward trend. θ, π^R, and π^M show a nonlinear downward trend, π^R has a larger decline, π^M is always greater than π^R, and π^U is the smallest and remains unchanged. The increase in i enables recycler to increase p_w^{R*} and reduce θ, but such decision-making changes have not stopped the decline of their own profits; Manufacturer thus raises p_u^{M*}, and then increase p_s^{M*}, so as to reduce consumer demand and eventually damage their own interests; The increase of i has little impact on cascade utilization enterprise, and the decision-making and profit of cascade utilization enterprise will not change.

7.2.4. Cost-Saving for Manufacturers in Remanufacturing. Keeping other parameters constant, Figure 6 shows the impact of changes in cost-saving in the manufacture of remanufactured products, Δ, on the dynamic system of the power battery CLSC.

With the increase of Δ, p_u^{M*}, and p_w^{R*} show a linear upward trend, p_s^{M*} shows a nonlinear downward trend. θ, π^R, and π^M show a nonlinear upward trend, π^M is always greater than π^R, π^U is the smallest and remains unchanged. The increase in Δ has greatly improved the enthusiasm and motivation of manufacturer to recycle resources, so that manufacturer can still be profitable whereas reducing p_s^{M*} to attract consumers, which reflecting the importance of manufacturer's relevant technology research and development and innovation; Recycler earns large profits by

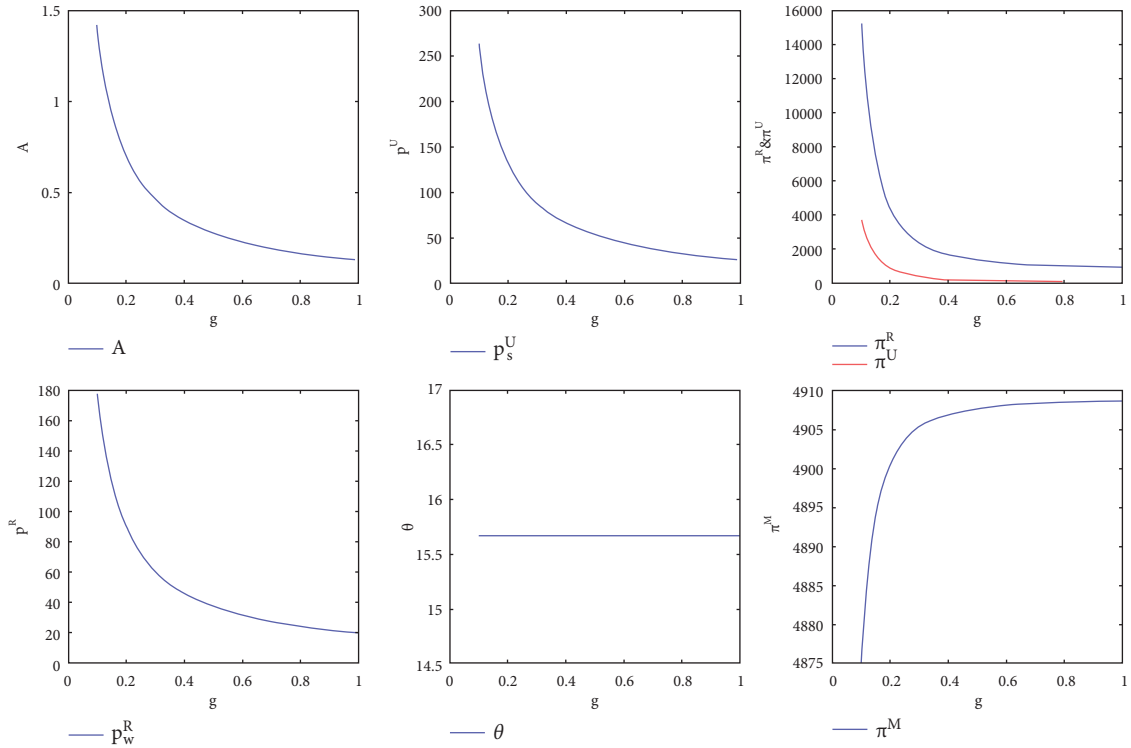

Figure 4: Sensitivity analysis of the price sensitivity coefficient of cascade utilization market.

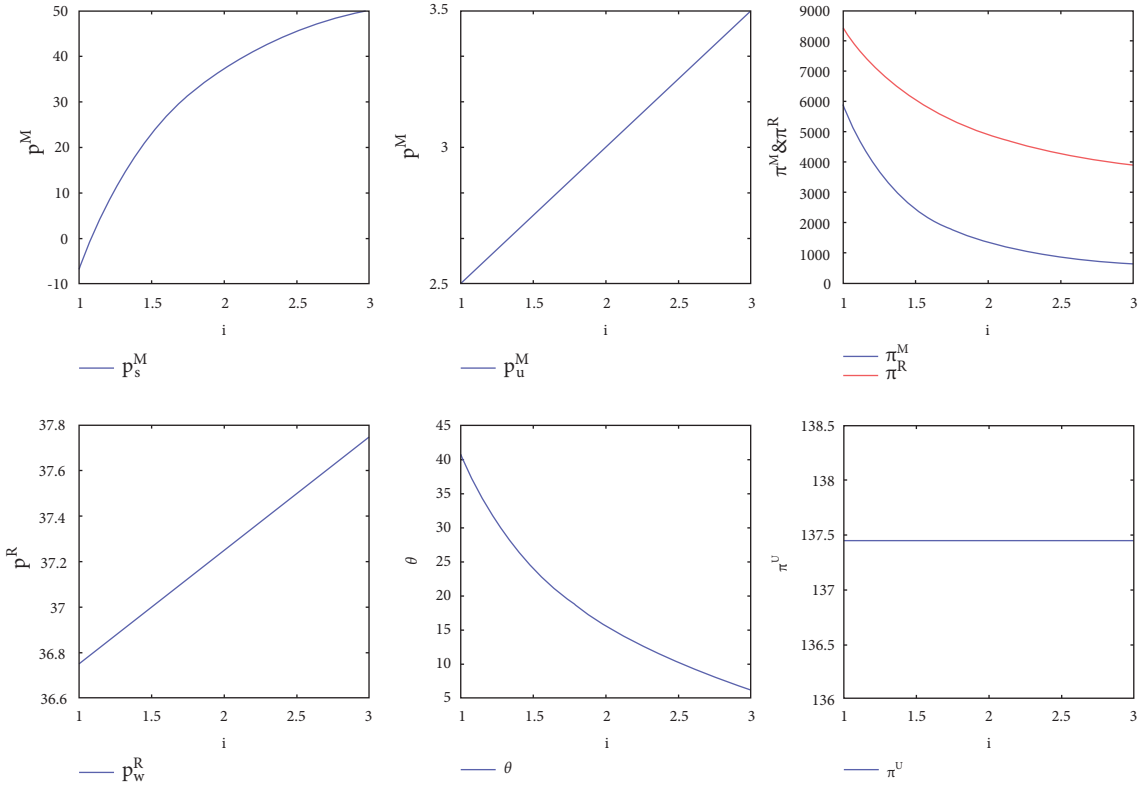

Figure 5: Sensitivity analysis of recycled battery price of recycler.

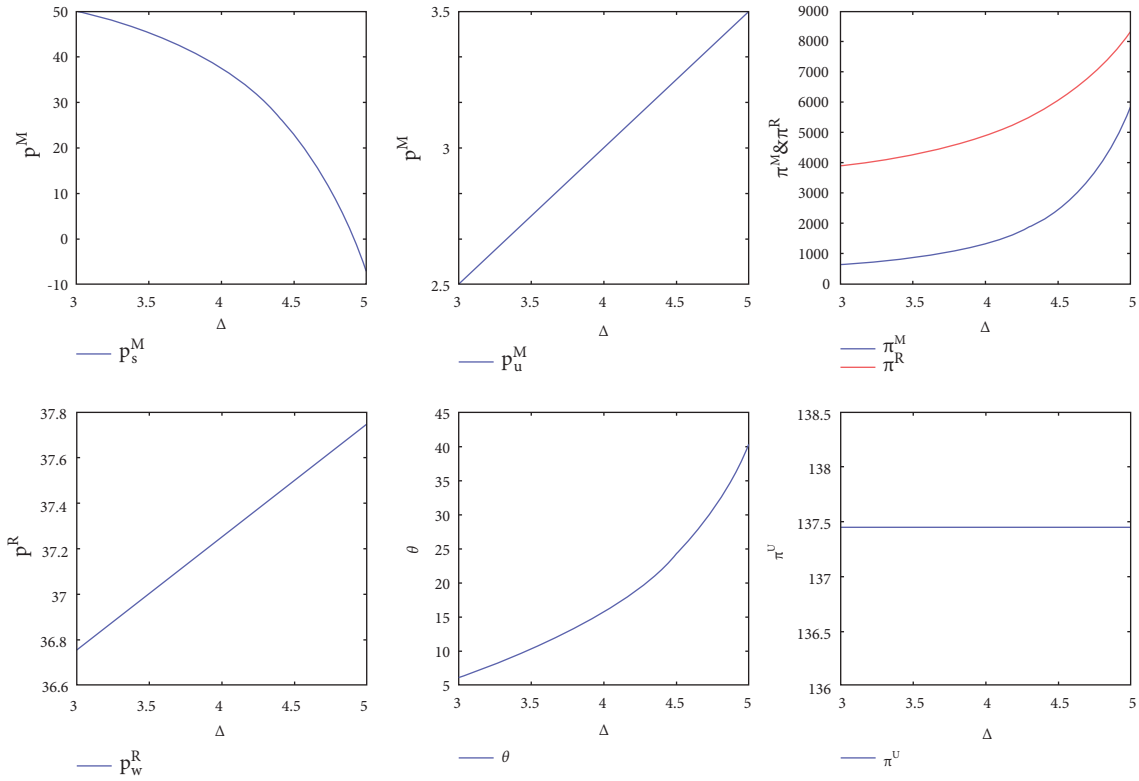

Figure 6: Sensitivity analysis of cost-saving for manufacturer in remanufacturing.

increasing p_w^{R*} and θ; cascade utilization enterprise is not affected by Δ, the decisions and profits remain unchanged.

8. Conclusions

This paper studies the dynamic equilibrium strategy of power battery CLSC members under the interference of uncertain factors. The stochastic evolution process characteristics of cascade utilization effort level of power battery CLSC dynamic system are described by using Ito process. According to the profit composition of participants, the target function of each participant pursuing profit maximization is constructed. Aiming at the dynamic system of power battery CLSC with the manufacturer as the leader, the stochastic differential game model is established, and the dynamic equilibrium control strategy of each participant is solved by using stochastic differential game theory and continuous-time dynamic programming theory. In order to reveal the evolution characteristics of random cascade utilization effort level, the stability of expectation and variance of random cascade utilization effort level is analyzed. Combined with numerical examples, the evolution path analysis of state variables and parameter sensitivity analysis of dynamic systems are carried out to verify the influence of relevant parameters on dynamic systems.

The results found that with the increase of cost-sharing ratio, the effort level of cascade utilization enterprise is improved, the manufacturer's profit is decreased slightly, but it does not affect its industry dominant position, the profits of recycler and cascade utilization enterprise are increased, which effectively improves the enthusiasm of resource recycling in the supply chain. Manufacturer shares part of the innovation cost of cascade utilization enterprise that can effectively improve the profit space of relevant subjects, stimulate the enthusiasm of relevant subjects to recycle resources, reduce environmental pollution, and guarantee the effective improvement of cascade utilization level, so as to promote the prosperity and development of the industry. At the same time, the price sensitivity degree of cascade utilization market has a significant negative impact on the members of the supply chain. The administrative supervision department should actively improve the industry regulations and strictly supervise the whole process of power battery production, recycling, and reuse, and at the same time, it can also enhance consumers' green awareness by carrying out relevant publicity work, supply chain members should also jointly build and improve the battery recycling platform and network system, formulate relevant industry standards and other measures to deepen customer trust, make joint efforts to effectively resist the interference of internal and external uncertain factors, reduce the potential risks of the industry, and ensure the long-term and steady development of the battery recycling industry. In addition, the increase in the cost-saving of manufacturer's remanufactured products can effectively improve the enthusiasm of manufacturers for recycling resources, reflect the importance of technology research and development and innovation, drive the development of the industry with innovation, and promote the effective improvement of resource recycling efficiency.

All parties should strengthen information exchange and cooperation, jointly build and share, link interests, achieve mutual benefit and win-win results, give full play to the effectiveness of the internal coordination mechanism of the supply chain, promote the coordinated development of the supply chain, effectively resist the interference of internal and external uncertain factors, and jointly undertake the responsibility of improving the level of industrial resource recycling. The contribution of this paper is to study and analyze the dynamic equilibrium strategy of the members of the power battery CLSC from the dynamic perspective, in view of the influence of uncertain factors and the cost-sharing coordination mechanism. At the theoretical level, it provides theoretical reference for the behavior decision-making of related enterprises, enriches, and expands the theoretical research in related fields. At the practical level, it provides ideas for improving and innovating the operation mechanism of the power battery CLSC. The research results have important guiding significance for relevant enterprises to fully and efficiently use the cascade, improve the level of resource utilization, and reduce environmental pollution.

However, this paper only considers the business strategy selection of enterprises in a single channel, and does not consider the impact of online and offline dual-channel recycling and sales, competitive cooperation game and other situations. The next research direction is to establish a dynamic cooperative game model considering factors such as consumers and different recycling and sales channels, and to study the influence of multi-channel sales and recycling of cascade products on the cascade utilization of power batteries.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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Retraction

Retracted: Exploring the Influence of Local Government Debt on Enterprise Investment through the Empirical Evidence at the Municipal Level

Mathematical Problems in Engineering

Received 17 October 2023; Accepted 17 October 2023; Published 18 October 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] M. Cao, K. Duan, and H. Ibrahim, "Exploring the Influence of Local Government Debt on Enterprise Investment through the Empirical Evidence at the Municipal Level," *Mathematical Problems in Engineering*, vol. 2022, Article ID 2531808, 18 pages, 2022.

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Research Article

Exploring the Influence of Local Government Debt on Enterprise Investment through the Empirical Evidence at the Municipal Level

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The data of new urban investment bonds in cities from 2011 to 2021 to represent the growth of local government debt is used in this article. This paper studies the relationship between the increase of local government debt and the underinvestment of A-share listed enterprises, which are nonfinancial companies in China. The research finds that the increase in local government debt will crowd out the debt financing of enterprises and then significantly the degree of underinvestment of enterprises, which is represented non-state-owned enterprises, enterprises with high financing constraints, and enterprises with nonlocal debt invested in the industry. As for listed enterprises with relatively low fixed assets, the increase in local debt will further lead to the degree of underinvestment. The above conclusions remain unchanged after a series of robustness tests in this paper. Further research shows that the increase in local government debt will weaken the stimulus effect of loose monetary policy and thus affect the underinvestment of enterprises. This paper expands the research on the factors affecting the underinvestment of enterprises and deepens the research on the consequences of the influence of local government debt on the economic activities of microsubjects.

1. Introduction

The problem of public debt and its risk have always been an important financial and economic problem faced by countries all over the world. Unlike the United States, Europe, and other developed countries, which mainly point to the central government, China's debt problem is mainly manifested in the continuous and rapid expansion of the scale of local government debt. In 1994, the Chinese government implemented the tax-sharing reform at the national level, shifting the fiscal power to the hand of the central government while keeping the local government's administrative power unchanged. In the same year, the Budget Law of the People's Republic of China was promulgated [1, 2]. It stipulates that local governments should not announce fiscal deficits or list funds raised through bonds. It also prohibits local governments from issuing local government bonds (LGBs). As stipulated, local governments legal and compliant financing channels are restricted. Also, lending policies are restricted due to the huge capital demand and the imbalance of administrative and fiscal powers of local governments. As a result, local governments lack funds to fulfill administrative powers to develop the local economy, livelihoods, infrastructure construction, etc. [3–5].

In the face of financial shortages, local governments had to establish platform companies through methods like land asset allocation and receive bank loans to make up for the huge financial gap [6]. Therefore, local government financial vehicles (LGFVs), as local governments' investment and financing carriers, came into being. At the same time, the tax-sharing reform led to the mismatching of administrative power and financial power in the central and local governments, reducing the local government fiscal revenue's share of the national fiscal revenue while the number of public welfare projects and quasi-public welfare projects increased [7–9]. The shifts in administrative and fiscal powers' funding widened the gap in local governments' funds. The financing methods are usually bank loans and the issuance of municipal corporate bonds, known as urban investment bonds. The 4 trillion yuan stimulus plan in China was launched after the global financial crisis in 2008. The central government has funded 1.18 trillion yuan, and most

of the remaining funds need to be raised by local governments [10–12]. In the same year, the People's Bank of China jointly issued the Guiding Opinions with the China Banking Regulatory Commission (CBRC). Local governments have started to establish their LGFVs. Financing instruments such as corporate bonds, short-term financing bonds, and medium-term notes were issued, and the number of LGFVs grew rapidly [13, 14]. Since then, LGFVs have prospered unprecedentedly with the rapid expansion of government debt and an increase in urban investment bonds. With years of development, huge scale, opaque information, and nonstandard management have led to great risks in urban investment bonds, which have become an important source of hidden debt risks for local governments [15, 16]. In addition to paying attention to the systemic risks posed by local government debt, the impact of local debt on the economy has also attracted great attention in academic circles. On the one hand, local government debt plays an important role in promoting the construction of public facilities and rapid economic recovery; on the other hand, the priority of local government financing leads to the redistribution of funds in the credit market, which has a negative impact on the overall efficiency of fund allocation.

Local fiscal and financial risks were accumulating gradually, which made the prevention of and solution to local government debt risks important. In 2012, benefiting from the National Development and Reform Commission's relaxation of the approval of corporate bonds, as well as the central government's strategy of expanding domestic demand and accelerating urbanization, urban investment bonds showed a blowout increase in the amount of nearly one trillion yuan, about three times that of 2011. In 2015, the restriction on the administrative level of the issuing body of urban investment bonds was relaxed while the urban investment bonds issued previously were due at maturity, making encashments prevailing [17–19]. The issuance of urban investment bonds reached a new level that year, doubling that of 2014. By December 2021, the debit balance of local governments rose to 30.5 trillion yuan, from 10.7 trillion yuan in 2010. Although the increase of government debt can improve basic public services to some extent, especially in a period of economic recession, governments' borrowing could increase their expenditure, which is conducive to driving consumers' demand, accelerating regional industrialization and urbanization, and narrowing the regional gap [20, 21]. However, most studies believe that local government bonds are advantageous in the capital market because of their features, including recessive guarantee and rigid redemption, which, to a certain extent, left little space for other credit resources and produced a crowding-out effect on private investment [22–24]. According to document No. 35 of 2011, issued by the National Audit Office, 46.38% of local government debt is issued by local financing platforms in China. Therefore, it is reasonable and representative to select the scale of additional urban investment bonds to measure the increase in local debt [25]. Urban investment bonds are enterprise bonds, medium-term notes, and short-term financing bonds publicly issued by local government investment and financing platforms as the issuing entities, which are mostly used for local infrastructure construction or public welfare projects. At present, China's urban investment bonds are mainly divided into three categories: corporate bonds, short-term financing bonds, and medium-term notes, of which corporate bonds are the main ones, and the development is relatively mature.

The current research on the relationship between government debt and corporate underinvestment can be categorized as follows: some scholars believe that the increasingly growing government debt ties up more social funds, which is detrimental to corporate financing. An excessive concentration of funds in local government debt and financing platforms can crowd out some highly productive SMEs. As a result, private capital cannott create a sufficient investment scale and enough opportunity in the real economy. As a large amount of floating debt is used in large-scale investments for the government and the public sector, and some floating debt is used for enormous due repayment, social funds will decrease. On the other hand, the government issues debt to raise funds from the capital market, which will lead to an increase in the market rate and a decrease in private investment and consumption. Therefore, it will have a crowding-out effect on corporate investment. In order to balance the budget deficit, the government issued government bonds to raise funds from the private borrowing market, which raised the market interest rate and reduced private investment and expenditure accordingly. This is the crowding-out effect of the fiscal deficit caused by public expenditure on private investment and expenditure. Some scholars suggest that the increase in government debt will reduce banks' loanable funds. It is worth noticing a negative correlation between the rise in government debt and corporate finance. With credit endorsement from the local government, local government debt enjoys high security and liquidity. Thus, financial institutions such as banks regard it as reserves, resulting in decreased loanable funds in banks.

Although there is massive existing research on the relationship between government debt and investment, there are still notable limits. First, there is a lack of relevant literature that uses data from municipal governments and enterprises at the prefecturelevel to study the relationship between local government debt and corporate underinvestment. Most of the literature solely focuses on the impact of local public debt on corporate financing and regional economic development, whereas prefecture-level cities and enterprises are the main driving forces for local economic development in China and are better placed to reveal the internal relationship between local government debt and corporate underinvestment. Second, there is little existing research exploring the impact of local government debts on corporate investment at the prefecture level and little research that directly examines how local debt influences underinvestment in enterprises. Besides, there is a lack of discussion on the impact of local debt on economic growth from microeconomic perspectives.

The contributions of this paper lie in the following three aspects: first, it provides new mechanistic validation and empirical evidence on the impact of local government debt

upon the investment activities of microentities in the market. This paper unveils the mystery of Chinese corporate investment from a brand-new angle, namely that neither easing policies nor stimulus measures contribute to mitigating corporate underinvestment. Second, by analyzing the debt of prefecture-level city governments and the underinvestment of enterprises, this paper offers a new perspective to explore how local governments' debt influences the underinvestment of enterprises. Third, it complements the mechanism of slowing growth. The article emphasizes that the increase in local government debt will exacerbate the misallocation of financial resources and lead to the underinvestment of enterprises, which is one of the factors contributing to the slowdown of economic growth.

Our research is based on the research background mentioned above by optimising investment structure as an essential part of economic stabilization and structural adjustment policies, we lay a solid foundation for policy discussion. It can also be viewed as a worth-exploring academic subject with Chinese characteristics to illustrate better the dynamic relationship and mechanism between local government debt and corporate underinvestment. Therefore, this paper will focus on the following research questions: 1. Does local government debt crowd out corporate debt financing? 2. Do enterprises with unmet funding needs suffer from underinvestment? 3. Will the increase of local debt affect the local effects of other monetary policies and further affect the underinvestment of enterprises?

Based on the annual data of Chinese A-shares listed nonfinancial companies from 2011 to 2021, this paper analyzes the impact of local government debt on corporate underinvestment. The results show that: first, there is a significant correlation between local government debt and underinvestment. The scaling up of local government debt will cause underinvestment in non-stated-owned enterprises and non-local debt-invested enterprises. Second, the influential mechanism of local debt on underinvestment is as follows: local government debt squeezes corporate debt financing, reinforces corporate financing constraints, and results in the underinvestment of enterprises. Third, further research has found that the increase in local debt will increase the degree of underinvestment and further reduce enterprise value. Last but not least, the increase in local debt will influence the stimulus effect of loose monetary policy on corporate investment. In the capital supply-demand relationship composed of the government, microenterprises, and financial institutions, the expansion of local government debt financing demand is likely to crowd out the credit resources of microenterprises, and the government's preferential access to capital market financing will also interfere with the market's allocation of credit resources. Capital is the lifeblood of enterprise production, investment, and R&D innovation. The financing constraint caused by the crowding effect of government debt on enterprise credit capital will have an unavoidable impact on enterprise investment and financing decisions and R&D innovation activities. These two are also important factors affecting the high-quality development of enterprises.

The remainder of this paper is structured as follows: Section 2 presents the analysis of related theories and the main hypotheses put forward on the basis of theoretical studies. Section 3 introduces the data and empirical strategies used. Section 4 focuses on the major empirical results of the analysis and the influential mechanism. Section 5 shows a series of robustness tests. Sections 6 and 7 summarize the key findings and offers relevant policy recommendations.

2. Literature Review and Research Hypothesis

The current literature on the subject, which pays attention to the question of how local government debt affects the investment and production activities of microenterprises, mainly focuses on the following three research viewpoints. The first view holds that government debt financing has a significant negative impact on the capital structure of enterprises, which will reduce private investment. Government debt may also crowd out corporate investment by crowding out bank credit resources and raising corporate financing costs. The traditional view of the budget deficit believes that when the budget deficit increases aggregate demand, it also leads to a rise in interest rates and a corresponding decrease in investment. The second study finds that government borrowing can increase public investment expenditure, improve the infrastructure environment, increase aggregate demand and investment opportunities, and then create a good investment environment for enterprises. In addition, the third view holds that the relationship between government debt financing and private investment depends on the type of public investment.

As the second largest economic entity in the world, China has made remarkable achievements in its economic development in the past, which are attributed to the government's characteristic of concentrating its efforts to accomplish large undertakings. To some extent, the investment of these local debts in public goods will have an "external" effect, such as improving local infrastructure and attracting investment, which will reduce the marginal cost of enterprises and promote enterprises' investment and production. However, the government will impose a financial backstop on local financing vehicles and other enterprises, which will lead to severe "soft budget constraint" between local financing vehicles and state-owned enterprises, and then make the interest rate sensitivity of state-owned enterprises to financing generally low. This means that ordinary enterprises, especially private enterprises, often have an "unfair disadvantage" in the competition with local financing platforms in the capital market. As local government debt increases, more ordinary enterprises will withdraw from the financing market and reduce the investment spending, which then lead to enterprises underinvestment.

At present, there are few empirical studies on the impact of local government debt on the investment and production activities of microenterprises in China, and the heterogeneity of this subject is also lacking. We believe that it is necessary to test the influence of local debt on the investment

activities of microenterprises and to test the mechanism of local government's influence on the investment of enterprises by using the data of prefecture-level cities in China. These studies will reveal the micromechanism of local debt affecting economic efficiency.

2.1. Corporate Financing and Under-Investment of Enterprises. As for the influencing factors of enterprise investment efficiency, existing research focuses on the aspects of corporate governance, information disclosure, accounting conservatism, characteristics of the board of directors and managers, and corporate heterogeneity. It can be summarized two points as the following: (1) based on principal-agent theory and the factors of corporate governance with information asymmetry theory, existing research literature has introduced the conflicts of interest between creditors and shareholders and the conflicts of interest between shareholders and managers into the decision-making of company investment. (2) Based on the status of investment and financing, the existing literature analyzes the impact of investment and financing on the underinvestment of enterprises. This paper will focus on the analysis of the impact of enterprises' investment and financing conditions on enterprises investment shortages.

Financing management refers to the financing strategy and corresponding financing mode selected by the enterprise through risk and feasibility analysis to meet its own capital needs and realize the dual control of the risk and cost of financing, so as to build a more reasonable enterprise capital structure. The main contents of financing management include: clarifying the financial objectives of the enterprise, scientifically predicting the demand for funds, selecting reasonable financing channels and methods, and ensuring the rationality of the capital structure. In a perfect capital market, there is no difference in the financing cost of all enterprises. No matter what kind of financing method an enterprise chooses, its capital cost is consistent. The change of financing mode will not affect the discount rate, so the investment decision of enterprises does not need to consider the financing factor, the investment decision of enterprises completely depends on the current investment opportunity. When enterprises are faced with investment projects with NPV greater than zero and investment projects with NPV less than zero, they will choose to expand investment expenditure and refuse to increase investment expenditure, respectively, which means that in a perfect capital market, the investment expenditure of enterprises can always be in the optimal investment decision. However, there are often financial frictions in the real capital market, making investment decisions not only depend on the investment opportunities they face, but also depends on the cost of using funds and the degree of financing constraints. Relying on external debt financing may restrict the ability of enterprises to invest in the future, and enterprises' investments may deviate from the optimal investment decision, resulting in insufficient investment.

