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Research on the Operation Strategy of Rural Logistics Network with Comprehensive Consideration of Cost, Efficiency and Benefit

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ABSTRACT

The high-cost and low-efficiency rural logistics network is a bottleneck that restricts the flow of commodities and economic development between urban and rural areas. In view of this, this paper uses the system dynamics modelling method to first analyse the constituent elements of the rural logistics network operation system and the relationship between them and draw the causal diagram. Secondly, quantify the causal diagram with the dynamics equations, and establish the stock and flow diagram. Thirdly, set the relevant parameters, and carry out the structural, parametric and sensitivity tests with Vensim software. Finally, for the scenarios of dealing with general commodities and fresh agricultural products, the simulation of rural logistics network operation is carried out, which reveals the feedback mechanism between network operation efficiency, logistics cost and operating enterprise benefits, and simulates the implementation effects of different operation strategies from both endogenous and exogenous levels to explore how to build a rural logistics network with high efficiency, low cost and increased benefits. The results show that networked, organised and intelligent operation plans, logistics land use policies, and carbon tax policies are high-leverage measures to reduce cost and increase efficiency in rural logistics networks. However, attention should be paid to distinguishing between implementation stages and the attributes of the implemented enterprises, focusing on the reduction of logistics land cost at the early stage of network construction, levying logistics carbon tax and paying attention to the reduction of the transport fee rate at the mature stage of network operation and increasing policy preferences for fresh agricultural products logistics enterprises.

KEYWORDS

rural logistics network; operation strategy; system dynamics.

1. INTRODUCTION

Rural logistics is a logistics activity that serves the production and life of rural residents, including the logistics of agricultural products into the city, the logistics of consumer goods to the countryside and the logistics of agricultural materials such as pesticides to the countryside [1]. As a bridge connecting urban and rural production and consumption, the rural logistics network is the foundation and important guarantee of economic and social development. However, due to a variety of factors such as policy, economic, demographic and historical factors, the development of rural logistics in various countries generally lags behind urban logistics and is at a lower level [2]. Among them, the problems of high operating costs and low efficiency and benefits are especially prominent. First, as far as cost is concerned, farmers and other rural logistics demand-side feel that rural logistics costs are too high, affecting their participation in fresh food e-commerce enthusiasm. For example, the cost of a single piece of express delivery to rural areas in China is about twice as much as the cost of delivery to a county within 30 kilometres; and it grows to five times as much as 60 kilometres[1]. Second, in terms of efficiency, queuing, congestion and other inefficiencies are frequent, and rural residents in the United Kingdom said that the fastest express delivery will take seven days to arrive[2]. Finally, as far as benefit is concerned, even though the demand side believes that the cost is high, but on the other hand, many small and medium-sized logistics enterprises have withdrawn from or are unwilling to step into the rural logistics market due to loss-making operations, such as October 2023, UPS (United Parcel Service) claimed that it would reduce the delivery service in rural areas in the United States to reduce costs; FedEx has also scaled down some rural services such as Sunday home delivery[3]. Behind this in addition to the demand for decentralised, carrying a variety of goods and other special attributes inherent in rural logistics itself, more rural logistics network construction and operation and management is not in place. In this context, how to realise the operation of a rural logistics network with low cost, high efficiency and high benefit has become the key issue at present.

However, what is the relationship between logistics costs, efficiency and benefits? What policies can simultaneously realise the cost reduction, efficiency and benefit increase of rural logistics network? In order to answer the above questions, this paper intends to introduce the system dynamics method to carry out the operation simulation and policy experiment of rural logistics networks. System dynamics is widely used in logistics research as a "policy laboratory", which quantifies the behavioural patterns of a system by computer simulation, helps researchers understand the structural reasons for the dynamic behaviour of the system, and is suitable for dealing with the interactions between complex factors [3]. In summary, this paper will develop a rural logistics network operation system model that integrally considers logistics cost, efficiency and benefits, on the one hand, with the help of causality analysis to intuitively reveal the interaction mechanism among logistics cost, rural logistics network operation efficiency and network operation enterprise benefits. On the other hand, it is hoped that by adjusting the policy parameters in the system, we can explore a rural logistics network with increased efficiency, reduced costs and improved operational benefits, which will provide a decision-making reference for the government and enterprises.

