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RESEARCH ARTICLE

Efficient Green Supply Chain Management for Transit Manufacturing Enterprises Integrating AHP, K-NN, and MILP in the Context of Sustainable Development

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ABSTRACT At present, most research on supply chain network design only considers the horizontal game of commodity greenness of the supply chain, and does not consider the vertical cooperative mode, and does not consider the impact of their own economic development on the environment. Therefore, the green supply chain network of transshipment manufacturing enterprises is designed. Firstly, the index of green supply chain is optimized and a more comprehensive index system is developed. Then, the K-nearest neighbor and decision tree algorithms are used to pre-process the partner data, and the partner is double-screened according to the index. To solve the large error in judging a single weight factor, the compound weight method is used to integrate the weight factors in two dimensions. Finally, the branch-and-bound algorithm mixed integer linear programming is used to solve the quantity of goods transported by the partners and the specific distribution route. Through the experimental analysis, compared with the traditional supply chain model, the supply chain network designed by the research reduces the cost expenditure by 34.26%, the pollution by 30.25%, the transportation loss by 37.12%, the transportation distance by 42.45%, and the transportation time by 28.47. It can effectively realize the sustainable development of enterprises and reduce the pollution generated by enterprises.

INDEX TERMS Green supply chain, K-nearest neighbor algorithm, composite weight method, sustainable development.

I. INTRODUCTION

A. INTRODUCTION

More enterprises adopt sustainable green supply chain management as an important part of enterprise strategy. It is particularly obvious that small and medium-sized manufacturing enterprises use green supply chain operation. These enterprises contribute a lot to the GDP of China, have a large potential market, and their production is relatively concentrated. The production frequency is high, the goods transported in a single time are low, limited by the capital chain, and the transportation mode and route are relatively single. After adopting the sustainable cooperation mode, the order production mode is merged between enterprises to increase the cooperation between enterprises. Under the active encouragement of the government, faced with the increasingly common green consumption behavior, small and medium-sized manufacturing enterprises have to improve the goods through green supply chain and other means. Commonly used green supply chain focuses on the impact of economic and environmental indicators. But it cannot achieve significant good effects on the development of enterprises and environmental protection, ignoring sustainable development. The indicators for the green supply chain of

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small and medium-sized manufacturing enterprises need to be considered, complicated and diversified. Therefore, by combining the compound weight method, K-nearest neighbor (K-NN) and decision tree algorithms, this study provides a comprehensive evaluation method of partner capability and resources. This approach allows for a more accurate assessment of partners' sustainability and environmental performance, which helps organizations make better decisions. And in the four-level network architecture of the traditional supply chain, the upstream and downstream transfer stations are newly introduced to integrate the vehicles that are not fully loaded, and the upstream transfer stations are transferred to the downstream transfer stations for railway transportation, which reduces the transportation cost and increases the complexity of the supply chain model. The traditional horizontal transportation is improved to horizontal and vertical cooperative transportation, which improves transportation efficiency.

B. INTRODUCTION WITH BULLET MARK

After the 20th century, developing countries entered a period of rapid economic development, as the excessive use of resources not only promoted rapid economic growth but also caused many environmental problems [1]. Driven by the times, traditional supply chains are slowly transitioning towards green supply chains. There are many shortcomings in traditional enterprise supply chain collaboration and management, such as incomplete communication, low utilization efficiency, offline procurement interaction and tracking methods, and lack of real-time performance [2]. Green supply chain management can involve involvement, procurement, production, logistics, marketing and recycling. The purpose of green is to cover the lifecycle of a product, rather than a certain stage [3]. The "supply chain collaboration" possessed by green supply chain is an efficient mode, which refers to the communication, transportation, and cost-benefit allocation and collaboration among various partners in the supply chain. And meet the needs of customers through good materials [4]. There are still some shortcomings in the current supply chain, and some methods have strong subjectivity, making it difficult to accurately measure various indicators of green supply chain [5]. The contradiction between economic development and environmental protection and social responsibility becomes increasingly prominent. As a result, the green supply chain supporting sustainable development receives more attention from small and medium-sized manufacturing enterprises and governments. Aiming at the problems of green supply chain, such as model simplification, single mode of transportation, unclear partner selection, and inaccurate index weight factors, a new model with transit is proposed. It considers carbon emission, water pollution, noise pollution, transportation time, transportation cost, transportation distance, accident rate and other indicators. To this end, the Commonly used green supply chain index system is improved, and K-NN and decision tree algorithms are used for dual location selection to screen partners. Then the composite weight method is used to integrate and select the weight factors, and XPLEX mixed integer linear programming is used to the goods transported by the partner and the specific distribution route. A green supply chain network for transshipment manufacturing enterprises based on K-NN algorithm is designed to realize the sustainable development of enterprises and environment.

The contribution of the research has the following three points:

1. Optimize and design the multi-layer architecture of the supply chain for small and medium-sized manufacturing enterprises that can be transitioned at the economic, social, and environmental levels. In response to the drawbacks of traditional transportation methods, the introduction of railway and road collaborative transportation reduces pollution and costs.

2. Introduce a new concept of upstream and downstream transfer stations as hubs on the basis of traditional model architecture.

3. Double screening of partners was conducted using machine learning, and the optimal allocation scheduling scheme was found using XPLEX mixed integer linear programming.

The study is divided into three parts:

The first chapter is the literature review, which analyzes the research of various technologies both domestically and internationally, and further elaborates on the content that needs to be studied in the future.

Chapter 2 is the design of the green supply chain, which conducts a detailed design and introduces the technologies and their related improvements required.

The third chapter is the analysis part. The experimental analysis is conducted on the practical application effect of the designed green supply chain.

II. LITERATURE REVIEW

A. REVIEW AND CLASSIFY LIT. REVIEW

Driven by the new era, traditional supply chain is slowly transitioning to green supply chain. As a global research hotspot, the green supply chain is increasingly attracting the attention in both domestic and foreign. Younis et al. investigated whether control variables have any impact on corporate performance when implementing green supply chain management practices. A comprehensive review was designed in the experiment and multiple regression analysis was used to investigate. It was confirmed that different control variables had four dimensions of impact on corporate performance [6]. Agyabeng-Mensah et al. aimed to examine the direct impact of internal green supply chain practices on green human resource management, supply chain environmental cooperation, and corporate performance. Quantitative methods were used, and customized questionnaires were used to collect data and analyze it [7]. Abdullahet al. conducted data analysis on the effectiveness and reliability of green supply chain using SPSS and Amos, and found that green supply chain management had a significant positive impact on environmental and operational performance [8]. Bag et al. investigated 15 potential obstacles related to the application of blockchain in green supply chain, analyzed their causal relationships using fuzzy decision experiments and evaluation experiments, and optimized the ranking of obstacles. It expanded new research directions for the application of blockchain ingreen supply chain management [9]. Ferreira et al. proposed a framework to determine the impact of wire and arc additive manufacturing (WAAM) technology on green supply chain performance, providing evidence for seven claims related to WAAM production capacity and green supply chain performance. The results showed that "relative advantage" and "supplier benefit" were key capabilities developed through WAAM [10].

K-NN algorithm is a simple classification method, which makes classification prediction based on the nearest neighbor relationship between samples to be tested and labeled. To provide decision support for the management of autonomous emission control ships, Maskooki et al. proposed a trajectory prediction method based on K-NN and applied it to a dual-objective routing problem, aiming to maximize the measurement tasks to be completed and minimize the corresponding total travel distance of emission control ships [11]. Paithane et al. studied and promoted an online food ordering system to realize the efficient delivery of food deliverers, and used K-NN algorithm to solve the traveling salesman problem (TSP) to guide the progress. The proposed strategy reduced delivery delays by 10-15 minutes per order compared to traditional methods [12]. Zhang et al. artificially realized the identification of different motivations of surrounding vehicles, thereby reducing traffic risks and realizing safe route planning. A semi-supervised method based on K-NN ensemble learning was proposed to classify the maneuvering behavior of surrounding vehicles. Finally, the error-driven representative learning and exponential decay function were used to update the model online [13]. To achieve efficient supply chain collaboration, Ali et al. provided a platform based on machine learning and used K-NN algorithm for data analysis [14]. Meng et al. proposed a prediction model based on support vector machine (SVM) and K-NN algorithm to predict the travel conditions of a section of Pan-Island Expressway East in Singapore. The experimental results showed that under the aggregated data, the prediction accuracy of this model reached 95% [15].

Thanks to the development of computers and continuous in-depth research in some related fields, comprehensive evaluation methods have been continuously developed and improved. The method of determining the indicator weight coefficient, as a key factor in comprehensive evaluation, has also achieved a lot of research in recent years. Pamucar et al. proposed a new subjective weighting method called Fuzzy Completely Consistent Method (FUCOM-F) to accurately determine standard weights in the absence of complete information and language evaluation by decision-makers. The weight values were obtained through minimal paired comparisons [16]. To objectively evaluate the quality stability of cigarette products, Qiet al. established a new method that combined weight and efficacy coefficient to evaluate the physical quality of cigarettes. And they normalized the weights calculated by the efficacy coefficient into the comprehensive score [17]. Ashley-Dejoet et al. investigated the length weight relationship and state factor of Tillapiazilli in the Yobe River in northeastern Nigeria. The LWR model was used to analyze the influencing factors of water bodies. They proposed new suggestions for sustainable utilization, decision-making, and policy formulation [18]. The actual measurement error evaluation of power metering equipment was often affected by environmental noise and insufficient input information. Therefore, Maet al. proposed an improved local outlier factor (ILOF) method to detect potential outlier. And an optimized distance function and an adaptive threshold constraint method based on box graph were used to improve the outlier detection performance of ILOF [19]. Sharma et al. proposed a control strategy based on Hilbert transform weight coefficient (HTWF) to improve the reliability of grid integrated solar photovoltaic system. In the experiment, delayed input vectors were used to extract the basic power supply voltage components from the distorted power supply voltage. And a complex filter was inserted to synchronize the photovoltaic system with the public power grid [20].

Seydanlou et al. put forward a practical optimization model for the sustainable closed-loop supply chain (SCLSC) management of agriculture in Iran, and made positioning, allocation, and inventory decisions under uncertain conditions. Simultaneously, a meta heuristic algorithm using multi-neighborhood programs was proposed to solve the complex network design [21]. Tian et al. found a lack of comprehensive review of multi criteria decision-making techniques in the fields of low-carbon transportation and green logistics. Considering the shortcomings of existing technologies, they constructed an overall structure of multi-criteria decision-making techniques in the article, conducted a comprehensive review and analysis, and elaborated on current practices [22]. Edalatpour et al. proposed a study on simultaneously designing optimal pricing and inventory management decision-making problems, first focusing on environmental and social standards as key indicators for selling products, and considering the possibility of shortages under budget and warehouse capacity constraints. In addition, the upper limit of environmental pollution and the lower limit of employment opportunities were considered as constraints for the model [23].

The ultimate goal of green logistics technology is the sustainable development of the ecological environment, which is not only for economic benefits, but also for environmental and social benefits. Aiming to identify the key role of green finance and logistics in sustainable production and a circular economy, Jinru et al. collected data from 240 respondents in China's manufacturing sector after the peak of the COVID-19 pandemic in late 2020 and analyzed it using structural equation models. The results showed that green financing and green logistics had a significant positive impact on sustainable production and circular economy. Moreover, sustainable production had a significant positive impact on the circular economy [24]. An et al. investigated the relationship between green logistics operation and economic, environmental and social value table of countries along the "Belt and Road", and conducted research using least square (FGLS) and system generalized moment method estimation techniques. The OFDI of China had significantly improved the quality and quantity of green logistics in terms of transport infrastructure, customs service, cost, time, tracking and reliability [25]. Du et al. Explored the concepts and objectives of green logistics and financial innovation in the BRICS context, with the aim of achieving carbon neutrality or net zero emissions. To test the research gaps identified, a new 2000-2018 dose-economics approach was adopted and the hypothesis of "carbon neutrality" was confirmed [26].

