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Research on Cold Chain Logistics Transport Strategies for Fresh Agricultural Products Based on FAHP

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Abstract

To address the common issues of high loss rates, high costs, and low efficiency in the cold chain logistics of fresh agricultural products, this paper takes a specific region as the research object and constructs a multidimensional evaluation model based on the Fuzzy Analytic Hierarchy Process (FAHP). The model systematically analyzes the key factors affecting cold chain logistics transportation strategies and their priorities. Through model calculation and expert evaluation, it is found that transportation cost, degree of informatization, and logistics efficiency are the three core factors influencing the development of cold chain logistics. Among these, energy consumption, temperature stability, and informatization management systems dominate specific indicators. The study indicates that the region has significantly higher transportation costs due to its complex geographical environment and weak infrastructure, while the mild climate conditions make temperature control management less urgent compared to other regions. However, the long-term impact on quality assurance still requires attention. Based on the analysis results, the paper proposes multidimensional optimization strategies: promoting the use of new energy transportation tools and integrating renewable energy technologies to optimize the energy structure, combined with intelligent route planning to reduce transportation costs; building an entire chain informatization monitoring platform and a data sharing mechanism to improve management efficiency; introducing automated equipment and hierarchical distribution models to optimize operational processes; and improving the temperature control early warning system and personnel training mechanisms to ensure transportation quality. The research results provide a theoretical basis for optimizing cold chain logistics systems in high-loss regions and offer practical references for reducing agricultural product losses and promoting the sustainable development of the agricultural supply chain.

Keywords

Fresh Agricultural Products, Cold Chain Logistics, FAHP

1. Introduction

As the pace of global economic integration accelerates, consumers' expectations for food quality continue to rise, making the issues surrounding the circulation and transportation of fresh agricultural products increasingly important (Ganesh Kumar et al., 2017; Chitra et al., 2023). One of the key challenges in this area is how to maintain the freshness and safety of food during the transportation process. With the assistance of cold chain logistics, fresh agricultural products can maintain their quality throughout transportation (Collison et al., 2019; Marufuzzaman et al., 2014), better meeting market demands. However, despite the widespread application of cold chain logistics, numerous problems still exist in actual operations, such as unstable temperature control, high costs, and low logistics efficiency. These factors undoubtedly limit further development in this market (Yang & Yao, 2024).

This issue is especially prominent in China, where transportation problems related to fresh agricultural products are even more significant. According to data from the National Bureau of Statistics, improper temperature control or unreasonable logistics arrangements result in a substantial loss of fresh agricultural products during transportation, with loss rates exceeding 20% (He, 2023; Han et al., 2020). Therefore, optimizing cold chain logistics strategies for fresh agricultural products, reducing transportation costs, improving efficiency, and ensuring stable temperature control during transportation have become core issues in agricultural supply chain management.

In this context, the continuous advancement of information technology, particularly the application of big data and intelligent algorithms, has brought new possibilities for logistics optimization. Among these, the Fuzzy Analytic Hierarchy Process (FAHP) has emerged as a powerful multi-criteria decision-making tool with great potential across various industries. FAHP can integrate multiple decision factors and resolve complex decision-making problems through quantitative analysis, providing precise support for decision-makers. In the field of cold chain logistics, FAHP not only optimizes transportation routes and selects the most suitable transportation modes, but also effectively evaluates the effectiveness of different transportation strategies, thereby improving the overall efficiency and reliability of the logistics system.

Research on the cold chain logistics transportation strategies for fresh agricultural products based on FAHP not only holds significant theoretical value but also has very substantial practical application significance. By deeply analyzing the FAHP model, new optimization solutions can be provided for cold chain logistics, helping related enterprises reduce costs, improve efficiency, and ensure the safety and high quality of food.

2. Current Status and Issues of Fresh Agricultural Product Cold Chain Logistics in Yunnan Province

2.1. Current Development Status

In recent years, the demand for fresh agricultural products in Yunnan Province has seen a continuous increase, particularly for vegetables, fruits, meat, poultry, and aquatic products. Both the production and market demand for these products have shown a remarkable growth trend, positioning Yunnan as one of the key bases for the "Southern Vegetables, Northern Transportation" initiative. Nationwide, Yunnan plays a significant role in the export of fresh agricultural products. According to data from the local statistical bureau, the total output value of fresh agricultural products in the region exceeded 80 billion RMB in 2022 (Akhter et al., 2024), with fruits and vegetables accounting for more than 60% of the total. This trend has not only driven the expansion of agricultural production but also directly fueled the rapid development of the cold chain logistics industry.