The remainder of this paper is organised as follows. Section 2 reviews the previous studies, on the basis of which the new contributions of this study are discussed. Section 3 conducts a system analysis of the rural logistics network operation, draws a causal loop diagram, and uses kinetic equations to represent the relationships between variables to establish a system flow diagram. Section 4 carries out the simulation of rural logistics network operation for two scenarios of handling general commodities and fresh agricultural products, and simulates the cost reduction and efficiency enhancement effects of the rural logistics network operation scheme and rural logistics land use policy, rural road traffic management policy, and carbon tax policy from both endogenous and exogenous levels. Section 5 provides a discussion and analysis, pointing out the limitations of the thesis as well as future research expansion. Section 6 describes the findings of the study.

2. LITERATURE REVIEW

Logistics network research began in the middle of the last century, and since then the number of scholars entering the field has continued to increase, and the research methodology covers the axial-spoke network model, complex network theory, gravitational model and so on, and the research objects can be categorised into logistics networks in different industries [4-5], logistics networks with different objectives [6-8] and logistics networks in different regions and so on. Among them, Zhu et al. studied the logistics network in the Beijing-Tianjin-Hebei region of China [9], Peng et al. studied the international logistics network [10] and Wang et al. studied the urban logistics network [11]. However, there are relatively few studies on logistics networks from a rural area perspective, and they focus on the layout planning of rural logistics networks, rural terminal distribution problems and the improvement of rural logistics service quality. For the layout planning of rural logistics network, Li et al. proposed a site selection model to optimise the location, number and capacity of "urban-rural" hierarchical hubs with the objective of minimising the expected total system cost, and developed a branch bending and cutting algorithm based on demand scenarios to solve the proposed model [12]. Tuti et al. developed a rural logistics system based on a conceptual model to improve the distribution of goods in villages [13]. Zhang et al. proposed an integrated rural logistics centre siting method with the objectives of maximising express service coverage and improving the operational profitability of logistics centres, which is highly feasible [14]. From the perspective of supply and demand, Peng et al. reasonably

[1] http://www.rmlt.com.cn/2019/0621/550161.shtml
[2] https://haokan.baidu.com/v?pd=wisenatural&vid=5724409393146798396
[3] https://baijiahao.baidu.com/s?id=1780461904419075062&wfr=spider&for=pc

optimised the organisation of each link in the urban and rural distribution network, so that the network routes and nodes can achieve the maximisation of supply and demand matching in terms of time, cost and quantity [15]. In addition, he also considered the environmental pollution problem brought by distribution and established a rural logistics network optimisation model that minimises the sum of distribution cost, environmental pollution control cost, operation cost and construction cost [16]. To address the rural end-of-line delivery problem, Yulia et al. investigated the effect of the type of residential area of e-consumers on the satisfaction and willingness to reuse rural delivery services [17]. Dai et al. developed a truck-drone delivery model for the rural last mile, focusing on optimising the rural delivery process, reducing delivery time and minimising costs [18]. Yang et al. similarly proposed a cooperative rich-vehicle path problem for the rural last-mile distribution problem [19]. For rural logistics service quality improvement, He et al. designed a government subsidy incentive contract and constructed a coalition payment incentive contract based on principal-agent theory from the participant's perspective in order to improve the quality of integrated public transit passenger and freight services in the countryside [20]. Dovbischuk investigated the quality of logistics services in the agri-food sector in terms of five dimensions, including reliability, digital transformation, corporate image, environmental sustainability and quality of customer focus [21].