2.2. Local Government Debt and Insufficient Enterprise Investment. Macroeconomic policies and environment (e.g., macroeconomic stability, economic cycle, monetary policy, credit policy, financial development level, and fiscal and tax policy) will directly or indirectly affect the financing cost and scale of enterprises, thus affecting the underinvestment of enterprises.

Local government debt refers to the debt that the local government, as the debtor, undertakes the obligation of fund repayment to the creditor in accordance with the provisions of the agreement or contract, including the direct debt formed by direct borrowing and default of project funds and the debt formed by providing credit support such as guarantee or rescue. In recent years, the rapid expansion of local government debt in China has occupied a considerable amount of bank credit funds. Existing studies at home and abroad have shown that with the increase of local government debt, the debt capital obtained by enterprises decreases correspondingly. The crowding-out effect of local debt makes the financing costs of Chinese enterprises, which are generally constrained by financing, rise and the scale of debt financing decrease. Therefore, the growth of local government debt will have an impact on the degree of underinvestment of enterprises. Even if there are good investment opportunities, enterprises will give up investment due to the crowding-out effect of local government debt. China's credit market has the characteristics of geographical segmentation, which provides an ideal environment for testing the local crowding out effect. However, the impact of the different nature of borrowing enterprises is not the same. In order to maximize profits, banks will tighten lending to higher risk borrowers. In the Chinese market, state-owned enterprises have explicit or implicit government guarantees, which makes it easier to obtain bank funds.

From the existing literature research, the crowding out effect of local government debt on corporate financing can be divided into bond financing channels and bank credit channels. From the perspective of bond financing channels, under the credit and financial guarantee of local governments, the default risk of government bonds and private corporate bonds are significantly lower than corporate bonds. Once a large number of new government bonds flood into the bond market, they will form a substitute role for corporate bonds, especially those issued by non-state-owned enterprises. In order to raise funds, companies have to raise the yield to maturity on the bonds they issue. The increase of yield to maturity makes the financing cost of corporate bonds rise and increases the financing constraint of enterprises.

From the bank credit squeezing channel: our country's enterprise departments and local debt financing sources have a lot of overlap parts, and bank loans for local government debt are huge. The two forms a strong competitive relationship between bank credit demand and government debt. Because of its government background and implicit guarantee, government debt enjoys an absolute advantage in the competition with bank loans in the enterprise sector.

First of all, in the bank-dominated financial system in China, the overall financing structure of enterprises is dominated by indirect financing. Compared with equity financing, enterprises prefer debt financing. In external financing, long-term corporate bank loans account for more than 60%, bond financing accounts for about 10%, other financing sources account for 20%, and equity financing only accounts for 10%. It can be seen that bank loans have long been the most important channel for Chinese enterprises to seek external financing. According to the audit results of local government debt nationwide in 2011, the growth rate of local government debt in 2010 and 2011 was 61.92% and 18.86%, respectively. In that year, new local government debt was 2.0472 and 2.021.3 billion yuan, respectively. Bank loans accounted for 79% of the financing sources of local government debt, and 1617.3 billion yuan and 1596.8 billion yuan of new local government debt came from bank credit. According to the statistical data report on the scale of social financing released by the central bank, the total amount of RMB loans in 2010 and 2011 was 7,904 billion yuan and 7,479.9 billion yuan respectively, accounting for 56.7% and 58.3% of the total scale of social financing. Local government debt accounted for 20.46% and 21.35% of bank loans in 2010 and 2011. Therefore, local debt is a very important force in the credit markets. Based on the above facts, the phenomenon of local debts competing with the private enterprise sector in corporate bank loans is an objective existence. Secondly, due to the government background attribute of local debt and the implicit guarantee of the government to the financing platform and the credit enhancement behavior of injecting assets such as land and other collateral. Banks and other financial institutions with "political motivation" and risk considerations are more inclined to lend funds to local debt. Therefore, compared with the bank loans of local government debt, the enterprise sector is at an absolute disadvantage. The amount of credit available to enterprises decreases as local government debt increases. In addition, the infrastructure construction industry to which local government debt funds are invested had a large capital demand with a long construction cycle, which occupied bank credit resources for a long time, aggravating the long-term occupation of bank credit funds. According to the financing priority theory, enterprise financing generally follows the sequence of internal financing, debt financing and equity financing. When the external financing cost rises, enterprises tend to choose internal financing. In addition, too much local government debt will lead to the increase of economic policy uncertainty, thus inhibiting the investment intention of enterprises and reducing the external financing demand of enterprises. As the local government debt pushes up the debt financing cost of enterprises through the price mechanism, and the debt financing cost rises, enterprises tend to replace debt financing through equity financing.

The article constructed a DID model based on the difference of the time of establishing local government financing platform in different counties, by matching the list of financing platforms of county-level local governments with the loan data of county-level financial institutions from 2006 to 2010. Therefore, with the expansion of local debt, the investment of bank credit to the nonefficient enterprise sector was largely influenced by the intervention of local governments. In addition, with the regulations on traditional sources of bank loans coming from the central government becoming increasingly strict, local governments have turned to nontraditional sources of credit loans for debt financing, such as the shadow banking system. As a result, local governments have greatly increased the demand for shadow banking products and have raised the borrowing rates of local shadow banks. This has increased the cost of financing for non-state-owned enterprises, crowding out non-state-owned enterprises.

To sum up, the crowding out of local government debt on corporate debt funds will lead to an increase of the underinvestment of enterprises.

Excessive growth of local government debt will crowd out private sector funds. However, compared with non-state-owned enterprises, state-owned enterprises have a great priority in obtaining bank credit funds due to their natural political relations and implicit government guarantees. The implicit guarantee provided to state-owned enterprises refers to the self-evident guarantee provided by the government for the competition failure and operational loss of state-owned enterprises. This kind of guarantee is an abuse of the government's credit. It is the offside of the government, which is beyond its functions. It excludes private credit and private guarantees that meet the requirements of market economy laws and regulations. The information it conveys also deviates from the market rules and undermines the market order of "survival of the fittest." In addition, the crowding-out effect of government debt had little impact on state-owned enterprises. As for these enterprises with low financing constraints, they are less dependent on debt funds. When debt funds are squeezed by local debts, they can make financing investments through more channels, such as internal financing, which relies on their own cash flow, and equity financing. Therefore, the crowding out effect of local government debt on enterprises with high financing constraints is stronger. Local debt funds can invest mainly in infrastructure projects in the region. The construction of infrastructure needs to cooperate with a class of construction enterprises, so the investment crowding out effect of local government debt on enterprises is weaker. The industry attributes of these enterprises are that local government debt mainly invests to industry.

Based on the above theoretical analysis, the following research hypotheses are proposed in this paper.

2.3. Local Government Debt, Proportion of Fixed Assets, and Underinvestment of Enterprises. Fixed assets are the main credit collateral provided by enterprises when they lend money to banks. With the increase of the proportion of fixed assets, the ability of enterprises to obtain bank credit is also enhanced. In particular, after the implementation of ≪the Property Law of the People's Republic of China in 2007, the real right system of security in China has been improved, and the mortgage guarantee value of fixed assets in bank credit has been further enhanced. The expansion of the debt

scale of local government squeezes the scale of bank credit financing of enterprises and further aggravates the scarcity of credit funds and the shortage of supply in the market. So banks will pay more attention to the guarantee of corporate credit collateral when they grant credit loans to enterprises. In the context of the rapid growth of local government debt, when enterprises carry out bank credit financing, enterprises with high fixed assets ratios are less squeezed by local government debt than those with low fixed assets ratios. Therefore, the impact of local government debt on the underinvestment of enterprises with a high fixed asset ratio will be relatively less. In other words, with the increase of the proportion of fixed assets of enterprises, the impact of the scale of local government debt on the underinvestment of enterprises decreases. We call this effect the "collateral effect" of fixed asset ratio.

In addition, the proportion of fixed assets in the total assets of an enterprise often means the strength of the liquidity of fixed assets in the capital market, namely the degree of reversibility of enterprise assets, which is mainly reflected in the sunk costs and transaction costs that enterprises have to bear when disposing of investment assets.

The effect is embodied in the following: on the one hand, when investment assets are realized, sunk costs of existing investments cannot be recovered due to factors such as asset specificity. On the other hand, in order to conclude a transaction to dispose of the investment assets, enterprises need to pay the transaction costs and bear the purchasing costs of assets. At the same time, when waiting for the right transaction opportunity, enterprises need to bear the opportunity cost of time in the waiting process. The reversibility of assets measures a firm's ability to protect itself in times of trouble. When external financing is tight, companies with more irreversible assets are more likely to cut down investment spending. Therefore, with the increase in the irreversibility of enterprise assets, the greater the degree of local government debt crowding out enterprise investment. This effect is called "the asset irreversible effect" of fixed asset proportion.

Based on the above theoretical analysis, this paper proposes the following hypotheses.

3. Research Design

3.1. Sample Sources and Data Description. The annual financial data of A-share listed companies used in the study is derived from the CSMAR database, and the data span is from 2011 to 2021. At the same time, we obtained the geographic information of enterprise registration and office location from the Wind database, and combined the information with that obtained from the CSMAR database. Based on the availability on data of local bonds, and local financing platforms in each city, the urban investment bonds issued by each prefecture-level city are used in the paper to represent the new local bonds of the prefecture-level city every year. The data of urban investment bonds used is from the Wind database which includes corporate bonds, corporate bonds, medium-term notes, short-term financing bonds, privately raised bonds and other types of bonds issued by various urban investment and financing platform companies in the bond market (including the interbank bond market and the exchange bond market) in the same year. It should be noted that, though most local government debt funding comes from bank loans, the crowding out effect of local government debt on enterprise investment will be underestimated, due to the availability of data. In the article, urban investment bonds instead of local government bonds. The paper also emphasizes the crowding out effect of local government debt on corporate bank credit is one of the important factors affecting cause enterprises' lack of investment. M2 money supply and other macro data are derived from the CEIC database. In this paper, samples were screened according to the following criteria: (1) excluding financial and insurance companies; (2) excluding these companies which are ST or ST*; (3) excluding insolvent companies; (4) the article winsorized the extreme value of each variable according to 1% quantile.

3.2. Variable Selection

3.2.1. A Measure of Underinvestment in a Business. The residual regression of this model ε_{it} represents the inefficient investment expenditure of the company. When $\varepsilon_{it} > 0$, it means that the company's investment is overinvested, which is denoted as Over_INV. When $\varepsilon_{it} < 0$, it means that investment of the company is underinvested, which is denoted as Under_INV.

$$\begin{aligned}\text{Invest}_{i,t} = {} & \alpha_0 + \alpha_1 \text{Growth}_{i,t-1} + \alpha_2 \text{Size}_{i,t-1} + \alpha_3 \text{Lev}_{i,t-1} \\ & + \alpha_4 \text{Cash}_{i,t-1} + \alpha_5 \text{Age}_{i,t-1} \\ & + \alpha_6 R_{i,t-1} + \alpha_7 \text{Invest}_{i,t-1} + \sum \text{Industry} + \sum \text{Year} + \varepsilon_{\text{it}}.\end{aligned} \tag{1}$$

Among them, variable Invest represents the investment expenditure of a business. Variable growth represents the growth rate of core operations of an enterprise, which measures the growth of the enterprise. Variable size measures the size of a company. Variable Lev represents the company's financial leverage ratio. Variable cash represents the cash holdings of a company. Age represents the company's age. R represents the return on shares. The detailed composition of variables is shown in Table 1.

3.2.2. Measurement of Financing Constraints. There are many indexes to measure corporate financing constraints, but most of them have strong endogenous problems with corporate financial indicators. For example, financing constraints are mutually determined by cash flow and leverage ratio. When the value of SA is negative, and the greater the value of SA, enterprises will face stronger financing constraints. Therefore, the financing constraint SA index is temporarily adopted as the grouping basis of corporate financing constraints to test the hypothesis1 in this paper. When the SA index of the companies is below 50%, the companies are classified into the low financing constraint group. When the SA index of the companies is above 50%, the companies are classified into the high financing constraint group.

Table 1: Main variables and description.

Variable name	Variable symbol	Variable definition
Underinvestment of enterprises	UnderInv	The residual of the expected investment model is greater than zero, and the absolute value is taken
Availability of debt financing	Loan	(Total borrowings in the current period - total borrowings in the previous period)/total borrowings in the previous period
The scale of local government debt	Debt	The additional quota of urban investment bonds issued by various prefecture-level city financing platforms pluses 1; then, we take its log
Proportion of fixed assets	PPE	Net value of fixed assets/total assets
The growth of the enterprise	Growth	Growth in the main business
The size of a company	Size	ln(total assets)
Leverage ratio	Lev	Total liabilities/total assets
Cash holdings	Cash	(Monetary funds + net short-term investments)/total assets
Firm age	Age	ln⁅Year established +1⁆
Return on equity	R	Annual return on a single stock taking into account the reinvestment of cash dividends-a weighted average method of the combined annual market return and current market value taking into account the reinvestment of cash dividends
Operating margin	OPR	Net profit/operating income
Investment opportunity	Q	Market value of the company/(total assets at year-end-net intangible assets)
Year-on-year growth rate of M2	M2R	Year-on-year growth rate of M2
Year-on-year GDP growth rate	GDPR	Year-on-year GDP growth

The specific calculation formula is as follows:

$$SA = -0.737^{*}\,\text{Size} + 0.043 * \text{Size}^2 - 0.04^{*}\,\text{Age}. \quad (2)$$

3.3. Model Setting

3.3.1. Local Government Debt and Insufficient Enterprise Investment. If corporate financing, especially bank credit financing, has been squeezed by local government debt, enterprises will face tighter financing constraints. This leads us to wonder whether local government debt is increasing the underinvestment of companies. In order to verify hypothesis 2, a benchmark model (4) was used to test the relationship between local government debt scale and enterprise underinvestment. The model is referenced by the underinvestment model in Zhang [26].

$$\begin{aligned} UnderInv_{j,i,t} = {} & \alpha_0 + \beta_1 Debt_{j,t} + \gamma_1 CF_{i,t} + \gamma_2 Lev_{i,t} cr \\ & + \gamma_6 OPR_{i,t} + \gamma_7 TobinQ_{i,t} + \gamma_8 GDPR_{j,t}\ cr \end{aligned} \quad (3)$$

In model (3), we mainly focus on the coefficient of $\beta 1$. If $\beta 1$ is significantly positive, it means that as the scale of local government debt grows, the underinvestment of enterprises rises.

3.3.2. Local Government Debt, the Proportion of Fixed Assets, and Insufficient Enterprise Investment. In the article, we need to explore whether there is a difference in the impact of local government debt on the underinvestment of enterprises with different fixed asset proportions. We need to find out whether the difference is dominated by the "collateral effect" of fixed assets or by the "irreversible effect" of fixed assets. Based on the basis of model (3), we add the variable L. PPE, which measures the proportion of fixed assets of enterprises lagging behind the first stage, and variable L.PPE × Debt is also added in the article. The interactive items L.PPE × Debt represents the product of the proportion of fixed assets of enterprises lagging behind in one period and local debt. Therefore, the empirical model 4 is constructed, which mainly examines the moderating effect of the ratio of fixed assets to local government debt and the underinvestment of enterprises.

$$\begin{aligned} UnderInv_{i,j,t} = {} & \alpha_0 + \beta_1 Debt_{j,t} + \beta_2 L.PPE_{i,t} \\ & + \beta_3 L.PPE_{i,t} * Debt_{j,t} + \gamma_1 CF_{i,t} \\ & + \gamma_2 Lev_{i,t} + \gamma_3 Growth_{i,t} + \gamma_4 Cash_{i,t} \\ & + \gamma_5 Size_{i,t} + \gamma_6 OPR_{i,t} \\ & + \gamma_7 TobinQ_{i,t} + \gamma_8 GDPR_{j,t} \\ & + \sum Individual + \sum Year + \varepsilon_{it}. \end{aligned} \quad (4)$$

In model (4), we mainly focus on the coefficient of β_3. If β_3 is significantly positive, it indicates that with the increase of the proportion of fixed assets, the influence of the scale of local government debt on the underinvestment of enterprises is strengthened, and the "irreversible effect of assets" of the proportion of fixed assets is dominant. If β_3 is significantly negative, it indicates that with the increase of the proportion of fixed assets, the influence of the scale of local government debt on the underinvestment of enterprises is weakened, and the "mortgage guarantee effect" of the proportion of fixed assets is dominant.

3.3.3. The Test of the Influence Channel of Local Government Debt on the Underinvestment of Enterprises. This paper argues that the increase in local government debt will reduce the availability of corporate debt financing through bank credit channels and bond financing channels, thus leading to the underinvestment of enterprises. This paper adopts a two-step empirical analysis order to verify the influence mechanism of local debt on the underinvestment of enterprises.. First of all, the loan growth rate of enterprises is used as the dependent variable, and the debt growth scale of local government is used as the explanatory variable for the regression. This regression mainly tests the crowding out effect of local debt issuance on corporate debt financing. Then, variable Invest, which represents investment expenditure of the company is used as the dependent variable, and variable Loan, which represents growth rate of corporate loans is used as the explanatory variable for the regression. This regression mainly tests the impact of debt financing on corporate investment. Model (5) and model (6) are as follows:

$$\begin{aligned} Loan_{i,j,t} = {} & \alpha_0 + \beta_1 Debt_{i,j,t} + \lambda_1 PPR_{i,t} + \gamma_2 CF_{i,t} \\ & + \gamma_3 Lev_{i,t} + \gamma_4 Growth_{i,t} \\ & + \gamma_5 Cash_{i,t} + \gamma_6 Size_{i,t} + \gamma_7 OPR_{i,t} + \gamma_8 TobinQ_{i,t} \\ & + \gamma_9 GDPR_{j,t} \\ & + \sum Individual + \sum Year + \varepsilon_{it}. \end{aligned} \tag{5}$$

In model (5), Loan is an indicator to measure the availability of corporate debt financing. If $\beta 1$ is less than 0, it indicates that the growth of local debt squeezes the debt financing of enterprises.

$$\begin{aligned} \mathrm{Invest}_{i,j,t} = {} & \alpha_0 + \beta_1 \mathrm{Loan}_{i,j,t} + \lambda_1 \mathrm{PPR}_{i,t} + \gamma_2 \mathrm{CF}_{i,t} \\ & + \gamma_3 \mathrm{Lev}_{i,t} + \gamma_4 \mathrm{Growth}_{i,t} \\ & + \gamma_5 \mathrm{Cash}_{i,t} + \gamma_6 \mathrm{Size}_{i,t} + \gamma_7 \mathrm{OPR}_{i,t} + \gamma_8 \mathrm{TobinQ}_{i,t} \\ & + \gamma_9 \mathrm{GDPR}_{j,t} \\ & + \sum \mathrm{Individual} + \sum \mathrm{Year} + \varepsilon_{\mathrm{it}}. \end{aligned} \tag{6}$$

In model (6), Invest is an indicator to measure the investment spending of a company. If $\beta 1$ is less than 0, it indicates that the reduced availability of debt financing makes enterprises reduce investment expenditure.

This avoids the influence of the clustering effect, which is at the company level and the annual level, on the standard error.

Table 1 shows the names, symbols, and definitions of the main variables.

4. Empirical Analysis

4.1. Descriptive Statistics. The main descriptive statistics are shown in Table 2.

4.2. Local Government Debt and Insufficient Enterprise Investment

4.2.1. Baseline Regression Results. The estimation results of model (3) on local government debt and enterprise investment underinvestment are shown in Table 3. The regression results of OLS regression were showed in column (1), column (2), and column (3). The individual fixed effect and annual effect were controlled during the regression. The results show that the regression coefficient between the scale of local government debt and the sample of enterprise underinvestment is significantly positive at the 1% level, respectively. Namely, the scale of local government debt (Debt) has a significant positive impact on the underinvestment level (Under_INV) of local listed companies. It means that, with the expansion of local government debt scale, the phenomenon of underinvestment in enterprises also increases. The results confirm the prediction in economic theory that the expansion of government debt will crowd out private investment, and hypothesis 1 is supported.

In terms of the regression results of microcontrol variables, the cash flow coefficient generated by the business activities of enterprises is significantly negative, indicating that enterprises with good cash flow can alleviate the degree of underinvestment. The coefficient of enterprise scale and leverage financial leverage is significantly negative, indicating that with the increase of enterprise scale and financial leverage, the phenomenon of underinvestment will be alleviated. The coefficient of cash holding and growth of enterprises is significantly positive, indicating that the increase in cash holding and growth level will increase the underinvestment of enterprises. The main reason is that enterprises with insufficient investment often lack relatively stable and low-cost financing channels, so they need to hold a certain cash flow to prepare for an unexpected "liquidity shock." As cash holdings are hoarded, the scale of enterprise investment expenditure will fall, thus resulting in underinvestment. Companies with good growth prospects are usually small-scale and have been established for a short time, and they are often faced with relatively strong financing constraints. The more a company grows, the more it shows strong precautionary cash holding. Therefore, with the growth of enterprises, the phenomenon of underinvestment increases. The coefficient of operating profit ratio (OPR) and investment opportunity (TobinQ) is significantly positive, but the coefficient value closes to zero, indicating that the underinvestment level of listed companies is not strongly correlated with profitability and investment opportunities.

4.2.2. Heterogeneity Analysis

(1) Heterogeneity of Ownership Attributes. State-owned enterprises in our country often have implicit government guarantees due to the care of fatherhood that comes from

Table 2: Descriptive statistics of major variables.

Variable	Mean	Sd	min	p50	Max
Under INV	0.0122	0.0148	0.0022	0.0314	0.0985
Over INV	0.0904	0.1135	0.0031	0.0547	0.3846
Loan	0.0632	0.4256	−0.3584	0.0221	0.2267
Debt	5.1324	2.3458	0.0017	4.5426	6.8642
PPR	0.1856	0.1435	0.0014	0.1359	0.9227
Growth	0.2654	0.5324	−0.4358	0.1046	3.2416
Size	26.2451	1.4652	18.7652	23.4508	24.5138
CF	0.0347	0.1138	−0.2541	0.0254	0.3385
Lev	0.3846	0.2456	0.0457	0.3184	0.8756
Cash	0.2754	0.1807	0.0216	0.1358	0.9648
OPR	0.3561	24.6859	−1.3568	0.1085	1.2648
TobinQ	3.1652	7.6258	0.1854	2.2437	72.1548
Age	2.4239	0.5429	1.0423	2.4585	2.4584
BC	0.6854	0.3755	0.0042	0.8756	0.8456
OC	53.1435	16.7548	13.2456	57.8546	97.5848
GDPR	0.1852	0.1854	−0.9617	0.1237	0.2345

Table 3: Local government debt and insufficient enterprise investment.

Variables	(1) Under_INV	(2) Under_INV	(3) Under_INV
Debt	0.006**	0.008**	0.012***
	(5.48)	(3.42)	(1.56)
CF	−0.018***	−0.126**	−0.026***
	(−11.24)	(−4.07)	(−5.64)
Lev	−0.107**	−0.042***	−0.068**
	(−18.65)	(−6.53)	(−5.14)
Growth	0.005***	0.002**	0.002**
	(4.99)	(2.34)	(2.26)
Cash	0.018***	0.124***	0.026***
	(12.15)	(4.25)	(6.12)
Size	−0.252***	−0.012***	−0.026***
	(−28.26)	(−4.14)	(−6.85)
OPR	0.001***	0.006***	0.006***
	(20.15)	(54.56)	(36.54)
TobinQ	0.008**	0.026***	0.011***
	(2.24)	(4.46)	(2.56)
GDPR	−0.015*	0.026***	0.002
	(−1.26)	(2.25)	(1.96)
Observations	9542	9542	9542
Adjusted *R*-squared	0.245	0.054	0.056
Individual effect	Yes	No	Yes
The annual effect	No	Yes	No
Control variables	No	No	Yes
F	565.4	618.6	258.6

Note : ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

local government [27]. The care allowed state-owned enterprises to be bailed out by the government in the event of failed investments and financial difficulties. Therefore, compared with private enterprises, state-owned enterprises have unique advantages in external financing because of their "soft budgetary constraint." In the context of the expansion of local government debt, the underinvestment level of state-owned enterprises is not affected. However, local government debt squeezes more external sources of capital for private companies, thus resulting in a rise in underinvestment. We need to investigate whether there is a heterogeneity between local government debt and enterprise

investment insufficiency, due to the difference in enterprise ownership attributes. Model (3) is used for sample regression. The cross product of dummy variable of ownership attribute (NSOE) and local government debt (Debt) is added into model (3), and then model (7) is constructed.

$$\begin{aligned} UnderInv_{i,j,t} = {} & \alpha_0 + \beta_1 Debt_{j,t} + \beta_2 NSOE_i \\ & + \beta_3 NSOE_i * Debt_{j,t} + \gamma_1 CF_{i,t} \\ & + \gamma_2 Lev_{i,t} + \gamma_3 Growth_{i,t} + \gamma_4 Cash_{i,t} \\ & + \gamma_5 Size_{i,t} + \gamma_6 OPR_{i,t} \\ & + \gamma_7 TobinQ_{i,t} + \gamma_8 GDPR_{j,t} \\ & + \sum Individual + \sum Year + \varepsilon_{it}. \end{aligned} \tag{7}$$

If the property of enterprise ownership is non-state-owned, the value of NSOE is 1. If the property of enterprise ownership is a state-owned enterprise, the value of NSOE is 0. We predict that the coefficient of β_3 is positive. It means that, compared with state-owned enterprises, non-state-owned enterprises will faced a more serious crowding-out effect, which comes from the local government debt.

Columns (1) and (2) of Table 4 show the regression results for model (3) based on the ownership attribute, In column (1), the scale of local government debt and underinvestment of enterprises is significantly negative, suggests that an increase in the scale of local government debt reduces the level of underinvestment of state-owned enterprises. In column (2), the scale of local government debt and underinvestment of enterprises is positive, suggesting that an increase in the scale of local government debt increases the level of underinvestment of non-state enterprises. In column (3), the dummy variable for ownership attributes, NSOE × Debt is significantly positive, which indicates that an increase in the scale of local government debt causes more severe underinvestment in private enterprises.