In the fresh agricultural product circulation system, cold chain logistics plays an irreplaceable role. Particularly in tropical and subtropical regions such as Yunnan, where the climate is warm and humid, a lack of proper temperature control measures can lead to the spoilage and deterioration of agricultural products during transportation and storage, causing significant losses. Therefore, an efficient and stable cold chain logistics system is crucial for ensuring the freshness, nutritional value, and stable market supply of agricultural products. Data from the local cold chain logistics association shows that in the past five years, the average annual growth rate of Yunnan's cold chain logistics industry has remained stable at around 12%, with a consistent upward trend. In 2020, the cold chain logistics market in the region reached a scale of 7 billion RMB, and it is expected that this figure will surpass 15 billion RMB by 2025, with an annual growth rate maintaining above 10%. This growth not only reflects the irreplaceable role of cold chain logistics in the circulation of fresh agricultural products but also highlights the increasing market demand for cold chain logistics.

It is noteworthy that the region has made significant progress in the construction of cold chain logistics infrastructure in recent years. In economically developed areas such as Kunming, Qujing, and Yuxi, supporting facilities such as cold storage and transportation networks have been increasingly improved. In 2022 (Götz et al., 2009), the region invested nearly 1 billion RMB in cold chain infrastructure construction, building several large cold storage centers and optimizing the cold chain transportation network connecting both domestic and international markets (Westgren, 1999). At the same time, related enterprises have been expanding their refrigerated truck fleets to improve the timeliness and safety of agricultural product transportation. According to data released by the local transportation department in 2023, the total number of cold chain logistics vehicles in the region has reached 4500, with refrigerated trucks accounting for about 35%.

However, despite the rapid development of Yunnan's cold chain logistics system in recent years, there are still shortcomings in overall transportation capacity, especially in remote mountainous areas, where the coverage of cold chain transportation is far lower than in economically developed regions within the province. To address this issue, the local government is increasing support for the cold chain logistics industry by introducing a series of supportive policies. For example, the government offers tax incentives to encourage enterprises to develop new cold chain technologies and increases financial support for cold chain infrastructure construction. The implementation of these measures not only provides a favorable development environment for the cold chain logistics industry but also strengthens the circulation system of fresh agricultural products in Yunnan.

2.2. Diagnosis of Existing Problems

Although significant progress has been made in the development of cold chain logistics for fresh agricultural products in Yunnan Province, several deep-rooted challenges still persist. These problems are not only reflected in high costs but also in issues such as low technological levels, inadequate network coverage, lagging informatization, and insufficient standardization. To fundamentally address these issues, the region needs to increase investments in technological innovation, policy support, infrastructure construction, and informatization management, in order to enhance the overall efficiency and sustainability of cold chain logistics.

The high cost of cold chain logistics remains a major bottleneck for the transportation of fresh agricultural products in the region. The costs are primarily concentrated in the construction of refrigeration facilities, energy consumption, and labor costs during transportation (Yan et al., 2020; Fan et al., 2024). According to statistics, the cost of cold chain logistics accounts for about 30% of the total transportation cost of fresh agricultural products in the region, which is much higher than the transportation cost of traditional logistics methods. In mountainous and remote areas, the high cost of cold chain logistics is even more pronounced due to poor transportation conditions and difficult logistics, further increasing the cost pressure. For instance, energy costs for refrigerated trucks in cold chain transportation typically account for about 40% of the total transportation cost. Moreover, the hot climate and complex terrain conditions undoubtedly increase the difficulty of transportation, leading to higher costs. For small and medium-sized agricultural enterprises, the high cost of cold chain logistics becomes a significant constraint to development.

However, the technological level of cold chain logistics in the region is relatively lagging, particularly in areas such as temperature control systems, transportation monitoring, and intelligent management (Han et al., 2020; Lin et al., 2025). According to a 2022 industry survey on cold chain logistics, about 60% of cold chain transport enterprises have not implemented real-time temperature monitoring. This means that the instability of temperature during cold chain transportation greatly affects the quality and safety of agricultural products. Even worse, some regions still rely on traditional manual methods for temperature control and adjustment, which is inefficient and inaccurate. Additionally, the lack of advanced transportation monitoring systems and data tracking methods hinders the flow of information, leads to unscientific logistics route planning, and results in low transportation efficiency. These technological bottlenecks directly impact the overall effectiveness and operational quality of cold chain logistics.