B. RESEARCH GAP

Based on the above literature, in terms of collaborative models for green supply chain models, although the design patterns vary greatly, the overall direction remains consistent. However, there are many shortcomings in the design of supply chain networks, and the results obtained are not ideal enough. The current research on green supply chain has problems such as simplified models, simplified transportation methods, unclear partner selection, and inaccurate indicator weighting factors [27].So, a new supply chain network design was proposed by introducing the K-NN algorithm, aiming to improve the traditional supply chain and identify green partners, the optimal scheduling, and allocation route. The study is divided into three parts. Firstly, the collaboration and transportation modes of traditional supply chains are improved. Horizontal and vertical transportation can be carried out between each layer, and collaborative transportation can be proposed to the transportation company to minimize transportation costs as much as possible. The traditional road transportation method not only has high transportation costs, low transportation efficiency, long transportation practices, and a small amount of goods transported in a single operation, but also has significant damage to nature and society. So, a collaborative transportation method that combines railway and road is introduced to reduce the costs and transportation time of manufacturing enterprises.

Secondly, the traditional model architecture is improved by introducing intermediate and downstream transfer stations as hubs. The concept of upstream and downstream transfer stations has been added to the research. The transportation method from the upstream transfer station to the downstream transfer station is railway transportation. The goods transported through the upstream transfer station need to be assembled and transported between transportation to ensure the maximum loading rate of the freight cars. After the goods are transported to the downstream transfer station, a transportation company is scheduled in advance for the same transportation and sent to the corresponding customers.

Finally, the K-NN and decision tree algorithms are used to double screen the partners and label the cooperative partners. The composite weight method is used to calculate the weight factors of each indicator of the partner. The composite weight method combines the decision tree algorithm (ID3) with strong objectivity and the principal component analysis (AHP) with strong subjectivity to calculate the more accurate weight factor size. Finally, the green partner and the optimal scheduling and allocation route of the green supply chain are found.

C. TABLE OF REVIEW

A review of current relevant studies is shown in the following Table 1:

D. STEP OF MODEL

The model steps are shown in Figure 1.

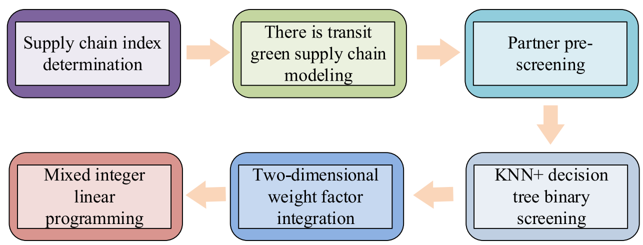

FIGURE 1. **The model steps.**

III. PROBLEM STATEMENT

A. PROBLEM STATEMENT

More enterprises adopt sustainable green supply chain management as the key part. Small and medium-sized manufacturing enterprises use the green supply chain operation mode in particular and their contribution to GDP is huge [37], [38].They have a large potential market, and the production is relatively concentrated. And the production efficiency is high, the goods transmitted in a single time are low, limited by the capital chain, and the transportation mode and transportation route are relatively single [39], [40]. After adopting the sustainable development writing mode, the order and production mode between enterprises are merged to increase the cooperation between enterprises. Under the active encouragement of the government, faced with the increasingly common green consumption behavior, small and medium-sized manufacturing enterprises have to improve the goods through green supply chain and other means. The Commonly used green supply chain focuses on the impact of economic and

TABLE 1. A review of the existing studies and the contents of this paper.

Serial number	Topic	Research content	Reiew
[28]	Viable medical waste chain network design by considering risk and robustness.	A new feasible MWCND is proposed through a new two-stage robust stochastic programming that takes into account both resilience (flexibility and network complexity) and sustainability (energy and environment) requirements. Therefore, they try to consider risk through conditional value at risk (CVaR) and improve the robustness and agility of demand fluctuations and networks, whichis solved by GAMS XPLEX solver.	This approach solves the medical waste management (MWM). Waste is reduced by locating and sorting. It is recycled and sent to waste procurement contractors.
[29]	Resilience and sustainable supply chain network design by considering renewable energy.	The resilience and sustainable supply chain network design by considering renewable energy sources are studied. A new two-stage robust stochastic optimization method is embedded for this network. The first level determines facility locations and renewable energy sources, and the second level determines the flow between the backbone components of the supply chain. The model is established by the GAMS-XPLEX solver, and the positions of the two components are determined.	By equipping renewable energy with renewable energy, renewable energy becomes a sustainable energy source that ADAPTS to fluctuations in demand and is compatible with the sustainable development goals
[30]	A robust optimization model for sustainable and resilient closed-loop supply chain network design considering conditional value at risk.	By considering sustainability, resilience, robustness and risk aversion, closed-loop supply chains are considered for the first time. A two-stage mixed integer linear programming model is proposed. A robust correspondence model is used to deal with uncertainty.	It provides decision-makers with some management insights and provides good estimates of total costs, pollution, energy consumption and employment levels
[31]	Viable Supply Chain Network Design by considering Blockchain Technology and Cryptocurrency.	A new two-stage robust optimization scheme is proposed. The VSCND's facilities and launching the blockchain are the first stages of the decision; Finally, the flow between components in the next stage are determined. GAMS-XPLEX is used to solve the model.	Equipping VSCND with BCT makes it more resilient, sustainable and flexible to fluctuations in demand.
[32]	Robust optimization of risk-aware, resilient and sustainable closed-loop supply chain network design with Lagrange relaxation and fix-and-optimize.	A robust, risk-aware, resilient and sustainable closed-loop supply chain network (3RSCLSCND) was explored, which can respond to demand fluctuations such as the COVID-19 pandemic. A two-stage robust stochastic multi-objective programming model is used to express the problems of the formula. The objective functions include minimizing costs, CO2 emissions, energy consumption, and maximizing employment through the application of conditional value at risk (CVaR) to achieve reliability by reducing risk. Risk entropy (EVaR) and minimax methodare used to compare the models.	The model has advantages in estimating costs, energy consumption, environmental pollution and employment levels. The model can be applied to other CLSC problems.
[33]	Hybrid Fuzzy and Data-Driven Robust Optimization for Resilience and Sustainable Health Care Supply Chain with Vendor-Managed Inventory Approach.	Three RSHCSC models are proposed. The first model is the average and mean absolute function, the second model is the conditional Value at risk (CVaR) model, the third model is the minimax model, and the last model is the traditional inventory model. The strengths and weaknesses of each model depend on how conservative policymakers are. The sensitivity analysis of key parameters such as fuzzy cutting, confidence level, robustness coefficient and elastic coefficient, size model, etc.	Fuzzy and data-driven hybrid robust optimization of resilient and sustainable healthcare supply chain (RSHCSC) using VMI approach is suitable for improving inventory management systems to address uncertainty and disruption in this case
[34]	Viable closed-loop supply chain network by considering robustness and risk as a circular economy.	The viable Closed Loop Supply Chain Network (VCLSCND) is a new concept that integrates sustainability, resilience and agility into the circular economy. This study performs hybrid robust stochastic optimization by minimizing the weighted expected value, maximum value and risk entropy (EVaR) of the cost function.	The difference in cost, energy and time between the proposed algorithm and the main problem is about 6.10%, −8.28% and 75.01%, respectively
[35]	Viable supply-chain with vendor-managed inventory approach by considering	By considering blockchain, risk, and robustness, a viable supply chain with a vendor approach to managing inventory is	Comparing the problems with and without BCT

TABLE 1. ***(Continued.)*** **A review of the existing studies and the contents of this paper.**

	blockchain, risk and robustness.	demonstrated. Blockchain technology (BCT) is embedded to improve the agility of supply chain. To solve the risk and robustness problem, a new objective function is proposed, which includes weighted expected value, worst-case and risk entropy to consider risk and robustness under different scenarios. The model is a mixed integer linear programming, which is solved by GAMS-Bonmin.	
[36]	Antifragile, sustainable and agile healthcare waste chain network design by considering blockchain, resiliency, robustness and risk.	It provides a new robust stochastic optimization method that combines risk criteria, especially risk entropy, to deal with uncertainty, risk interruptions, and demand fluctuations. In addition, anti-vulnerability, sustainability, and agility principles are incorporated into the HWCND framework, which includes blockchain technology (BCT), flexible capabilities, CO2 emissions, energy consumption, and population risk limits.	The framework of the Medical Waste Chain Network (HWCND) is constructed, which includes basic components such as medical centers, waste sorting, waste procurement contractors, and landfills.
This article studies	-	Firstly, the index of green supply chain is optimized and a more comprehensive index system is developed. Then, K-nearest neighbor and decision tree algorithms are used to pre-process the partner data, and the partner is double-screened according to the index. To solve the large error in judging a single weight factor, the compound weight method is used to integrate the weight factors in two dimensions. Finally, the branch-and-bound algorithm mixed integer linear programming is used to solve the quantity of goods transported by the partners and the specific distribution route.	The index solving quality of the improved transshipment supply chain model is obviously better than that of the non-transshipment supply chain model. And with the increase of the scale of the example, the optimization effect of each index becomes more obvious. This method improves the efficiency of partner solving in supply chain.

environmental indicators, but it cannot develop enterprises and environmental protection significantly, ignoring sustainable development.

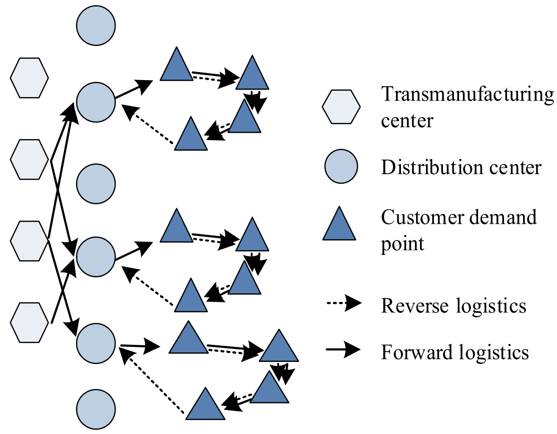

FIGURE 2. **The existing supply chain network structure.**

B. PICTURE OF PROBLEM STATEMENT

The green supply chain of small and medium-sized manufacturing enterprises needs to consider more than that. The purpose is to save the economic costs of the enterprise, or to minimize the damage to the environment, so as to achieve sustainable development. The existing supply chain network structure is shown in Figure 2.

The research objective is to screen the partners of the supply chain network and make decisions on the transportation path to minimize the total cost and minimize pollution of the entire supply chain network. To this end, the research mainly focuses on the optimal design of the green supply chain architecture of small and medium-sized manufacturing enterprises at the economic, social and environmental levels. The green supply chain model for small and medium-sized manufacturing enterprises includes: the selection of partners: allocating the orders of merchants and customers, controlling the safe inventory of merchants; how to optimal allocate and allocate the goods to the positioned customers, and the corresponding best transportation mode selection; based on the basic model of green supply chain, an optimized mixed integer model for small and medium-sized manufacturing enterprises is proposed to integrate the network architecture composed of multiple merchants, multiple upstream and downstream transfer stations and multiple customers.

Assumptions

To facilitate modeling, the following hypotheses are proposed:

(1) Any merchant has its own maximum inventory and maximum production, when the customer order quantity exceeds must choose another candidate merchant.

(2) The demand of each customer for each commodity is determined.