(2) Heterogeneity under Different Financing Constraints. Debt financing is the main external financing for enterprises. It refers to the working capital or capital expenditure raised by the enterprise through the sale of bonds and notes to individual or institutional investors. Individual or institutional investors lend funds, become the creditors of the company, and obtain the commitment of the company to repay the principal and interest. The financing decision-making of enterprises should consider the financing channels and financing costs, so a series of financing theories have been produced. As for enterprises with tight financing constraints, when they face the "squeeze" of local government debt on bank credit resources and the "substitution" of corporate bonds, the degree of underinvestment will increase. Compared with enterprises with lower financing constraints, enterprises with tight financing constraints tend to reduce the scale of their investments scale. In order to investigate whether there is a heterogeneity between local government debt and enterprise investment insufficiency due to the difference in the degree of financing constraints, model (3) is used for sample regression, according to the degree of financing constraints. The cross product of dummy variables of financing constraints (FC) and local government debt (Debt) is added into model (3), and then model (8) is constructed.

$$\begin{aligned} UnderInv_{i,j,t} = {} & \alpha_0 + \beta_1 Debt_{j,t} + \beta_2 FC_{i,t} \\ & + \beta_3 FC_{i,t} * Debt_{j,t} + \gamma_1 CF_{i,t} \\ & + \gamma_2 Lev_{i,t} + \gamma_3 Growth_{i,t} + \gamma_4 Cash_{i,t} \\ & + \gamma_5 Size_{i,t} + \gamma_6 OPR_{i,t} \\ & + \gamma_7 TobinQ_{i,t} + \gamma_8 GDPR_{j,t} \\ & + \sum Individual + \sum Year + \varepsilon_{it}. \end{aligned} \tag{8}$$

According to the financing constraint SA index, the samples were divided into two groups according to the quantile statistics. Those with less than 50% quantile were in the low financing constraint group, while those with more than 50% quantile were in the high financing constraint group. When the sample enterprise is in the group with high financing constraints, the value of FC is 1. When the sample enterprise is in the group with low financing constraints, the value of FC is 0. We predict that the coefficient of $\beta 3$ is positive. That is, compared with enterprises with low financing constraints, enterprises with high financing constraints will face a more serious crowding out effect.

The regression results of model (8) are shown in columns (1) and columns (2) in Table 5. According to the financing constraint SA index, the underinvestment enterprises were divided into two groups: enterprises with low financing constraints and enterprises with high financing constraints. In the group with high financing constraints, the coefficient between local debt and underinvestment was significantly positive. It shows that regardless of whether enterprises have low financing constraints or high financing constraints, the increase in local debt causes an increase in the level of underinvestment in enterprises. Meanwhile, the positive effect of local debt on the level of underinvestment of enterprises with low financing constraints is slightly greater than that of enterprises with high financing constraints. In column (3), the cross product of the dummy variable CF, which represents the degree of financing constraint, and local government debt (Debt), is significantly positive. This means that the increase in local government debt will cause more serious underinvestment for enterprises with tight financing constraints. The impact of local government debt on underinvestment has different results among enterprises with different financing constraints.

4.2.3. The Heterogeneity of Different Investment Industries. Local debt funds mainly flow to infrastructure projects in the region. The project investment process is an organizational configuration process based on the project's own stakeholders. The investment subject of the project needs to focus on the construction of the infrastructure project and gather the construction party, investor, and material supplier of the project. Among the infrastructure enterprises cooperating

Table 4: The regression results of local debt and enterprise investment under different ownership attributes.

Variables	(1) State-owned enterprises Under_INV	(2) Non-state-owned enterprises Under_INV	(3) Under_INV
Debt	−0.008** (−0.85)	0.009*** (3.26)	−0.007*** (−0.46)
NSOE × Debt			0.008** (3.37)
Adjusted *R*-squared	0.207	0.158	0.254
Individual effect	No	Yes	Yes
The annual effect	Yes	Yes	No
Control variable	No	Yes	Yes
F	257.6	18.52	248.7

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

Table 5: The regression of local debt and enterprise investment under different financing constraints.

Variables	(1) Low financing constraints Under_INV	(2) High financing constraints Under_INV	(3) Under_INV
Debt	0.017** (0.46)	0.012*** (3.14)	0.019 (0.46)
FC			−0.253 (−1.89)
FC × Debt			0.038** (1.85)
Adjusted *R*-squared	0.168	0.047	0.185
Individual effect	Yes	No	Yes
The annual effect	Yes	Yes	No
Control variable	No	Yes	Yes
F	286.4	11.37	314.5

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

with the government, construction enterprises account for most of the enterprises. According to the results of the national local debt audit in 2011 and 2013, the outstanding expenditures of local government debt were mainly used for basic and public welfare projects such as municipal construction, land purchase and storage, transportation, low-income housing, education, science, culture, and health, agriculture, forestry, water conservancy, and ecological construction, accounting for 86.54% and 86.77% of the total local debt in the same year, respectively. Therefore, the sharp increase in local government debt has less impact on the investment of enterprises investing in the industry. However, it has a greater impact on enterprises that are not invested in the industry. In order to analyze whether the impact of the expansion of local government debt on the underinvestment of listed companies is related to their industries, the paper divides the local government debt expenditure into the following industries: (1) Transportation, warehousing, postal services;(2) water conservancy, environmental , public facilities management; (3) electricity, heat, gas , water production and supply; (4) residential services, repairs, and, other services; (5) education; (6) health, and, social work; (7) culture, sports, and, recreation; (8) construction. If the enterprise does not invest money to the industry above, the value of INDU is 1. If the enterprise invests the money to the industry above, the value of INDU is 0. In order to investigate whether there is the heterogeneity between local government debt and enterprise investment insufficiency, due to the difference of industry attributes, model (3) is used for sample regression, according to the difference of industry attributes. The cross product of dummy variable of financing constraints (FC) and local government debt (Debt) is added into model (3), and then model (9) is constructed.

$$\begin{aligned} UnderInv_{i,j,t} = {} & \alpha_0 + \beta_1 Debt_{j,t} + \beta_2 INDU_i cr \\ & + \gamma_2 Lev_{i,t} + \gamma_3 Growth_{i,t} + \gamma_4 Cash_{i,t} cr \\ & + \gamma_7 TobinQ_{i,t} + \gamma_8 GDPR_{j,t}\ cr \end{aligned} \quad (9)$$

We predict that the coefficient of β_3 is positive. It means that if companies do not belong to one of these eight sectors, the squeeze from government debt is significant.

The regression results of model (9) are shown in the columns (1) and column (2) in Table 6, according to the industry group. The dummy variables for the degree of financing constraints are all significantly positive, suggesting that in both enterprises that are invested in the industry and enterprises that are not invested in the industry, an increase in local debt causes an increase in the level of

Table 6: Insufficiency under the attribute of different industries.

Variables	(1) Invet to the industry Under_INV	(2) Invet not to the industry Under_INV	(3) Under_INV
Debt	0.019** (0.26)	0.004*** (1.86)	0.065** (0.16)
INDU × Debt			0.016* (1.28)
Adjusted *R*-squared	0.108	0.208	0.135
Individual effect	No	Yes	Yes
The annual effect	Yes	Yes	No
Control variable	Yes	Yes	No
F	942.5	22.15	308.6

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

underinvestment by firms, while the positive effect of enterprises that are invested in the industry level of underinvestment is slightly greater than that of enterprises that are not invested in the industry. As for the results in column (3), the cross term between the dummy variable INDU, which represents the industry attribute and local government debt (Debt) is significantly positive, indicating that local government debt will cause more serious underinvestment for these enterprises that do not belong to the industry that local government debt invests in.

4.3. Local Government Debt, Proportion of Fixed Assets, and Insufficient Enterprise Investment. The regression results of model (4) are shown in Table 7. The coefficient of PPE × Debt of the ratio of fixed assets and local debts is significantly greater than 0, indicating that the increase of local government debt will have a greater impact on the underinvestment of enterprises, that have a higher ratio of fixed assets. This shows that the "irreversible effect of assets" plays a dominant role in regulating the relationship between local government debt and enterprise investment deficiency. With the increase in the proportion of fixed assets, enterprises will have greater probability to bear the sunk cost, transaction cost and fall into financial difficulties. With external financing constrained by local government debt, companies with more irreversible assets are more likely to cut investment spending.

4.4. The Test of the Influence Channel of Local Government Debt on the Underinvestment of Enterprises. The regression results of model (5) are shown in Table 8. On the whole, the regression coefficient between the scale of local government debt and the availability of corporate debt financing is negative significant, which is at the significance level of 1%. It means that local government debt has a crowding-out effect on corporate debt financing.

In columns (2) and (3), the regression coefficients between the scale of local government debt of SOEs, and *n* non-SOEs enterprises and the availability of corporate debt financing are *s* significantly negative at levels of 1% and 5%, respectively, the absolute value of the impact coefficients is larger than the coefficients of the whole sample. It shows that whether state-owned or non-state-owned enterprises, local debt increases crowding out affect the availability of corporate debt financing. The negative impact of the scale of local government debt on corporate debt financing is greater for nonSOEs than for SOEs, indicating that the scale of local debt has a greater significant impact on nonSOEs. In columns (4) and (5), the regression coefficients between the scale of local government debt of invet to the industry and Invet not to the industrial enterprises and the availability of corporate debt financing are significantly negative in levels 1% and 5%, respectively, the absolute value of the impact coefficients is larger than the coefficients of the whole sample, It shows that whether invet to the industry enterprises or Invet not to the industry enterprises, local government debt increases crowding-out effect the availability of corporate debt financing. The negative impact of the scale of local government debt on corporate debt financing is greater for Invet not to the industrial enterprises than for invet to the industry enterprises, indicating that the scale of local debt has a greater significant impact on not to the industry enterprises.

The regression results of model (6) are shown in Table 9, which mainly test the change of corporate debt financing on corporate expenditure. The coefficient of corporate debt financing and local debt is significantly positive at the significance level of 1%. This result is not affected by the overall regression results nor the sample regression results. The samples mainly refer to state-owned enterprises and non-state-owned enterprises, invested industries and non-invested industries. The increase of corporate debt financing can increase corporate investment expenditure. In other words, enterprise's investment expenditure is highly sensitive to the change of enterprise's debt financing. When enterprise's debt financing is squeezed by local debt, enterprise will reduce investment expenditure.

Based on the regression results in Tables 8 and 9, the influence mechanism of local debt on the underinvestment of enterprises is verified. The expansion of local government debt is crowding out the debt financing channels of corporations in the bond market and financial institutions such as banks. However, the investment expenditure of enterprises is very sensitive to the increase or decrease of debt financing, and the reduction of debt financing makes

Table 7: Regulating effect of different fixed assets proportion.

Variables	(1) Invet to the industry Under_INV	(2) Invet not to the industry Under_INV	(3) Under_INV
Debt	0.019** (0.26)	0.004*** (1.86)	0.065** (0.16)
INDU × Debt			0.016* (1.28)
Adjusted *R*-squared	0.108	0.208	0.135
Individual effect	No	Yes	Yes
The annual effect	Yes	Yes	No
Control variable	Yes	Yes	No
F	942.5	22.15	308.6

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

Table 8: Local government debt and the availability of corporate debt financing.

Variables	(1) Whole sample	(2) State-owned enterprise	(3) Non-state-owned enterprise	(4) Invet to the industry	(5) Invet not to the industry
	Loan	Loan	Loan	Loan	Loan
Debt	−0.038*** (−2.86)	−0.045*** (−0.68)	−0.107** (−3.16)	−0.054*** (−0.39)	−0.113** (−3.25)
Adjusted R^2	0.249	0.165	0.254	0.281	0.217
Individual effect	Yes	Yes	No	Yes	No
The annual effect	Yes	Yes	Yes	Yes	Yes
Control variable	Yes	Yes	Yes	No	Yes
F	59.65	33.24	24.25	25.64	30.13

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

Table 9: Regression of debt financing and corporate investment.

Variables	(1) Whole sample	(2) State-owned enterprise	(3) Non-state-owned enterprise	(4) Invet to the industry	(5) Invet not to the industry
	Invest	Invest	Invest	Invest	Invest
Loan	0.146*** (17.54)	0.234*** (11.36)	0.068** (14.17)	0.124*** (16.54)	0.023** (8.64)
Adjusted R^2	0.314	0.185	0.264	0.288	0.184
Individual effect	Yes	Yes	Yes	No	Yes
The annual effect	Yes	No	Yes	No	Yes
Control variable	Yes	Yes	Yes	Yes	No
F	64.38	28.65	38.46	58.64	13.56

enterprises reduce investment expenditure, thus showing the phenomenon of underinvestment.

5. Robustness Test

To a large extent, the robustness of the above research conclusions depends on the reliability measured by underinvestment and the reliability of urban investment bond data. The methods of reducing the number of sample and changing the estimation method of underinvestment are used to further test the robustness of the above conclusions. The regression of model (3) is carried out again by using these urban investment bond data, collected and published by existing scholars.

5.1. Reducing the Number of the Sample and Changing the Estimation Method of Underinvestment. First of all, considering that there are few enterprises that meet the expected investment expenditure in the expected investment model (1), the residual value, which is greater than 25% quantile and less than 75% was eliminated in this paper. The residual represents the cost of the firm's inefficient investment. If the residual is

Table 10: Regression results of reducing the sample and reestimating firm underinvestment.

Variables	(1) Under_INV	(2) Over_INV	(3) Under_INV	(4) Over_INV
Debt	0.128***	0.025**	0.008***	0.006**
	(1.85)	(0.32)	(2.58)	(0.54)
Adjusted *R*-squared	0.118	0.238	0.164	0.224
Individual effect	Yes	Yes	Yes	Yes
The annual effect	No	Yes	Yes	Yes
Control variable	Yes	Yes	Yes	Yes
F	8.567	9.234	225.6	16.58

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

greater than 0, it means the company has overinvested, which is recorded as Over_INV. If the residual is less than 0, it means that the company has underinvested. For the convenience of understanding, the absolute value of the sample with a residual of less than 0 is taken in the regression analysis to measure the degree of underinvestment, which is recorded as Under_INV. Secondly, the growth of investment opportunities in the expected investment model is replaced by the TobinQ with a lag phase. And then the underinvestment was reestimated and the model (3) was reregressed. The regression results of the reduction sample are shown in column 1 and column 2 in Table 10. The regression results of changing the underinvestment estimation method are shown in column 3 and column 4. The regression results of enterprise underinvestment and local government debt are consistent with the above results, both of which are significantly positive. The increase in local government debt will reduce enterprises' underinvestment, which is specifically manifested as underinvestment.

5.2. Substitution Independent Variable. In this paper, two alternative independent variables are used to test the robustness of the results. First of all, the independent variable Debt was replaced by a dummy variable Debt_Dum. Variable debt represents the number of urban investment bonds issued in the city where the enterprise is located. If the city where the enterprise is located has issued urban investment bonds, the value of Debt_Dum is set to 1 in that year, otherwise it is set to 0. This can reduce the influence of some extreme values on the regression results. In addition, Inverse Hyperbolic Sine (IHS), the amount of bonds issued after the transformation, is used as a variable to reflect the issuance scale of urban investment bonds, according to some research by Mao Jie [28]. The regression result after replacing the independent variable is shown in Table 11. The calculating formula is ln (Debt IHS) = ln [the number of debt issuance + ((the number of debt issuance)^2 + 1)$^{1/2}$].

Table 11: The regression result is after replacing the independent variable.

Variables	(1) Under_INV	(2) Under_INV
Debt_Dum	0.122***	
	(3.16)	
DebtIHS		0.018***
		(2.26)
Adjusted *R*-squared	0.215	0.264
Individual effect	Yes	Yes
The annual effect	Yes	No
Control variable	Yes	Yes
F	265.4	282.4

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

6. Further Studies

6.1. A Quasi-Natural Experiment Based on the New Budget Law. The debt capital is financed by a local financing platform and is mainly used for the construction of local infrastructure and public goods. The payback of a project invested in debt is longer, and the return on the project is low. If we only rely on the low yield of the financing vehicle itself, it is difficult to repay the principal and interest when the debt matures. Based on this, if local financing vehicles are "real" debt subjects, banks and bond market investors will not lend money and buy the issued bonds at a lower rate, which is less than the average corporate loan interest rate and average corporate bond yield. And then the "crowding out effect" of local debt on corporate debt financing will be weakened or even nonexistent. However, in our country, the government often acts as the "actual controller" of the local financing platform. The government can inject a large number of land assets controlled by local state-owned enterprises' equity into the financing platform and also increase government subsidies for financing platforms. Therefore, the government not only provides invisible guarantees for financing platform, but also helps to improve enterprise profitability to meet the regulatory 'threshold' for issuing of corporate bond [29]. Based on this, banks and investors assess the default risk of financing vehicles and urban investment bonds to be much lower than that of general corporate bonds. Therefore, government debt can have a "squeeze effect" on corporate debt financing, thus affecting corporate investment and resulting in underinvestment. In other words, if the relationship between the government and urban investment companies is weakened and the confidence of banks and investors in the implicit government guarantee is shaken, then the crowding out effect of local debt on corporate debt financing will also be weakened. Since January 1, 2015, the implementation of the New Budget Law has provided us with an excellent opportunity for quasi-natural experiment. After the new law takes effect, local government debt can only be in the form of

government bonds. At the same time, local government debt is implemented through quota management. Now the debts that come from financing platforms don't't belong to the government debt. The introduction of the ≪New Budget Law≫ clarifies the responsibilities of the government and enterprises. It means that government debts shall not be borrowed through corporate financing platforms, and corporate debts shall not be repaid by the government, which ensures that who borrows what and who pays what and take risks on their own, further demarcating the boundary between financing vehicles and local government debt. Therefore, after the establishment of the new law, the implicit guarantee and guarantee effect brought by the local government to enterprises will be reduced, and the "crowding out effect" on enterprises will be weakened. The status quo of enterprises' underinvestment will be alleviated.

Based on the above analysis, the DID model was constructed in this paper to study the impact of the ≪New Budget Law≫ on the underinvestment of enterprises. In this paper, the dummy variable was designed to represent the implementation of the ≪New Budget Law≫. The value of the dummy variable is 1, when the years are 2015 and after 2015. While in other years, the value of the dummy variable is 0. The phenomenon of under-investment appeared in non-state-owned enterprises, because that the local debt significantly squeezed out the debt financing of non-state-owned enterprises. However, this crowding out effect is not obvious in state-owned enterprises. Therefore, non-state-owned enterprises were set as the experimental group and state-owned enterprises as the control group. And then a double difference model (10) and triple difference model (11) were constructed.

$$\begin{aligned} UnderInv_{i,j,t} &= \alpha_0 + \beta_1 Law_t * NSOE_i + \gamma_1 CF_{i,t} + \gamma_2 Lev_{i,t} \\ &\quad + \gamma_3 Growth_{i,t} + \gamma_4 Cash_{i,t} + \gamma_5 Size_{i,t} + \gamma_6 OPR_{i,t} \\ &\quad + \gamma_7 TobinQ_{i,t} + \gamma_8 GDPR_{j,t} \\ &\quad + \sum Industrial + \sum Year + \varepsilon_{it}, \\ Loan_{i,j,t} &= \alpha_0 + \beta_1 Law_t * NSOE_i + \beta_2 debt_{j,t} \\ &\quad + \beta_5 Law_t * NSOE_i * debt_{j,t} + Control_{i,t}. \end{aligned} \tag{10}$$

In model (9), the coefficient β_1 is the mainly concern. If β_1 is less than 0, it indicates that the underinvestment of enterprises has been alleviated after the implementation of the new law. In model (10), the coefficient β_5 is mainly concerned. If β_5 is less than 0, it indicates that the crowding out effect of local debt on corporate debt financing decreases after the implementation of the new law.

The regression results of model (10) and model (11) are shown in column (1) and column (2) of Table 12, respectively. Since the annual fixed effect and enterprise fixed effect have been controlled in the model, the regression results do not include the variables Law and SOE separately. The coefficient β_1 of model (9) is significantly negative at the significance level of 5%. It means that the underinvestment level of enterprises has improved after the implementation of the New Budget Law. The coefficient β_5 in model (10) is significantly negative at the significance level of 5%. It means that the crowding out effect of local debts on enterprises' debt financing has weakened after the implementation of the new law.

Table 12: Quasi-natural experiment and the economic consequence of regression based on the new budget law.

Variables	(1) Under_INV	(2) Loan	(3) TobinQ
Debt		−0.207***	−0.214***
		(−1.36)	(−1.86)
Law × NSOE	−0.128**	0.148*	
	(−1.86)	(1.84)	
NSOE × Debt		0.128	
		(0.84)	
Law × Debt		0.058**	
		(1.86)	
Law × Debt × NSOE		−0.186***	
		(−2.64)	
Under_INV			−5.546**
			(−3.18)
Debt × Under_INV			2.126***
			(7.58)
Adjusted R-squared	−0.426	−0.152	−0.138
Individual effect	Yes	Yes	Yes
The annual effect	Yes	No	Yes
Control variable	Yes	Yes	Yes
F	44.58	62.58	90.18

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

6.2. The Economic Consequences of Insufficient Investment. With the increase of local government debt, the amount of enterprise investment will be significantly reduced, leading to the underinvestment of enterprises. Then what are the economic consequences of underinvestment? We analyze the economic consequences caused by local debt from the perspective of enterprise value. The information about an enterprise investment decision is easily captured by relevant stakeholders and market investors. And investors will judge the value of the business. Therefore, the lack of debt funds may cause enterprises to miss a lot of development opportunities, thus adversely affecting the market value of enterprises. In order to verify this hypothesis, Tobin Q as the measurement index of enterprise value was used in this paper. The interaction term of Debt × Under_INV was added into the model, which is the product of local government debt (Debt) and underinvestment (Under_INV), to test the impact of underinvestment driven by local government debt on enterprise value. The result of column (3) in Table 12 shows that the regression coefficients of local government debt and underinvestment are both negative, and he regression coefficients of Debt × Under_INV are positive which are both significant at the 1% significance level. This indicates that the increase of local government debt and the increase of underinvestment significantly reduce the value of enterprises. With the increase of local government debt, the investment of enterprises is gradually squeezed out, which is not conducive to the improvement of enterprise value.

Table 13: Partial effect of local government debt on the effect of monetary policy (underinvestment).

Variables	(1) Whole sample Under_INV	(2) Non-state-owned enterprise Under_INV	(3) State-owned enterprise Under_INV	(4) Invet not to the industry Under_INV	(5) Invet to the industry Under_INV
Debt	0.124*** (6.38)	0.014*** (5.68)	0.018** (0.86)	0.018*** (5.18)	0.009** (0.46)
MP	−0.024*** (−2.18)	−0.004*** (−1.58)	−0.034*** (−3.68)	−0.218*** (−1.58)	−0.128 (−0.84)
MP × debt	−0.015** (−1.46)	−0.008** (−1.58)	−0.028*** (−0.26)	−0.009** (−2.86)	−0.014*** (−0.18)
CF	−0.038*** (−5.65)	−0.142*** (−5.64)	−0.128*** (−4.86)	−0.114** (−2.56)	−0.128*** (−2.68)
Lev	−0.108** (−8.42)	−0.318*** (−7.52)	−0.026*** (−6.52)	−0.028** (−7.85)	−0.084*** (−1.85)
Growth	0.014** (2.58)	0.018** (3.58)	−0.018*** (−0.15)	0.023*** (1.84)	0.014** (1.08)
Cash	0.014*** (7.58)	0.028*** (5.68)	0.012** (5.42)	0.142*** (8.56)	0.108*** (6.25)
Size	−0.024** (−5.46)	−0.024*** (−6.58)	−0.018*** (−3.86)	−0.084*** (−6.58)	−0.065** (−3.86)
OPR	0.028*** (38.18)	0.008** (0.14)	0.005*** (53.46)	0.018 (0.68)	0.264*** (34.58)
TobinQ	0.018** (1.84)	0.003** (1.46)	0.024*** (3.54)	0.082** (3.48)	0.124*** (2.14)
GDPR	−0.014*** (−0.24)	−0.008** (−0.38)	0.005** (0.24)	−0.007*** (−0.58)	0.468* (0.86)
Adjusted R-squared	0.034	0.018	0.104	0.034	0.028
Individual effect	Yes	Yes	NO	Yes	Yes
The annual effect	NO	NO	NO	Yes	NO
Control variable	Yes	Yes	Yes	Yes	Yes
F	181.54	17.64	482.28	18.46	332.46

Note. ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

6.3. Indirect Impact of Local Government Debt on Underinvestment in Enterprises. In the above benchmark equation, we analyzed the direct impact of local government debt on the underinvestment of enterprises. The expansion of local government debt has a wide and far-reaching impact. Will it affect the investment of enterprises through the partial effect of other variables? Therefore, the indirect impact of local government debt on the underinvestment of enterprises was discussed in further research: Does local government debt affect the effectiveness of monetary policy?.

The traditional theory holds that loose monetary policy can effectively reduce the market interest rate on money by increasing the money supply. The short-term price of the means of production can stimulate enterprises to expand the scale of investment and improve the phenomenon of underinvestment. However, enterprises (especially non-state-owned enterprises and manufacturing industries) have been suffering from sluggish investment in China. It seems that not all the funds released by the central bank have gone into industrial investment. The effect of stimulating industrial investment is relatively weak, resulting in an increasingly high cost of stimulus policies. This situation may be due to the expansion of local government debt rules. In addition, a considerable part of the liquidity released by the loose monetary policy flows into local government debt, thus affecting the transmission effect of monetary policy to boost the real economy. Based on this, the dummy variables of monetary policy and the cross product of local debt and monetary policy were added into model (3):

$$\begin{aligned} UnderInv_{i,j,t} = {} & \alpha_0 + \beta_1 debt_{j,t} + \beta_2 Mp_t \\ & + \beta_3 debt_{j,t} * Mp_t + \gamma_1 CF_{i,t} \\ & + \gamma_2 Lev_{i,t} + \gamma_3 Growth_{i,t} + \gamma_4 Cash_{i,t} \\ & + \gamma_5 Size_{i,t} + \gamma_6 OPR_{i,t} \\ & + \gamma_7 TobinQ_{i,t} + GDPR_{j,t} \\ & + \sum Individual + \varepsilon_{it}. \end{aligned} \tag{11}$$

The annual monetary policy variable was set in this paper. If the year is a year of tight monetary policy, the value of the variable is 0. If this year is a year of loose monetary policy, the value of the variable is 1. Monetary policy is

defined as follows: HP filtering was applied to the M2 growth rate time series to generate long-term trend terms and periodic fluctuation terms. If the periodic fluctuation is greater than zero, then the corresponding year is defined as the year of monetary policy easing, and if it is less than zero, it is defined as the year of monetary policy tightening. Within the sample period, 2011–2015 are the years of monetary easing, 2016–2021 are the years of monetary tightening.

The estimated results of equation (11) are reported in Table 13. The coefficient of MP is negative significant, which indicates the loose monetary policy can alleviate the problem of underinvestment by businesses. The coefficient of cross product between MP, a dummy variable of loose monetary policy, and local government debt (Debt) is significant negative. This suggests that the increase in local government debt has weakened the effect of easy monetary policy. The weakening effect is significant between non-state-owned enterprises and enterprises in nonlocal government debt input industry, but not significant between state-owned enterprises and enterprises in nonlocal government debt input industry. This suggests that the money injected by loose monetary policy is likely to be absorbed as local government debt rises in short term. The money should have gone to private and noninvested companies.