Although cold chain logistics facilities in major cities and transportation hubs are relatively well-established, the coverage of the cold chain logistics network remains severely insufficient in remote mountainous areas and border regions. According to statistics from the local agricultural department, in 2019, the coverage rate of the cold chain logistics network in the region was only 45%, while in developed countries, this figure typically exceeds 90%. Especially in mountainous and minority regions, complex geographical conditions and poor transportation networks make it difficult for cold chain logistics to provide timely coverage. For example, in Xishuangbanna, although the region has strong agricultural production capacity, the cold chain logistics delivery capacity has been relatively weak due to inconvenient transportation, causing large amounts of agricultural products to fail to reach the market on time, resulting in significant losses.

The lag in informatization management is also a major constraint on improving the efficiency of cold chain logistics (Westgren, 1999; Li et al., 2024). Cold chain logistics enterprises in the region have made slow progress in informatization, with about 70% of small and medium-sized enterprises still not adopting intelligent logistics management systems, relying instead on manual management and scheduling. This inefficient management model leads to low efficiency in logistics scheduling and route planning. For cold chain logistics enterprises, the lack of an efficient information management system significantly increases the difficulty of precise optimization in resource scheduling and distribution, resulting in a considerable reduction in overall transportation efficiency. Moreover, the standardization of cold chain logistics remains insufficient, and the industry management model is still imperfect. The lack of standardization leads to difficulties in quality control during transportation, which in turn affects the effectiveness of logistics management. For instance, in cold chain transportation, there are significant differences in packaging standards, time control for transportation, and special temperature control requirements. Due to the lack of unified industry standards, cold chain logistics companies in the region often face problems such as inaccurate temperature control and excessive losses during transportation, ultimately leading to uncontrollable service quality and a decline in customer trust. In short, Compared to eastern coastal provinces (e.g., Guangdong, Zhejiang), Yunnan faces distinct challenges: Cold chain coverage: 45% in mountainous areas vs. 75% in Guangdong; Unit transportation costs: 30% higher due to complex terrain; Informatization level: <50% adoption of management systems in Yunnan vs. >80% in Zhejiang. These disparities highlight Yunnan's urgent need for infrastructure expansion and route optimization.

3. FAHP-Based Cold Chain Logistics Influencing Factors Evaluation System Construction and Empirical Analysis

3.1. Research Methods and Index System Construction

FAHP (Fuzzy Analytic Hierarchy Process) is a decision analysis method based on traditional analytic hierarchy process (AHP) and fuzzy mathematics theory. Its main purpose is to solve the challenges brought by fuzzy or uncertain information in the decision-making process. FAHP is especially suitable for decision makers who cannot provide accurate values, such as in situations involving social impact, environmental factors or strong subjective judgment. By introducing fuzzy numbers, FAHP can effectively deal with these uncertainties, thus providing more flexible and accurate analysis results for decision makers. Establish a fuzzy hierarchical structure model: FAHP is similar to AHP, and it needs to establish a hierarchical decision-making model, including target layer, criterion layer and scheme layer. In FAHP, fuzzy numbers are used for the comparison between levels, rather than the exact values commonly used in AHP. Constructing fuzzy judgment matrix: In the second step of FAHP, the relative importance of elements is expressed by constructing fuzzy judgment matrix. Decision makers use fuzzy numbers to compare elements in pairs. The comparison results of each pair of elements are transformed into a fuzzy number, forming a fuzzy judgment matrix, which represents the fuzzy judgment of decision makers. Calculation of fuzzy weights: According to the fuzzy judgment matrix, the Fuzzy Weighted Average Method is used to calculate the fuzzy weights of all levels. The calculated weight is a fuzzy interval, which reflects the importance evaluation of each factor by decision makers. Fuzzy consistency test: In order to ensure the consistency of fuzzy judgment matrix, FAHP needs to carry out fuzzy consistency test. Similar to consistency check in AHP, FAHP judges the rationality of judgment matrix by calculating fuzzy consistency index (CI_fuzzy) and fuzzy consistency ratio (CR_fuzzy). If CR_fuzzy is close to zero, it shows that the judgment matrix has good fuzzy consistency. Deblurring: FAHP needs to convert fuzzy numbers into accurate numerical results through deblurring. The commonly used methods of defuzzification include central average method and maximum membership method. After defuzzification, the numerical results will provide clear weights and decision-making basis for decision makers.