(3) The transportation distance between all merchants and merchants and customers is known.

(4) The fixed costs generated by the construction, operation and shutdown of the factories of merchants and upstream and downstream transfer stations are known. And the unit carbon emission, unit water pollution, and unit noise pollution are known.

(5) The operating status of merchants and upstream and downstream transfer stations is known.

(6) The transport cost per unit of different modes of transport is known.

(7) The carbon emissions, accident rate, transportation loss rate and average speed of full load of different transportation modes are known.

(8) The characteristic factors of all commodity evaluations are known.

(9) The maximum cargo load of the truck is known.

C. NOTATION LIST

The relevant comments of each variable symbol are shown in Table 2:

TABLE 2. Variable comment table.

Variable	Annotation
$obj8$	Fixed cost and transportation cost of green supply chain model for small and medium-sized manufacturing enterprises
$obj9$	CO2 emissions from plant construction, operation, shutdown and transportation
$obj10$	Water pollution discharge during plant construction, operation and shutdown
$obj11$	The amount of noise pollution during plant construction, operation, shutdown and transportation
a	Weight factor of CO2 pollution control cost conversion
b	Weight factor of water pollution treatment cost conversion
c	Weight factor of noise pollution control cost conversion
$xDCP$	Road transport Quantity of goods shipped from distributor k
k	Distributor number
l	Customer number
p	Item number
D_{lp}	Order quantity
$CC'P$	The quantity of goods transported by road from customer l to l'
$xDHCP$	The quantity of goods transported to the customer from the downstream transfer station
aD	The total number of trucks shipped by the distributor to all levels of business
HCN	The number of trucks used in the merchant's stage
DP	Quantity of goods transported at each stage
$D_{lp\max}$	The maximum quantity of goods transported by road for 1 km at a time

D. MATHEMATICAL MODEL

More enterprises adopt sustainable green supply chain management as the key part of strategy. A new green supply chain model with transit is proposed, which considers carbon emission, water pollution, noise pollution and transportation time. This chapter describes the supply chain network in detail, and introduces and improves the technology used.

1) CONSTRUCTION OF ENTERPRISE GREENSUPPLYCHAINAND PRELIMINARY SELECTION OF PARTNERS

The Commonly used green supply chain focuses on considering the impact of economic and environmental indicators.

TABLE 3. Common green supply chain indicators used by enterprises.

Business	Economic indicators	Environmental indicators	Social indicators
Supplier	Production cost of raw materials	Transport carbon emissions	Carbon emission indicators
	Transportation cost	Transport noise pollution	Water pollution indicators
	-	-	Noise pollution indicators
Manufacturer	Factory construction cost	Production carbon emissions	Carbon emission indicators
	Operating costs	Operational carbon emissions	Water pollution indicators
	Transportation cost	Production water pollution	Noise pollution indicators
	Shutdown costs	Operational water pollution	-
	-	Production noise pollution	-
	-	Operational noise pollution	-
Distributor	Factory construction cost	Operational carbon emissions	Carbon emission indicators
	Operating costs	Operational water pollution	Water pollution indicators
	Transportation cost	Transport carbon emissions	Noise pollution indicators
	Shutdown costs	Transport noise pollution	-
Upstream transfer station	Factory construction cost	Operational carbon emissions	Carbon emission indicators
	Operating costs	Operating water consumption	Water pollution indicators
	Transportation cost	Transport carbon emissions	Noise pollution indicators
	Shutdown costs	Transport noise pollution	-
Downstream transfer station	Factory construction cost	Operational carbon emissions	Carbon emission indicators
	Operating costs	Operating water consumption	Water pollution indicators
	Transportation cost	Transport carbon emissions	Noise pollution indicators
	Shutdown costs	Transport noise pollution	-

Its purpose is to minimize the economic costs or minimize the environmental damage. Table 3 shows the indicators involved.

However, this supply chain collaboration model does not have a significant and excellent effect on the sustainable development of enterprises and environmental protection. According to some studies, uncertainties can be eliminated by considering the recovery amount, recovery rate, transportation loss and other parameter indicators in the supply chain indicators [41]. There are also studies that consider the

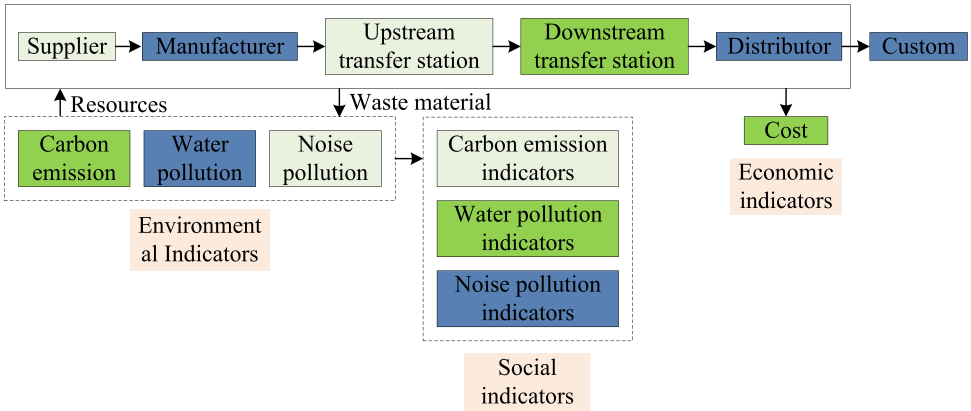

FIGURE 3. Logistics process of small and medium-sized manufacturing enterprises.

incoordination of transport vehicles, dynamic carbon emission factors, and supply ratio in the green supply chain index. It is found that adding these indicators to the model can effectively reduce supply chain costs [42]. Based on economic and environmental goals in the supply chain model, another study built a supply chain that includes transportation cost, carbon emissions, industrial productivity and transportation time [43]. By considering the above research content and the actual application environment of the existing supply chain, the supply chain index in Table 3 is optimized. Therefore, based on Table 3, the study introduced indicators such as noise pollution, transportation loss rate, transportation distance, transportation cost, transportation time, supply ratio, productivity, and return rate. For economy, the costs of environmental pollution treatment, recycling, and utilization are added. For society, measurements and calculations are mainly conducted on carbon emissions, water pollution, and noise pollution. This can reduce the ecological damage caused by various types of pollution to the environment and build a sustainable green supply chain collaboration model.

To concretize environmental indicators such as carbon emissions, water pollution, and noise pollution, the study calculates the governance costs of environmental indicators in supply chain cost. Different emission indicators have different weighting factors, and the final costs of governance are calculated based on the emissions of different indicators.

For small and medium-sized manufacturing enterprises with transit, the network optimization problem of green supply chain can be defined as the random order quantity of customers. The products owned by distributors will be redistributed. In this regard, an upstream midstream station is added after the distributor layer, and the upstream intermediate station can assemble and transport the goods transported by the distributor. This can ensure the full load rate of the carriages and use railway transportation to transport the goods to downstream transfer stations for acceptance. The goods transferred through downstream can be handed over to a pre-contacted transportation company and transported to designated customers. Green supply chain, a transit manufacturing enterprise, can choose multiple potential merchants from different regions to build a complete supply chain network. And the order demands of multiple customers were counted.Then a distributor finally allocates them to each customer. Finally, the manufacturer returns to the supplier for raw material procurement. Figure 3 shows the entire logistics process.

This study is based on the evaluation data provided by the government through the green supply chain simulation of small and medium-sized manufacturing enterprises in recent years. It ensures the rationalization of indicators such as carbon emissions, water pollution, and noise pollution. And it also inputs some basic constants as model construction.

To concretize environmental indicators such as carbon emissions, water pollution, and noise pollution, the study calculates the governance cost of environmental indicators in the supply chain costs. Different emission indicators have different weighting factors, and the governance costs are calculated based on the emissions of different indicators finally. Equation (1) is the total economic costs for the green supply chain network of small and medium-sized manufacturing enterprises.

$$obj7 = obj8 + a \times obj9 + b \times obj10 + c \times obj11 \quad (1)$$

In Equation (1), $obj8$ means the fixed costs and transportation costs of green supply chain for small and medium-sized manufacturing enterprises. $obj9$ is CO_2 emissions during construction, operation, shutdown, and transportation. $obj10$ represents the water pollution emissions during the construction, operation, and shutdown processes. $obj11$ is noise pollution during construction, operation, shutdown, and transportation. a, b, and c are the weight factors for conversion of pollution control costs. Certain constraints were set in supply chain. All orders from each customer need to meet Equation (2).

$$\sum_{l\in L} D_{lp} = \sum_{l\in L}\Big(\sum_{k'\in K} xDCP_{k,l,p} + \sum_{l'\in L(l\neq l')} C'CP_{l',l,p} + \sum_{dh\in DH} xDHCP_{d,l,p} - \sum_{l'\in L(l\neq l')} CC'P_{l,l',p}\Big)\ (p\in P) \quad (2)$$

In Equation (2), $xDCP$ is goods quantity transported by road transportation from distributor k. k is distributor number, l

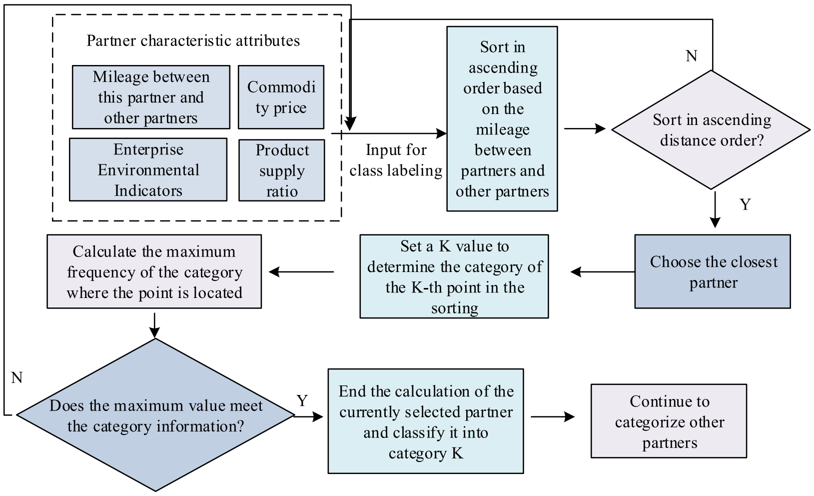

FIGURE 4. K-NN algorithm flowchart.

is customer number, p is product number, and D_{lp} is order quantity. $CC'P$ is goods quantity transported by road from customer l to l'. $xDHCP$ is goods quantity transported from downstream transfer stations to customers. Equation (3) represents truck constraint.

$$aD \leq \sum_{p \in P} \frac{DP}{D_{lp\max}} \leq HCN + 1 \tag{3}$$

In Equation (3), aD is the total trucks transported by distributors to various merchants. HCN is the trucks used bymerchant at the current stage. DP represents goods quantity transported in each stage. $D_{lp\max}$ is the maximum goods quantity transported by road for a single kilometer. So, a complete green supply chain mathematical model was constructed.