7. Conclusions and Policy Recommendations

This paper mainly studies the impact of local government debt on the underinvestment of enterprises. Conclusions are drawn in the article that with the increase in local debt, business underinvestment has increased. This kind of phenomenon is most obvious in state-owned enterprises, enterprises with high financing constraints, and enterprises with local debt invested in the industry. The issuance data of urban investment bonds at the city level, which is a proxy indicator to measure local debt growth, is used in the empirical process. The main reason is that the increase in local debt has squeezed the channels of debt financing for local companies. This crowding out effect is obvious in nonstate-owned enterprises and enterprises whose nonlocal government debts are invested in the industry. We compared with enterprises with a low fixed assets ratio, enterprises with high fixed assets ratio will have a less positive impact of local debt on the underinvestment in enterprises. This is mainly due to the role of fixed assets as collateral. In the further study, the conclusion is drawn that the "crowding out effect" of local debt will cause the decline of enterprise value. Finally, it is found that the monetary fund brought by the loose monetary policy in the short-term are likely to be absorbed by the increase in local government debt. However, this fund should have gone to private enterprises and enterprises whose money is not invested in industry.

The conclusion of this paper provides new clues and empirical evidence for the current sluggish investment in China's enterprise sector, which has very important policy implications. For a long time, local governments have been expanding their own debt to achieve the goal of economic development while ignoring the fact that the increase in local debt will squeeze out financing channels of real enterprises that are in urgent need of external capital support, thus leading to the underinvestment of enterprises. Local governments should properly handle the scale of government debt issuance in the course of steady economic growth, and should not interfere too much in the flow of credit funds. The government should give full play to the role of the market in resource allocation and let capital flow to efficient sectors.

Data Availability

The tables used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Implementation of Sustainable Supply Chain Management considering Barriers and Hybrid Multiple-Criteria Decision Analysis in the Healthcare Industry

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This research aims to find the barriers that affect the implementation of sustainable supply chain management (SSCM) and rank them using hybrid multiple-criteria decision analysis (MCDA) methods in the healthcare industry. As companies seek to earn revenue by providing goods or services to customers, they must also consider social responsibility, economics, and the environment as other multiple external factors. One of the most crucial factors is the company's stewardship of the environment, but economic factors must be regarded when keeping the environment clean by balancing the economic situation to make a profit. This study extracts the barriers to implementing SSCM from previous studies, adapts these barriers to the healthcare industry, and ranks them using a hybrid best-worst method (BWM) and combined compromise solution (CoCoSo) method. The result indicates that hospital 7 should rank SSCM higher than the other six healthcare centers evaluated. Moreover, among the barriers, high disposal costs is the most crucial factor when considering implementing SSCM.

1. Introduction

Healthcare is one of the most significant industries that play a critical role in life. It is also a crucial factor in assessing a country's level of development [1]. The healthcare industry can help people survive illnesses, and it can be a source of profit for a country in terms of attracting healthcare tourism [2]. Even though healthcare is one of the most significant sources of pollutant materials for the environment, recycling such materials requires large budgets and unique processes [3]. However, providing materials for hospitals and healthcare centers is very important [4]. A delay in delivering critical materials and facilities to these centers translates into multiple deaths [5]. Hence, implementing supply chain management (SCM) with a protected environment at a fair profit is an arduous task.

SCM is converting raw materials into final goods or services delivered to end-users, encompassing procurement, processing, inventory, shipping, etc [6]. Designing the best approach for these activities decreases production costs and increases customer satisfaction [7]. The SCM process consists of many parts, each having a crucial role in delivering the best result [8]. Many other relevant concepts have emerged after the SCM concept such as green SCM, fourth-party logistics (4PL), third-party logistics (3PL), etc. One such concept is sustainable SCM (SSCM), which is closely

related to green SCM. Whereas green SCM focuses on environmental issues only; SSCM, in addition to environmental issues, encompasses substantial other problems such as economics [9]. Hence, SSCM is a more developed and complex approach than green SCM.

SSCM has many barriers to implementation in the real world [10]. However, companies are challenged to design improvement programs to eliminate these barriers because of limited resources in terms of human resources (HR), financial issues, information, time, etc. Therefore, first and foremost, barriers must be identified. Second, barriers must be customized according to the research environment and then ranked to find each barrier's degree of importance. Many methods have been used for ranking factors. One of the most popular and valuable methods is multi-criteria decision analysis (MCDA). In this study, the best-worst method (BWM) and the combined compromise solution (CoCoSo) method will be applied to rank both the barriers and the hospitals to find which hospitals need to give more attention to implementing SSCM.

The contribution of this research is the combination of BWM and CoCoSo methods to rank barriers to implementing sustainable supply chain management (SSCM) in the healthcare industry. Although ranking barriers to SSCM is one of the most popular topics among researchers, using a combination of BWM and CoCoSo is a novel approach to implementing SSCM in the healthcare industry. The next section will describe the reasons for combining these methods.

The research questions of this study are as follows:

RQ1. What are the barriers to implementing SSCM in the healthcare industry?

RQ2. What are the weights of these customized barriers?

RQ3. Which of these hospitals must put a focus on eliminating SSCM barriers?

The rest of the study is organized as follows: Section 2 gives the literature review. Section 3 describes the research methodology, while Section 4 consists of the data analysis. The final section covers the conclusion and managerial implementation.

2. Literature Review

SSCM seeks to protect the environment, but implementing this method and other methods faces many barriers. Hence, many studies have been done to learn how to mitigate these barriers.

Regarding the implementation of SSCM, Paul et al. [11] did a review study about using MCDA in SSCM. Their study lists which kinds of MCDA methods have been applied in SSCM. Kouhizadeh et al. [12] explored the barriers to using blockchain in SSCM and found 21 barriers categorized into technological context; organizational context; environmental context from an SCM standpoint; environmental context from an external perspective; and then the relationship among these methods was identified according to the decision-making trial and evaluation laboratory (DEMATEL) method. The result indicated that supply chain and technology were the most significant barriers to using blockchain in implementing SSCM. Moktadri et al. [13] modelled the relationship of barriers to SSCM in the leather industry using Grey-DEMATEL. They found 35 barriers to implementing SSCM in the leather industry in Bangladesh. The relationship between these barriers was then identified using the DEMATEL method in an uncertain environment (Grey method). The result suggested that the largest barriers included (a) lack of awareness of local customers in green products and (b) lack of commitment from top management. Moreover, the most common barriers were the lack of reverse logistic practices and outdated machinery. Yadav et al. [14] designed a model to eliminate barriers to SSCM in an Industry 4.0 environment in the automobile industry. First, the barriers to SSCM were extracted then they were ranked based on Elimination and Choice Expressing Reality (ELECTRE) and BWM, both MCDA methods. The results indicated that among 28 barriers, the highest were lack of budget, technology, and HR; conflict between free trade and the product sustainability policy; provisions; and a penurious commitment from management to adopting sustainability. Then, using Industry 4.0, they sought to find a solution to tackling these barriers among 22 solutions. The best solutions were the companying adopting the 6 Rs, lifecycle analysis and environmental product design, and automation of supply chain activities. Paliwal et al. [15] undertook a review of previous studies using blockchain in SSCM. They classified related research into eight categories.

Kumar et al. [16] designed the SSCM method according to Industry 4.0. In this research, the primary barriers to implementing SSCM are extracted and then the barriers are ranked based on ELECTRE and the Analytical Hierarchy Process (AHP). The result indicated that ineffective strategies combined with a lack of funds were the most significant barriers. Torkabadi et al. [17] implemented hybrid MCDM (multiple-criteria decision-making) methods for improving SSCM. The study, which focuses on sustainable production and consumption in terms of SSCM and its barriers, used a fuzzy analytical network process (FANP) to rank these barriers with the most significant barrier being the organization dimension. Gardas et al. [18] evaluated SSCM in the oil and gas industry. This research identified the SSCM factors that affected business operating performance using the ISM method. The results indicated which of these factors affected the others. Gupta et al. [19] illustrated how to cope with barriers to implement SSCM and used BWM for ranking these barriers. Their results suggested that a lack of expertise, "lack of R&D capabilities," "commitment to use traditional technology," "high priority to investment in the latest technology," and "fear of loss of flexibility and over workload" were the most critical factors. Delmonic et al. [20] evaluated barriers to the implementation of SSCM in emerging economies. The study showed that organizational culture was the most crucial factor. Sanchez-Flores et al. [21] carried out a literature review of SSCM in emerging

economies and evaluated 56 papers from 2010 to 2020, compiling and organizing the relevant factors.

Moheimani et al. [22] studied hospital preparation when they faced the COVID-19 disaster by rough set. They evaluated 25 hospitals in Tehran and showed how these hospitals could cope with this disaster by using fit rules. Sarkar and Sana [23] used a data mining method to predict disease in the healthcare industry. By using two-step DSS, the best prognosis for these diseases is obtained. The result pointed out that this model can predict the illnesses for initial diagnosis. Moheimani et al. [24] evaluated agile hospitals whenever they faced disaster by using interval type-2 fuzzy. In this study, the relationship between agile and disaster management is evaluated according to four agile steps for hospitals. The result indicated which hospital is agile whenever it is faced with disaster.

Table 1 shows the method employed in previous studies.

2.1. Research Gap. Although many papers about ranking barriers to SSCM implementation have been published using MCDA methods both in certainty and uncertainty environments, this study sought to use the hybrid MCDA methods with high accuracy and reliability. Hence, the BWM and CoCoSo methods were combined to form a hybrid MCDA method with high accuracy and reliability. The healthcare industry is one that disposes dangerous substances into the environment, while destroying or recycling used hospital equipment is very hard and costly. Therefore, SSCM is crucial for the hospital in the environment as equipment must be provided for all patients. Hence, balancing between SSCM and providing equipment for the patient is essential. This research demonstrates that hospitals must focus on that to not only implement SSCM, but also provide all necessary patient equipment and afterwards recycle or destroy them without harmful effects on the environment. As Table 1 implies, no paper has been published about ranking barriers to SSCM using these two methods, especially in healthcare industries. Some DMs were selected for answering the questionnaires. These DMs have expertise in the hospital subjects and training and in SSCM, so these DMs can answer these questionnaires accurately. Some of the drawbacks of the Analytical Hierarchy Process (AHP) methods, such as less pairwise and increased model accuracy, have been removed by BWM. Moreover, BWM is more user-friendly than other families such as AHP, Analytical Network Process (ANP), etc.

Most of the MCDA methods generate a single result such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VIekriterijumsko KOmpromisno Rangiranje (VIKOR), multi-objective optimization based on ratio analysis (MOORA), and multiple objective optimization based on ratio analysis plus full multiplicative form (MULTIMOORA). However, one of the crucial advantages of using the CoCoSo method is that the result generates three aggregate rankings, which leads to increased accuracy and reliability [25].

Table 1: Previous studies.

Author(s)	Methods
[12]	DEMATEL
[13]	Grey-DEMATEL
[14]	ELECTRE-BWM
[16]	ELECTRE-AHP
[17]	Fuzzy-ANP
[18]	ISM
[19]	BWM
This research	CoCoSo-BWM

Table 2: Barriers to implementing SSCM.

Author(s)	Barriers
[28, 29]	Lack of legislation
[30]	Lack of strategy
[31, 32]	Lack of highly skilled workforce
[33, 34]	Organizational culture
[35, 36]	Lack of management support
[32, 34]	Lack of training
[37, 38]	Lack of sustainability awareness
[39, 40]	High cost of sustainability
[41, 42]	High disposal cost
[43, 44]	Limitation of knowledge
[34, 45]	Lack of waste management technology
[32, 34]	Lack of sustainable supplier

Table 3: DM composition.

DMs	Education	Years of experience
DM1	PhD	27
DM2	PhD	25
DM3	MSc	29
DM4	PhD	31
DM5	MSc	26
DM6	MSc	27
DM7	PhD	28

3. Research Methodology

3.1. MCDA Techniques

3.1.1. Best-Worst Method. The BWM method is a kind of MCDA method that ranks factors according to pairwise comparison. This method is the invention of Rezaei [26]. The computation of this method involves several steps:

Step 1. The criteria and alternatives of the model (C) are found as follows:

$$C = \{c_1, c_2, \ldots, c_n\}. \quad (1)$$

Step 2. The best criterion is identified and denoted as B. Then, this criterion is compared with the rest of the criteria according to a 1–9 scale. The preferences of the best criterion B are indicated as $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$. The criterion of a_{BB} is 1.

Step 3. The worst criterion is denoted as W. This criterion is compared with the other criteria according to a

Table 4: Screening the barriers to SSCM.

	DM1	DM2	DM3	DM4	DM5	DM6	DM7	Average	Result
Lack of legislation	5	5	5	4	4	5	4	4.57	Accepted
Lack of strategy	3	4	4	3	3	4	5	3.71	Rejected
Lack of highly skilled workforce	4	5	5	4	3	4	5	4.28	Accepted
Organizational culture	4	4	3	3	4		5	3.83	Rejected
Lack of management support	5	5	5	4	4	3	4	4.28	Accepted
Lack of training	3	3	4	3	5	3	4	3.57	Rejected
Lack of sustainability awareness	5	5	5	4	4	3	4	4.28	Accepted
High cost of sustainability	4	4	5	5	4	3	4	4.14	Accepted
High disposal cost	4	4	4	5	5	3	4	4.14	Accepted
Limitation of knowledge	5	5	4	4	3	4	5	4.28	Accepted
Lack of waste management technology	4	4	5	5	5	5	3	4.42	Accepted
Lack of sustainable supplier	3	4	5	4	5	3	4	4	Accepted

1–9 scale. The worst preference of the worst criterion is indicated as $A_w = (a_{w1}, a_{w2}, \ldots, a_{wn})$. The a_{ww} is 1.

Step 4. Weights (W) are obtained per the following formula, which are $(W_1^*, W_2^*, \ldots, W_n^*)$.

The maximum absolute differences $|w_B/w_j - a_{Bj}|$ and $|w_j/w_w - a_{wj}|$ such as the ratio of weights related to best relative preferences are minimized for all j, while n shows the number of iterations and j demonstrates the number of criteria. The following equation shows this computation [26]:

$$\min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_w} - a_{wj} \right| \right\}. \tag{2}$$

Subject to

$$\sum_j w_j = 1, w_j \geq 0, \text{for all } j. \tag{3}$$

The following is another form of equation (3) [25]:

$$\max_j \left\{ \left| w_B/w_j - a_{Bj} \right|, \left| w_j/w_w - a_{wj} \right| \right\} \tag{4}$$

$$\min \xi$$

Subject to

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi \text{ for all } j,$$

$$\left| \frac{w_j}{w_w} - a_{wj} \right| \leq \xi \text{ for all } j, \tag{5}$$

$$\sum_j w_j = 1, w_j \geq 0 \text{ for all } j.$$

3.1.2. CoCoSo Method. The combined compromise solution (CoCoSo) method is one of the MCDA methods that uses a decision matrix for computation data. This model consists of two kinds of MCDA methods:

(i) Simple additive weighting (SAW) and

(ii) Exponentially weighted product (EWP) [27].

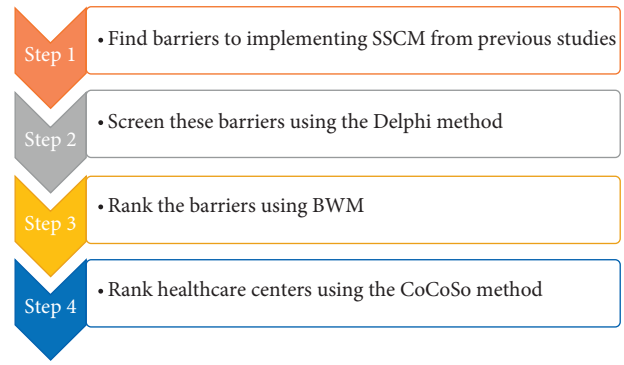

Figure 1: Research methodology procedure.

The steps of the CoCoSo method are as follows:

Step 1:

Create decision matrix

$$x_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}. \tag{6}$$

x_{ij} is the preference of a DM for criterion j to alternative i.

Step 2:

Normalize the decision matrix according to the following equations:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \tag{7}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}. \tag{8}$$

Step 3:

Compute the sum of the sequences of weighted comparability (Si) and the power-weighted comparability sequence (Pi) for each estimated alternative: w_j is weights of criteria obtained from BWM.

Table 5: Preferences of DMs for best criterion.

Best	Lack of legislation	Lack of highly skilled workforce	Lack of management support	Lack of sustainability awareness	High cost of sustainability	High disposal cost	Limitation of knowledge	Lack of waste management technology	Lack of sustainable supplier
High disposal cost	9	8	9	7	9	1	8	8	9

$$S_i = \sum_{j=1}^{n} \left(w_j r_{ij}\right). \tag{9}$$

$$P_i = \sum_{j-1}^{n} \left(r_{ij}\right)^{w_j}. \tag{10}$$

Step 4:

Compute the similar weights of the alternatives:

Use three aggregate evaluation scores to produce relative performance scores for the other options, which are as follows:

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} \left(P_i + S_i\right)}, \tag{11}$$

$$k_{ib} = \frac{S_i}{S_i} + \frac{P_i}{P_i}, \tag{12}$$

$$k_{ic} = \frac{\lambda\left(S_i\right) + (1-\lambda)\left(P_i\right)}{\left(\lambda S_i + (1-\lambda)P_i\right)}, \quad 0 \ll \lambda \ll 1. \tag{13}$$

Equation (11) expresses the arithmetic mean of the sum of the weighted product model (WPM) and weighted sum model (WSM) scores. Meanwhile in (12), the best alternative shows the sum of the relative WPM and WSM scores. Also, a balanced/accurate compromise score of the WPM and WSM models is computed in equation (13). Also, in Equation (13), λ (the threshold $\lambda = 0.5$) ranges from 0 to 1, as selected by the decision-maker.

Step 5:

The ranking of the alternatives is calculated based on k_{i} values.

The rank of alternatives k_{i} is demonstrated below [27].

$$k_i = \left(k_{ia} k_{ib} k_{ic}\right)^{1/3} + \frac{1}{3}\left(k_{ia} + k_{ib} + k_{ic}\right). \tag{14}$$

3.2. Barriers to Implementing SSCM and Its Customization. According to previous studies, the barriers to implementing SSCM are as listed in Table 2:

3.3. Customized Barriers. Many methods have been used for screening factors. One of these methods is the Delphi method for screening factors according to the DM's viewpoint. For the preliminary screening, the questionnaire was designed according to these barriers. The questionnaires were distributed among DMs who have the best knowledge about this subject. The appropriate number of DMs is a matter of dispute among academics. Some in the scientific community believe that this number must be between 5 and 15, while others believe that this number must be more than 100. In this research, the number of DMs is seven. These DMs are not only specialists about hospital procedures, but they also have implemented many SCM projects in the healthcare industry and spent more than 100 hours in most of the SCM fields such as SSCM.

Table 6: Preferences of DMs for worst criterion.

Weakest barrier	Ranking
Lack of legislation	4
Lack of highly skilled workforce	6
Lack of management support	4
Lack of sustainability awareness	7
High cost of sustainability	7
High disposal cost	8
Limitation of knowledge	5
Lack of waste management technology	4
Lack of sustainable supplier	1

The DM information is tabulated in Table 3.

Then a related questionnaire according to the 5-point Likert scale was distributed among the DMs. If the average score equaled four or more, the factor was accepted, otherwise it was rejected. The results of the screening variables are shown in Table 4.

The result shows that only three of the twelve obstacles were eliminated with nine remaining.

3.4. Research Procedure. We adopted the following procedure in this research:

Step 1: The barriers related to implementing SSCM are compiled from previous studies.

Step 2: The barriers are screened using the Delphi method.

Step 3: The customized barriers are ranked by BWM.

Step 4: Seven healthcare centers are organized to implement SSCM using the CoCoSo method. Figure 1 shows this procedure.

4. Data Analysis

First, the barriers are ranked using the BWM. In this method, the best criterion is selected. This criterion is then

Table 7: Final weights.

	Lack of legislation	Lack of highly skilled workforce	Lack of management support	Lack of sustainability awareness	High cost of sustainability	High disposal cost	Limitation of knowledge	Lack of waste management technology	Lack of sustainable supplier
Weights	0.068	0.077	0.068	0.088	0.068	0.443	0.077	0.077	0.034

Table 8: Initial matrix.

Weights of criteria	0.0682095	0.07673569	0.0682095	0.08769793	0.0682095	0.443361754	0.076736	0.076736	0.034105
	−1	−1	−1	−1	−1	−1	−1	−1	−1
Kind of criteria	Lack of legislation	Lack of highly skilled workforce	Lack of management support	Lack of sustainability awareness	High cost of sustainability	High disposal cost	Limitation of knowledge	Lack of waste management technology	Lack of sustainable supplier
*A*1	9.29	5.91	6.76	9.39	6.29	6.22	6.17	9.27	6.57
*A*2	6.08	6.18	6.83	9.29	6.43	9.76	6.62	5.94	7.09
*A*3	9.07	9.05	7.36	5.72	5.5	9.77	9.45	7.72	7.66
*A*4	8.49	9.79	5.23	6.05	9.49	7.35	5.64	8.68	6.28
*A*5	9.58	6.4	6.93	7.47	8.48	6.29	7.51	5.1	6.38
*A*6	9.09	8.24	9.08	7.55	8.42	7.61	9.81	9.66	6.1
*A*7	5.62	9.61	5.1	8.97	7.1	6.86	7.57	5.54	5.6
Max	9.58	9.79	9.08	9.39	9.49	9.77	9.81	9.66	7.66
Min	5.62	5.91	5.1	5.72	5.5	6.22	5.64	5.1	5.6

Table 9: Normalized matrix.

Weights of criteria	0.068	0.076	0.068	0.087	0.068	0.44	0.07	0.07	0.03
	−1	−1	−1	−1	−1	−1	−1	−1	−1
Kind of criteria	Lack of legislation	Lack of highly skilled workforce	Lack of management support	Lack of sustainability awareness	High cost of sustainability	High disposal cost	Limitation of knowledge	Lack of waste management technology	Lack of sustainable supplier
*A*1	0.0732	1.0000	0.5829	0.0000	0.8020	1.0000	0.8729	0.0855	0.5291
*A*2	0.8838	0.9304	0.5653	0.0272	0.7669	0.0028	0.7650	0.8158	0.2767
*A*3	0.1288	0.1907	0.4322	1.0000	1.0000	0.0000	0.0863	0.4254	0.0000
*A*4	0.2753	0.0000	0.9673	0.9101	0.0000	0.6817	1.0000	0.2149	0.6699
*A*5	0.0000	0.8737	0.5402	0.5232	0.2531	0.9803	0.5516	1.0000	0.6214
*A*6	0.1237	0.3995	0.0000	0.5014	0.2682	0.6085	0.0000	0.0000	0.7573
*A*7	1.0000	0.0464	1.0000	0.1144	0.5990	0.8197	0.5372	0.9035	1.0000

compared with the other criteria according to DM preferences. The DMs ascribe their preferences using a 9-point Likert scale. The top criterion is "high disposal cost." The mode of DM answer is used for calculation in BWM for reaching only one answer. After finding the mode of the answer, the result informs all DMs to confirm them. Table 5 shows the preferences of DMs regarding the best criterion.

The weakest criterion is "lack of sustainable suppliers." Table 6 shows the preferences of DMs regarding the worst criteria, and Table 7 points out the final weights.

The result shows the ranking and weights of each criterion. These weights were obtained according to equations (3)–(5).

High disposal cost > lack of sustainability awareness, high cost of sustainability > lack of highly skilled workforce > limitation of knowledge > lack of waste management technology, lack of legislation, lack of management support > lack of sustainable supplier.

Moreover, the inconsistency rate of this computation was 0.17. The best ratio for the accepted inconsistency rate is less than 0.18, which this research was included in this range.

The CoCoSo method was then used to rank these seven healthcare systems.

First, an initial matrix was created according to Table 8. This matrix was created according to DM preferences who ascribed scores from 1 to 10. The average scores show the final preferences (equation (6))

The normalized matrix shown in Table 9 was created according to equations (7) and (8).

Weighted comparability sequence and Si are demonstrated in Table 10 according to equation (9).

Exponentially weighted comparability sequence and Pi are displayed in Table 11 based on equation (10).

Table 10: Weighted comparability sequence.

	Lack of legislation	Lack of highly skilled workforce	Lack of management support	Lack of sustainability awareness	High cost of sustainability	High disposal cost	Limitation of knowledge	Lack of waste management technology	Lack of sustainable supplier
*A*1	0.0050	0.0767	0.0398	0.0000	0.0547	0.4434	0.0670	0.0066	0.0180
*A*2	0.0603	0.0714	0.0386	0.0024	0.0523	0.0012	0.0587	0.0626	0.0094
*A*3	0.0088	0.0146	0.0295	0.0877	0.0682	0.0000	0.0066	0.0326	0.0000
*A*4	0.0188	0.0000	0.0660	0.0798	0.0000	0.3022	0.0767	0.0165	0.0228
*A*5	0.0000	0.0670	0.0368	0.0459	0.0173	0.4346	0.0423	0.0767	0.0212
*A*6	0.0084	0.0307	0.0000	0.0440	0.0183	0.2698	0.0000	0.0000	0.0258
*A*7	0.0682	0.0036	0.0682	0.0100	0.0409	0.3634	0.0412	0.0693	0.0341

Table 11: Exponentially weighted comparability sequence.

	Lack of legislation	Lack of highly skilled workforce	Lack of management support	Lack of sustainability awareness	High cost of sustainability	High disposal cost	Limitation of knowledge	Lack of waste management technology	Lack of sustainable supplier
*A*1	0.8367	1.0000	0.9639	0.0000	0.9851	1.0000	0.9896	0.8280	0.9785
*A*2	0.9916	0.9945	0.9618	0.7291	0.9821	0.0740	0.9797	0.9845	0.9571
*A*3	0.8695	0.8806	0.9444	1.0000	1.0000	0.0000	0.8286	0.9365	0.0000
*A*4	0.9158	0.0000	0.9977	0.9918	0.0000	0.8438	1.0000	0.8887	0.9864
*A*5	0.0000	0.9897	0.9589	0.9448	0.9105	0.9912	0.9554	1.0000	0.9839
*A*6	0.8672	0.9320	0.0000	0.9412	0.9141	0.8023	0.0000	0.0000	0.9906
*A*7	1.0000	0.7901	1.0000	0.8269	0.9656	0.9156	0.9534	0.9922	1.0000

Table 12: Final weight.

Alternatives	*KA*	Ranking	*KB*	Ranking	*KC*	Ranking	*K*	*K*	Final ranking
*A*1	0.1545	3	4.2585	3	0.9028	3	2.6125	2.6125	**3**
*A*2	0.1492	4	2.8439	5	0.8721	4	2.0064	2.0064	**5**
*A*3	0.1250	6	2.1858	7	0.7302	6	1.5979	1.5979	**7**
*A*4	0.1343	5	3.5656	4	0.7846	5	2.2163	2.2163	**4**
*A*5	0.1579	2	4.4105	1	0.9228	2	2.6933	2.6933	**2**
*A*6	0.1089	7	2.6001	6	0.6362	7	1.6798	1.6798	**6**
*A*7	0.1703	1	4.3676	2	0.9953	1	2.7491	2.7491	**1**

Table 13: Sensitivity analysis.

Lambda	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
*A*1	3	3	3	3	3	3	3	3	3
*A*2	5	5	5	5	5	5	5	5	5
*A*3	7	7	7	7	7	7	7	7	7
*A*4	4	4	4	4	4	4	4	4	4
*A*5	2	2	2	2	2	2	2	2	2
*A*6	6	6	6	6	6	6	6	6	6
*A*7	1	1	1	1	1	1	1	1	1

The final weights are shown in Table 12. Lambda is 0.5. The final weights were found according to equations (11)–(14).