In the construction of FAHP-based evaluation system for influencing factors of cold chain logistics, it is first necessary to clearly evaluate the key factors in the process of cold chain logistics and form a scientific and comprehensive index system. Cold chain logistics involves a wide range of factors, including transportation cost, logistics efficiency, temperature control management and information level, etc. These factors are interrelated and influence each other, which determines the overall performance of cold chain logistics system. Therefore, constructing a reasonable index system can not only provide theoretical basis for the optimization of cold chain logistics, but also provide practical guidance for decision makers.

1) Transportation cost factors

Transportation cost is an important factor in cold chain logistics, which directly determines the operating cost and transportation efficiency of logistics enterprises. Transportation cost contains many components in cold chain logistics. The cost of transportation vehicles required for cold chain transportation is a key factor, and the purchase cost, operation cost and maintenance cost of refrigerated transportation vehicles will directly affect the transportation cost. In addition, energy costs are also a part of cold chain logistics that can't be ignored, especially fuel and electricity costs. Cold chain transportation needs to operate in a low temperature environment for a long time, so energy consumption is large and it becomes an important source of pressure for transportation costs. Labor costs also occupy a part of transportation costs. In cold chain logistics, due to special operational requirements and management needs, labor costs are usually high, especially in the expenses of drivers, stevedores and warehousing personnel, which further increases the overall transportation costs.

2) Logistics efficiency factors

Logistics efficiency is another important criterion to determine the benefit of cold chain logistics system. The timeliness and economic benefits of fresh agricultural products often depend on the efficiency of cold chain logistics. Transportation timeliness is directly related to the timeliness of cold chain logistics, which determines the time needed from departure to destination. Any delay will affect the quality of products and market competitiveness. The efficiency of loading and unloading reflects the efficiency of warehousing and distribution in logistics operation, and the efficiency of loading and unloading process can effectively reduce transportation time and cost. Distribution coverage is another key factor to evaluate logistics efficiency, which represents the coverage of cold chain logistics network. Covering a wide network can ensure the smooth flow of cold chain transportation and improve distribution efficiency.

3) Temperature control management factors

Temperature control management plays a vital role in cold chain logistics, because temperature fluctuation will directly affect the quality and safety of fresh agricultural products. The stability of temperature control is one of the most important indicators in temperature control management, which ensures that a constant low temperature environment can be maintained during cold chain transportation. The technical level of temperature control reflects the technical performance of refrigeration equipment and temperature control system. The more advanced technology can realize more accurate temperature control and reduce the quality risk during transportation. Real-time temperature monitoring, as an integral part of temperature control management, can monitor and feedback the temperature in the transportation process in real time by means of information technology, which can find and solve the abnormal temperature problem in time and ensure the product quality.

4) Factors of informatization degree

The degree of informatization is also an important factor affecting cold chain logistics. In modern logistics, the application of information management system can greatly improve logistics efficiency and reduce errors in operation. Whether cold chain logistics enterprises adopt modern information management systems, such as transportation management system (TMS) and warehouse management system (WMS), determines the accuracy and efficiency of their operation. The ability of data sharing and cooperative operation reflects the real-time data exchange and cooperation ability of all logistics links under the information system, which is helpful to improve the flexibility and response speed of the whole supply chain and reduce the problem of information islands in the logistics process.

Table 1. Hierarchy model of influencing factors of cold chain logistics development of fresh agricultural products in a certain place.