It is summarised that the existing studies on the planning and operation of rural logistics networks include the low-carbon objective [22], the time window objective [6], the reliability objective [7], the service satisfaction objective [8] and the cost-optimisation objective, which is the objective that most scholars consider. For example, Zhang et al. established a three-level network layout optimisation model of "warehouse node – rural county distribution centre – village and town demand point" with the objective function of minimising the total cost of construction cost, transportation cost and transportation loss cost [23]. Peng et al. established a rural logistics network optimisation model with the minimum sum of distribution cost, environmental pollution control cost, operation cost and construction cost [16]. Yao et al. constructed a hybrid hub-and-spoke integrated rural-urban logistics network planning model that simultaneously meets the logistics needs of agricultural and non-agricultural products and allows for direct transportation based on cost orientation [24]. Li et al. proposed a hierarchical hub location model for a rural logistics network under the condition of demand uncertainty, which minimises the total system cost such as hub construction cost, transportation cost and excess penalty cost by optimising the location, number and capacity of the hierarchical logistics hubs in "city-town-village" [25]. Luo takes into full consideration the current situation of rural logistics development and the problems of rural distribution mode and establishes a rural logistics network model based on common distribution to minimise the total cost of the system based on the analysis of the cost composition of the rural logistics network [26]. Hong et al. aimed to reduce the high distribution cost associated with a "long transportation chain + low consumption density" in rural logistics, and carried out a study on the optimisation of two-tier two-way logistics vehicle paths in rural areas [27]. It can be seen that scholars are mainly concerned about the cost minimisation of rural logistics network planning, but few scholars consider the multi-objective optimisation of the rural logistics network, how to better play the economic multiplier effect of logistics cost reduction, i.e. the lack of research from the perspective of "efficiency and benefit enhancement".

With the expanding scale of urban and rural commodity circulation, we believe that the study of rural logistics network operation with comprehensive consideration of cost, efficiency and benefit is more in line with the real needs and will attract more scholars to explore it and become an important research direction in the future. However, considering that the rural logistics network is a complex system with many types of goods, wide-coverage, many routes and nodes, many types of participating subjects, and the logistics cost has complex characteristics such as benefit reversal, it is more suitable to carry out the research with system dynamics simulation. System dynamics based on feedback control theory can start from the system as a whole, effectively combining quantitative and qualitative analysis, constructing a nonlinear, multiple feedback, time lag dynamic system, to realise the simulation of the real social and economic system and the simulation of the effect of relevant policy factors [28].

The application of system dynamics in logistics research can be traced back to the last century, e.g. Abbas and Bell (1994) assessed the advantages and disadvantages of system dynamics as a transportation modelling method [29]. For their part, Bian et al. introduced the system dynamics modelling approach to the field of rural logistics to study the coordination between rural logistics development and low-carbon transition [30]. However, their model lacks feedback on logistics costs, efficiency and benefits.

In summary, this paper will make some innovations in the following aspects on the basis of previous research. Firstly, this paper focuses on rural logistics network operation and considers the two-way flow of fresh produce agricultural products and general commodities in the network operation simulation for its special attributes. Second, unlike the single perspective that only considers cost, this paper integrates cost, efficiency and benefit objectives and embeds them in a framework for system analysis. Finally, the system dynamics modelling approach used in this paper can more accurately portray the nonlinear, multichannel and dynamic conduction process between the turnover of operation schemes and the change of network operation effects, so that it can be presented in an intuitive and quantitative way to help network operators identify and recognise the core issues.