4.1. Sensitivity Analysis. In this section, the different Lambda amounts were ranked from 0.1 to 0.9 to find whether this change affected the result. Table 13 shows the sensitive analysis of the result.

The result of this sensitivity analysis suggested that with different Lambda amounts, between 0.1 and 0.9, all responses are the same as each other.

5. Conclusion and Managerial Implementation

SSCM has a critical role in industries. Many companies are eager to implement SSCM whether arbitrarily or by legal force. Additionally, other vital factors such as customer sentiment force them to adopt SSCM. The method advanced in this work considers all comprehensive factors such as environment, economics, and society for implementing SCM. However, implementing SSCM is not a trivial task as there are many barriers to SSCM and therefore companies must cope with all of them. Unfortunately, none of the companies can directly access resources such as HR, budget, etc., so they must first rank these factors and then, according to their priority, design improvement projects to eliminate them. This study sought to do so in the healthcare industry, which is an industry that significantly pollutes the environment, thus hospitals must allocate more of their budget to process these materials, including seeking ways to increase revenues to tackle the lack of funding. Additional funding must be allocated to develop their departments, acquire new technology to treat disease, and help the poor with affordable

health treatment pricing or free of charge, so this contradiction surrounding the implementation of SSCM must be balanced. The two research questions tackled in this research are outlined in the introduction.

First, related barriers are compiled from previous studies to address the first question. Twelve factors have been extracted for addressing this question of earlier research, but these factors must be customized. The Delphi method, which is used in this research, helps customize these factors. Using this method showed that nine of them were accepted among these factors and three were rejected. The second research question sought to find which of the seven hospitals had the implementation of SSCM as its highest priority, which was achieved using CoCoSo and BWM. First, all customized barriers are weighted using BWM, a model with several advantages compared to the AHP method. Among these barriers, high disposal costs was given the highest priority, which means that hospitals must pay more attention to this factor. Then, seven healthcare industries are ranked using CoCoSo. The result of ranking hospitals by the CoCoSo method demonstrated that hospital 7 must focus on implementing SSCM. This method has the advantage over other similar techniques in that the result is obtained in just three stages.

This study demonstrated a road map for the healthcare industry to implement SSCM. This industry is critical because it directly impacts people's lives. Healthcare is a hybrid industry because it must focus on earning revenue while still respecting environmental issues. Hence, the implementation of SSCM is vital for this industry. The limitation of this research is that the DMs who contributed to this research are doctors and head nurses and unfamiliar with MCDA methods. For future research, researchers could investigate an uncertain environment using a variety of kinds of fuzzy numbers such as Pythagorean, hesitant, and so on.

Data Availability

Data available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Sustainable Tourism Supply Chain Assessment Using Hybrid Decision-Making Methods under Fuzzy Uncertainty

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In recent years, sustainable environmental issues have attracted attention from all circles due to environmental variation and the depletion of natural resources. Modern thinking about the environment contains the human environment, historical tradition, and social life of the whole ecosystem. In this research, the design, development, and construction of the environmental system are assessed. In this regard, sustainable development, environmental issues, venue administrators and staff, tourists' education, and service quality evaluation are investigated. After correction to build four broad categories of 26 education venue service quality evaluation indexes, the ecological environment issues venue service quality of the Hakka Romantic Avenue project was conducted by questionnaire survey in Taiwan. Moreover, the VIKOR method is used for service quality evaluation of different subjects, sorting visitors to the evaluation results of the reference, finding the government supervisors, and environmental planning venue administrators. The results showed that the Service Preference (SERVPERF) model combined with Fuzzy-AHP and VIKOR method was effective in the ranking of service quality evaluation of environmental planning venues, and it was significant to eliminate the complacent tendency of the administrators of environmental planning venues to improve the service quality of education venues.

1. Introduction

In recent years, the environmental problems caused by global warming have become increasingly serious. In order to restore the environment after being damaged, it is not enough to engage in pollution prevention and ecological conservation [1–3]. The only way is to let people understand the seriousness of environmental problems and change their attitude. Therefore, environmental planning has become very important for a country, and some countries have taken measures to promote environmental planning [4–6]. In order to protect and promote the development of good and popularization of environmental education, various forms of environmental planning legislation are carried out. The 1972 United Nations Conference on the human environment issued a "declaration of Human" that caused humans to pay attention to environmental problems, the starting of the Human and Natural Environment harmonious co-existence of the benign interaction with the natural ecological concept in the new era. Environmental rehabilitation cannot catch up with the pace of human development, and the concept of coexistence with nature needs to be transmitted and internalized through education and be deeply rooted in the living environment so as to actively restore the overall operation of the large ecological system [7–10].

For environmental protection, people need to have the same feeling of "human being is one of all things" and rethink the relationship between humans and nature. Environmental planning is an education mode that exists in all aspects of people's life. It is new thinking that obtains respect

for ecology and the balance between manmade and ecology through living experience [11–13]. Its scope and projects are numerous and wide. At present, Taiwan has set up many environmental planning venues for citizens, aiming at strengthening the idea of implementing ecological environment education in living areas, looking for planning factors of ecological environment education field from existing regional conditions and community development, injecting local care of environmental conservation and cultural inheritance, and trying to achieve the goal of environmental sustainability [14–16].

Environmental planning venues not only assist local teaching but also bring about attention to local tourism. The motivation of this study is how to provide unique and innovative services to attract more tourists to environmental planning venues [17–19]. In the public sector management evaluation stage, the biggest problem is not yet establishing environmental planning venue in the Taiwan certification system and evaluation standard. At present, only less than 50% of the environment education venue permits a legal registration certificate. And the operator is doing everything they can to design features of leisure venues. The "service quality" is the good, and bad are intermingled, for tourists, as the advantages and disadvantages of environmental planning could not be distinguished, may be under the condition of insufficient information of the environmental planning of the lower quality of service venue, evaluation of environmental planning venue, and the shadow's impression of the whole industry. The uneven quality of "service quality" will impact the development of environmental planning venues [20–23].

Industry supervisors, administrators, and staff of environmental planning venues and tourists, as the four main participants of environmental planning venues, stand from different perspectives of service providers and demanders, respectively, and there may be differences in evaluation results of environmental planning service quality [24–27]. According to the service gap model, service quality is ultimately determined by the gap between customer perceived performance and expectation, which is formed in other gaps in the delivery process of enterprise managers and front-line employees to customers [28–30]. Service providers estimate the quality of service is too high or underestimated or overestimated, can produce complacency, and make the service personnel service [31–33]. Peiró et al. [20] found that, from the awareness to the cognitive process, pleasant information will be processed to be more accurate and efficient, and service quality evaluation of employees will enlarge the information to form a "positive law" (Pollyanna Principle) [3]. Schneider et al. [23] confirmed the perception gap between the service provider and customer is negatively related to the final service quality evaluation. Unlike most of the services sector, the government subsidies for environmental planning venue administrators or staff in accordance with the requirements of industry management departments to provide the corresponding services, such as professional knowledge, dress, manners, etc., and accept the inspection; regulators will pass audit means adjustment of environmental planning venue or cancel subsidies amount [3, 6]. By establishing the gap model of environmental planning service quality, different types of perceived gaps in the service delivery process can be found, but to narrow or eliminate these gaps, the consistency of service quality evaluation of the participants should also be conducted, and the root causes of different gaps should be analyzed. Therefore, this paper takes the evaluation of tourist service quality as a reference to measure the consistency between the evaluation of service providers and tourists, which not only is conducive to the development of service guidelines according to the needs of tourists but also helps to implement regulatory policies in a tourist demand-oriented manner.

2. Literature Review

The definition of the word "environmental education" by UNESCO (United Nations Educational Scientific and Cultural Organization) is as follows: "the environment education is a kind of education process; in this process, personal and social understanding of their environment and the environment of the interaction between the biological, physical, and social culture, get the knowledge, skills, and values can individually or collectively solve the present and future environmental problems." Many environmental pollution problems are caused by global warming, climate change, and industrialization. It affects the whole ecology. The more advanced the civilization, the more problems we have with the Earth's resources. People care about nature and environment; however, it comes mainly from the scope of their exposure to the environment, so if we would like to raise public concern degree on the nature and environment, the environmental governances should be emphasized; despoiled tourism should be replaced by the ecological tourism formulate, which is a good method of environmental education. The concept of ecological tourism was first proposed by Hetzer in 1965 [11]. He called on cultural, educational, and tourism operators to rethink the meaning of "recreation" and first proposed the concept of "ecological tourism." The concept of Eco-tourism is to provide tourists with the greatest satisfaction and bring the greatest economic efficiency to the local area with the minimum impact on the local culture and environment.

This study analyzes the definitions of several scholars, and the connotation of Eco-tourism should cover the following major projects: (1) Eco-tourism is based on resources. Some scholars emphasize that the resources used in Eco-tourism are mainly natural resources, especially landscapes and wildlife [18, 25]. In addition, Ziffer [29] believes that resources should include local historical relics and indigenous culture. (2) Most Eco-tourism activities take place in undisturbed natural areas: Ziffer [29] and Valentine [26] emphasize that Eco-tourism mainly goes to relatively undeveloped areas. (3) Special tourist motivation/purpose: The Eco-tourism society emphasizes that Eco-tourism is a purposeful journey to natural areas to learn about nature and culture; Boo [4] and Sirakaya [25] believed that appreciating, participating, feeling, learning, and studying scenery, plants and animals are the main motivation and purpose for

tourists to participate in ecological tourism activities. Eco-tourism is not only an ecologically reliable journey but also an effort to strengthen protection through tourism. Accordingly, Eco-tourism is actually nature tourism that promotes conservation. (4) Concept of sustainable development: Buckley [5] emphasized that ecological tourism must be managed in the concept of sustainability; Eco-tourism emphasizes that recreation activities should reduce the impact on the local area and reduce the consumption of local resources to make the sustainable use of local resources and make the sustainable development of local tourism industry be repeated in relevant literature [26]. (5) Emphasis on the concept of conservation: Wight [28] argues that Eco-tourism must contribute to ecosystem conservation. Hvenegaard and Dearden [12] further believed that ecological tourism should emphasize the protection of the local natural environment in tourism and convey the important connotation of ecological tourism as an ecosystem. (6) Contribution to local communities: Martin [15] stresses that ecological tourism must maintain the welfare of local communities; (7) Responsible tourist behavior: Tourists must behave in a responsible way when participating in ecological tourism activities, and the so-called responsible tourist behavior means that there will be no tourist behavior that may cause damage to the environment [12, 15]. (8) The concept of local community participation: Ziffer [29] argues that ecological tourism implies local community participation in the tourism development model. The purpose is to make the development of local tourism meet the needs of the community and properly set marketing, tourism management regulations of the standards and industry, and reasonable financial sources to support and improve the quality of resources and environment of the residential area.

Parasuraman et al. [17, 18] hold that service quality is the order and condition of service in the process of delivery and the interaction between service providers and consumers. Parasuraman et al. [17, 18] defined the service quality in the form of user authentication, the quality of service is defined as a gap, and SERVQUAL (Service Quality) model is established. Reichheld and Sasser [19] adopted a "quality of technology" and "functional" quality dimensions to measure the service quality and formulated the multi-item of agricultural tourism service quality attributes in accordance with the technical and functional dimensions proposed by Fleischer and Pizam [10] under the measure of multi-item. Akama and Kieti [1] investigated the satisfaction of service quality in a national park in Kenya's wildlife safari, where the service quality dimensions are measured by five service quality dimensions [18], and they formulated national park service-oriented quality attributes to further study and explore the visitors' satisfaction. Khan et al. [13] discussed the expected service quality of participation in Eco-tourism. Through factor analysis, the desired service quality will be involved in ecological tourists' identified six dimensions , respectively, "ecological tangibility," "authenticity," and "reliability," "reactivity," and "empathy" and "tangibles," and name it "ECOSERV." They set up a pointer in the direction of service quality in Eco-tourism and concluded that the "ecological tangible service quality for ecological tourism" is one of the most overlooked by tourists' dimensions; the tangible behavior of visitors is friendly to the environment, with minor damage. This study also verified the feasibility of the application of service quality in the study of ecological tourism.

Cronin and Taylor [9] proposed a revised and improved version of the SERVQUAL evaluation model of Parasuraman et al. [17, 18] and came up with a service quality evaluation method, which is the inheritance and development of the SERVQUAL evaluation method. The SERVPERF (Service Performance) evaluation model is also known as the performance perception service quality evaluation method. The SERVPERF model abandons the SERVQUAL concept of difference comparison, takes the customer perception performance evaluation score as the measurement standard, and measures the service quality with 22 indicators in 5 dimensions as the scale. Five dimensions include tangibility of physical facilities, equipment needed for the service, guarantee (such as needed to complete the service skills, knowledge of affordable factors), responsiveness (timely and active ability to fulfill the service content), reliability (the ability to service commitments accurately), and empathy (people-oriented, service level upgradeability). Subsequently, the SERVPERF model has been widely used in measuring the service quality of catering, hotel, tourism, railway, port, and air transport. In view of the invisibility, synchronicity, difference, and nonstorage of tourist services, the modified SERVPERF model was used to measure the quality of tourist services in this study.

3. Methodology

3.1. Evaluation Index. We modified 22 multi-item on the basis of the classical SERVPERF model so as to conform to the characteristics of tourist service quality and delivered the questionnaire to five experts with respect to ecology, industry, and enterprise management. The experts reviewed, revised, deleted, and finally retained the 26 multi-item after classification as the evaluation index, and four categories in this questionnaire are interpretation services, facilities, recreation facilities, and spiritual experience, as shown in Table 1.

3.2. Index Attribute Values and Weights. The attribute value of the evaluation index is obtained through the questionnaire survey, and five levels of "very good" to "very bad" are used to determine the service quality of tourists. When the survey results are processed, the value 5 means "very good," 1 means "very bad," and 4, 3, and 2 mean the degree value between the two, respectively. At the same time, the weights of evaluation indexes will be obtained through Fuzzy-AHP.

3.3. Economic Justification of the Proposed MCDM Methods. In order to provide a coherent and accurate analysis of the various effects of the tourism industry on sustainable development, it is necessary to gather extensive information from various tourism areas. This requires a lot of time and money. However, using the MCDM method helps us to

Table 1: Service quality evaluation index of environmental planning venues (Q).

Index type	Index notation	Evaluation content
Interpretation services	Q_{11}	The narrator's explanation was clear and intelligible
	Q_{12}	The narrator's voice sounded just right
	Q_{13}	The narrator and tourists have good interactive
	Q_{14}	The narrators know how to use body language to strengthen interpretation content
	Q_{15}	To let me know environmental resources treatment and cherish the focus of the environmental resources
	Q_{16}	The narrator's explanation form and process makes me feel satisfied
	Q_{17}	Content on the venue with announcer richness
	Q_{18}	The narrators on the interpretation of content have sufficient preparation
	Q_{19}	Time arrangement of the interpretation is very appropriate
Interpretation facilities	Q_{21}	Explanation on the placard setting place carefully design
	Q_{22}	Explanation of the font size of clear moderate site on the placard
	Q_{23}	Visit route smooth
	Q_{24}	Placards with auxiliary text images
	Q_{25}	Placards commentary content illustrated
	Q_{26}	Site lighting, the light is downy brightness
	Q_{27}	Proper interpretation of the words difficult to understand
Recreation facilities	Q_{31}	Clean toilet
	Q_{32}	The number of the toilets
	Q_{33}	Parking convenience/the number of parking lots
	Q_{34}	Safety facilities adequate
	Q_{35}	Number of trash can settings
	Q_{36}	Rest area/tourist center comfortable
	Q_{37}	Environment clean
Spiritual experience	Q_{41}	Satisfy curiosity
	Q_{42}	Experience novelty
	Q_{42}	Augmented experiences improve relations with family and friends

provide a coherent and complete analysis of the tourism industry with the help of experts and with the least time and cost.

3.4. Analytic Hierarchy Process (AHP). The Hierarchical Analysis (AHP) method was developed by Saati in 1980. This technique is a powerful and flexible method in the category of multicriteria decision-making methods by which complex problems can be solved at different levels. For this reason, it is called a hierarchical model because it is a tree model and hierarchy. The AHP method combines both objective and subjective evaluations into an integrated structure based on scales with even comparisons, and it helps analysts organize the essential aspects of a problem into a hierarchical framework. The advantages of this method can be mentioned: measuring the consistency of decision makers' judgments, creating pairwise comparisons in choosing the optimal solution and option, the ability to consider criteria and subcriteria in evaluating options, and creating the ability to achieve the best option through paired comparisons.

Analytic Hierarchy Process (AHP) is a way to assist in decision-making and emphasizes the importance of a decision maker's intuitive judgments and the consistency of comparing alternative options in the decision-making process. Because a decision maker makes their judgments based on knowledge and experience and therefore makes decisions based on that, the AHP approach is consistent with the behavior of a decision maker. The strength of this approach is that it regularly organizes tangible and intangible factors and offers a structural but relatively simple solution to decision problems.

3.5. Fuzzy-AHP. The traditional analytic hierarchy process (AHP) uses the 1–9 scale method. By comparing the evaluation objects in pairs, a fuzzy judgment matrix is obtained, and the qualitative and quantitative problems are comprehensively analyzed and processed to obtain a clear quantitative conclusion, which is presented in the form of an evaluation of advantages and disadvantages. But as a result of this method to an integer between 1 and 9 as a scale structure judgment matrix, this judgment does not well reflect the fuzziness of human judgment. Therefore, the Dutch scholar Van Laarhoven and Pedrycz [27] proposed fuzzy-AHP using triangular fuzzy number and fuzzy judgment method and using the arithmetic of triangular fuzzy number and logarithm least squares method, element for evaluation, thereby expanding the AHP to the fuzzy linguistic investigation. The main steps of fuzzy-AHP are shown in Table 2.

(1) Establish a hierarchical structure of the system according to the overall goal of the problem.

(2) The evaluation index and object are compared in pairs by experts, and the fuzzy judgment matrix is constructed by using triangular fuzzy numbers. The

Table 2: The scale conversion of semantic variables.

Fuzzy scale	Linguistic variable	Triangle fuzzy number
1 or (1 : 1)	Equally important	(1, 1, 1)
2 or (2 : 1)	Somewhere between equally important and slightly important	(1, 2, 3)
3 or (3 : 1)	Slightly important	(2, 3, 4)
4 or (4 : 1)	Somewhere between slightly important and very important	(3, 4, 5)
5 or (5 : 1)	Quite important	(4, 5, 6)
6 or (6 : 1)	Somewhere between quite important and very important	(5, 6, 7)
7 or (7 : 1)	Very important	(6, 7, 8)
8 or (8 : 1)	Somewhere between very important and absolutely important	(7, 8, 9)
9 or (9 : 1)	Absolutely important	(8, 9, 10)

triangular fuzzy number M can be defined by its membership function μ_M: $R \longrightarrow [0, 1]$ as follows:

$$\mu_M = \begin{cases} \dfrac{1}{m-l}x - \dfrac{1}{m-l}, & (x \in [l, m]), \\ \dfrac{1}{m-u}x - \dfrac{1}{m-u}, & (x \in [l, m]), \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

In the formula, $l \le m \le u$, l and u, respectively, represent the lower bound and upper bound supported by M, and m is the median of M. Generally, the triangular fuzzy number M can be denoted as (l, m, u). The fuzzy judgment matrix is A generalization of the AHP judgment matrix, which is composed of triangular fuzzy numbers, denoted as $A = (a_{ij})_{n\times m} = [l_{ij}, m_{ij}, u_{ij}]$, and $a_{ji} = a_{ij}^{-1} = [1/l_{ij}, 1/m_{ij}, 1/u_{ij}]$ When five experts make judgments on the k th criterion, it is the comprehensive triangular fuzzy number, which is the synthesis of the judgments of the five experts. It can be obtained from the following equation:

$$a_{ij} = \frac{1}{T} \otimes \left(a_{ij}^1 + a_{ij}^2 + \cdots, +a_{ij}^T\right), \tag{2}$$

where $a_{ij}^T = [l_{ij}^t, m_{ij}^t, u_{ij}^t]$ $(i, j = 1, \cdots, k, t = 1, \cdots, 5)$ is the triangular fuzzy number given by the t th expert.

Value of triangular fuzzy number in fuzzy judgment matrix follows the 1–9 scale of AHP method; the triangular fuzzy number of lower bound l and upper bound u can be confirmed according to the fuzzy degree; the greater the $u - l$, the fuzzier the judgment; $u - l$ is smaller and the judge is crisper; when $u - l = 0$, the judge is nonfuzzy, then $l = m = u$ with the same value judgment under the general scale. For a given criterion, if the i th element is significantly more important than the j th element, the triangle fuzzy number = (4, 5, 6) or (3, 5,7) can be expressed, where (3, 5, 7) is more ambiguous than (4, 5, 6).

The relative importance of evaluation criteria is subjective, fuzzy, and not suitable to be expressed in numerical form. Through linguistic variables, the narration of language can be changed into logical narration, and instead of numerical values, words or sentences in natural language can be used as values to convey the degree of perception of things. After selecting the appropriate linguistic meaning, the actual value can be calculated through various predetermined linguistic scale fuzzy numbers. The scale conversion of semantic variables is shown in Table 2 [5]:

(3) Calculation of relative weight value: this study normalized the geometric mean of vectors as proposed by Buckley [5] and calculated the weight of the fuzzy pairwise comparison matrix. The calculation formula is as follows:

$$\widetilde{Z}_i = \sqrt[n]{\widetilde{a}_{i1} \otimes \widetilde{a}_{i2} \otimes \cdots \otimes \widetilde{a}_{ik}}, \forall i = 1, \ldots, k, \tag{3}$$

$$\widetilde{\omega}_i = \widetilde{Z}_i \otimes \left(\widetilde{Z}_1 \oplus \widetilde{Z}_2 \oplus \cdots \oplus \widetilde{Z}_k\right), \tag{4}$$

where $\widetilde{a}_{ij}$: fuzzy paired comparison matrix $\widetilde{A}$ of the ith row the jth column of triangular fuzzy number, $\widetilde{Z}_i$: geometric average of the column vector of a triangular fuzzy number. $\widetilde{\omega}_i$ a fuzzy eigenvector, the fuzzy weight of ith item factors of $\widetilde{A}$

(4) Defuzzification: general methods of defuzzification are Gravity Method, α-cut set method, the maximum average method, average solution center fuzzification method, etc. The focus of this study used the simplest and most practical method (Center of Gravity Method) to calculate the fuzzy numbers membership function of the geometric center (the center of gravity) and the center of gravity of the crisp values of fuzzy numbers. Assuming that the triangular fuzzy number $\widetilde{A} = (L_i, M_i, U_i)$, the formula for defuzzification is as follows:

$$DF_i = \frac{(M_i - L_i) + (U_i - L_i)}{3} + L_i \approx \frac{L_i + M_i + U_i}{3}; \forall i = 1, \ldots, k, \tag{5}$$

where DF_i is the crisp value after defuzzification.

(5) Normalization: in order to compare the importance of each evaluation criterion, the weight value of the fuzzy solution should be normalized to obtain the relative weight value. The formula of normalized weight value is as follows:

$$\omega_i = \frac{DF_i}{\sum_{i=1}^{n} DF_i}, \tag{6}$$

(6) Maximum eigenvalue $\lambda_{\max}$: First, the paired comparison matrix $\widetilde{A}$ is multiplied by the eigenvector ω_i to obtain a new vector ω_i', and then the average multiple between the two is calculated to obtain the following:

$$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1k} \\ a_{21} & 1 & \cdots & a_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ a_{k1} & a_{k2} & \cdots & 1 \end{bmatrix} * \begin{bmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_k \end{bmatrix} = \begin{bmatrix} \omega_1' \\ \omega_2' \\ \vdots \\ \omega_k' \end{bmatrix}. \tag{7}$$

$$\lambda_{\max} = (1/n) * \left(\omega_1'/\omega_1 + \omega_2'/\omega_2 + \cdots + \omega_n'/\omega_n\right). \tag{8}$$

(7) Consistency verification: consistency verification is needed to confirm whether decision makers are consistent when comparing evaluation criteria. Firstly, the consistency index (C.I.) was calculated to verify the consistency or inconsistency of the decision makers' comparison so that it could be corrected in time to avoid bad decisions. When there are more comparison elements, the order of the paired matrix will also increase, and it is more difficult to maintain the consistency judgment. Therefore, Saaty [22] proposed the random index (R.I.) to adjust the different C.I. generated under different orders to get the consistency ratio (C.R.), C.I., and C.R. The calculation is shown in formulas (9) and (10), and C.R. ≤ 0.1 represents the consistency level.

$$C.I. = \left(\lambda_{\max} - k\right)/(\pi k - 1). \tag{9}$$

$$C.R. = C.I./R.I. \tag{10}$$

3.6. VIKOR Method. Multicriterion compromise decision-making (VIKOR for short) is a compromise decision-making method that can take into account the maximization of group benefits and the minimization of individual regrets against opinions, as well as the subjective preferences of decision makers. Therefore, it is more reasonable to use the VIKOR method to study multiattribute decision-making problems.

The evaluation subject of tourist service quality is A_i, $i = 1, 2, 3, 4$. The evaluation set of government supervisors, environmental planning venues administrators, venue staff, and tourists is $A = \{A_1, A_2, A_3, A_4\}$; The evaluation index is C_j, $j = 1, 2, \ldots, 26$, the evaluation index set $C = \{C_1, C_2, \ldots, C_{26}\}$, x_{ij} is the service quality evaluation attribute value of the participant i to the index C_j, and ω_{ij} is the service quality evaluation index weight of the participant i to the index C_j. The steps of ranking tourist service quality by VIKOR are as follows:

(1) Determine the maximum and minimum values of the evaluation index x_j^+ and x_j^-, namely $x_j^+ = \max_i x_{ij}$, $x_j^- = \min_j x_{ij}$. And then we get the following:

$$r_{ij} = \frac{\left|x_j^+ - x_{ij}\right|}{\left|x_j^+ - x_j^-\right|}. \tag{11}$$

(2) Calculate the weighted evaluation value of tourist service quality S_i and Q_i of each participant. Since each evaluation index has the same dimension and its attribute value and weight do not need to be standardized, then calculate the evaluation value of tourist service quality of each participant and get the weighted evaluation matrix as follows:

$$S_i = \sum_{j=1}^{25} \omega_{ij} \cdot x_{ij} \tag{12}$$

where $\sum_{j=1}^{26} \omega_{ij} = 1$. At the same time, let $Q_i = \max_j \{r_{ij} | j = 1, \ldots, 25\}$, then calculate S^+, S^-, Q^+ and Q^- where $S^+ = \max_i S_i$, $S^- = \min_i S_i$, $Q^+ = \max_i Q_i$, $Q^- = \min_i Q_i$

(3) Calculate R_i,

$$R_i = \nu \frac{S_i - S^-}{S^+ - S^-} - (1 - \nu) \frac{Q_i - Q^-}{Q^+ - Q^-}. \tag{13}$$

Where ν is the decision-making mechanism. Under the balanced decision-making mechanism of general compromise group benefit maximization and individual regret minimization, $\nu = 0.5$.

(4) Rank the tourist service quality evaluation of participant i according to the value of R_i, rank R_i from small to large, and the top scheme in each sequence is higher than the latter.