Target layer	Criterion layer	Index layer
Influencing factors of cold chain logistics development of fresh agricultural products in a certain place B	Transportation cost C1	Transportation vehicle cost D1
		Energy cost D2
		Labor cost D3
	Logistics efficiency C2	Transport limitations D4
		Handling efficiency D5
		Distribution coverage D6
	Temperature control management C3	Temperature stability D7
		Technical level of temperature control D8
		Real-time temperature monitoring D9
	Degree of informatization C4	Information management system D10
		Data sharing and collaborative work ability D11

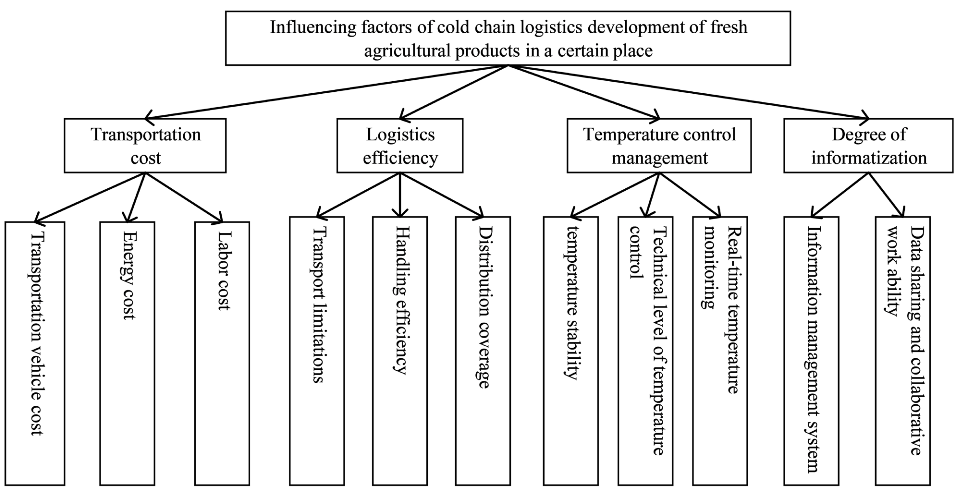

Figure 1. Hierarchy model of influencing factors of cold chain logistics development of fresh agricultural products in a certain place.

Through the reasonable selection of evaluation indicators, the paper establishes a hierarchical structure model for the influencing factors of the cold chain logistics development of fresh agricultural products in a certain place, and sets the evaluation of the influencing factors of the cold chain logistics development of fresh agricultural products in a certain place as the target layer, the four aspects of transportation cost, logistics efficiency, temperature control management and informatization level as the criterion layer, and then further refines each evaluation indicator into three specific indicators and sets them as the index layer, as shown in Table 1 and Figure 1.

3.2. FAHP Model Application

1) Evaluation and judgment matrix of influencing factors of cold chain logistics development of fresh agricultural products in a certain place.

In the form of online questionnaire, the paper invites experts, teachers and enterprise personnel of cold chain logistics companies with relevant fresh agricultural products to rate the importance of comparing the influencing factors and indicators. The choice of experts is usually influenced by subjective factors such as work experience, work field, experience and thinking, so the expert authority model will be introduced in group decision-making, which usually considers the influence of experts and the degree of knowledge mastery. When selecting experts, the paper focuses on the rich working knowledge and experience in this industry, so all experts are required to have more than 6 years working experience in the cold chain logistics industry, and all experts are given the same weight. Twenty experts in cold chain logistics were invited via online questionnaires, including: Industry Practitioners (60%): Technical directors and operations managers from enterprises like SF Cold Chain and JD Logistics, with an average of 10 years of experience; Academia (25%): Researchers from Yunnan University Logistics Institute and China Agricultural University; Industry Associations (15%): Policy advisors from the China Cold Chain Alliance and Yunnan Logistics & Procurement Federation. All experts had over 6 years of industry experience to ensure authority and representativeness. In this survey, a total of 20 questionnaires were distributed, and 20 questionnaires were collected. The survey results were tested for consistency one by one through calculation, and the results that failed the test were removed, and then the individual values with great differences were removed. The weight of the remaining questionnaire results brought into experts was calculated and summarized by weighted arithmetic average method. As shown in Tables 1-6.

Table 2. Criteria level scoring table.

Criteria	Transportation Cost	Logistics Efficiency	Temperature Control Management	Information Technology Level
Transportation Cost	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(2, 3, 4)
Logistics Efficiency	(1/3, 1/2, 1)	(1, 1, 1)	(1, 2, 3)	(1/3, 1/2, 1)
Temperature Control Management	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)	(1, 1, 1)
Information Technology Level	(1/4, 1/3, 1/2)	(1, 2, 3)	(1, 1, 1)	(1, 1, 1)

Table 3. Transportation cost scoring table.