For the green supply chain of manufacturing enterprises, partner selection is more important. The research first performs preprocessing operations to screen out partners with poor feature attributes, and uses machine learning KNN and decision tree (DT) algorithms for dual location selection. Firstly, K-NN is used to preprocess partner data and classify partners. The selection of K directly affects the training and subsequent prediction performance. Therefore, cross validation method is adopted to determine the optimal K in this study. After selecting the appropriate K, the distance between each partner is calculated using Euclidean distance in Equation (4).

$$L_p = \left(x_i, x_j\right) = \left(\sum_{i=1}^{n} |x_i^{(l)} - x_j^{(l)}|\right)^{\frac{1}{2}} \tag{4}$$

In Equation (4), x_i and x_j are real vectors in the feature space.To ensure equal importance of each feature, the study normalized each feature using the specific method in Equation (5).

$$d\left((y_1, y_2, \ldots, y_n)(z_1, z_2, \ldots, z_n)\right) = \sqrt{\sum_{j=1}^{n} \left(\frac{y_j}{M_j} - \frac{z_j}{M_j}\right)^2} \tag{5}$$

In Equation (5), M_j is the maximum value minus the minimum value on each axis. d is the coordinate distance. The study uses different feature attributes of partners for classification. The selected feature attributes are shown as follows. 1. Euclidean distance was used to record the distance between the partner and other partners. 2. Product price. 3. The third characteristic value is the product supply ratio. Three feature attributes of multiple partners were collected and calculated. The partner with the shortest total distance, the lowest product price, and the highest supply ratio was selected and marked as a frequent partner in the future. Partners with moderate distance, price, and supply ratio will be marked as occasional partners in the future. In addition, partners with poor feature attributes are marked as partners who will not cooperate. Figure 4 shows the K-NN algorithm.

Although the K-NN algorithm can accurately classify partners, its biggest drawback for specific data is that it cannot provide the intrinsic form and meaning of partner data. To this end, the study usesthe DT algorithm for the secondary filtering of data. Firstly, the partner training set was used as input data. Then, a tree-based classification rule is selected from an unordered and irregular dataset. Then, a small amount of test data is used to test DT. Finally, its structure is modified and adjusted. Firstly, the construction starts with a single node of training sample. If sample data belong to the same class, the node becomes a leaf and is marked with that class. Otherwise, the attribute with the highest information gain is selected as current DT node. Afterwards, based on the different feature attributes of the current tree node, the training set is divided into several subsets, each value forming a branch. Repeated tests are conducted on the subset obtained in previous step, so that each sample is reflected on DT. When an attribute appears on the same node, there is no need to consider any sub bands of node. When the constraint conditions for recursive partitioning are reached, the repeat test ends. The study uses a top-down recursive function to construct DT. The basis for classification is to use characteristic factors number in each indicator for branching operations. Indicators with

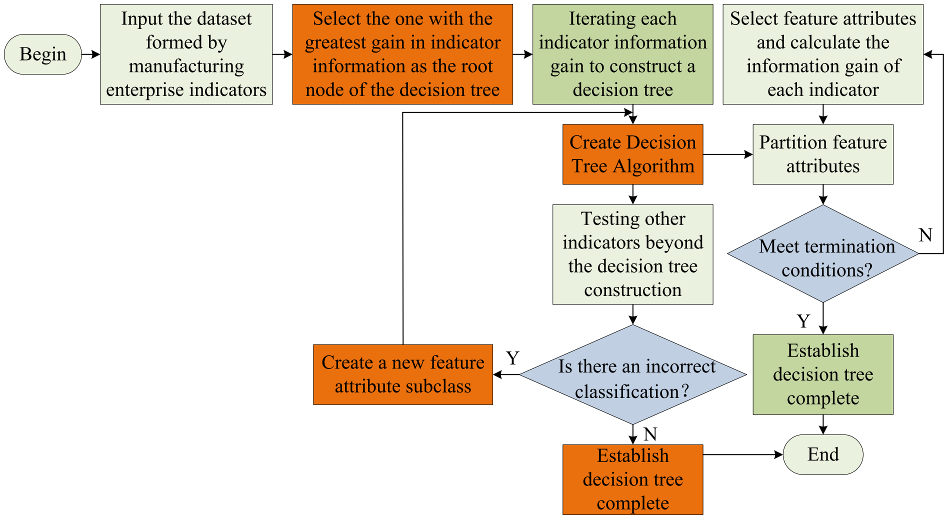

FIGURE 5. **Decision tree algorithm creation process.**

larger feature factors are placed at top tree, while indicators with smaller feature values are placed at the bottom of DT. Figure 5 shows the creation process.

2) DESIGN OF GREENSUPPLYCHAIN NETWORK BASED ON CWM AND K-NN

For various indicators of partners, a single weight factor judgment is prone to subjective or objective evaluations. This results in a significant error between the evaluation indicators and the actual indicators. Therefore, research has abandoned the single-dimensional weighting factor measurement method. Iterative Tree Third Generation (ID3) algorithm and Analytic Hierarchy Process (AHP) were used to process weight factors for two-dimensional integration. By integrating subjective and objective evaluations through a dual-dimensional weighting factor integration method, the weighting factors for each indicator of partner can be obtained. This makes the weighting factors more reasonable and accurate. ID3 algorithm takes initial set S as root node. All attributes in the set are traversed in each iteration. Set S is divided into different data using the selected attributes. The algorithm only considers attributes that were not previously selected and continues to recursively process each of itself. When each element of the subset belongs to the same class, then this node is a leaf node and marked as the category to which the instance belongs. When there are no more attributes to choose from in the subset, the last leaf node of this node is marked as a subset to summarize the classes that most instances belong to. If the subset has no instances, the leaf node is created and marked as the most common class for instances in the parent set. That is, if there are no instances in its parent set that fully match the characteristic values of the selected attribute. Equation (6) is the calculation for entropy.

$$H(S) = -\sum_{x \in X} p(x) \log_2 p(x) \tag{6}$$

In Equation (6), S is the current dataset used to calculate entropy, X is the classes set. $p(x)$ is the ratio of class elements number to the total sets number. When entropy is 0, the set is completely separable, meaning that all elements in the set have the same class. The attribute with the lowest entropy is used for set segmentation during iteration. In addition, the study further segments the set by calculating information gain in Equation (7).

$$\begin{cases} IG(A,S) = H(S) - \sum_{t \in T} p(t) H(t) \\ S = U_{t \in T} t \end{cases} \tag{7}$$

In formula (7), $H(S)$ is the entropy of set S, T is the subset obtained by combining the classification set S of attribute A, $p(t)$ is the number of elements in t and the number of elements in set S, and H is the entropy of the subset. After dividing the set on attributes, its uncertainty decreases. The steps to apply ID3 algorithm to partner evaluation for small and medium-sized manufacturing enterprises are as follows. Firstly, various indicators of partners are selected to evaluate whether cooperation can be carried out. And the evaluation indicators of partners are selected to form a training set. Then, the information entropy is calculated according to different indicators in training set. And it is divided according to the maximum weight factor of the attribute. After subnode is formed, it is iteratively divided according to the indicator information gain until all the indicator information is traversed. The execution of the ID3 algorithm is shown in Figure 6.

AHP is a hierarchical analysis method that combines qualitative and quantitative analysis. The problem is decomposed into different sub-problems based on the attributes of the complex problem and the requirements of the overall goal. And the sub-problem factors are clustered and combined at different levels based on their mutual influence. A multi-level analysis model is constructed to determine weights. The study takes manufacturer indicators as the highest indicator,

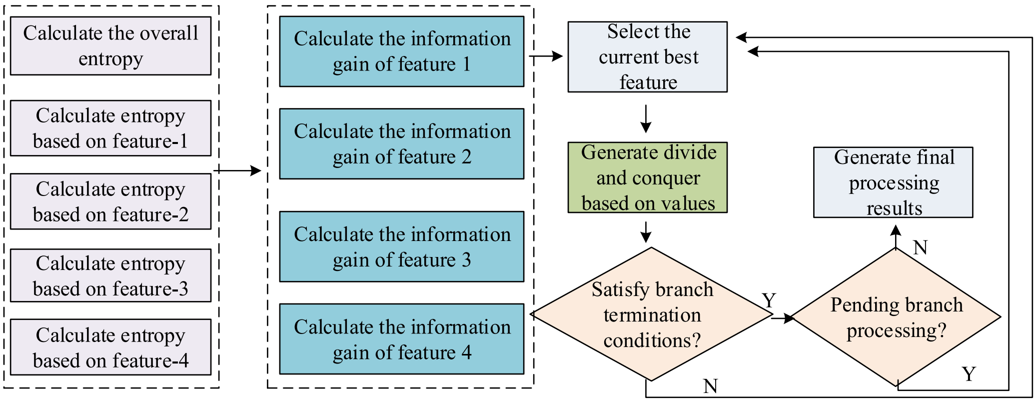

FIGURE 6. Execution process of ID3 algorithm.

economic indicators, environmental indicators, and social indicators as the middle layer, and other coordinates as the bottom layer. Figure 7 shows the hierarchical results among various indicators.

Given the diversity and complexity of green supply chain evaluation indicators, research is conducted to filter indicators and then test the remaining indicators. ID3 algorithm requires a large number of historical datasets as algorithm foundation. And the numerical size of each indicator is calculated based on sample set data. The determination of weight factors through historical cooperative relationships has strong subjectively and bias in weight factors. The evaluation indicators of AHP algorithm are subjectively determined by experts based on the importance relationship, with strong subjectivity. To this end, research will average the two algorithms to obtain the weight factors of each indicator. So, the subjective and objective evaluations are balanced, and a more reasonable and accurate weight factor can be obtained. The CWM is shown in Figure 8.

For small and medium-sized manufacturing enterprises green supply chain, the objective functions are linear. They include economic costs, environmental governance costs, transportation costs, environmental pollution, transportation time, transportation distance, transportation accidents, and transportation loss rate. The research uses XPLEX mixed integer linear programming to solve the goods transported by partners and specific distribution routes. The core of XPLEX is the branch and bound method, which applies the search and iteration. Usually, all feasible domain spaces are repeatedly divided into smaller and smaller subsets, called branch operations. And a target lower bound for the solutions within each subset is calculated, which is called a bound. After each branch, any subset whose boundary exceeds the target of the known feasible region will not further branch, and many subsets can be ignored, which is called pruning. This is the main idea of the branch and bound method. After obtaining the optimal solution, the decision variables with non-integer values are divided into two closest integers and added to the original problem to form two sub-problems for separate solving operations. By this way, the upper or lower bounds of the objective function value are obtained, and the optimal solution is found. The algorithm is shown in Figure 9.

The mixed integer linear programming model aims at the green supply chain of small and medium-sized manufacturing enterprises, and its objective functions are economic cost, environmental governance cost, transportation cost, environmental pollution amount, transportation practice, transportation distance, transportation accident, transportation loss rate, etc. The objective function is linear, and the constraint conditions are the vehicles, which are the positive integer constraints, the goods, which are the positive integer constraints, and the constraints are linear, and the decision variable can take any positive integer.

After establishing the relevant mixed integer optimization model, the study uses particle swarm optimization algorithm to solve the relaxed scheduling problem. The basic particle swarm optimization algorithm has received great attention due to its simple structure and easy implementation. The research introduces solution information sharing strategy and elite learning strategy, and uses solution information sharing strategy to accelerate the convergence process during the iteration process. When particles fall into the local optimal solution, elite strategy is used to drive particles towards the global optimal solution.

For the network optimization of green supply chain in transit manufacturing enterprises, this study sets the customer's order quantity to be random and redistributes the goods owned by distributors. The upstream transfer station is joined after the distributor, where the goods transported by the distributor can be assembled and transported to ensure the full load of the carriages. The goods can be transported by railway to the downstream transfer station for reception. These goods can be exchanged with the transportation company in advance and transported to the designated customers. A green supply chain network based on K-NN and composite weight method is designed for different numbers of partners, transit stations, and customer orders. Partners are selected based on the designed green indicators and customers are selected with high satisfaction, good quality, high supply ratio, and low transportation time and loss rate. Of course,

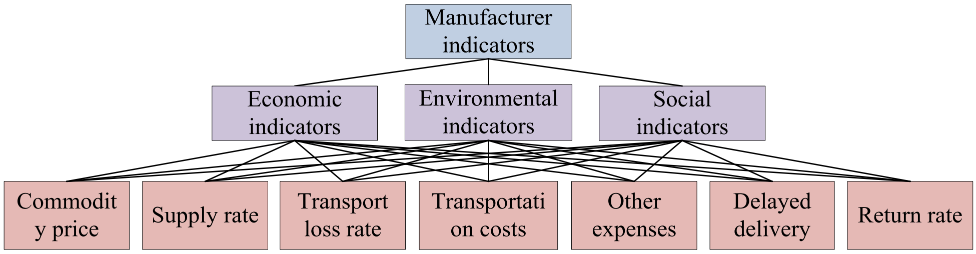

FIGURE 7. Hierarchy structure between various indicators.