4. Results and Discussion

4.1. Research Background and Research Design. The plan of Hakka Romantic Avenue in Taiwan will be launched in 2018, connecting 16 key development areas of Hakka culture in Taiwan to promote the trend of leisure Eco-tourism. The first part of this survey includes respondents' occupation, gender, age and education background, etc. The second part includes 26 service quality evaluation indexes of environmental planning venues, which are obtained after modification by the classic SERVPERF model.

The survey was conducted in five counties and cities in northern Taiwan in February 2019. The respondents included the Ministry of Culture and Culture, Hakka Affairs Council, Council of Agriculture, Sports Administration of the Ministry of Education, Ministry of Education and other government supervisors, administrators of environmental planning venues, venue staff, and tourists. A total of 1,150 questionnaires were issued by means of snowball sampling. This research of government supervisors surveys , 350 questionnaires of 800 to participate in other subjects. 12 investigators in 7 days, respectively, to 15 Hakka

Table 3: Questionnaire on service quality of environmental planning venues.

Survey objects	Government supervisors	Venue administrator	Venue staff	Tourist
Issuing questionnaires (copies)	350	200	300	300
Collecting valid documents (copies)	332	112	235	240
Effective recovery rate (%)	94.85	56.00	78.33	80.00

environmental planning venues to issue 200 questionnaires to administrators, to rest, eating venue staff to issue 300 questionnaires, and 300 questionnaires distributed to the tourists. Questionnaires were filled in and collected on-site, and the distribution and recovery of questionnaires were shown in Table 3.

In this study, factor analysis was used to test questionnaire validity, and Cronbach α was used to test the reliability of the questionnaire. The overall KMO value of the questionnaire was 0.935, which exceeded 0.7, and Bartlett's spherical test was remarkable, the significance of which is 0.000. After 21 orthogonal iterations by principal component analysis, common factors with an eigenvalue greater than 1 and factor loading greater than 0.4 were extracted and selected. The cumulative variance interpretation rate was 64.423%, and the overall Cronbach α was 0.942. It indicates that the overall validity and reliability of the questionnaire are both high.

4.2. Survey Results. Through the data collection and data processing of the collected questionnaires, the results are shown in Table 4: evaluation results of service quality for government supervisors (R), environmental planning venues administrators (M), venue staff (S), and tourists (T). According to the attribute values of service quality evaluation indicators in Table 4, the comparison of the mean gap of service quality evaluation between government supervisors, environmental planning venues administrators, venue staff, and tourists was obtained by an independent normal test. On the whole, by comparing the tourist evaluation results of the service quality of the environmental planning venues with those of government supervisors, administrators of the environmental planning venues, and tourists, it can be found that the gap between the venue staff and tourists is the largest, and it is difficult to determine the gap between the government supervisors and administrator of the environmental planning of venues and tourists. Therefore, to further analyze the gap of service quality evaluation among different participants, the above evaluation results should be ranked by the VIKOR method.

4.3. FAHP Weighting Results. Firstly, the evaluation experts of ecology, tourism management, and environmental planning who are both academic and practical (a total of 5 experts) can construct the fuzzy paired comparison matrix of the criterion layer and the target layer by comparing the importance of each criterion in pairs, as shown in Tables 5–10. Then, the relative weights of the corresponding evaluation criteria (Table 9) are calculated according to formulas (3)–(6), and the judgments are consistent before and after.

5. VIKOR Evaluation Ranking

The questionnaire data in Table 4 are used to rank the service quality evaluation results of government supervisors, environmental planning venues administrators, venue staff, and tourists according to the calculation steps of formulas (11)–(13), and the S_j, R_j, and Q_j values of each questionnaire item are obtained, as shown in Table 11. According to VIKOR calculation, the final result is $S > R$; $M > T$. That is, the quality ranking order of the four projects is as follows: venues' staff > government supervisors; administrators of environmental planning venues > tourists, indicating that the venues' staff is the highest, followed by the evaluation value by the government supervisor and the venues administrator, and the evaluation value by the tourists is the lowest.

6. Discussion

Sustainable development has been defined as the process by which the current needs of society are met without affecting the ability of future generations to meet their own needs. By definition, sustainable development has four dimensions: (1) environmental development, (2) economic development, (3) social development, and (4) legal development. Each of these dimensions has indicators. Environmental indicators of sustainable development include the atmosphere, land, oceans and seas and coastlines, freshwater, and biodiversity. Today, attention to the urban environment and urban ecological development has been reborn. People have realized that the connection between the city and the natural environment is inseparable. For most people in the future, living in a quality environment means living in a city where the environment is carefully managed. One way to improve the environmental management of a city is to analyze the city as an ecological system. For the sustainability of the city ecosystem, the biological capacity and carrier of these cities should be measured, and efforts should be made to maintain, develop, and distribute its proper location. Over time, positive and negative changes in carrier capacity that can be used to measure the practicality of management activities should be given serious attention by officials and those involved in urban management in the field of preservation, development, and maintenance of natural spaces. To improve the living conditions of cities, measures such as determining the desired population for each city according to the possibility of providing water and other essential needs and adequate,

Table 4: Service quality survey results.

Criterions		Attribute values of environmental planning venues				Gap		
		R	*M*	*S*	*T*	*R-T*	*M-T*	*S-T*
Q_1	Q_{11}	4.307	3.876	4.382	3.825	0.482 (***)	0.051	0.557 (***)
	Q_{12}	4.185	3.895	4.325	3.794	0.391 (***)	0.101	0.531 (***)
	Q_{13}	3.568	3.532	4.125	3.428	0.14	0.104	0.697 (***)
	Q_{14}	3.387	3.342	4.011	3.381	0.006	−0.039	0.63 (***)
	Q_{15}	3.652	3.713	3.976	3.573	0.079	0.14	0.403 (***)
	Q_{16}	4.014	3.901	4.125	3.612	0.402 (***)	0.289 (***)	0.513 (***)
	Q_{17}	3.896	4.121	3.987	3.428	0.468 (***)	0.693 (***)	0.559 (***)
	Q_{18}	3.874	4.085	4.385	3.45	0.424 (***)	0.635 (***)	0.935 (***)
	Q_{19}	3.69	3.923	4.136	3.574	0.116	0.349 (***)	0.562 (***)
Q_2	Q_{21}	3.845	3.802	4.203	3.768	0.077	0.034	0.435 (***)
	Q_{22}	3.598	3.702	3.895	3.255	0.343 (***)	0.447 (***)	0.64 (***)
	Q_{23}	3.458	3.325	4.015	3.342	0.116	−0.017	0.673 (***)
	Q_{24}	3.765	3.854	4.155	3.488	0.277 (***)	0.366 (***)	0.667 (***)
	Q_{25}	3.856	3.751	3.965	3.456	0.4 (***)	0.295 (***)	0.509 (***)
	Q_{26}	3.788	3.875	4.214	3.332	0.456 (***)	0.543 (***)	0.882 (***)
	Q_{27}	3.876	3.758	4.133	3.125	0.751 (***)	0.633 (***)	1.008 (***)
Q_3	Q_{31}	3.952	3.858	3.856	3.133	0.819 (***)	0.725 (***)	0.723 (***)
	Q_{32}	3.874	3.955	3.863	3.245	0.629 (***)	0.71 (***)	0.618 (***)
	Q_{33}	3.855	3.763	4.033	3.565	0.29 (***)	0.198	0.468 (***)
	Q_{34}	3.896	3.957	4.135	3.655	0.241 (***)	0.302 (***)	0.48 (***)
	Q_{35}	3.955	3.845	3.931	3.339	0.616 (***)	0.506 (***)	0.592 (***)
	Q_{36}	3.896	3.967	4.223	3.64	0.256 (***)	0.327 (***)	0.583 (***)
	Q_{37}	3.485	3.587	3.782	3.32	0.165	0.267 (***)	0.462 (***)
Q_4	Q_{41}	3.659	3.788	3.855	3.599	0.06	0.189	0.256 (***)
	Q_{42}	3.95	4.113	3.982	3.623	0.327 (***)	0.49 (***)	0.359 (***)
	Q_{43}	4.307	3.876	4.382	3.825	0.482 (***)	0.051	0.557 (***)

Notes: *p* values of ***Represent 0.001 significance level.

Table 5: Fuzzy judgment matrix of Q_1–Q_4 to Q.

Q	Q_1	Q_2	Q_3	Q_4
Q_1	(1, 1, 1)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 2, 3)
Q_2	(1, 1/2, 1/3)	(1, 1, 1)	(1/2, 1/3, 1/4)	(1, 2, 3)
Q_3	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	(2, 3, 4)
Q_4	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1/2, 1/3, 1/4)	(1, 1, 1)

Table 6: Fuzzy judgment matrix of Q_{11}–Q_{19} to Q_1.

Q_1	Q_{11}	Q_{12}	Q_{13}	Q_{14}	Q_{15}	Q_{16}	Q_{17}	Q_{18}	Q_{19}
Q_{11}	(1, 1, 1)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1, 1)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)
Q_{12}	(1, 1/2, 1/3)	(1, 1, 1)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1, 1)
Q_{13}	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(1, 2, 3)	(1, 2, 3)	(2, 3, 4)	(2, 3, 4)
Q_{14}	(1, 2, 3)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	(1, 2, 3)	(1, 2, 3)
Q_{15}	(1, 1, 1)	(1, 2, 3)	(1/3, 1/4, 1/5)	(1/2, 1/3, 1/4)	(1, 1, 1)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1, 1)
Q_{16}	(1, 1, 1)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 2, 3)	(1, 1, 1)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1, 1, 1)
Q_{17}	(1, 2, 3)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)
Q_{18}	(1, 2, 3)	(1, 2, 3)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1, 2, 3)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1/2, 1/3)
Q_{19}	(1, 2, 3)	(1, 1, 1)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1, 1)	(1, 1/2, 1/3)	(1, 2, 3)	(1, 1, 1)

Table 7: Fuzzy judgment matrix of Q_{21}–Q_{27} to Q_2.

Q_2	Q_{21}	Q_{22}	Q_{23}	Q_{24}	Q_{25}	Q_{26}	Q_{27}
Q_{21}	(1, 1, 1)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)
Q_{22}	(1, 2, 3)	(1, 1, 1)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)
Q_{23}	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)
Q_{24}	(1, 2, 3)	(1, 2, 3)	(1/3, 1/4, 1/5)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)
Q_{25}	(1, 2, 3)	(1, 2, 3)	(1/2, 1/3, 1/4)	(1/2, 1/3, 1/4)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)
Q_{26}	(2, 3, 4)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1, 1)	(2, 3, 4)
Q_{27}	(1, 2, 3)	(1, 2, 3)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1/2, 1/3)	(1/2, 1/3, 1/4)	(1, 1, 1)

Table 8: Fuzzy judgment matrix of Q_{31}–Q_{37} to Q_3.

Q_3	Q_{31}	Q_{32}	Q_{33}	Q_{34}	Q_{35}	Q_{36}	Q_{37}
Q_{31}	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)
Q_{32}	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)
Q_{33}	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)		(1, 1, 1)	(2, 3, 4)	(1, 1, 1)
Q_{34}	(1/2, 1/3, 1/4)	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1/2, 1/3)
Q_{35}	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)
Q_{36}	(1/2, 1/3, 1/4)	(1, 1/2, 1/3)	(1/2, 1/3, 1/4)	(1, 1, 1)	(1, 1/2, 1/3)	(1, 1, 1)	(1, 1/2, 1/3)
Q_{37}	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)

Table 9: Fuzzy judgment matrix of Q_{41}–Q_{43} to Q_4.

Q_4	Q_{41}	Q_{42}	Q_{43}
Q_{41}	(1, 1, 1)	(1, 1, 1)	(1, 1/2, 1/3)
Q_{42}	(1, 1, 1)	(1, 1, 1)	(1, 1/2, 1/3)
Q_{43}	(1, 1/2, 1/3)	(1, 1/2, 1/3)	(1, 1, 1)

Table 10: Weights of indicator layer relative to target layer.

Q	Q_1	0.069	Q_{11}	0.021114
		0.034	Q_{12}	0.010404
		0.209	Q_{13}	0.063954
		0.174	Q_{14}	0.053244
		0.055	Q_{15}	0.01683
		0.087	Q_{16}	0.026622
		0.162	Q_{17}	0.049572
		0.122	Q_{18}	0.037332
		0.089	Q_{19}	0.027234
	Q_2	0.037	Q_{21}	0.007141
		0.079	Q_{22}	0.015247
		0.248	Q_{23}	0.047864
		0.182	Q_{24}	0.035126
		0.162	Q_{25}	0.031266
		0.175	Q_{26}	0.033775
		0.116	Q_{27}	0.022388
	Q_3	0.193	Q_{31}	0.086078
		0.193	Q_{32}	0.086078
		0.193	Q_{33}	0.086078
		0.029	Q_{34}	0.012934
		0.170	Q_{35}	0.07582
		0.029	Q_{36}	0.012934
		0.193	Q_{37}	0.086078
	Q_4	0.219	Q_{41}	0.012264
		0.219	Q_{42}	0.012264
		0.561	Q_{43}	0.031416

Table 11: Evaluation indexes of S, R, and Q of government supervisors (R), administrators of environmental planning venues (M), staff (S), and tourists (T).

Subject	S		R		Q		The overall rank
	Value	Rank	Value	Rank	Value	Rank	
R	0.4139	2	0.0553	3	0.4909	2	2
M	0.4412	3	0.0544	2	0.4992	3	2
S	0.0371	1	0.0112	1	0.0000	1	1
T	0.9968	4	0.0861	4	1.0000	4	3

and appropriate establishment of production and industrial activities with respect to environmental issues, especially in the field of pollution, seem necessary.

7. Conclusions

An environmental planning venue is an area with environmental characteristics that provides appropriate fields, exhibits, education, facilities, and activities, supplemented by professional instruction, guidance, and education, to enable people of all ages to develop responsible environmental behavior. How to ensure that tourists can achieve the purpose of environmental planning and Eco-tourism is the focus of this study. Based on the point of view of Parasuraman et al. [17, 18], tourist service quality is the core of environmental planning venue service quality management. The study measured environmental planning venue service quality evaluation. The evaluation result shows that government supervisors, environmental planning venue managers, and its staff overestimate the environment education venues' service quality. As service providers, administrators, and staff of environmental planning venues overestimate the service quality, which confirms the "Pollyanna Principle" proposed by Peiró et al. [20] also exists in the service field of environmental planning venues, the survey found that there were significant differences in interpretation services, interpretation facilities, recreation facilities, and spiritual experience between the venue's staff and tourists. Since the optimistic estimation of service providers tends to lead to service degradation, the most optimistic evaluation of the venue staff should be to reduce the complacency of the venue's staff, which should be the main task of improving the service quality of the environmental planning venues. At the same time, we should also pay attention to the administrators' optimistic estimate of the service quality of the environmental planning venues. In addition to interpretation services and spiritual feelings, administrators' evaluation of service quality of environmental planning venues also lags behind that of tourists in the evaluation of interpretation facilities and recreation facilities. Eliminating the blind optimism of the administrators of environmental planning venues will help to formulate and implement the service standards of environmental planning venues that better meet the needs of tourists.

Different from the previous studies that only focused on service providers, this paper compares the consistency of government supervisors' and tourists' evaluations of the service quality of environmental planning venues. Theoretically, the public sector subsidies in environmental planning venues are less likely to cause moral hazards and adverse selection caused by information asymmetry, so the government will decide on the follow-up subsidy scheme based on the service quality of environmental planning venues. Therefore, the evaluation of government supervisors should be consistent with that of tourists. However, the evaluation results show that there are significant differences with tourists in interpretation services, interpretation facilities, recreation facilities, and spiritual experiences. The results appear, on the one hand, maybe environmental planning venues service quality policy measures by government supervisors, administrators of environmental planning venues; its staff multiple hierarchies can be passed to the tourists; degree of execution or complaint mechanism is not sound, causes the distortion of information feedback, and makes the government supervisors have errors of perception of tourist demand. On the contrary, the daily supervision of the government supervisors may pay more attention to the opinions of the administrators or staff of the environmental planning venues but ignore the communication with tourists and have insufficient understanding of the needs of tourists.

Based on the results of empirical research, the following suggestions are developed and provided for the administrators of environmental planning venues, government environmental planning supervisors, and subsequent researchers as references. (1) The venues can design some mixed environment teaching courses for the physically and mentally disabled or vulnerable groups so that they can understand and learn from each other under the common topic of caring for the environment. (2) Manpower cultivation is a very important subject in environmental education. Taiwan is becoming an aging society. If the competent authority can use these high and middle-aged volunteers and give them appropriate professional training, it will help develop more diversified environmental planning courses and achieve mutual benefit. (3) Environmental planning venues are not only places with the characteristics of natural resources, environmental planning value, and practice opportunities but also need four elements, namely program, facility, personnel, and operation management. By promoting the process of Eco-tourism, people can understand the natural ecology and local and global environmental issues, which will generate more positive environmental attitudes and responsible environmental behaviors. (4) Strengthening the perception of tourists' demands by staff, government supervisors, and administrators of the environmental planning venues has become an important issue of service quality management. First of all,

the consistency between venue staff and tourists should be improved to eliminate the blind optimism of venue staff. The staff of the venues is encouraged to pass the national tour guide qualification examination. Tour guides should communicate with tourists emotionally and hone their skills in practice. In order to improve the service quality of the venues. (5) It is suggested that future researchers should first identify specific types of places and extensively search for venue administrators, teaching plan providers, and activity participants with different backgrounds for an in-depth discussion of venues with different characteristics.

Data Availability

The data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Rotating Machinery Fault Diagnosis Based on Adaptive Vibration Signal Processing under Safety Environment Conditions

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At present, the degree of industrialization in China is deepening, and various types of production equipment appear. However, during the startup and operation of mechanical equipment, fracture and wear will occur due to various factors. Therefore, once the mechanical equipment fails, it must be diagnosed as soon as possible to avoid serious economic losses and casualties. Rotating machinery is an important power device, so it is necessary to regularly detect and monitor equipment signals to avoid the consequences of wrong control methods. In this study, the fault diagnosis of rotating machine based on adaptive vibration signal processing is studied under the safe environmental conditions. The fault diagnosis process of rotating machinery is to first collect vibration signals, then process signal noise reduction, and then extract fault characteristic signals to further identify and classify fault status and diagnose fault degree. This study briefly introduces several rotating machinery vibration signal processing methods and identifies the fault state of the rotating machine based on the high-order cumulant. By building a DDS fault diagnosis test bench, the chaotic particle swarm parameter optimization algorithm is used to calculate the accurate stochastic resonance parameters. After noise processing, the high-frequency part is significantly reduced. The results show that, after stochastic resonance wavelet decomposition and denoising processing, the number of intrinsic functions can be significantly reduced, the fault frequency can be increased, the high-frequency noise can be reduced, and the fault analysis accuracy can be improved. We identify the fault state of rotating machinery based on the high-order cumulant, train the four states of the bearing, and compare the four types of faults, no fault, inner ring fault, rolling element fault, and outer ring fault through the comparison of the actual test set and the predicted test set. It is concluded that the rotating machinery fault belongs to the rolling element fault and the identification accuracy rate is 95%. Finally, based on the LMD morphological filtering, the rotating machinery fault diagnosis is carried out, and the feature extraction is carried out based on the LMD algorithm to decompose the bearing fault signal. Finally, the result after the morphological filtering and LMD decomposition and extraction can avoid noise interference.

1. Introduction

In recent years, modern industry and modern technology have shown a rapid development trend. In the future, rotating machinery will develop towards high-speed, integrated, and automated trends, and the level of intelligence is increasing, the structure is more complex, and the components are closely connected [1, 2]. In case of failure, it will form a chain reaction, seriously damage the normal operation of the equipment, cause incalculable economic losses, and even cause casualties [3]. There have been many casualties caused by this factor at home and abroad.

Rotating machinery is a common power plant, mainly used in ships, power generation, aerospace, and other fields, and has a certain role in promoting the national economy in China [4, 5]. Mechanical fault diagnosis is based on a comprehensive grasp of the actual operating status of equipment, to determine whether equipment is partially or overall faulty and to find the fault and the causes of the fault in advance [6]. The main measure of fault diagnosis is to extract fault features. Since the mechanical equipment system is complex and requires a large number of components, the signal obtained by the signal measurement and acquisition system is the effect of the interaction of all components, and the transmission state of the signal in the channel makes each component [7, 8]. The degree of mixing of signal components is increased. Therefore, when diagnosing faults, it is necessary to first process the mixed signals

formed in the system to obtain signal information characteristics and then further diagnose the faults of large or complex mechanical equipment [9–11].

The economic benefits formed by fault diagnosis technology after years of development are huge. Countries around the world have recognized the advantages of rotating machinery fault diagnosis and invested a lot of manpower and funds to study this field [12, 13]. By using the advanced level of diagnostic technology, the United States is at the forefront of the world. The monitoring products developed by some companies in the United States, as the current frontier of diagnostic technology, have multiple monitoring functions and powerful diagnostic functions, which can be used in chemical, military, and other fields [14, 15]. Chinese experts use local mean decomposition (LMD) algorithm combined with LabVIEW software to analyze bearing experimental signals, and some other experts use LMD and order tracking analysis method to diagnose rotating bearing faults under variable speed conditions [16, 17].

This study analyzes the fault diagnosis process of rotating machinery, uses sensors to collect vibration signals, performs noise reduction processing based on stochastic resonance theoretical model, identifies rotating machinery fault status based on high-order cumulants, and uses LMD morphological filtering to diagnose rotating machinery faults. The research shows that the most important part in the fault diagnosis of rotating machinery is to extract the fault features. Effectively dealing with the faults of the mechanical equipment is convenient for the reliable and safe operation of the equipment.

2. Materials and Methods

2.1. Rotating Machinery Fault Diagnosis Process. More than 70% of the faults in rotating machinery and equipment are shaft and bearing faults. Bearing faults include inner ring faults, rotor faults, and outer ring faults. The main factors leading to the failure are unreasonable assembly, long-term overload operation, fatigue operation, and shortage of lubricant, which causes various faults in the shaft parts and the bearings of the rotating parts, such as friction, cracks, and eccentricity [18, 19]. Therefore, it is necessary to denoise and process the vibration signal collected by the sensor. To diagnose the fault of the rolling shaft of a rotating machine, it is necessary to first collect vibration signal, process signal noise reduction, extract fault characteristic signals, identify and classify fault states, and diagnose fault degrees [20, 21]. Figure 1 shows the diagnostic flow of rotating machinery equipment.

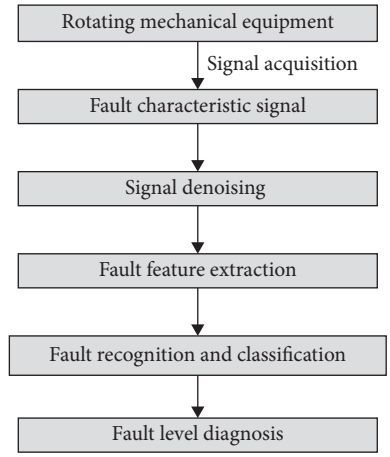

Figure 1: Flowchart of fault diagnosis of rotating machinery equipment.

2.2. Rotating Machinery Vibration Signal Processing Method. In the early stage of failure during engineering application, the weak rotating machinery vibration signal collected will be submerged by the background noise signal, so the core of feature extraction is to eliminate the background noise accurately.

2.2.1. Stochastic Resonance Theoretical Model. A bistable system of stochastic resonance is represented by the following equation:

$$\left\{\begin{array}{c} \dfrac{dx}{dt} = ax - bx^3 + A\cos\,\Omega t + \Gamma(t) a > 0, b > 0 \\ f(t) = ax - bx^3 \\ E[\Gamma(t)] = 0 \\ E[\Gamma(t)\Gamma(t)\imath] = 2D\delta\left(t - t'\right) \end{array}\right\}. \quad (1)$$

The above formula $A\cos\Omega t$ represents the external periodic driving force, a and b are both constants, x is the signal, A and O represent the amplitude and angular frequency of the external periodic driving force, $\Gamma(t)$ represent white noise, D represents noise intensity, E represents mean function, and $\delta(t - t\imath)$ represents shock function. If there is no external noise and driving force, that is, A and D are equal and zero, the potential well equation of the above equation is expressed as

$$V(t) = -\frac{a}{2}x^2 + \frac{b}{4}x^4, \quad (2)$$

where $V(t)$ is the potential well. The periodic signal passes through the system, and its signal is very weak, which makes it difficult to push the particles from one potential well to other potential wells. If a driving noise synchronized with the periodic force is actively added from the outside, the particles can pass over the potential well, and random resonance can be generated.

2.2.2. Chaos Particle Swarm Optimization Algorithm. We initialize the particle position and velocity based on chaos theory, let the standard particle swarm algorithm form a chaotic state after initialization, and make the initialization show the characteristics of regularity, diversity, and ergodicity. Logistic map is one of the most representative chaotic systems:

$$Z_{n+1} = \mu Z_n\left(1 - Z_n\right) n = 0, 1, 2, \ldots, \quad (3)$$

where μ represents the control variable. Assuming that the value of μ is 4 and the value range of Z_0 is (0, 1). Logistic is in a chaotic state. Based on the convenience, randomness, regularity, and other characteristics of chaotic variables, we initialize the random resonance position and initial speed and make them traverse differently, so as to improve the individual quality of particles and improve the search effect.

2.2.3. Variational Mode Decomposition (VMD) Algorithm. In this study, the variational mode decomposition (VMD) algorithm is used to solve the problem of rotating machinery vibration signal processing and the empirical mode decomposition (EMD) end effect problem. The VMD algorithm is used when decomposing and reconstructing the rotating machinery vibration signal, and the characteristic signal is reconstructed. We run the modal formation of the envelope spectrum analysis and then further extract the fault signal features. The VMD algorithm decomposes the $f(t)$ input signal into a series of intrinsic modal function u_{k} models of band-limited blocks; each u_{k} model surrounds w_k; the following is the calculation formula:

$$\min_{(u_k)(w_k)} \left\{ \sum \left\| \partial t \left[\left(\delta(t) + \frac{j}{\pi t} \right) * u_k(t) \right] e^{-jwk^t} \right\|_2^2 \right\}, \quad (4)$$

where $\{u_{\mathrm{k}}\} = \{u_1, u_2, ..., u_{\mathrm{k}}\}$ represents the entire model set and $\{w_k\} = \{w_1, w_2, \ldots, w_k\}$ represents the center frequency of the model set.

2.3. Fault State Identification of Rotating Machinery Based on High-Order Cumulants. Based on modern signal processing theory, high-order moments and high-order cumulants are obtained by derivation of characteristic functions, and the high-order cumulants are regarded as a kind of high-order statistics. Assuming that x represents a continuous random variable and $f(x)$ represents the probability density function, the calculation formula in the moment generating function $\Phi(w)$ is as follows:

$$\Phi(w) = \int_{-\infty}^{\infty} f(x) e^{\mathrm{j}\omega x} dx. \quad (5)$$

The moment generating function needs to calculate the k-order derivative of the moment generating function $\Phi(w)$. Assuming that the value of ω is 0, the calculation formula of the k-order moment m_{k} of the random variable x is as follows:

$$m_k = (-j)^k \frac{d^k \Phi(\omega)}{d\omega^k} \bigg|_{w=0} = (-j)^k \Phi^{(k)}(0). \quad (6)$$

The natural logarithm $\Phi(w)$ in the moment generating function is the cumulant generating function, and the calculation formula is as follows:

$$\Psi(\omega) = \mathrm{In}\Phi(\omega). \quad (7)$$

We calculate the k-order derivative of the cumulant generating function; assuming that the value of ω is 0, the k-order cumulant $\mathrm{C_{kx}}$ of the random variable x can be obtained based on the following formula:

$$C_{k\,c} = (-j)^k \frac{d^k \Psi(\omega)}{d\omega^k} \bigg|_{w=0} = (-j)^k \Psi^{(k)}(0). \quad (8)$$

Generally, cumulants exceeding the 3rd order is regarded as high-order cumulants.