Transportation Cost Criteria	Vehicle Cost	Energy Cost	Labor Cost
Vehicle Cost	(1, 1, 1)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)
Energy Cost	(3, 4, 5)	(1, 1, 1)	(2, 3, 4)
Labor Cost	(1, 2, 3)	(1/4, 1/3, 1/2)	(1, 1, 1)

Table 4. Logistics efficiency scoring table.

Logistics Efficiency Criteria	Transportation Time	Loading/Unloading Efficiency	Distribution Coverage
Transportation Time	(1, 1, 1)	(1/3, 1/2, 1)	(1, 1, 1)
Loading/Unloading Efficiency	(1, 2, 3)	(1, 1, 1)	(1, 2, 3)
Distribution Coverage	(1, 1, 1)	(1/3, 1/2, 1)	(1, 1, 1)

Table 5. Temperature control management scoring table.

Temperature Control Management Criteria	Temperature Stability	Temperature Control Technology Level	Real-Time Temperature Monitoring
Temperature Stability	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)
Temperature Control Technology Level	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 2, 3)
	(1/4, 1/3, 1/2)	**(1/3, 1/2, 1)**	(1, 1, 1)

Table 6. Information technology level scoring table.

Information Technology Level Criteria	Information Management System	Data Sharing & Collaborative Work Capability
Information Management System	(1, 1, 1)	(1, 1.25, 1.5)
Data Sharing & Collaborative Work Capability	(2/3, 0.8, 1)	(1, 1, 1)

(2) Determine the weight of influencing factors of cold chain logistics development of fresh agricultural products in a certain place.

Calculate the data in Table 1 and get the following results (Table 7):

Table 7. Analytical hierarchy process (AHP) results for criterion level indicators.

Indicator	Fuzzy Weight Interval	Defuzzified Weight
Transportation Cost	[0.42, 0.48]	0.455
Logistics Efficiency	[0.19, 0.22]	0.205
Temperature Control Management	[0.15, 0.17]	0.16
Information Technology Level	[0.20, 0.23]	0.215

Similarly, the weight values of the judgment matrix of secondary indicators are solved, and the consistency test is carried out to obtain the results, such as Tables 8-11.

Table 8. Summary of transportation cost judgment matrix results.

Indicator	Fuzzy Weight Interval	Defuzzified Weight
Vehicle Cost	[0.12, 0.15]	0.135
Energy Cost	[0.60, 0.64]	0.62
Labor Cost	[0.22, 0.25]	0.235

Table 9. Summary of logistics efficiency judgment matrix results.

Indicator	Fuzzy Weight Interval	Defuzzified Weight
Transportation Time	[0.28, 0.33]	0.305
Loading/Unloading Efficiency	[0.45, 0.52]	0.485
Distribution Coverage	[0.18, 0.22]	0.2

Table 10. Summary of temperature control management judgment matrix results.

Indicator	Fuzzy Weight Interval	Defuzzified Weight
Temperature Stability	[0.55, 0.62]	0.585
Temperature Control Technology Level	[0.23, 0.27]	0.25
Real-Time Temperature Monitoring	[0.14, 0.17]	0.155

Table 11. Summary of information technology level judgment matrix results.

Indicator	Fuzzy Weight Interval	Defuzzified Weight
Information Management System	[0.53, 0.57]	0.55
Data Sharing & Collaborative Work Capability	[0.43, 0.47]	0.45

Table 12. Comprehensive weights of factors influencing the development of fresh agricultural products cold chain logistics.

arget Level	Criterion Level	Criterion Level Weight	Indicator Level	Comprehensive Weight
Factors Influencing the Development of Fresh Agricultural Products Cold Chain Logistics	Transportation Cost	0.455	Vehicle Cost	0.033
			Energy Cost	0.152
			Labor Cost	0.058
	Logistics Efficiency	0.205	Transportation Time	0.076
			Loading/Unloading Efficiency	0.12
			Distribution Coverage	0.048
	Temperature Control Management	0.16	Temperature Stability	0.142
			Temperature Control Technology Level	0.061
			Real-Time Temperature Monitoring	0.038
	Information Technology Level	0.215	Information Management System	0.135
			Data Sharing & Collaborative Work Capability	0.1110

Summarize the index weights in Table 6, Table 8 and Table 11 above and calculate the comprehensive weight of the index layer to the target layer. The results are shown in Table 12.