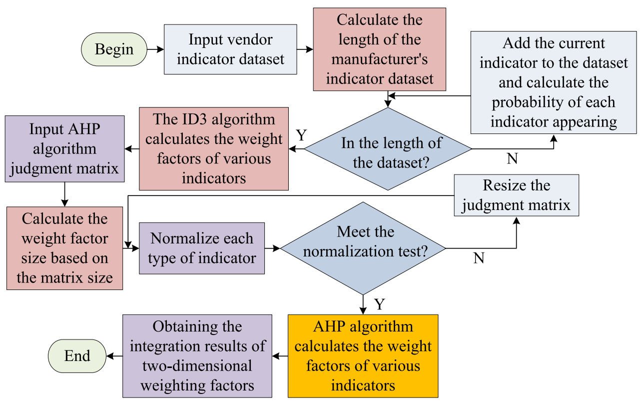

FIGURE 8. Algorithm flow of composite weight method.

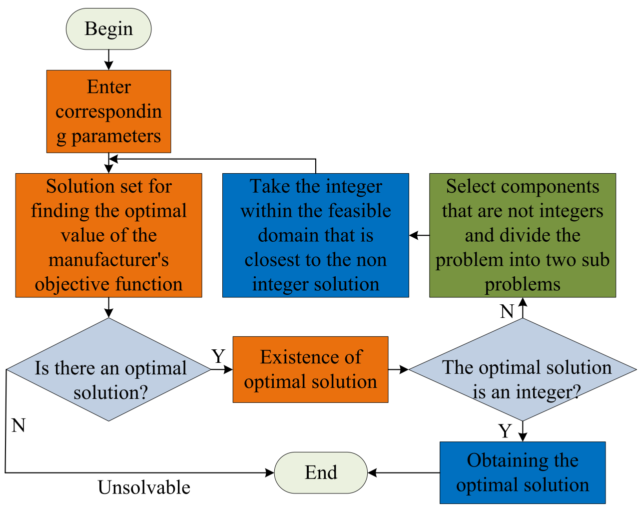

FIGURE 9. Branch and bound algorithm flow.

the water pollution, noise pollution, and the carbon emission indicators of enterprises are the evaluation criteria. By screening partners to obtain partners that meet the requirements of the green supply chain network, reasonable optimization is carried out for the selection of partners in the green supply chain of small and medium-sized manufacturing enterprises. The green supply chain network designed by the research institute is shown in Figure 10.

Based on the above operations, the study first optimizes the indicators in the green supply chain and develops a more comprehensive indicator system. Then, K-NN algorithm and decision tree algorithm are used to preprocess partner data and screen, and double screen partners based on various green indicators. For the subjective or objective evaluations, they are prone to occur when judging a single weight factor, resulting in significant errors between evaluation indicators and actual indicators. So the composite weight method is studied for the integration of two-dimensional weight factors. Finally, XPLEX mixed integer linear programming is used to solve the goods transported by partners and specific distribution routes. Therefore, the design of a green supply chain network based on K-NN and composite weight method is studied.

a: SOLUTION APPROACH

Firstly, the focus of the research is to improve the Commonly used green supply chain cooperation and transportation. Horizontal and vertical cooperation can be carried out between the layers, and collaborative transportation can be proposed to the transportation company to minimize costs. Traditional road transport not only has high costs, low efficiency, long time, and a small amount of goods transported, but also has greater damage to nature and society. To solve these problems, a cooperative transportation of railway and road is introduced to reduce the costs and time of manufacturing enterprises.

Secondly, the research is to improve the traditional model architecture and introduce the upstream and downstream transfer station as the hub. The transportation from upstream to downstream stations is the railway, and the goods transported through the upstream need to be assembled and transported to ensure that the full load of the train is maximum. After the goods are transported to the downstream, the company is booked in advance for unified transportation and sent to the corresponding customers.

The final focus is how to choose partners and future partners. The K-NN and the decision tree algorithms are used to double filter the partners and label them that can cooperate. The composite weight method is used to calculate the weight of each partner index. The compound weight method fuses ID3, which is more objective, with AHP, which is more subjective, so as to calculate more accurate weight. And the XPLEX mixed integer linear programming is used to solve the quantity of goods transported by partners and specific allocation routes.

AHP is an analytical method that combines qualitative and quantitative analysis. By decomposing complex problems into multiple constituent factors and grouping them into hierarchical structures based on dominant relationships, the

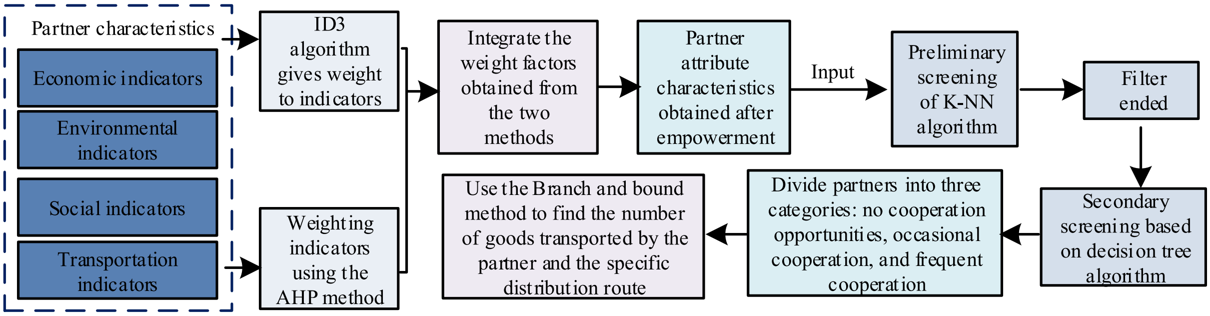

FIGURE 10. Green supply chain network design.

evaluation process is more structured and hierarchical, thus providing a relatively reliable decision-making method. And AHP considers the interrelationships and constraints among multiple factors, thus more systematically considering the problem. It not only comprehensively analyzes the evaluation factors, but also considers the weight relationships between various factors, thus more accurately reflecting the essence of the problem. However, AHP is prone to failure when there are too many indicators, so a study has proposed an improvement plan. In order to solve the problem of ineffective AHP method when there are too many indicators, an improved Analytic Hierarchy Process (IAHP) is proposed in the study. The basic idea of this method is to introduce the entropy weight method and grey correlation analysis method on the basis of traditional AHP, so as to more objectively determine the weights of each indicator and accurately reflect the degree of correlation between various schemes.

Specifically, the improved Analytic Hierarchy Process first uses the entropy weight method to objectively weight each indicator, and then uses the grey correlation analysis method to calculate the correlation degree of each scheme. This can avoid weight determination errors caused by subjective judgment or lack of experience, and also more accurately reflect the advantages and disadvantages of each scheme.

The improved Analytic Hierarchy Process is not only applicable to the evaluation of green supply chains in small and medium-sized manufacturing enterprises, but can also be widely applied to multi indicator decision-making problems in other fields. Through the application of this method, it is possible to evaluate the partners of the green supply chain more scientifically and objectively, providing more accurate and reliable basis for enterprise decision-making.

IV. RESULTS

A. DESCRIPTION

The green supply chain of small and medium-sized manufacturing enterprises has more spatial complexity, and the cooperation between partners is not only the original horizontal cooperation, but also the vertical cooperation. The transport has changed from the original single mode to the common mode. The upstream and downstream transfer stations make the maximum load rate of goods. Aiming at different partners, transfer stations, customers and customer orders, a green supply chain network based on K-NN and compound weight method is designed. To test the performance of the designed network, experiments are designed.

B. ASSIGN VALUE FOR PARAMETERS BASED ON NOTATION LIST

The basic data of green supply chain is generated according to the platform and market conditions, including raw material cost, commodity cost, operating cost, operating water pollution control cost, operating carbon emission control cost, operating noise control cost, supply cap and other information. The specific parameter Settings of some suppliers are shown in the Table 4.

TABLE 4. Basic data of evaluation indicators.

Data type	Data range
Air pollutant	U[11,20]
Water pollutant	U[8,16]
Solid waste	U[5,10]
Noise	U[6,12]
Greenhouse gas	U[15,30]
Delivery ratio	U[0,5,2]
Loss rate of supply	U[000.5,0.200]
Delay in delivery	U[1,10]
Return rate	U[000.8,0.100]
Price	U[1,20]
Transportation cost per kilometer	U[4,9]
Other expenses	U[900,2500]

The supplier evaluation index data are shown partly in the Table 5.

The basic data of some suppliers are shown in the Table 6.

1) COMPUTATIONAL RESULTS

A green supply chain network based on K-NN and CWM was studied and designed for different partners, transfer stations, customers, and customer orders. Based on the industry characteristics of small and medium-sized manufacturing enterprises, this study aims to obtain the characteristic attributes of partners from their electronic order transaction data. The K-NN algorithm is used for attributes classification, and the classification results are shown in Figure 11.

In Figure 11, the initial number of K-NN is 20, with 95% initialized as training samples and the remaining 5% as test samples, with an error of 6%. Preliminary classification of partners is carried out through three different feature attributes, and partners are recorded to prepare for