3. METHOD

3.1 Description of the composition and boundaries of the rural logistics network operation system

Composition of rural logistics network operation system

Clarifying the modelling objective is a prerequisite for the construction and simulation of system dynamics models. Considering that the purpose of this paper is to reveal the interaction between logistics costs, rural logistics network operation efficiency and operating enterprise benefits, as well as to explore the operational decision-making that promotes the rural logistics network to reduce costs and increase efficiency, the rural logistics network operation system is defined to be composed of three modules, namely, logistics costs, network operations and the development of network operating enterprises. The system is composed of three modules: logistics cost, network operation and network operation enterprise development. First, the logistics cost module is mainly composed of all kinds of logistics costs generated by the operation of rural logistics networks. Combined with the current enterprises' attention to different logistics costs and the specificity of rural logistics networks, this paper defines that the costs generated by the operation of rural logistics networks include node construction costs, transportation costs, fresh agricultural products cargo damage costs, environmental costs and logistics shortage costs. Among them, the node construction cost refers to the cost generated by the construction of logistics parks, distribution centres and other network nodes. Transportation cost is the cost of transporting goods from one node of the network to another node and is related to the transportation distance, the number of transported goods, and so on. The environmental cost is the environmental pollution losses and resource depletion costs generated by the network operation, such as carbon emission costs. For the logistics industry, which is a high-energy consumption and high-emission industry, the impact and control of environmental costs have now become a new type of cost that enterprises should pay attention to when operating rural logistics networks. The cost of cargo damage of fresh agricultural products is the value loss of fresh agricultural products due to collision, natural decay, etc. in the logistics process. This part of the cost of the rural logistics network operation should not be ignored. Logistics supply shortage costs are losses due to network inefficiencies and lack of capacity. In the face of the current trend of randomness and suddenness of logistics demand, rural logistics network operations should be paid attention to, good transportation and warehousing plans, good risk management and control, etc. to minimise the cost of logistics supply shortage. Secondly, the network operation module includes the enterprise's construction and operation program of the rural logistics network and the description of the network operation effect, such as network operation efficiency, logistics service level and logistics supply shortage. Finally, the network operations business development module focuses on the abstraction of business operations such as assets, market share and various investments.

There are extensive links and interactions among the three modules, constituting a complex and dynamic rural logistics network operation system. As shown in *Figure 1*, firstly, from the network operation efficiency, it can be seen that the network operation efficiency improvement means that the logistics service level of the network will be improved, which will be conducive to the development and growth of enterprises, and behind the development of enterprises is the increase of investment in the construction of the network and the improvement of operation and management, which will ultimately have a positive impact on the network operation efficiency improvement. Secondly, the network operation efficiency means that the network to handle the current increase in the flow of goods, the transport costs, environmental costs, etc. will also increase, and the increase in these logistics costs will obviously bring a burden to the development of enterprises, and thus inhibit the network to improve the efficiency of the operation. Thirdly, there is a negative feedback loop between network operation efficiency and logistics cost through the shortage of logistics supply, that is, the network operation efficiency is conducive to alleviating the shortage of logistics supply, which in turn reduces the logistics cost and promotes the development of enterprises and network operation efficiency. Finally, after grasping the law of endogenous loop, the network operation can be influenced by the exogenous variables of network construction and network operation, which can promote the system to operate in accordance with the goal of “reducing costs and increasing efficiency”.

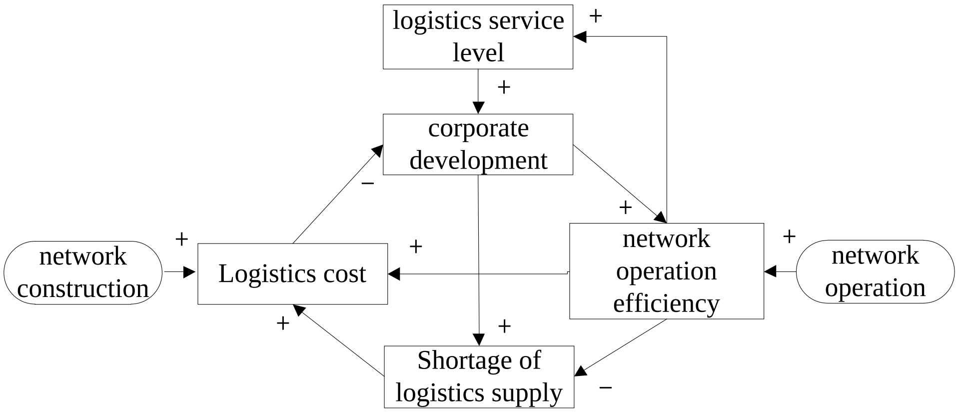


Figure 1 – System structure of rural logistics network operation

Description of the boundaries of the operational system of the rural logistics network

System dynamics modelling is an abstraction and simplification of complex reality, where a description of the system boundaries and modelling assumptions are made.