In this section, the factors affecting the development of cold chain logistics of fresh agricultural products in a certain place are screened and summarized through expert interviews, and four important risk indicators are obtained: transportation cost, logistics efficiency, temperature control management and informatization degree. The analysis of the total data leads to the following conclusions:

1) The five indexes with the highest weight in the index layer are energy cost, temperature stability, information management system, loading and unloading efficiency, data sharing and cooperative operation ability, which are 15.2%, 14.2%, 13.5%, 12% and 11.1% respectively.

2) The weights of the influencing factors in the standard layer are transportation cost 45.5%, logistics efficiency 20.5%, temperature control management 16% and informatization degree 21.5% respectively.

Finally, the consistency of the output results is tested, and the consistency of all indicators passes smoothly, thus proving that the constructed judgment matrix and the final result are effective.

4. Conclusions and Suggestions

4.1. Conclusion

Through the Fuzzy Analytic Hierarchy Process (FAHP), the key factors affecting the development of cold chain logistics of fresh agricultural products in a certain place were studied, among which the transportation cost was rated as the most critical factor, with a weight of 45.5%. This result can well reflect the unique geographical and economic conditions of a certain place. Yunnan is located in the southwest border, with complex terrain, many mountains and hills, and relatively poor traffic conditions. Especially in some remote areas, the logistics infrastructure is not perfect, which leads to high transportation costs. Long-distance transportation not only needs more fuel and labor costs, but also faces longer transportation time and lower transportation efficiency, which further increases the cost pressure. Secondly, the degree of informatization and logistics efficiency accounted for 21.5% and 20.5% respectively. The degree of informatization is becoming more and more important in modern logistics management, which can improve the transparency and visual management of transportation process, help monitor temperature and humidity changes and optimize scheduling. The improvement of logistics efficiency means reducing costs and improving overall competitiveness by optimizing transportation routes, rationally dispatching vehicles and improving the efficiency of operation processes. The weight of temperature control management is relatively low, only 16%, which can be explained by the mild climate conditions in Yunnan. Although Yunnan's mild climate reduces short-term urgency for temperature control, the high weight of temperature stability (14.2%) underscores its critical role in long-term quality assurance, especially for high-value products (e.g., flowers, wild mushrooms). Thus, temperature management remains essential and should be dynamically adjusted based on climatic conditions.

In the index layer, energy cost, temperature stability, information management system, loading and unloading efficiency and other indicators occupy higher weights respectively. Energy cost accounts for 15.2%, which directly reflects the core role of energy consumption in cold chain logistics, especially the fuel consumption of refrigeration equipment and refrigerated trucks in cold chain transportation. The high proportion of energy costs shows that reducing fuel and electricity consumption is the key way to reduce transportation costs. Temperature stability followed closely, accounting for 14.2%, which emphasized the importance of temperature control management to product quality assurance. Temperature fluctuation has a great influence on perishable food, and stable temperature control can avoid the quality degradation or decay of agricultural products during transportation. Information management system and data sharing ability also occupy an important position, accounting for 13.5% and 11.1% respectively. In cold chain logistics, information management system can help enterprises realize real-time monitoring, path planning and scheduling management, while data sharing can help improve the collaborative ability of all parties in the supply chain and ensure the improvement of transportation efficiency. The efficiency of loading and unloading accounts for 12%, which reflects the standardization of operation in cold chain logistics, especially in loading and unloading. If automatic equipment can be introduced, the efficiency of operation can be significantly improved. While the optimization strategies in this study are contextualized in Yunnan, the methodology and core findings are universally applicable. Regions with harsher climates (e.g., high temperatures or humidity) or weaker infrastructure should prioritize temperature control technologies and energy structure optimization. In contrast, areas with developed transportation networks and higher economic levels may focus on informatization platforms and automation upgrades. Tailoring strategies to local conditions will significantly enhance the adaptability and sustainability of cold chain logistics systems.