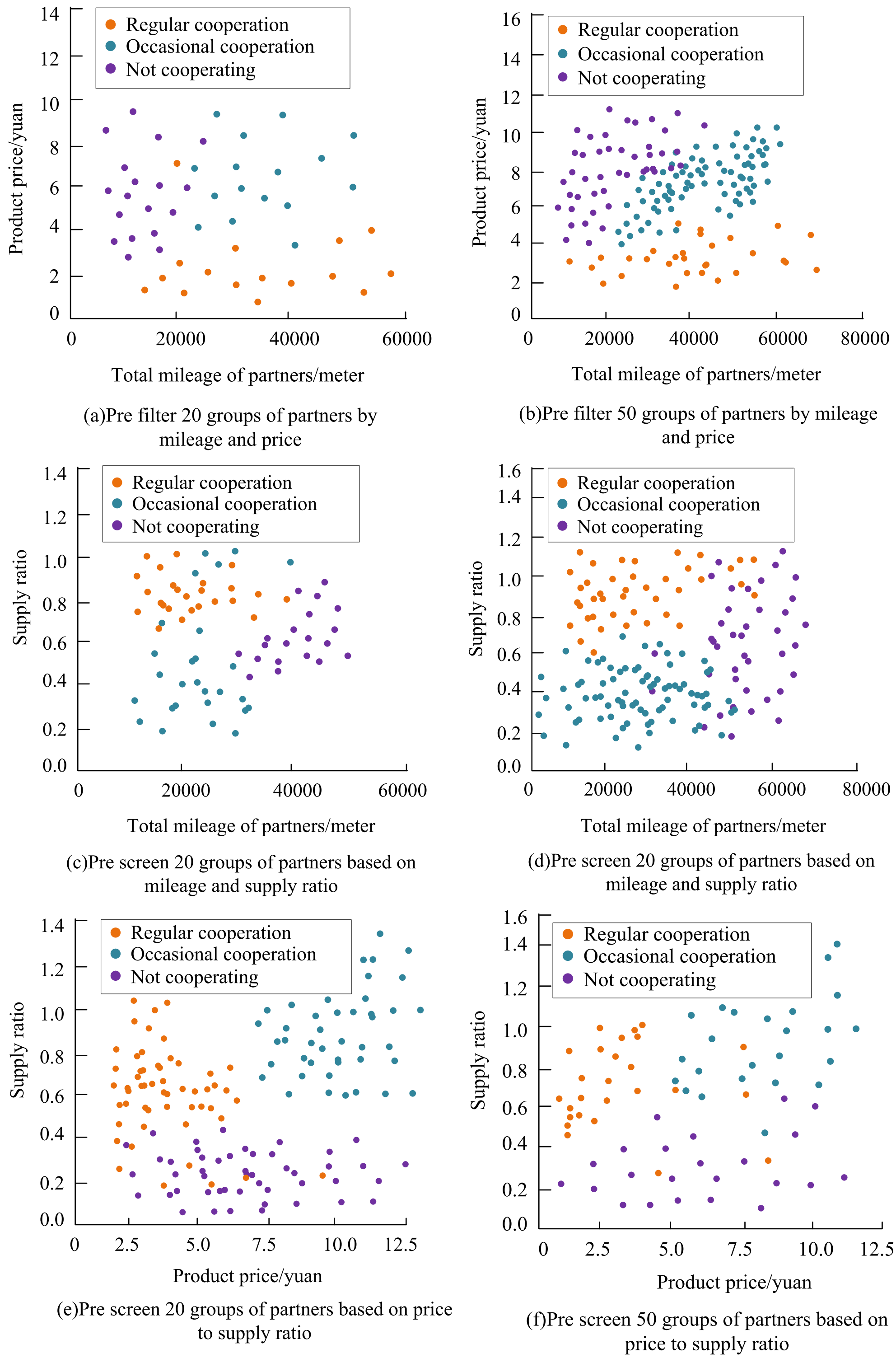

FIGURE 11. Classification results based on K-NN.

secondary preprocessing. Based on the indicators frequently considered by domestic and foreign small and medium-sized manufacturing enterprises green supply chain, this study evaluates 7 characteristic attributes of partners. Then the supply datasets provided by nine partners were listed. Nine suppliers were evaluated for quality and a secondary screening of partners was achieved. Table 7 shows the evaluation results.

In Table 7, based on the various indicators, the DT algorithm evaluates each supplier quality. And based on the comprehensive evaluation of indicators, the screening results

TABLE 5. Basic data of evaluation indicators.

ID	1	2	3	4	5	6	7	8
Air pollutant	11.4	14.3	13.5	18.9	14.5	16.4	13.1	14.3
Water pollutant	11.1	12.5	15.7	14.2	12.4	11.1	14.5	12.3
Solid waste	6.7	7.7	9.4	7.0	6.5	7.8	7.3	8.0
Noise	8.6	6.2	6.1	8.9	7.5	5.9	7.3	5.9
Greenhouse gas	16.8	27.1	17.3	22.5	21.4	28.5	23.3	18.4
Delivery ratio	1.9	0.8	0.8	1.8	0.7	1.4	0.6	1.5
Loss rate of supply	0.010	0.040	0.030	0.070	0.120	0.040	0.050	0.042
Delay in delivery	8	3	4	5	6.5	5.5	3	7
Return rate	0.0033	0.0222	0.0231	0.0231	0.0334	0.0525	0.0132	0.0451
Price	8.32	7.15	7.44	6.83	9.16	13.27	9.68	13.15
Transportation cost per kilometer	5.2	4.5	5.4	5.5	6.4	7.4	7.8	4.7
Other expenses	1600	1400	1500	1200	2200	1900	1200	1800

TABLE 6. Basic data of some suppliers.

ID	Raw material cost	Commodity cost	Operating cost	Cost of water pollution treatment	Carbon emission control costs	Noise control cost	Supply ceiling
1	0.36	0.66	2430	0.0076	0.072	0.077	32334
2	0.24	0.64	2670	0.0088	0.063	0.088	43523
3	0.51	0.46	2460	0.0078	0.064	0.086	53525
4	0.41	0.58	2450	0.0077	0.080	0.087	83525
5	0.48	0.88	2770	0.0066	0.055	0.090	97654
6	0.65	0.66	2550	0.0056	0.061	0.083	115643
7	0.21	0.56	2650	0.0058	0.062	0.084	165453
8	0.94	0.78	2580	0.0063	0.053	0.073	187574
9	0.77	0.45	2590	0.0062	0.067	0.072	24633
10	0.83	0.78	3050	0.0055	0.069	0.076	55363
11	0.67	0.48	2420	0.0065	0.065	0.090	73525
12	0.34	0.28	2730	0.0057	0.051	0.084	33525
13	0.35	0.56	2520	0.0068	0.063	0.088	87654
14	0.57	0.56	2350	0.0062	0.057	0.077	135343
15	0.83	0.72	2650	0.0052	0.057	0.078	115553

were obtained. Among them, 4 companies were listed as optional partners, and 5 companies were not selected. The final screening results were obtained. However, a single weighting factor cannot objectively and accurately evaluate supplier quality. For this study, CWM was used to determine each indicator weight. To test the rationality of the composite algorithm, the study compared two single-weight determination methods and composite method (CWA), as well as partner screening without using weight factor calculation methods. And the screening evaluation results obtained by four methods were recorded in Figure 12.

In Figure 12, as the data increase, the evaluation accuracy, F1 score, and recall of each method all slightly decrease, while RMSE increases. The average accuracy of the partner selection method using CWM is 93.65%, with an average F1 score of 92.76%, a recall of 91.98%, and an RMSE of

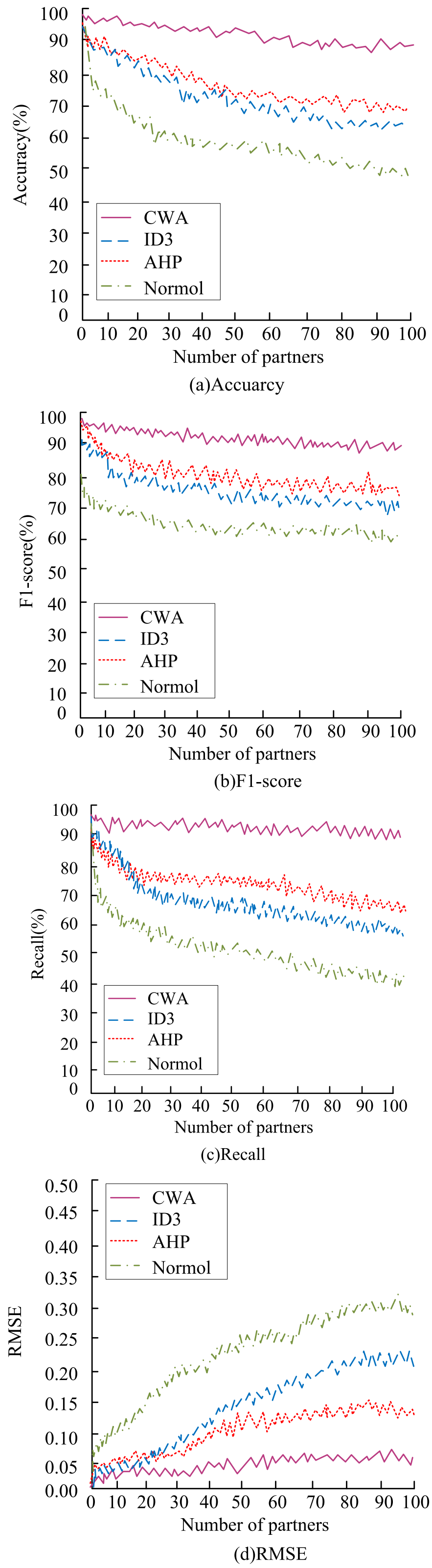

FIGURE 12. Comparison of various indicators for selecting partners before and after the introduction of composite weight method and single weight method.

0.06. Compared to the single-weight determination method, the curves of the composite method all undergo amplitude

TABLE 7. Quality evaluation index data of suppliers after secondary screening.

Serial number	Commodity price	Supply ratio	Transport loss rate	Return rate	Transportation costs	Other expenses	Delayed delivery	Partner evaluation
1	Low	High	Low	Low	Low	High	Have	Optional
2	Low	Low	Low	Low	High	High	Have	Not selected
3	Low	High	High	Low	High	Low	Nothing	Optional
4	High	High	Low	High	High	Low	Have	Not selected
5	High	High	Low	High	Low	Low	Nothing	Optional
6	High	High	High	High	Low	Low	Have	Not selected
7	High	Low	High	High	High	Low	Have	Not selected
8	High	Low	High	Low	Low	Low	Have	Not selected
9	Low	Low	Low	Low	High	Low	Nothing	Optional

TABLE 8. Comparison of Various Indicator Data between New and Old Models.

Number of partners	Primary indicators	Specific indicators	Original model	New model	Improvement rate(%)
Month1 3/2/3	Initial indicators	Distance (meters)	210933.00	187628.00	11.05
	Economic indicators	Transportation time (hours)	3056.87	2587.14	15.37
		Transportation cost (yuan)	1578325.04	1306248.52	17.24
		Other expenses (yuan)	4215.48	3709.22	12.01
	Environmental indicators	Water pollution (kg)	1533.42	1359.86	11.32
		Air pollution (kg)	3669.41	2978.59	18.83
		Noise pollution (kg)	1918.31	1654.18	13.77
		Total pollution (kg)	7121.14	5992.63	15.85
	Social indicators	Accidents (times)	4600.23	3974.12	13.61
	Self indicators	Transport loss rate	8644.25	7455.05	13.76
Month2 10/3/10	Initial indicators	Distance (meters)	343655.00	309684.00	9.89
	Economic indicators	Transportation time (hours)	4980.51	4275.70	14.15
		Transportation cost (yuan)	24056.42.99	2065332.63	14.15
		Other expenses (yuan)	6873.10	6278.52	8.65
	Environmental indicators	Water pollution (kg)	2498.37	2235.84	10.51
		Air pollution (kg)	7866.26	7039.61	10.50
		Noise pollution (kg)	3161.63	2831.33	10.44
		Total pollution (kg)	13526.26	12106.78	10.50
	Social indicators	Accidents (times)	7495.12	6697.69	10.64
	Self indicators	Transport loss rate	14089.86	12627.88	10.38
Month3 20/5/20	Initial indicators	Distance (meters)	659563.0	544537.00	17.44
	Economic indicators	Transportation time (hours)	9558.88	7880.42	17.56
		Transportation cost (yuan)	4617094.31	3809854.28	17.48
		Other expenses (yuan)	13191.25	10977.04	16.79
	Environmental indicators	Water pollution (kg)	4795.02	3943.62	17.76
		Air pollution (kg)	15097.39	12417.11	17.75
		Noise pollution (kg)	6067.97	4992.49	17.72
		Total pollution (kg)	25960.38	21353.22	17.75
	Social indicators	Accidents (times)	14385.06	11821.43	17.82
	Self indicators	Transport loss rate	27042.08	22259.84	17.68
Month4 30/10/30	Initial indicators	Distance (meters)	982934.0	843303.00	14.21
	Economic indicators	Transportation time (hours)	14245.42	12210.37	14.29
		Transportation cost (yuan)	6880703.88	5901266.70	14.23
		Other expenses (yuan)	19658.67	16952.36	13.77
	Environmental indicators	Water pollution (kg)	7145.93	6115.65	14.42
		Air pollution (kg)	22499.35	19255.82	14.42
		Noise pollution (kg)	9042.99	7741.15	14.40
		Total pollution (kg)	38688.27	33122.63	14.41
	Social indicators	Accidents (times)	21437.79	18337.60	14.47
	Self indicators	Transport loss rate	40300.29	34509.25	14.37

changes on it, resulting in significantly better performance. The study aims to make the overall planning of supply chain more reasonable by transforming the non-transitive model into a transitive one. To test the optimization effect, experimental analysis was conducted over four months. Before processing, partners were divided into 10 groups, 30 groups, 50 groups, and 200 groups. The partners processed were 3, 10, 20, and 30 groups, respectively. Under the condition of sufficient quantity of trucks and goods, without considering other objective factors, comparative experiments were conducted on various indicators. The data were shown in Table 8.