First, according to the different logistics demands, the commodity category factor is set to distinguish the commodities carried by the rural logistics network into general commodities (such as consumer goods) and fresh agricultural products. Among them, the transportation rate, storage unit price and carbon emission factor of fresh agricultural products and general commodities are not the same, so the model is divided into two scenarios to deal with fresh agricultural products and general commodities for network operation simulation. Secondly, the model can only handle the same type of commodities on the same transportation route in a single run and does not consider the situation of mixed transportation of various types of commodities. Finally, the logistics subcontracting scenario is not considered, and the remaining logistics demand during the processing time is stored and waited for the next cycle.

3.2 Analysis of the causal relationship between the operating systems of rural logistics networks

The components of the rural logistics network operating system are refined and a specific causal loop diagram is drawn as shown in *Figure 2*, and the feedback loops in the diagram are as follows:

Loop 1: Enterprise assets→+marketing investment→+enterprise market share→+logistics demand volume →+enterprise assets (positive feedback). Investment is a business behaviour in which a firm spends money on its own infrastructure, technical equipment, etc. with a view to obtaining more revenue in the future. Here, an increase in the enterprise’s investment in marketing will expand the enterprise’s market share, which in turn will increase the logistics demand volume, and ultimately return to the accumulation of enterprise assets, completing a cycle of enterprise investment, development and growth.

Loop 2: Enterprise assets→+network operation investment→+network working level→+rural logistics network operation efficiency or enterprise assets→+network operation investment→+network informatisation level/→+network organisation coordination degree→+network scheduling level→+rural logistics network operation efficiency→+logistics service level→+logistics service satisfaction→+enterprise market share→ +logistics demand volume→+enterprise assets (positive feedback). Similarly, the enterprise’s investment in network operation will improve the network operation efficiency by improving the working level and scheduling level of the rural logistics network, and the improvement of network operation efficiency is conducive to the improvement of logistics service level and logistics service satisfaction, the latter will further positively affect the enterprise’s market share and the increase of the enterprise’s assets, which is a self-reinforcing dynamic process.

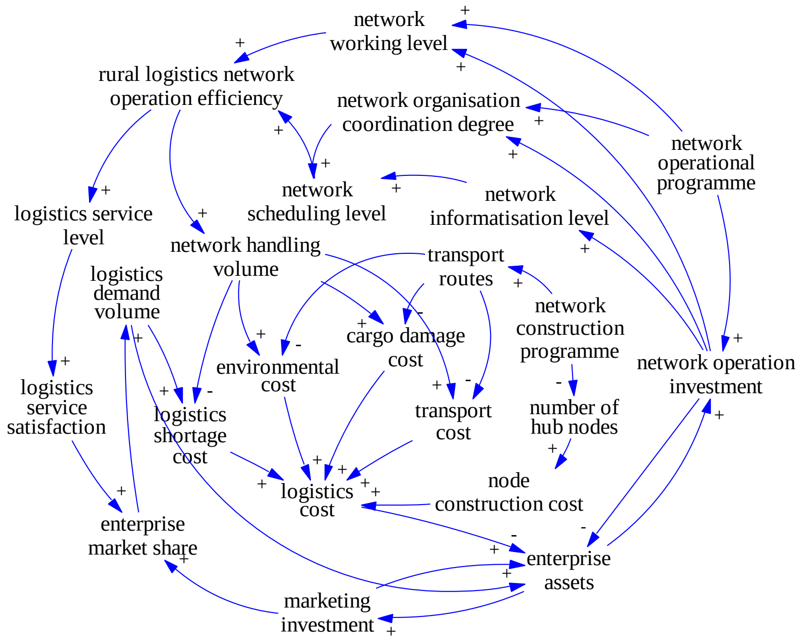


Figure 2 – The causal loop diagram

Loop 3: Enterprise assets→+network operation investment→+network informatisation level /→+network organisation coordination degree→+network scheduling level or enterprise assets→+network operation investment→+network working level→+rural logistics network operation efficiency→+network handling volume→-logistics shortage cost→+logistics cost→-enterprise assets (positive feedback). Similarly, the investment in network operation by enterprises will improve the operation efficiency of rural logistics networks, and the essence of the improvement of network operation efficiency is the expansion of network handling capacity in a fixed period of time, i.e. the improvement of logistics supply capacity and the reduction of logistics shortages, which will reduce the logistics cost and increase the assets of the enterprise.