2.4. Fault Diagnosis of Rotating Machinery Based on LMD Morphological Filtering. The local mean decomposition method belongs to the adaptive signal analysis method. It forms pure FM signal and envelope signal by separating any nonstationary signal $x(r)$. The following is the detailed decomposition process:

(1) Calculate the local extreme point envelope value a_i and average value m_{i} based on $x(t)$:

$$m_i = \frac{n_i + n_{i+1}}{2}, \qquad a_i = \frac{|n_i - n_{i+1}|}{2}. \quad (9)$$

(2) Connect a_{i} and m_i with a broken line to obtain the mean function $\mathrm{m11}(t)$ and the local envelope estimation function $\mathrm{a11}(t)$. Subtract $m_{11}(t)$ within $x(t)$:

$$h_{11}(t) = x(t) - m_{11}(t). \quad (10)$$

(3) After dividing $h_{11}(t)$ by $a_{11}(t)$, we can get $\mathrm{S_{11}}(t)$ FM signal:

$$S_{11}(t) = \frac{h_{11}(t)}{a_{11}(t)}. \quad (11)$$

(4) The value of $a_{12}(t)$ is 1. $\mathrm{S_{11}}(t)$ represents the standard FM signal; assuming $\mathrm{a12}(t) \neq 1$, $\mathrm{S_{11}}(t)$ represents the original data repetition process. When $S_{1\mathrm{n}}(t)$ is the standard FM signal, $\mathrm{a1_{(n+1)}}(t) = 1$.

(5) The envelope signal can be obtained by multiplying the local envelope estimation function:

$$a_1(t) = a_{11}(t) a_{12}(t) ... a_{1n}(t) = \Pi_{q=1}^{n} a_{1q}(t). \quad (12)$$

(6) The product of the first PF component is obtained by decomposition and the envelope signal $a_1(t)$ and $\mathrm{S_{1n}}(t)$. The first PF component obtained by decomposition is equal to the envelope signal.

(7) Decompose $x(t)$ into the sum of kth PF components and U_{k} as follows:

$$x(t) = \sum_{p=1}^{k} PF_p(t) = u_k(t). \quad (13)$$

3. Results

3.1. Build an Experimental Platform. One of the most used parts in various rotating machinery is rolling bearings. In

Table 1: Basic parameters of bearings selected for DDS experimental platform.

Bearing type	Number of balls	Ball diameter	Pitch diameter
6205-2RSJEMSKF	9	0.3206	1.524

Table 2: Fault characteristic frequency.

Fault type	Inner ring failure (Hz)	Outer ring failure (Hz)	Rolling element failure (Hz)
Eigenfrequency	23.16	36.54	55.2

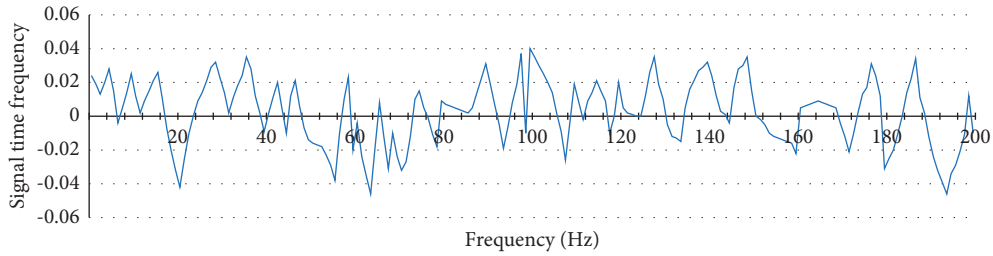

Figure 2: Time-frequency diagram of the acquired signal under the background of strong noise.

this study, a DDS power transmission fault diagnosis test bench is built, and the model is 6205-2RSJEMSKF bearing, 9 balls, and pitting damage is formed at the position of the bearing balls by electric sparks. Once the bearing has defects, the uniformly rotating rolling elements are affected by the defect to form a periodic shock signal, which is usually lower in frequency than the shock signal [22–24].

Rolling bearing is one of the most commonly used general components in all kinds of rotating machinery. This experimental platform is a comprehensive experimental platform for DDS power transmission fault diagnosis. The experimental bearing model is 200 Hz, and this frequency is the characteristic frequency of bearing faults. The data acquisition selects 16 channels, the bandwidth is 40 kHZ, the sampling frequency of the data collector is 100 kHz, and the collector is connected to the computer host by the USB interface [25, 26]. Table 1 is the basic parameters of the bearing. The motor speed is set to 600 r/min, and the sampling frequency is 1000 Hz. Forty percent of each group of data is collected, and 10 groups of data in four different modes are collected as training sample data, and then, 10 groups of data are collected, respectively. The group signal is regarded as the sample signal to be collected. Based on the fault characteristic frequency formula, three kinds of fault characteristic frequencies are obtained, and the specific results are listed in Table 2.

We substitute this parameter into the formula, and $\mathrm{COS}\alpha = 1$. The rotation frequency is 600r/min; the fault frequency can be obtained after calculation, which is listed in Table 2.

3.2. Noise Reduction Processing Results of Rotating Machinery Vibration Signals. In this study, accurate stochastic resonance parameters are obtained based on the chaotic particle swarm parameter optimization algorithm, and the fault sample signal is selected arbitrarily. Figure 2 is the spectrum diagram of the bearing rolling fault signal obtained through acquisition. It is difficult to distinguish accurately because the characteristic signal with strong noise is completely submerged.

Based on the chaotic particle swarm algorithm, $a_{\mathrm{best}} = 0.563$, $b_{\mathrm{best}} = 0.915$, and $h_{\mathrm{best}} = 0.194$ are obtained. At this time, the stochastic resonance effect of the bistable stochastic resonance system is the most ideal, so the signal at the fault frequency position has a significant increase. Then, the VMD parameters are optimized based on the mixed particle swarm algorithm, and the value of a is 1801, the value of k is 4, and the VMD is used to decompose the signal. After the adaptive chaotic particle swarm optimization stochastic resonance denoising process, the vibration signal VMD of the bearing can be decomposed to obtain the mode component of this certificate, of which the high-frequency part is significantly reduced.

Figure 3 is the result of the reconstruction of the measured signal, and the fault characteristic signal between the frequencies of 23 Hz and 24 Hz can be clearly viewed. Therefore, after denoising by stochastic resonance wavelet decomposition, the number of proof functions can be reduced so that the fault frequency increases and the high-frequency noise part decreases, thereby improving the analysis accuracy. Table 3 shows the vibration signals actually measured in a strong noise environment, so it is concluded that the processing effect of the noise reduction method used in this study is more ideal than the traditional VMD method.

3.3. Rotating Machinery Fault State Identification Results Based on High-Order Cumulants. Based on the high-level accumulation algorithm, this study selects 56 data points as one segment and selects the first ten segments of the four bearing state data as the training data and the last ten segments as the test data. In Figure 4, we draw four different

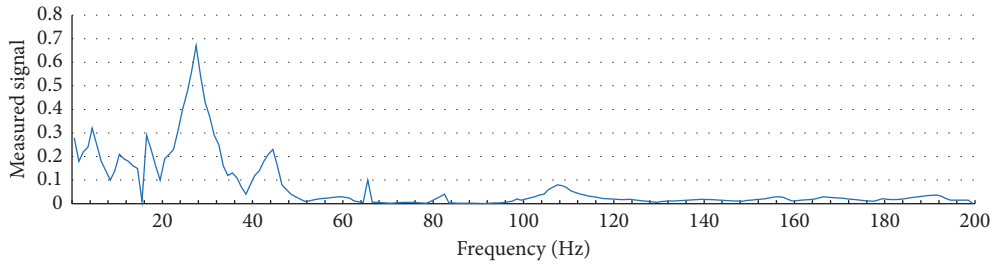

Figure 3: Measured signal reconstruction results.

Table 3: Comparison of the measured signal noise reduction effects of the two algorithms.

/	SA-VMD	VMD
SNR before processing	−23.71	−23.71
SNR after processing	−8.69	7.91

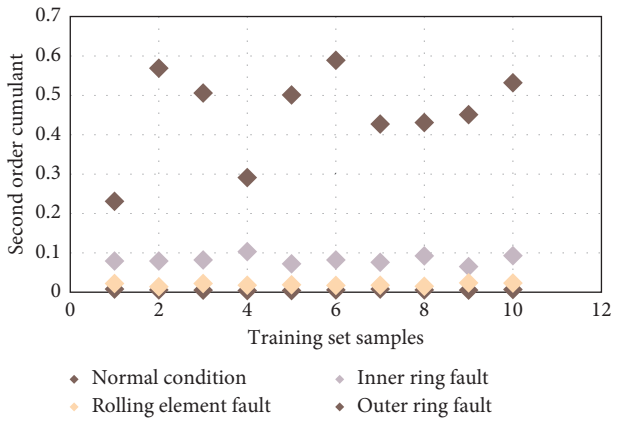

Figure 4: Second-order cumulant graph of bearing training samples.

states of the bearing and use different marks to indicate the second-order cumulative amount of the bearing state, as shown in Figure 4 [27–29].

According to the data in the figure, the normal state and the rolling fault state of the rear adjustment are similar, and the exact difference cannot be seen. We combine the second-order cumulants and fourth-order cumulants of the first ten training sample data to the feature vectors, accumulate them in high order, and then select the second-order and fourth-order cumulants in the ten test sample data as feature vectors to identify the vector state. Figure 5 displays the recognition results [30].

In Figure 5, 1 is the fault-free state, 2 is the inner ring fault, 3 is the rolling element fault, and 4 is the outer ring fault. According to the figure, only the eighth test sample among the forty test samples belongs to normal data, and its identification result is shown as a rolling element failure, and the state identification accuracy rate reaches 95%. Table 4 shows the classification and identification results of the predicted test set.

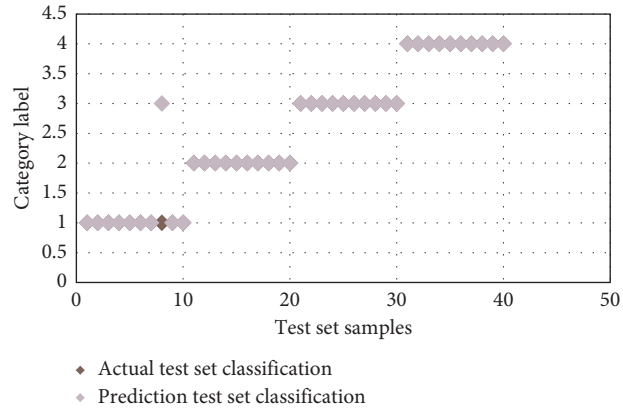

Figure 5: The high-order cumulative training and bearing identification results.

Table 4: Classification and recognition results of the prediction set.

Bearing status	Number of samples in the prediction set	Correct number of judgments	Recognition rate (%)
Normal situation	10	8	80
Inner ring failure	10	10	100
Rolling element failure	10	10	100
Outer ring failure	10	10	100
Total	40	38	95

There are certain differences in the vibration signals generated after the failure of the bearing roller, outer ring, and inner ring. Therefore, a number of indicators should be selected to calculate various fault vibration signals, and the number of indicators has dispersion. If the selected index is suitable, the obtained value has an ideal degree of discrimination for various fault signals. Since the accumulators have a good degree of discrimination for the fault signals of each bearing, various faults on the bearings can be accurately identified, and the fault identification effect is ideal.

3.4. Fault Diagnosis Results of Rotating Machinery Based on LMD Morphological Filtering. Most of the faults of rolling bearings are caused by local defects, and there are potential damages, which are difficult to detect in the early stage. Usually, the working environment of rolling bearings is

harsh, and the external environment is noisy. The vibration signal mainly includes other vibration responses of the machine system and the signal characteristics of the excitation mapping relationship, resulting in a low signal-to-noise ratio of the field vibration signal. The external environment will directly interfere with the bearing fault signal.

Local mean decomposition (LMD) is an adaptive time-frequency analysis method. It has strong mathematical morphological impact feature extraction ability and strong noise reduction ability. It can use morphological filtering in processing bearing vibration signals, which can fully reflect its own value. The original signal is processed by noise reduction to obtain a higher signal-to-noise ratio, and it can also extract the shock features in the fault. The following simulation signals are used to test the effect of extracting the signal-to-noise signal impulse characteristics by this method:

$$y(t) = x_1(t) + x_2(t) + nt, \tag{14}$$

where $x_1(t)$ represents a periodic exponential decay signal with a frequency of 16 Hz and n(t) represents a Gaussian white noise with a signal-to-noise ratio of −10 dB.

The bearing fault signal is decomposed based on LMD, and there is very little high-frequency fault data in the fourth PF component obtained through decomposition. Here, the first three IMF components are required and reconstructed. Then, the morphological filter is used to extract the characteristic frequency of the shock, and the adaptive morphological scale is optimized. The Hilbert envelope spectrum of the reconstructed signal is obtained after adaptive morphological filtering, which can accurately extract the 88 Hz shock signal and the frequency doubled component. The obtained result is similar to the fault frequency of the bearing inner ring, which means that there is a local peeling fault in the inner ring, which is in line with the actual situation and suppresses the noise spectral line, improving the signal-to-noise ratio. Through experiments, this extraction method can suppress white noise and various harmonic signals. The results after morphological filtering and LMD decomposition and extraction can avoid noise interference, and the analysis results after the harmonic order is higher than the third level have little interference to the spectrum with a higher signal-to-noise ratio.

4. Conclusion

(1) When studying the fault diagnosis of rotating machine based on adaptive vibration signal processing of safe environmental conditions, this study briefly introduces the basic process of fault diagnosis of rotating machine and points out that most of the faults of rotating machine come from bearing faults. By building the DDS dynamic rotation fault diagnosis test bench, the bearing model 6205-2RSJEMSKF is selected, and the common fault types are listed, namely, inner ring fault, outer ring fault, and rolling element fault. Based on the formula of fault characteristic frequency, different fault characteristic frequencies of three kinds of faults are calculated.

(2) This study describes in detail several methods commonly used in rotating machinery vibration signal processing, namely, random vibration theoretical model, chaotic particle swarm optimization algorithm, and variational mode decomposition (VMD) algorithm. Based on the chaotic particle swarm parameter optimization algorithm, the accurate stochastic resonance parameters are calculated. The results show that, after the stochastic resonance wavelet decomposition and noise reduction, the number of intrinsic functions can be reduced, the fault frequency can be increased, and the high-frequency noise can be reduced so that the characteristic signals can be accurately identified.

(3) This study identifies the fault state of rotating machinery based on high-order cumulants, trains the four states of the bearing, and compares the actual test set and the predicted test set with no faults, inner ring faults, rolling element faults, and outer ring faults. Results show that the rotating machinery fault is a rolling element fault and the averge recognition accuracy rate is as high as 95%. LMD morphological filtering is used to diagnose rotating machinery faults, and the bearing fault signal is decomposed based on the LMD algorithm.

Data Availability

The figures and tables used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Accurate Marketing Algorithm of Network Video Based on User Big Data Analysis

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Due to the continuous progress of the era of mega data, it is more and more important to carry out accurate marketing of online video. Based on the analysis of users' big data, this paper proposes and implements an online video precision marketing algorithm, which provides a reference for the precision marketing strategy of video websites. This paper introduces the concept and characteristics of precision marketing and analyzes the application forms of precision marketing of video websites. It also summarizes the operation system, operation mode of precision marketing, and the influence of online video advertising on enterprises and users. In order to realize the accurate marketing of big data, it needs to be carried out from three parts: data collection, data analysis, and marketing plan formulation and implementation. Through continuously collecting customer data, it gradually and clearly acquires the characteristics of customers and constantly dynamically adjusts the marketing strategy to customers, so as to accurately conduct video marketing to customers and greatly improve the marketing efficiency. In order to test the effectiveness of the marketing algorithm in this paper, we conducted an experiment. The research in this paper has important practical value and reference significance for reducing the cost of video advertising of enterprises and improving the communication effect of online video advertising.

1. Introduction

In recent years, the continuous progress of the Internet has had a profound impact on human beings [1]. No matter the application of digital technology or its spreading influence, it has greatly promoted the progress of global economy in the past decade, and it has undergone unimaginable changes [2]. The era of Internet is characterized by "cloud" as the foundation, carrier, and "data" accumulation and driving, which reflects that it can be changed according to different users anytime and anywhere [3]. The arrival of the era of mega data indicates that the Internet economy is increasingly tapping opportunities with the help of huge database, and, at this time, social media is also beginning to develop rapidly with huge user resources and sufficient channels [4]. In this environment, how to collect and integrate data more deeply and how to properly apply the results of data analysis to commercial marketing activities have become a new proposition to be solved urgently in various industries. With the wide application of various mobile intelligent terminal devices, it has a close connection with people's lives. By collecting and analyzing the data on the mobile intelligent devices, we can get the consumption information and characteristics of users, which makes it possible to carry out accurate network marketing [5]. In the era of big data, the channels of marketing communication have shown explosive expansion [6]. Faced with massive information, consumers are more willing to spend their time and energy on information and products closely related to themselves [7]. Through the data analysis of precision marketing cases, we can see that enterprises are more willing to change from wasteful mass marketing to precision marketing designed based on building strong customer relationships [8]. The basis of accurate marketing of big data is that it needs a huge database and user data of various dimensions related to users, which can be effectively cleaned, integrated, mined,

and modeled and can be applied to daily enterprise marketing activities [9]. Through precise marketing and big data analysis, it can help enterprises to accurately lock the target users and provide users with products or services that can more accurately meet their needs, thus achieving the marketing objectives of enterprises [10]. Therefore, enterprises should pay attention to network promotion, strengthen the application of mega data technology, continuously improve the accuracy of network marketing, and provide help for the continuous development of enterprises [11]. This paper studies the precision marketing of online video. Its innovations are as follows:

(i) This paper studies the precision marketing from the innovative perspective of users' big data analysis and online video, making use of all links with content production, video marketing, and communication to improve the coverage of media, the degree of communication, and the precision of marketing, so as to achieve the purpose of precision marketing.

(ii) In terms of user data, this paper opens up the serial data identification of anonymous users and real-name users, which can effectively identify all browsing behaviors of users on the Internet and collect data of users' decision-making behaviors more comprehensively. Through data analysis, we can gain insight into the individual needs of users and accurately deliver marketing information to users.

Firstly, this paper sorts out the purpose and significance of the research, including the research summary of precision marketing under the background of megadata era. At the same time, it actively explores the new changes of online advertising marketing methods, comprehensively classifies and analyzes the related basic theories, characteristics, and advantages of precision marketing, and summarizes the realization methods and effect evaluation of mobile online video precision marketing. Then it analyzes the development status of the big data era and its influence on online video marketing. Finally, the realization of precise marketing algorithm based on user big data analysis is studied. Combined with big data, network marketing, customer relationship management, and other related technologies and knowledge, this paper constructs the process of network video precision marketing under the background of mega data and puts forward corresponding suggestions according to the reality, which can provide reference for enterprises to implement network video precision marketing. Experiments verify the superior performance of this algorithm, which can realize the accurate marketing of online video. The research in this paper has certain practical significance.

2. Related Work

Yin et al. emphasized that enterprises can better optimize the relationship between enterprises and customers by combining rational data and perceptual thinking through the sharing and integration of network database resources [12]. Sun et al. summarized the three steps for big data to help precision marketing: insight into demand, precise delivery, and service assistance, emphasizing the core thinking of "beginning with customers and ending with customers" [13]. Li et al. proposed that enterprises can comprehensively and deeply mine consumers' hobbies and behaviors through big data processing technology, so as to accurately predict changes in customer needs and deepen the dynamics of precision marketing [14]. Vukoti et al. analyzed the current status of social media marketing, including an overview of social media marketing methods and existing problems and trends, and discussed specific strategies for social media marketing in the era of megadata [15]. In terms of user identification, Cheng et al. established rich user portrait data through the analysis and mining of user data. It can effectively identify users from 360 degrees, and the marketing to users is more accurate and the marketing effect is better [16]. Khan et al. pointed out that, in the era of megadata, although enterprises have massive data, not all data information is valuable, and many data are only redundant, resulting in its value density being inversely proportional to its quantity [17]. Wu et al. believed that enterprises must be customer-centric and make use of "big data" resources in order to better implement and optimize online precision marketing [18]. Su et al. pointed out that, in order to promote the continuous development of online precision marketing under the background of megadata, it is necessary to send corresponding product advertisements according to the environment where consumers are located, so that consumers have more independent choices for advertisements, and improve the effectiveness of online marketing advertising promotion. It is necessary to improve the accuracy of the market positioning of network marketing products [19]. Gupta and others believe that precision marketing is based on precise positioning, relying on information technology to establish a personalized customer communication service system, a marketing communication plan that focuses on results and actions, and achieves more accurate, measurable, and high return on investment [20]. Huang et al. discussed the profit model of video websites, combined with the theory of precision marketing, and proposed a method for formulating strategies for implementing precision marketing. It also has utility for other video sites [21]. Chen et al. took a website as an example, through in-depth analysis of its development status, current opportunities, and challenges in the era of megadata, combined with the formulation of the website's existing marketing strategies, to explore its future development direction and construct a marketing system and marketing strategy with guiding significance in the era of online media big data [22].

Based on the in-depth study of related literature, this paper takes the progress of big data and online video as the background and starting point, summarizes and analyzes the continuous progress of big data and the influence, opportunities, and challenges faced by online video, takes the corresponding marketing theory and development as the research theoretical basis, and summarizes the relevant marketing strategy combinations. It also explores the potential opportunities and inherent potentials of the progress

of online video precision marketing in the era of megadata and summarizes the innovative marketing system and marketing model. This paper also analyzes and studies the key technologies used in network precision marketing and puts forward the network video precision marketing algorithm based on user big data analysis. The application of this algorithm in the network video precision marketing scene can obtain all kinds of customer data, thus more effectively discovering potential users and bringing new ideas and new kinetic energy to the progress of the industry.

3. Methodology

3.1. Operation System and Mode of Precision Marketing. Due to the continuous progress of IT, a large amount of user data is produced in all walks of life, and these data packets contain a lot of information [23]. How to better screen and use information has become the focus of the era of megadata, and the precision marketing that came into being has become the secret weapon to win this war. The nature of precision marketing determines the improvement of total customer value. Precision marketing can not only meet the initial needs of customers but also meet the individual needs of customers through one-to-one marketing. The characteristics of precision marketing are as follows: ① relevance, ② having measurable and accurate system guarantee and means, ③ sustainable development with low cost being able to carried out, ④ precision marketing being based on the target market that can accurately distinguish and ensure effective market description and product brand positioning, and ⑤ precision marketing being an integrated sales method suitable for one-to-one distribution.

The other part is the real-name data of users on the Internet. Big data pursues the analysis of all data. Because of the huge amount of data to be studied and analyzed, it no longer pursues accuracy. This seems to be contrary to the requirement of precision marketing, but it is not [24]. Big data requires a huge amount of data. Precision marketing does not pursue absolute precision but pays more attention to grasping the general development direction of things. Precision marketing is based on accurate segmentation and positioning of users, finding out users' needs, and recommending products to the right users in the right way at the right time to achieve accurate, low-cost, and effective results. After processing the collected data and information, the platform can roughly grasp the basic personal situation of users and roughly judge the basic needs and economic strength of users according to their interest topics and behavior preferences, so as to accurately locate users and provide corresponding advertising services. Figure 1 is the flow chart of network precision marketing.

Compared with database marketing, which relies on hand database, Internet-based precision marketing relies on the Internet to identify customers' psychology and characteristics and then carries out marketing according to these data. Precision marketing focuses on personalized persuasiveness and information relevance. Through precise marketing, enterprises personalize the content and methods for customers, so as to connect enterprises with customer needs. The implementation of precise marketing strategy can be improved by means of communication, thus improving the efficiency [25]. In the context of precision marketing, the communication between marketers and customers is direct, which shortens the distance, thus enabling enterprises to establish quick-response customer centers, which is particularly important for the long-term development of enterprises. The core of precision marketing is to deliver accurate and measurable marketing information. If the information delivered is valuable, it is required that this information be closely related to the audience, because only the relevance is valuable and effective. At present, Internet-based precision marketing methods mainly include ① portal advertisement, ② keyword search advertisement, ③ blog, ④ e-mail advertisement, and ⑤ incoming advertisement.

The premise of accurate marketing is that enterprises need to master more accurate customer information. After establishing the corresponding database, users' images fed back from the database can be used to segment the market. The application of megadata enables marketers to attach importance to the interaction with target consumers in order to adjust marketing strategies in time. From the perspective of the whole marketing activities, the use of precision marketing highlights the user value, refines the marketers' cognition of user psychology and consumer behavior, and deepens the marketing concept of "people-centered" and marketing activities based on user experience, which can effectively stimulate consumption [26]. Accurate marketing means standing on the benchmark of consumer demand, digging deeply, and fully satisfying users' real inner needs and desires, rather than simple correlation and advertising push based on data analysis. Accurate positioning of consumers can make users more likely to accept marketing information, and it is more likely to guide target consumers to produce purchasing behavior, so that marketing activities can achieve better results. Based on the concept of precision marketing, enterprises need to establish higher-quality marketing communication in the operation process. High quality refers to three aspects, namely, more accurate user portrait, measurable return on investment, and traceable marketing effect. Operating system generally includes ① clear target market, ② clear and unique market positioning, ③ efficient customer communication system, ④ channel system suitable for niche distribution, and ⑤ customer value-added service system. The accurate marketing of video websites is based on the analysis of users' information and behaviors. As users, their behaviors on video websites can be divided into three aspects: searching, browsing, and interacting. Therefore, video websites also plan accurate marketing activities according to these three user behaviors.