In Table 8, all indicators in four months have improved, with a basic improvement of around 14%. The model optimization effect with a transfer station is relatively obvious, and all indicators have been significantly improved. To comprehensively optimize each indicator, research has set calculation examples as 3/2/3, 10/3/10, 20/5/20, 30/10/30, 50/15/50, respectively. Five different experimental groups were used to compare the various indicators and optimal solutions of the new and old models in Figure 13.

In Figures 13 (a) and 13 (b), when the number of partners is small, the optimal solution between old and new models

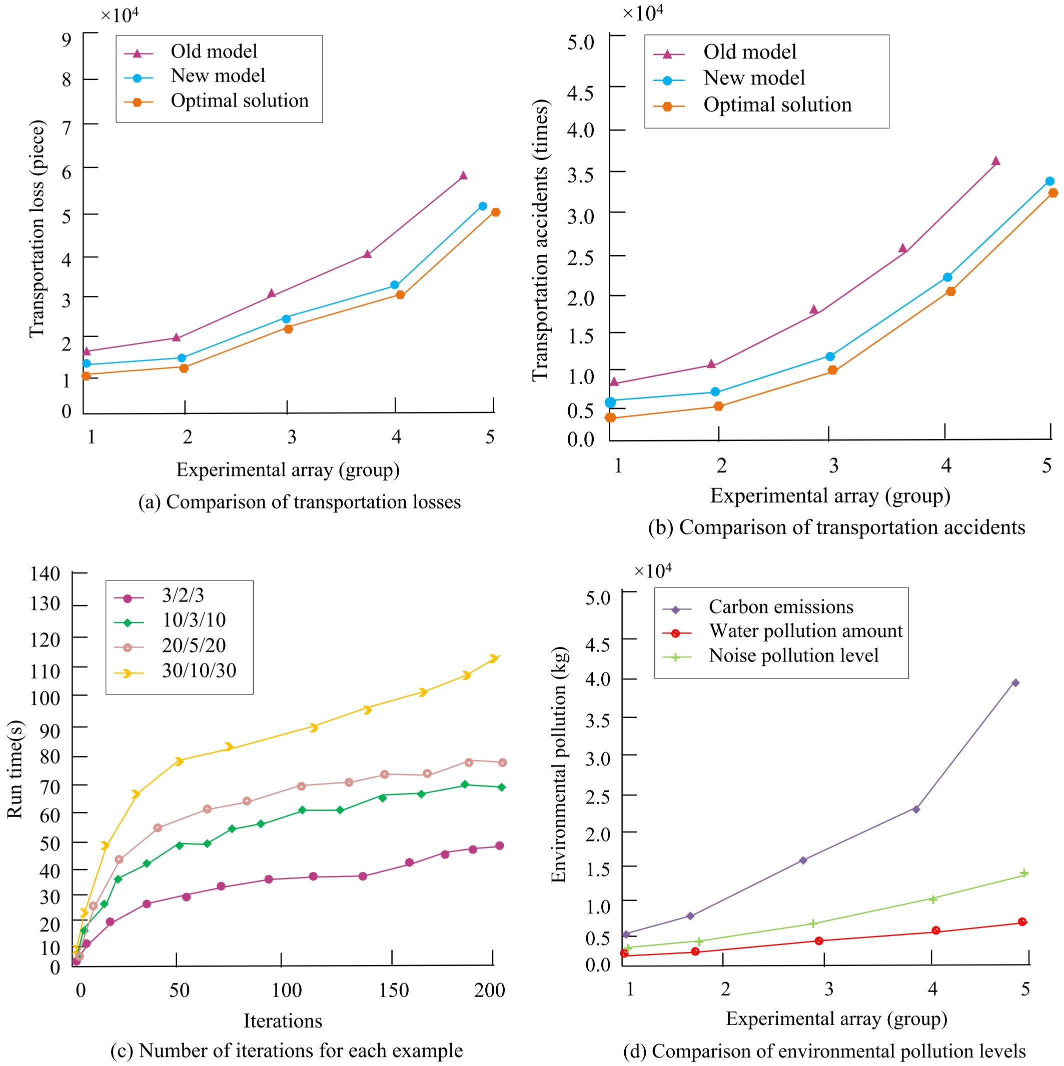

FIGURE 13. Changes in various indicators of new and old models under different experimental groups.

is not significant. When the number of partners is large, the optimization effect of the new model slightly decreases. As the number of partners gradually increases, the optimization effect of the new model relative to the old one becomes increasingly apparent. In Figure 13 (c), for different partner groups, XPLEX is used for solving. When there are few examples, the solution speed is faster and the iteration is less. As partners increase, the model complexity increases and iteration is longer. In Figure 13 (d), carbon emissions are significantly higher than water pollution and noise pollution. This indicates that carbon emission indicators are more important in the green supply chain and need to be focused on governance.

C. COMPARING MODEL

To further test the performance of the green supply chain (SC1) designed by the research institute, the study compared it with several popular green supply chain methods. The comparison methods include: the supply chain network considering uncertainty and risk preference (SC2),the supply chain network considering greenness (SC3), the supply chain network based on improved whale optimization algorithm (SC4), and the elastic supply chain network based on multiple recovery strategies (SC5). The details are shown in Table 9.

TABLE 9. Comparison of the improvement effects of various indicators of green supply chains compared to traditional supply chains.

Proje ct	Optimization effect (%)				
	Cost expenditu re	Pollutio n generati on	Transportati on losses	Distan ce	Transportati on time
SC 1	34.26	30.25	37.12	42.45	28.47
SC 2	25.14	20.46	29.48	36.14	20.15
SC 3	20.15	18.84	27.23	32.45	17.59
SC 4	26.48	23.14	31.54	38.47	22.62
SC 5	18.45	16.48	25.85	30.14	15.87

In Table 9, SC1 reduced the costs of traditional supply chain by 34.26%, generated pollution by 30.25%, losses by 37.12%, distance by 42.45%, and time by 28.47%. Compared

TABLE 10. **Comparison of survey results after operation of each supply chain.**

Project	SC 1	SC 2	SC 3	SC 4	SC 5
Very satisfied	83.52	68.23	66.41	71.24	70.45
Relatively satisfied	11.14	21.45	22.85	18.49	19.32
Satisfied	3.41	8.54	9.02	10.12	8.23
Dissatisfied	1.84	1.45	1.25	0.1	1.64
Very dissatisfied	0.09	0.33	0.47	0.05	0.36

to other methods, the improvement effect on various indicators is the most significant. Based on the data analysis in the comprehensive table, the green supply chain network designed by the research institute can effectively achieve sustainable development of enterprises and reduce pollution.

To further test the excellent performance of green supply chain, the study applied it to the actual operation of enterprises. And the operational situation was compared through a questionnaire survey. The survey selected 654 people from enterprise as survey subjects and recorded the final survey results in Table 10.

In Table 10, the satisfaction rate of each supply chain exceeds 90%. The supply chain designed by the research achieves a higher satisfaction rate, with over 80% of people choosing highly satisfied options. Other methods are slightly smaller than SC1, all above 60%. Based on the comprehensive table, the green supply chain network designed by the research institute has good executable performance in practical applications.

To test the rationality of the supply chain indicator (indicator 1), several index systems commonly used were selected for comparison. The comparison indicators included the index proposed in reference [24] (indicator 2), the index in reference [25] (indicator 3), and the green logistics index system of China Industrial Development Center (indicator 4). The supply chain network was constructed using four different index systems, and the cost, pollution and transportation loss of each network increase with the increase of partners. The results were shown in Figure 14.

In Figure 14, with the increase of the partners, all indicators generated by the supply chain gradually increase. The result of indicator 1 is reduced by 30%, 25.46%, and 16.47% compared with the original supply chain networks. The values of indicator 1 are similar to those of indicator 4. The values of indicators 2 and 3 are relatively low. Based on the above content, it can be seen that the supply chain index selected by the research is reasonable and can effectively realize the green and sustainable development.

To test the rationality of the selected AHP, the experiment compares it with many modern multi-attribute decision making algorithms. The comparison algorithms include TOPSIS, VIKOR, and FUCOM-F. They are used to filter the partner data, and the filtering results are shown in Figure 15.

From Figure 15, the accuracy of the four algorithms gradually decreases, while the RMSE gradually increases. AHP and FUCOM-F are the most stable, and their index values

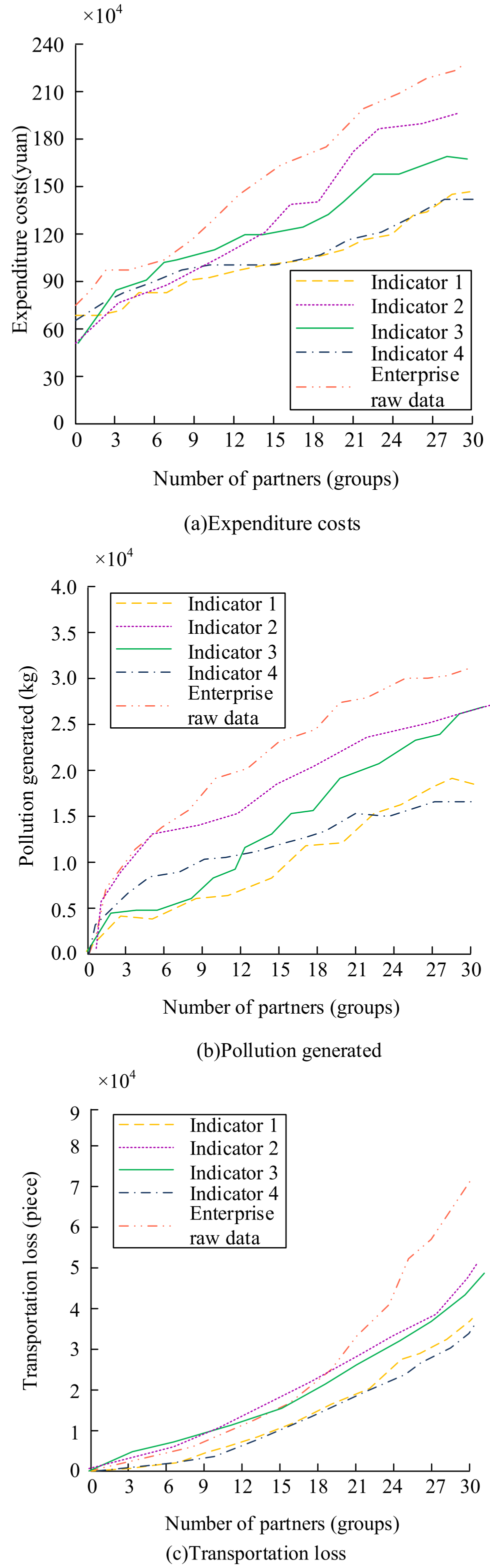

FIGURE 14. **Cost expenditure, pollution generation, and transportation losses of the network constructed by each indicator system as the number of partners increases.**

do not change much. However, the accuracy of AHP is relatively high, which is different from FUCOM-F. The indicators of other two algorithms are slightly worse than these two

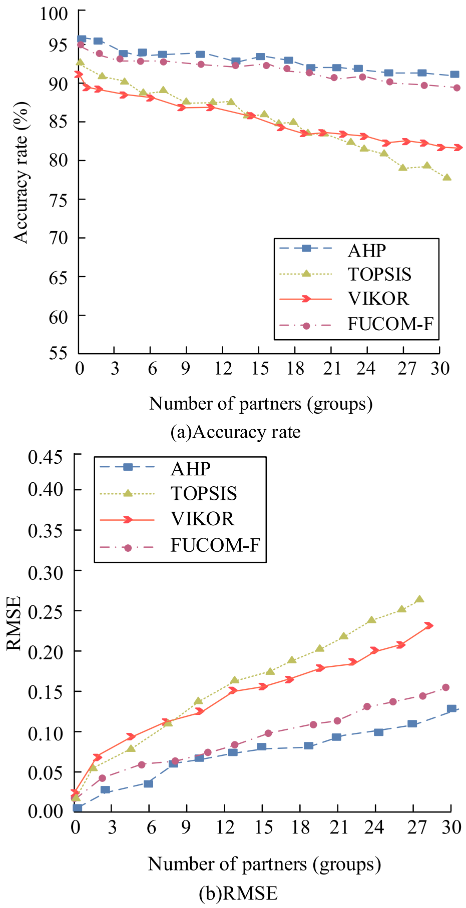

FIGURE 15. Partner filtering results of the four algorithms.