Loop 4: Enterprise assets→+network operation investment /→+marketing investment→-enterprise assets (negative feedback). Obviously, the investment in marketing and network operation in each operation cycle of the enterprise will reduce the enterprise assets in the current period.

Loop 5: Enterprise assets→+network operation investment→+network working level→+rural logistics network operation efficiency→+network handling volume or enterprise assets→+network operation investment→+network informatisation level/→+network organisation coordination degree→+network scheduling level→+rural logistics network operation efficiency→+network handling volume→+environmental cost/ + cargo damage cost/ + transport cost→+logistics cost→-enterprise assets (negative feedback). This causal loop indicates that the improvement of network operation efficiency will increase the handling capacity of the network in a fixed period of time, and the corresponding environmental cost, cargo damage cost, and transport cost will also increase, thus restricting the continuous accumulation of enterprise assets. In summary, the increase in network handling capacity, or the improvement of network operation efficiency, has two results. One is to increase logistics costs and constrain the accumulation of business assets, and the other is to reduce the cost of logistics shortages and help the accumulation of business assets, i.e. the third and the fifth causal loops that work in opposite directions to bring the system into equilibrium.

Loop 6: Enterprise assets→+network operation investment→+network informatisation level/→+network organisation coordination→+network scheduling level→+rural logistics network operation efficiency→+logistics service level→+satisfaction with logistics services→+enterprise market share→+logistics demand volume→+logistics shortage cost→+logistics cost→-enterprise assets (negative feedback). Similar to the second feedback loop, the enterprise through increased investment in network operation to improve network operation efficiency, logistics service level and logistics service satisfaction, etc., thereby expanding the enterprise market share and logistics demand volume. However, the difference is that the expansion of logistics demand volume here will increase the logistics cost and reduce the enterprise assets when the processing capacity of the rural logistics network is less than the logistics demand. It can be seen that if the operation of the rural logistics network of enterprises falls behind and cannot meet its own logistics demand, it will restrict the development of enterprises.

3.3 Development of SD (system dynamic) model for rural logistics network operation system

The system structure and causality analysis is a static analysis, while the stock and flow diagram is a tool that can realise the simulation of the dynamic operation of the model through the determination of the functional relationship between variables in the causal loop diagram and the establishment of the system dynamics equations. This is shown in *Figure 3*.