3.2. Status and Development of Big Data Era and Its Influence on Online Video Marketing. With the rapid development of Internet technology, the Internet has had a significant impact on all walks of life. Due to the continuous progress of the era of megadata, information explodes, information is requested anytime and anywhere, and the amount of information generated and acquired by people has shown a

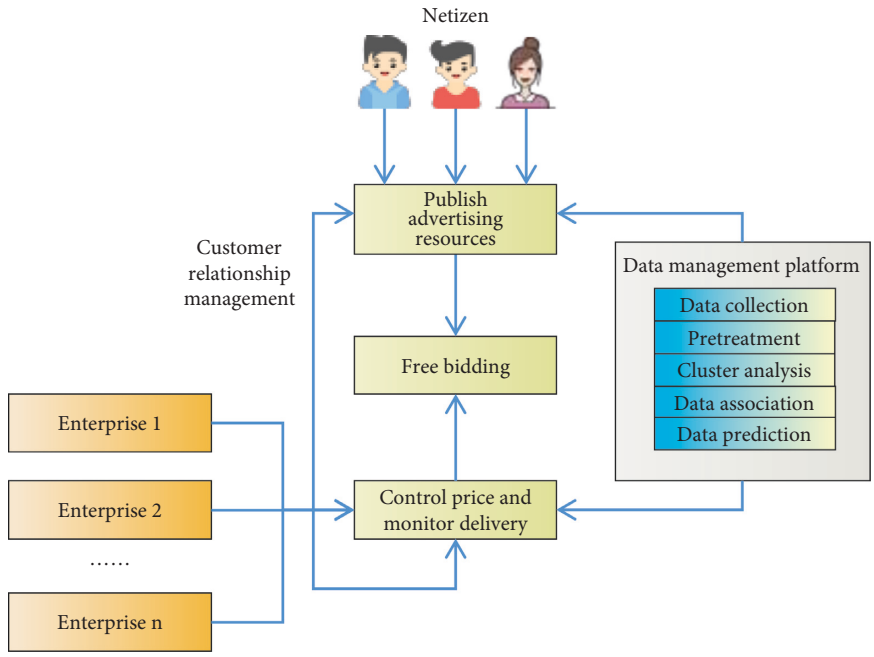

Figure 1: Flow chart of network precision marketing.

series-level growth. In particular, with the wide application, popularization, and development of digital media and smart devices, people have not only produced massive data in production and life. How to use these data to better promote people's life and production has also become a hot topic. Big data is a huge collection of data that is difficult to collect, analyze, and mine in a short time by mainstream software tools.

With the deepening of big data knowledge and technology, enterprises can process data in a more efficient and reliable way, which brings a new thinking-precision marketing to network marketing. Big data precision marketing is also called data-driven marketing. The core idea of using big data analysis for precise marketing is to match "people, goods, and markets." It guides consumers to actively participate in it and is committed to establishing one-to-one product marketing mode, giving full play to the advantages of big data mining technology, collecting external information resources of enterprises, and combining with the huge data information owned by itself, through analysis, providing help for enterprises to formulate long-term marketing strategies. The precision marketing service platform based on big data analysis is shown in Figure 2.

Different from traditional network marketing, network precision marketing under the background of megadata emphasizes the accuracy of market positioning. Specifically, the precision marketing of big data mainly covers three parts: ① data collection part, ② data analysis part, and ③ marketing plan implementation part. Accurate marketing of big data requires enterprises to understand, analyze, and predict the consumption behaviors of different consumers more comprehensively and deeply with the help of various information technologies and network platforms, so as to find out the target market, make effective positioning, and continuously track and optimize the relevant data system to improve the accuracy of enterprise market positioning. The change of consumers' ideas and behaviors also prompted brand merchants to adjust their delivery strategies. The Internet has become the new favorite of marketing and promotion activities, even leapt to the traditional media, such as TV and newspapers, and became the most popular promotion channel for brand merchants.

Advertising, as the most basic business model of the Internet, has become more efficient, but this efficient advantage has gradually become insignificant under the impact of the mobile Internet. Traditional video network marketing is based on enterprises, and more well-known and widely viewed video websites are selected as the target of advertising, but the cost is high and the effect is not satisfactory. It pays attention to customer value and better grasps the real demands of consumers by tracking and analyzing the structured, semistructured, and unstructured consumption data of customers, so as to provide them with more personalized marketing services. There are two forms of online video advertising: video advertising on web pages and video advertising on online video streaming media. The video website industry uses data for precision marketing. Compared with traditional marketing methods, precision marketing improves the marketing efficiency from the production of video content to the promotion and then to the broadcast. Online video advertising is an online video booth that integrates traditional video advertising into the network by using advanced digital technology and can be used by enterprises to live online. This is actually a very representative form of rich media advertising.

Social resources are limited, but the phenomenon of resource waste is everywhere. In this regard, online video precision marketing in the era of megadata emphasizes the coordination of resources. Accurate prediction of user

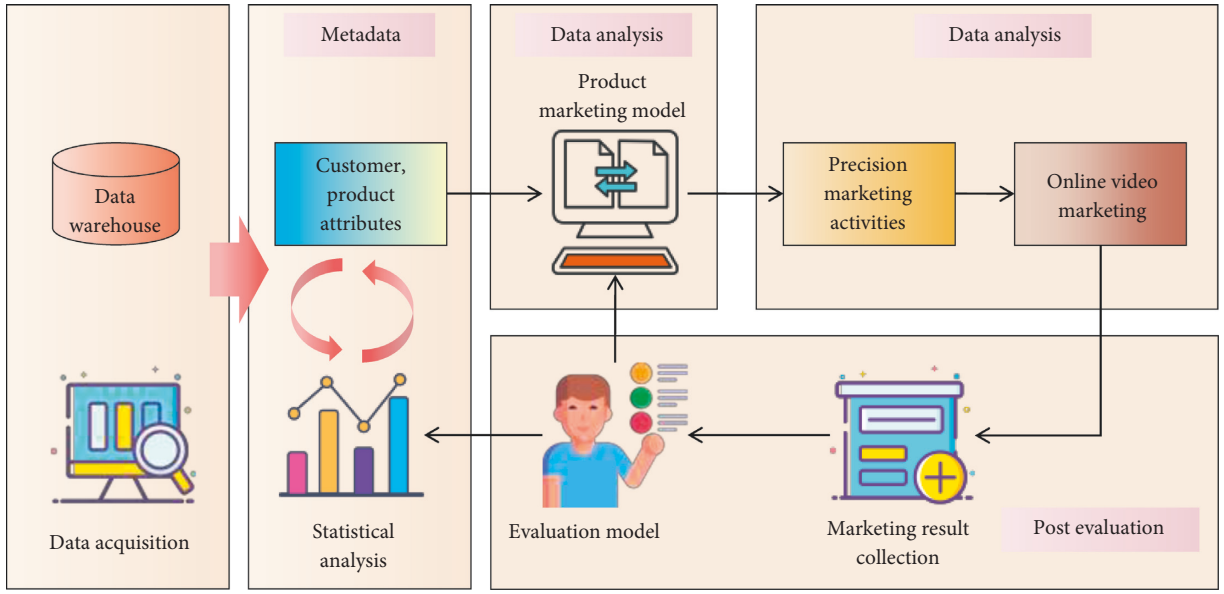

Figure 2: Precision marketing service platform based on big data analysis.

demand can help enterprises to produce and market more efficiently. Therefore, big data can be transformed into the source of enterprise economic value. In the big data environment, through the establishment of an open virtual data platform, data, information, and other resources of all parties can be integrated to realize exchange of needed goods, reduce transaction costs, and optimize transaction process. Associated enterprises can share customer data resources, formulate matching network precise marketing strategy combination, optimize resource allocation, and achieve win-win goals. The application of accurate video marketing on websites will make users integrate multiple identities and become producers, disseminators, and consumers of video content.

3.3. Realization of Precise Marketing Based on User Big Data Analysis. The essence of big data is to find the laws, reasons, trends, and so forth reflected behind the data and to find the known number with unknown numbers. The core goal of data analysis is to get customers' needs based on the analysis application of megadata and, at the same time, give customers a feeling of being valued and satisfied and generate benign interaction. At present, there are mainly two mainstream ways to collect, analyze, and process customer data: ① get corresponding technical support and data services with the help of specialized "big data" service companies and ② establish a corresponding data platform for data collection and analysis.

Collect basic data information on the Internet and build a consumer database. In this stage, we should try our best to ensure that the obtained consumer information has good comprehensiveness. Therefore, in the process of information collection, we should use various ways and different ways to collect information. According to the analysis of product sales history information, the characteristics of target customers are analyzed, and the customer-product marketing model, product-product cross-marketing model, and so on are constructed through the mapping of customer metadata, so as to realize the precise marketing of products to customers and improve the marketing efficiency.

Because it is difficult to directly extract the multimedia features of the network video and the content is numerous, the variety is numerous, the video quality is uneven, and so forth, it is impossible to directly classify the theme of the network video by using the traditional artificial film classification method. In this paper, the correlation degree between user u and video i is defined as

$$\text{preference}(u,i) = p_u^T q_i = \sum_{k=1}^{K} P_{u,k} q_{k,i}. \tag{1}$$

In the above equation, $P_{u,k}$ and $q_{k,i}$ are parameters in the latent semantic model, $P_{u,k}$ measures the relationship between user u and the k-th latent feature, and $q_{k,i}$ measures the relationship between the k-th latent feature and item i; P_u is composed of $P_{u,k}$; q_i is an item-latent feature association vector composed of $q_{k,i}$. The latent semantic model evaluates the relationship between user u and item i through P_u and q_i.

For a virtual rating matrix M, let all rating items in it form a set:

$$R = \{(u, i, r_{ui})\}. \tag{2}$$

In the above equation, r_{ui} is the virtual rating of video i by user u. In order to obtain the specific parameters of the latent semantic model in equation (1), it is necessary to use the scoring set in R to learn the latent semantic model. To this end, the loss function corresponding to parameters $P_{u,k}$ and $q_{k,i}$ can be constructed as follows:

$$L = \sum_{(u,i)\in R} \left(r_{ui} - \overline{r}_{ui}\right)^2 + \lambda \left\| q_i \right\|^2 = \sum_{(u,i)\in R} \left(r_{u,i} - \sum_{k=1}^{K} p_{u,k} q_{k,i} \right)^2 + \lambda \left\| p_u \right\|^2 + \lambda \left\| q_i \right\|^2. \tag{3}$$

In the above equation, $\overline{r}_{ui}$ is the rating value of user u on video i predicted by the existing model parameters, and $\lambda\|p_u\|^2 + \lambda\|q_i\|^2$ is the regularization term used to prevent overfitting of the latent semantic model, which can be used to punish the complexity of the latent features.

In the era of megadata, real-time bidding technology is indispensable to truly realize accurate network marketing. This emerging technology model breaks the traditional online advertising trading mode, integrates technologies such as category search and big data, and helps enterprises to carry out marketing activities more pertinently, thus improving the utilization rate of enterprise resources and realizing low-cost expansion. Relying on data mining technology, data information is divided according to consumers' age, gender, consumption ability, and consumption habits, and the attributes of each consumer group are defined. The characteristics of enterprise products are matched with the attributes of consumer groups to get the approximate product market positioning. Through the collection, analysis, and processing of a large amount of data, the platform extracts customer attributes and purchasing behavior information as metadata and at the same time constructs the relationship model between customer attributes and products, so as to achieve accurate delivery of distinguishable and customizable product information.

Interest fit indicates the stability of users' browsing network video types. The higher the interest fit is, the closer the users' browsing video types are, and the lower the interest fit is, the greater the fluctuation of users' browsing video types is. p is defined as

$$p = 0.5^{|ap - wp|/wp}. \tag{4}$$

In the above equation, ap represents the average type of video users browsed, and wp represents the weighted average type. Let op represent the original video type, and ap is defined as

$$\mathrm{ap} = \frac{\sum_{i=1}^{n} \mathrm{op}_i \times t_i}{\sum_{i=1}^{n} t_i}. \tag{5}$$

wp is defined as

$$\mathrm{wp} = \frac{\sum_{i=1}^{n} \mathrm{ap}_i \times \mathrm{be}_i}{\sum_{i=1}^{n} \mathrm{be}_i}. \tag{6}$$

Interest fit reflects the concentration of users browsing online videos. The higher the degree of interest fit, the higher the user's attention to a video and the stronger the intention of browsing the video.

Unlike traditional online marketing, which emphasizes creativity and click rate, online precision marketing under the background of megadata emphasizes technology more. It relies on the corresponding technology to mine massive data, so as to obtain more useful customer information. According to the multidimensional historical data information of customers, the platform processes and maps to metadata that can reflect the general situation of customers. At the same time, through analyzing the historical sales data of products, we can find out the common characteristics of customers and generate metadata that can reflect the sales characteristics of products. The data in the database is widely used. By mining the data in the consumer database, it is possible to judge the consumer's consumption grade and brand loyalty according to the consumer's characteristics. At the same time, not only is the data in the database valuable to this enterprise, but also it may be of high value to other enterprises, so the data in the database can also be sold, and so forth. After the model is built, customers can be identified according to the channel access information, and accurate product information can be delivered to customers through product marketing model matching. At the same time, a network sharing mechanism can be provided to amplify the marketing effect. After the information is released, actively collect marketing results for feedback.

With the continuous marketing activities, customer information will be continuously returned to enterprises. The arrival of these data can update the database and reflect the latest situation of customers, which is very important for the subsequent marketing activities of enterprises. The analysis algorithms and tools of big data analysis are completely unfamiliar to ordinary enterprises. Data analysis is a complicated process, which requires comprehensive docking between traditional manufacturing enterprises and data analysis departments, and the results of data analysis can not only guide the upstream production process but also promote the downstream sales process.

Record the user's usage behavior or access behavior every time and establish a description database. Describe the user's behavior by using these access data and identify the effect of describing the user's behavior by weighting the description data, and then basically establish the user's interest preferences and other attributes for precise marketing. The prediction of users' online video preferences is calculated as follows:

$$P_{u,i} = \overline{R}_u + \frac{\sum_{m=1}^{n} \left(R_{m,i} - \overline{R}_m\right) \times \mathrm{sim}(u,m)}{\sum_{m=1}^{n} \mathrm{sim}(u,m)}. \tag{7}$$

In the above equation, $\overline{R}_u$ is the average rating of user u to online videos, $R_{m,i}$ is the rating of user m to video i, $\overline{R}_m$ is the average rating of user m to online videos, and $\mathrm{sim}(u,m)$ is the similarity between users u and m.

After the nearest neighbors of the target user are obtained, user interest analysis can be performed on the videos that are not rated by the target user according to the scores of these neighbors, thereby generating recommendations. User u's predicted rating for unrated video i is

$$P_{u,i} = \overline{R}_u + \frac{\sum_{v \in N_u} \text{sim}(u,v) \times \left(R_{v,i} - \overline{R}_v\right)}{\sum_{v \in N_u} |\text{sim}(u,v)|}. \quad (8)$$

In the above equation, N_u represents the nearest neighbor set of the target user u, $\text{sim}(u,v)$ represents the similarity between the target user u and its nearest neighbor v, and $R_{v,i}$ represents the rating of video i by user v. $\overline{R}_u$ and $\overline{R}_v$ represent the average ratings of target user u and neighbor user v, respectively.

In the process of network marketing, users can be identified and analyzed in groups, and, according to the historical purchasing behaviors of the same user groups, the purchasing behaviors and purchasing decision-making time points of relevant user groups can be predicted, and the behavior analysis of users who have already purchased can also be realized, the correlation degree of purchasing other products can be predicted, and the related sales of network marketing can be realized. In essence, big data analysis needs to realize the comprehensive linkage of various departments within the manufacturing industry. Under the condition of improving the overall management level of enterprises, select some professionals who are proficient in business, know about production, and have technical ability in data analysis. If you want to achieve this effect quickly, the operation process of big data analysis should be more humanized, which will be a better way. If people who have knowledge of production and sales and brand awareness in the enterprise conduct big data analysis, the enterprise can quickly realize scientific and refined marketing.

4. Result Analysis and Discussion

In order to ensure the high accuracy of the online video accurate recommendation obtained through big data technology, it is necessary to verify the rationality of the video accurate recommendation through practice and relying on the actual marketing effect. Complex test mainly uses software to do stress test on network video precision marketing system, focusing on the performance of its components in stability and performance. The test cycle is long, which is mainly divided into four steps, namely, test plan writing, test case design, test implementation, and test execution. If the marketing plan has achieved satisfactory marketing results, it shows that the marketing plan has high accuracy, and marketing work can be carried out based on this plan in the later period.

The user activity statistics provided by the social platform are used as the "activity" feature to depict the user portrait, so as to improve the extra active days required and the elapsed time since the user last logged in. The statistics of correlation coefficient of personal information characteristics are shown in Table 1.

According to the common points of related consumers, we can get the common points of consumers in the database and then get the data of ideal consumers. Some statistics of social platform data for user portraits are shown in Table 2.

Taking the statistical results of users' video preferences for big data as the research object, data clustering and information fusion processing are carried out. Comparison of accuracy data of the two analysis methods is shown in Figure 3.

Table 1: Correlation coefficient statistics of personal information characteristics.

Gender	Correlation coefficient
Age	5.15×10^{-2}
Education	4.35×10^{-2}
Geographical location	4.18×10^{-2}
Work	4.88×10^{-2}
Activity	5.02×10^{-2}

Table 2: Social platform data statistics of user portraits.

Statistics	Parameter
Number of posts	856302
Total vocabulary	321225
Posting tool	4037
Emoji	86
Post time	25

The data acquisition module mainly collects and stores the original data. The analysis module realizes the analysis and processing of users' usage in the mobile Internet and is used to identify all the business content that users used in the past and the related web page content information that users have visited. First, the data just entered into the database is extracted, converted, and clearly processed, so that the original data can be converted into data that can be analyzed. Then, with the support of statistical software and decision support software, the detailed database required by each department is generated. Looking for ideal consumers, consumers of the same type generally have a lot in common, which can generally be reflected in the database. The algorithm in this paper is compared with the marketing recommendation algorithm in the literature, and the comparison result of marketing accuracy is shown in Figure 4.

It can be seen from the figure that the marketing accuracy of this algorithm has obvious advantages when the sample data is large. The users of the system are mainly enterprise users. After registering in the system, enterprises become users of the precision marketing system, which can manage themselves, apply for marketing orders, and so on. Enterprises should constantly improve and adjust the way of network marketing based on big data technology to make it more accurate. When the system completes the original data collection, the first step is to start data processing, then submit the results to the analysis engine, and back up the original data. The feedback information from customers will also be collected to correct the customer preference information and revise the recommendation model. The analysis engine simultaneously analyzes and mines various data and saves the analysis results into the analysis database.

Considering the running time and the sufficiency of algorithm comparison, the first 20000 records of two datasets are used as experimental data. The statistical information of different datasets is shown in Table 3.

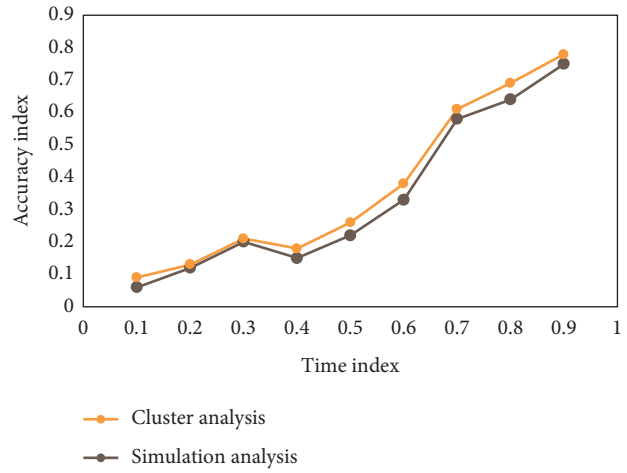

Figure 3: Comparison of accuracy data of two analysis methods.

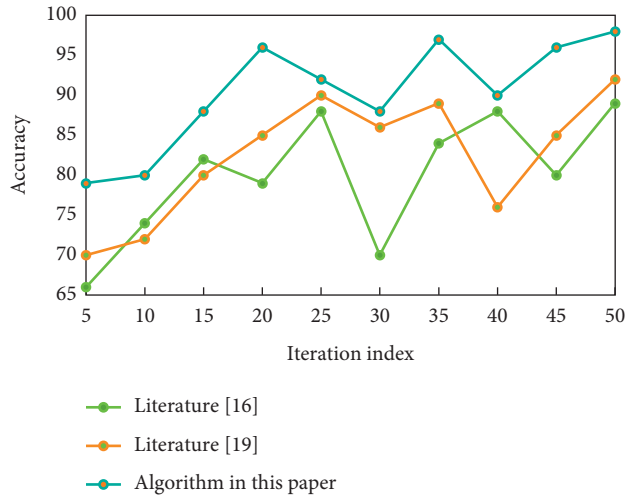

Figure 4: Marketing accuracy comparison results.

Table 3: Statistics of different datasets.

Data set	Trans	Items	Length
Short documentary	885	1132	1758
Sitcom	1255	1569	2211
Popular science video	1523	2223	2017
Funny video	2235	3164	2211

If the value is too large, it is too small to explain the feasibility of the recommendation method, and if the value is too large, the result is difficult to predict. Figure 5 shows the relationship between recommendation list length and precision.

Through the third-party monitoring tools, strictly record the user's ID, password, browsing history and stay time, and so forth to help enterprises collect data sources of network precision marketing. Get as much potential information as possible from limited information and find valuable association rules hidden in the records visited by different customers in a certain period of time. By combining with practice, we can further judge the usefulness of the mining

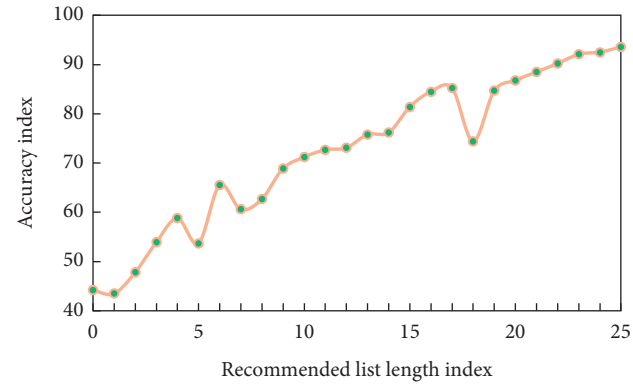

Figure 5: Relationship between recommendation list length and precision.

results. Big data storage tools include MPP database for static data, Hadoop storage platform for unstructured data, and big data all-in-one machine integrating software and hardware. According to the data in the created database, the data warehouse of the system is built after collection and analysis, and the data mining model of data warehouse access, dimensional dataset analysis, and knowledge reflection is completed. Then create a multidimensional dataset, define a new data source view, extract and convert the data map in the database into marketing data table, website classification data table, and so forth, and identify the fact data table and dimension table, create a multidimensional dataset, and select appropriate measurement values.

The experimental conditions for testing the length of the list are optimized, so the accuracy may be higher. After many experiments, the length of the list is finally set to 50, so the relationship between the accuracy of the two recommendation methods and the time series is shown in Figure 6.

Through cluster analysis of common users in enterprises, targeted analysis of individual users, cross analysis of category users, and so forth, we can grasp the trend of customer demand more comprehensively and then improve customer satisfaction. The system creates the sqlmapcon Figurexml configuration file, which contains the database links and information corresponding to sql requested by users and also describes the mapping relationship between the data provided by customers and Action Form components. Sqlmapcon Figurexml is used to load and configure various components used by Struts framework and establish the relationship between controller and model. The analysis of users' web page access data is mainly to obtain the HTTP log information of users' web pages for related data analysis. The analysis contents include users' access time period, access frequency, access habits, search habits, commonly used search keywords, and other information contents. With the increase of the number of topics, the complexity and time consumption of the model increase. The evaluation results of interest model of the marketing algorithm in this paper and the algorithm in literature [16] are shown in Figure 7.

Because big data is massive, fast, flexible, diverse, and low in value density, it is out of date to use traditional business

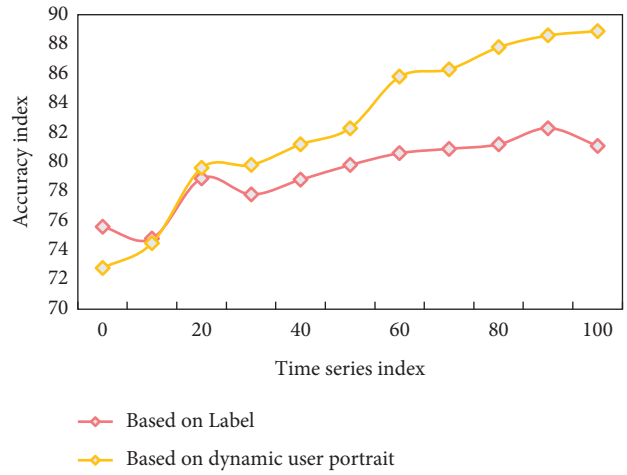

Figure 6: Accuracy comparison.

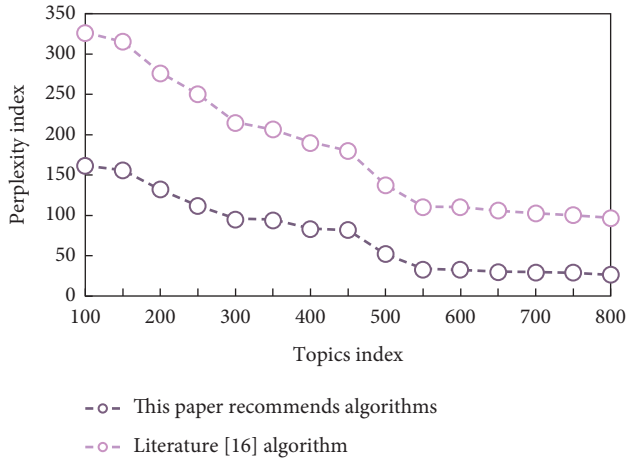

Figure 7: Interest model evaluation results.

intelligence. Enterprises need to distinguish different occasions and adopt different treatment methods according to different business objects. Do not make the analysis and processing of data extremely complicated. The framework structure of model components dealing with hierarchical Struts framework is distinct, giving full play to the advantages of Struts framework. The division of labor is clear when developing projects, which is beneficial for developers to realize modular programming, thus improving the development efficiency of the program and making it easier to maintain and expand the program. Only by collecting, processing, analyzing, and forecasting the scattered mass data can the advertising suppliers and demanders make better use of network data and achieve the goal of precise marketing.

This chapter focuses on the performance test of the core algorithm of data mining in this paper, as well as the functional test of the system. Because the early system analysis and system design work of the project are meticulous and thorough, the coding completed according to the detailed design can basically eliminate logic errors after unit testing. The basic functions of this test are qualified. During the whole test process, the system runs stably and successfully passes all kinds of tests.

5. Conclusions

As a new marketing model, video precision marketing is sought after by more and more enterprises with the thinking of "emphasizing customers as the center and relying on big data technology to realize personalized marketing." Accurate marketing under the big data environment can timely discover various unmet needs of customers, and the products and services provided to customers are products and services that can truly meet customer needs. This paper takes users as the center and closely combines big data with content, video marketing, and management, and, through the application of recommendation algorithm, we can gain a better and more scientific insight into the information needs and preferences of the audience. In order to verify the effectiveness of this algorithm, we carry out experiments. It can meet the needs of accurate recommendation and has certain practical value. Due to the continuous progress of the era of megadata, more and more enterprises will use big data to make accurate recommendations, accurately depict the potential needs of users in more dimensions, continuously improve the accuracy of marketing, user maintenance, and service, and seek new growth momentum for the progress of enterprises. On the one hand, big data can effectively improve the effect of precision marketing; on the other hand, it can also bring more consumer choices to consumers, so that consumers can consume according to their own wishes, make up for the shortcomings of passive marketing in the past, and further strengthen the efficiency of online marketing. In the future work, we should improve the technical level, break through the application barriers of big data, and enable enterprises to obtain data conclusions that are really conducive to the growth of enterprises when using big data analysis for precise marketing.

Data Availability

The figures and tables used to support the findings of this study are included in the article.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

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