4.2. Suggestions

Based on the weight analysis of influencing factors, this paper puts forward a number of optimization strategies, aiming at reducing transportation costs and improving overall efficiency. First of all, reducing energy costs should be the focus of optimization. Popularizing new energy cold chain vehicles, such as electric cold chain vehicles or hydrogen cold chain vehicles, is an effective way to reduce fuel consumption. Taking new energy refrigerated trucks as an example, the initial investment is 20% higher than diesel trucks, but annual fuel costs decrease by 40%, with a payback period of ~3 years. Government subsidies could reduce this to 2 years, demonstrating long-term feasibility. This can not only significantly reduce operating costs, but also help reduce greenhouse gas emissions, which is in line with the goal of sustainable development. Combining the innovative mode of "photovoltaic + cold chain storage", using renewable energy such as solar energy to provide electricity for cold chain storage will further reduce the dependence on traditional electricity, thus effectively reducing the energy consumption in the whole cold chain transportation process. In addition, by optimizing the transportation path planning, using GIS technology to build a multi-objective path optimization model, and comprehensively considering factors such as road conditions, energy consumption and transportation timeliness, invalid mileage can be reduced, thus further reducing the overall transportation cost.

We should build a perfect cold chain logistics information platform to enhance the information capability. The platform can integrate the GPS data of transport vehicles, the data of temperature and humidity sensors and the upstream and downstream information of the supply chain, and realize the whole visual monitoring. Through this platform, enterprises can grasp the temperature and humidity changes in the transportation process in real time, find and solve potential problems in time, and significantly improve the transparency and reaction speed of logistics. Data standardization and collaborative sharing can not be ignored. The unified temperature control data interface standard can realize data interconnection among production enterprises, logistics companies and retail terminals, effectively improve the overall logistics efficiency and reduce errors and delays in the information transmission process.

In order to further improve the efficiency of logistics, it is very important to standardize the operation process. Especially in the agricultural products distribution center, the introduction of automatic loading and unloading equipment, such as intelligent sorting line and automatic forklift, can greatly improve the loading and unloading efficiency, reduce manual operation and lag, and reduce losses. The application of this automation technology can help to achieve a more efficient and accurate workflow. It is also important to implement the distribution mode of "partition + classification" to improve logistics efficiency. According to the transportation distance, characteristics and other factors of agricultural products, the distribution area is reasonably divided, and priority direct transportation is provided for high value-added products to avoid unnecessary transit links, thus effectively improving distribution efficiency and shortening transportation time. The improvement of temperature control management system is also the key to improving the quality of cold chain transportation. In order to ensure that temperature fluctuation will not affect the quality of agricultural products, a sound early warning mechanism for temperature fluctuation must be established. By installing multi-point temperature sensors in cold chain transport vehicles and combining with edge calculation technology, the temperature control equipment can be monitored and adjusted in real time to ensure the stability of temperature control during transportation and prevent the quality loss caused by temperature fluctuation. It is also very important to strengthen the training of temperature control technology for drivers and stevedores. Through professional technical training, the operational errors caused by human factors can be reduced, and the temperature control management can be effectively implemented in the whole cold chain transportation process, thus further ensuring the transportation quality and efficiency.

4.3. Research Limitations and Future Prospects

Although FAHP model is used to analyze the key factors of cold chain logistics development in a certain place, there are some limitations. First of all, the study did not fully consider the differentiated needs of different regions in a certain place. For example, there is a big difference in logistics demand between the urban agglomeration in central Yunnan and the border mountainous areas, and the traffic conditions in mountainous areas are more complicated, which may lead to different performance of cost and efficiency of cold chain logistics in these areas. Therefore, the future research should pay more attention to the differences between regions and explore the specific needs of cold chain logistics in different regions. Secondly, the current weight calculation is based on static expert scoring, without considering the influence of dynamic factors such as policy changes and technological progress. In the fast-developing industry of cold chain logistics, changes in policies and technologies may have a greater impact on the weight of each factor, and future research can introduce dynamic data and make real-time adjustments.

For the future research direction, we can deepen from the following aspects. We can build a dynamic weight evaluation model, introduce time series data, and analyze the evolution law of each factor's weight, so as to help enterprises flexibly adjust the strategy of cold chain logistics. Carry out multi-regional comparative research, compare the differences in cold chain logistics between a certain place and the eastern coastal provinces, and refine the optimization strategy of cold chain logistics suitable for a certain place. The fusion path of intelligent algorithm is also an important research direction in the future. Combining FAHP with machine learning algorithm to realize adaptive adjustment and strategy generation will help to improve the intelligent level of cold chain logistics management and improve the overall transportation efficiency.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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