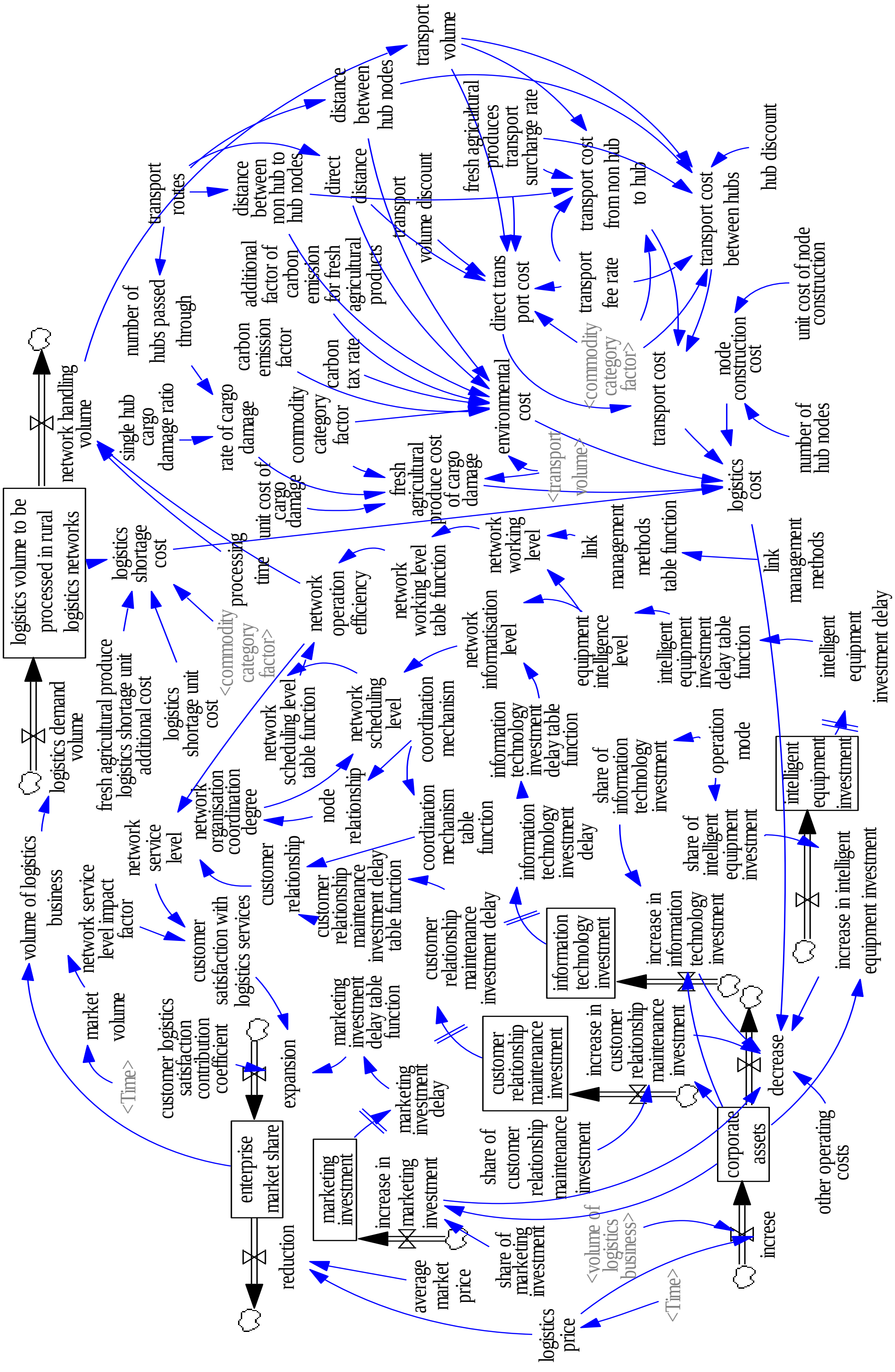


Figure 3 – Stock and flow diagram

Table 1 – Summary of variables

Variable name	**Definition**	**Nature**	**Unit**
Logistics volume to be processed in rural logistics networks	Number of commodities awaiting logistics services from rural logistics networks	L	box
Corporate assets	Economic resources owned or controlled by the corporation that are measured in monetary terms	L	￥1,000
Enterprise market share	Volume of logistics operations of the enterprise as a proportion of total market volume	L	%
Marketing investment	Expenditure on corporate image promotion, e.g. advertising cost	L	￥1,000
Customer relationship maintenance investment	Investment in maintaining partnerships with customer	L	￥1,000
Information technology investment	Enterprise's investment in the development, introduction or adoption of IT	L	￥1,000
Intelligent equipment investment	Cost of purchasing intelligent devices for corporate	L	￥1,000
Increase in marketing investment	Monthly corporate investment in marketing investment	R	￥1,000
Increase in customer relationship maintenance investment	Monthly corporate investment in customer relationship maintenance	R	￥1,000
Increase in information technology investment	Monthly corporate investment in information technology research and development	R	￥1,000
Increase in intelligent equipment investment	Monthly cost of purchasing intelligent devices for corporate	R	￥1,000
Network handling volume	Number of goods undergoing logistics services in rural logistics networks	R	box
Logistics demand volume	Number of goods requiring logistics services in rural logistics networks	R	box
Decrease	Decrease in corporate assets due to operating cost	R	￥1,000
Increase	Increase in corporate assets	R	￥1,000
Reduction	Reduction of enterprise market share	R	%
Expansion	Expansion of enterprise market share	R	%
Network informatisation level	Evaluation of the capacity of rural logistics networks to access information, analyse it and use it for network management	A	%
Network organisation coordination degree	Measure the degree of harmony between the organisation's internal and external customers	A	%
Logistics shortage cost	Cost of goods storage or time spent due to insufficient network processing capacity	A	￥1,000
Network operation efficiency	Volume of goods handled per unit of time by rural logistics networks	A	box/ month
Network service level	Comprehensive judgement on the timeliness and quality of rural logistics network services	A	%
Customer satisfaction with logistics services	Customer evaluation of rural logistics network services	A	%
Customer relationship	The closeness of the relationship between the enterprise and the customer	A	%
Node relationship	The closeness of the relationship between the network operator and other cooperating logistics nodes	A	%