TABLE 11. Reasonausibility analysis of the AHP method in the partner screening process.

Project	RMSE	Precision	F1	Recall
AHP	0.08	0.95	0.93	0.92
TOPSIS	0.23	0.81	0.81	0.79
VIKOR	0.15	0.86	0.84	0.83
FUCOM-F	0.12	0.90	0.89	0.88

methods. In summary, AHP has better analysis effect, and it is more suitable for screening enterprise partners. The combined ID3 algorithm can further improve the performance. And the AHP is simple, its operation is more convenient, and its results obtained are simple and clear.

In order to further test the applicability of the selected AHP method in the index system of the research design, the research conducted partner screening with the above comparison algorithm in the evaluation index of the research partner screening process, and the comparison results were shown in Table 11.

As shown in Table 11, there are ten types of evaluation indicators in the study, which are carbon emission, water pollution, noise pollution, commodity price, supply ratio, transportation loss rate, transportation cost, other costs, delayed delivery, and return rate. These are modest numbers. For AHP algorithm, it can achieve better screening effect. In comparison with the other three algorithms, it can be found

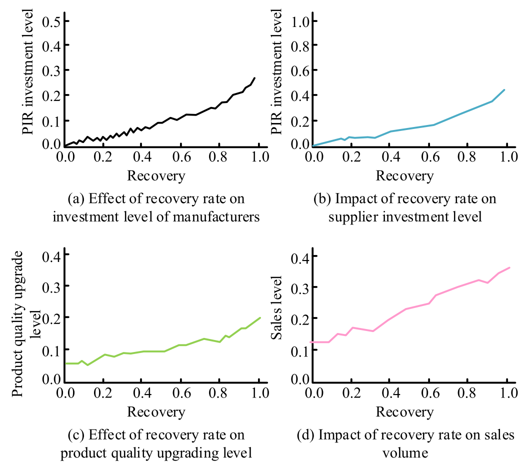

FIGURE 16. Sensitivity analysis of enterprise recovery rate and enterprise investment level, product quality upgrade level and sales volume.

that the RMSE of AHP algorithm is below 0.10, while the other three algorithms are significantly higher than 0.1. The Precision, F1 value and Recall value of the model using AHP algorithm reached 0.95, 0.93 and 0.92 after screening. Obviously due to the model constructed by other algorithms. It can be seen that it is reasonable to use AHP method to select partners for the index system designed by the research institute.

D. SENSITIVITY ANALYSIS 1

To further show the influence of each parameter on decision variables and profits, the study uses Matlab to draw images and analyzes the impact of recovery rate, investment, product quality upgrade and sales for sensitivity analysis. The results are shown in Figure 16.

In Figure 16, a higher recovery will not only improve the PIR investment of upstream and downstream enterprises, but also improve the product quality upgrade of downstream manufacturers, thus promoting the increase of the sales. As recycling rates rise, so do sales.

E. SENSITIVITY ANALYSIS 2

To further examine the impact of the recovery on corporate profits and the impact of remanufacturing cost savings on investment, a corresponding sensitivity analysis has been made, and the specific results are shown in Figure 17.

In Figure 17, the manufacturing profit always increases with the recovery. For the profit of supplier, it increases with the increase of the recovery only within [0, 0.13] or [0.88, 1]. The higher recovery rates will increase the profits of manufacturers, but the higher post-production rates are not necessarily beneficial to suppliers. Remanufacturing costs lead to lower production costs, and higher remanufacturing cost savings always encourage upstream and downstream enterprises to increase PIR levels.

F. DISCUSSION

The average accuracy of the partner screening method was 93.65%, with an average F1-score value of 92.76%, a Recall

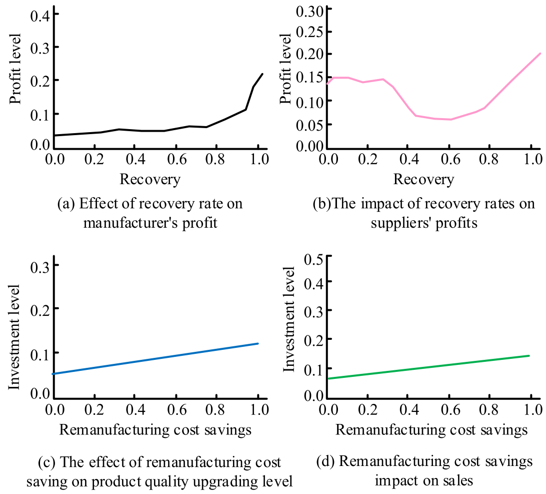

FIGURE 17. The impact of recovery rate on corporate profits and the sensitivity analysis of remanufacturing cost savings to investment level.

value of 91.98% and an RMSE value of 0.06. Compared with the single weight determination method, the curve of the compound method changes in magnitude, and the performance is significantly better. Supply chain 1 for the traditional supply chain model cost expenditure reduced by 34.26%, pollution by 30.25%, transportation loss by 37.12%, transportation distance by 42.45%, and transportation time by 28.47. Compared with other supply chains, the improvement effect in each indicator is the most significant. More than 80% of the supply chain were very satisfied with the options. It has a good executability in practical application.

V. MANAGERIAL INSIGHTS AND PRACTICAL IMPLICATIONS

Managerial insights and practical implications

According to the research results and the current status of green supply chain in manufacturing industry, the research puts forward the following suggestions:

First, the green supply chain management ''pilot enterprises'' and ''excellent enterprises'' are encouraged to further improve the green supply chain management, and the peer effect is used to be ''point with line'' and ''line with surface''. And relevant enterprises are encouraged to summarize the successful experience of the model that can be replicated and promoted, so as to enhance the subjective initiative of enterprises in carrying out green supply chain management activities. It can rely on international cooperation platforms and mechanisms such as the ''Belt and Road'' Green Development International Alliance and the APEC Green Supply Chain Cooperation Network. Meanwhile, enterprises can strengthen international exchanges and cooperation, and promote the visualization of green supply chain management results. The supply chain and the industry within the subjective initiative can be driven for sustainable development. The second is to attach importance to the information transmission of the supplier, and promote the construction of a complete and efficient supplier management system. It is necessary to gradually expand the management scope from the existing ''first-tier suppliers'' to the upstream, achieve full coverage of suppliers, and coordinate the interests between upstream and downstream to a greater extent. And enterprises should further improve the relevant smart infrastructure, encourage the laying and promotion of technologies such as information systems, 5G, and the Internet of Things, and guide manufacturing enterprises to shift from traditional functional management to process collaborative management through technology upgrading, and from the linear to the non-linear structure. Meanwhile, enterprises can promote the construction of an integrated green supply chain management platform with resource coordination, information sharing and reasonable structure, so as to promote the benign linkage relationship of value coordination and friendly cooperation within the supply chain. The third is to pay attention to the differentiated needs of manufacturing enterprises, and build a more targeted green supply chain management evaluation system in combination with the actual industry. Enterprises can establish and improve internal management evaluation standards for green procurement and supplier evaluation. They should strengthen the implementation of external work such as carbon information disclosure legislation and the development of carbon accounting tools in key areas, and ensure that green supply chain management plays an active role in reducing pollution and carbon. And enterprises should actively solve the various difficulties and blocked points in the green supply chain management. Through policy coordination or the establishment of temporary coordination institutions, large, small and medium-sized enterprises can benefit from the management, so as to better mobilize the enthusiasm of manufacturing enterprises.

Practical significance of the research method:

Based on the optimization of various mathematical models of green supply chain, a new green supply chain for small and medium-sized manufacturing enterprises based on compound weight method is designed. The newly introduced cooperative transportation improves efficiency, reduces time, and reduces accidents. In the four-level network architecture of the traditional supply chain, the upstream and downstream transfer stations are newly introduced to integrate the vehicles that are not fully loaded. And the upstream transfer stations are transferred to the downstream for railway, to reduce the transportation cost and improve the complexity. To solve the insufficient memory when solving a large amount of data in the supply chain, K-NN algorithm and decision tree algorithm are used for double preprocessing of partners, and compound weight method is used to measure the indicators. The evaluation indicators include economic, environmental, social, and transportation indicators. The traditional horizontal transportation is improved to horizontal and vertical cooperative transportation. In addition, to solve the unclear partner selection in green supply chain, a machine learning algorithm is proposed to double screen partners.

VI. CONCLUSION AND OUTLOOK

Conclusions: The current supply chain still has some shortcomings, such as some methods are subjective and difficult to accurately measure the various indicators of green supply chain. To this end, the Commonly used green supply chain index system is improved, and K-NN algorithm and decision tree algorithm are used for dual location selection to screen partners. Then, the composite weight method is used to integrate and select the weight factors, and XPLEX mixed integer linear programming is used to solve the quantity of goods transported by the partner and the specific distribution route. A green supply chain network for transshipment manufacturing enterprises based on K-NN algorithm is designed. The following results are obtained through the experiment:

1. Pre-processing effect of K-NN on data:

The initial number of the K-NN algorithm is 20, 95% is initialized as the training sample, the remaining is used as the test sample, and its error rate is 6%. This algorithm can realize better data processing and provide the basis for the second preprocessing and partner screening.

2. Rationality analysis of the selection of composite weight method:

The average accuracy of the partner screening method using the compound weight was 93.65%, the average F1-score value was 92.76%, the average recall was 91.98%, and the RMSE was 0.06. Compared with the single-weight determination method, the curve of the composite method changes, and the performance is obviously better.

3. The performance analysis of supply chain designed by the study:

For the traditional supply chain, the cost expenditure is reduced by 34.26%, the pollution is reduced by 30.25%, the transportation loss is reduced by 37.12%, the transportation distance is reduced by 42.45%, and the transportation time is reduced by 28.47. Compared with other supply chains, the improvement effect in various indicators is the most significant. The supply chain designed by the study is selected by more than 80% of people who are very satisfied with the options. It has a good feasibility in practical applications.

A. LIMITATION

The limitations are: under the today's carbon emission policy, it is necessary to find a balance between economic, environmental and social indicators to a greater extent, so that the development of enterprises and the stability of ecological environment are in a state of balance.

B. FUTURE RESEARCH

For the choice of partners, there is an error in machine learning methods, and choosing the most appropriate partner still needs to conduct field trips.

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