Variable name	Definition	Nature	Unit
Network scheduling level	Evaluation of the capacity of rural logistics networks to carry out operational arrangements	A	%
Equipment intelligence level	Evaluation of the capacity of logistics equipment in rural logistics networks to acquire information and automatically process operations	A	%
Network working level	Evaluation of the speed and accuracy of logistics operations handled by rural logistics networks	A	%
Marketing investment delay	Lag between marketing investment and actual increase in market share	A	month
Volume of commodity sales	volume of goods entrusted to network operators by customers	A	box
Customer relationship maintenance investment delay	Lag between investment in customer relationship maintenance and actual improvement in customer relationships	A	month
Information technology investment delay	Lag between information technology investment and actual enhancement of network informatisation level	A	month
Share of information technology investment	Enterprise information technology investment as a percentage of total investment	A	%
Intelligent equipment investment delay	Lag from equipment investment to actual improvement in equipment smartness	A	month
Share of intelligent equipment investment	Investment in equipment purchases as a percentage of total investment in the enterprise	A	%
Distance between hub nodes	Distance between two hub nodes	A	km
Distance between non-hub to hub nodes	Distance between the non-hub node to be transhipped and the corresponding hub node	A	km
Direct distance	Distance between non-hub nodes and non-hub nodes	A	km
Transport volume	Volume of goods transported via the network	A	box
Transport cost between hubs	Cost of transporting goods between hub nodes (trunk transport)	A	￥1,000
Transport cost from non-hub to hub	Cost of transporting goods over the distance from a non-hub node to a hub node, or consolidation and breakbulk cost	A	￥1,000
Transport cost	Total cost incurred in the delivery of goods from the place of origin to the customer	A	￥1,000
Number of hub nodes	The number of hub nodes through which different transport routes pass, with only three values, 0, 1, 2	A	Piece
Rate of cargo damage	Percentage of losses caused by fresh produce during loading, unloading and handling operations	A	%
Fresh agricultural product cost of cargo damage	Value of the portion of fresh product damaged by loading, unloading and handling	A	￥1,000
Environmental cost	Cost of carbon tax paid on carbon emissions from transport of goods	A	￥1,000
Node construction cost	Total cost to the enterprise of building all logistics hub nodes	A	￥1,000
Logistics cost	Logistics costs to enterprises of constructing and operating rural logistics networks at one time	A	￥1,000

Note: L denotes system state variables, R denotes system rate variables and A denotes system auxiliary variables, box denotes the number of boxes, pieces and units of a package of goods, that is, this paper considers the number of parcel pieces handled by the rural logistics network instead of the weight.

3.4 Parameter estimation

Here we take the operation data of the rural logistics network of the Yangzhou branch of China Postal Express & Logistics Corporation as an example for assigning relevant parameters. China Postal Express & Logistics Corporation is a joint-stock company established in June 2010 by China Post Group Corporation as the main sponsor and is the comprehensive service provider of express and logistics with the longest history of operation and the widest network coverage in China[4]. Yangzhou Branch is the branch of China Postal Express & Logistics in Yangzhou City, Jiangsu Province, responsible for logistics services in Hanjiang, Guangling, Jiangdu districts and Yizheng, Gaoyou, Baoying counties and their rural areas[5]. Yangzhou City is located in an economically developed area on the east coast of China, with a high level of farmers' income, and at the same time, rich in agricultural resources, it is an important commercial grain base and aquatic products' main production area of the country. In recent years, the scale of commodity circulation between urban and rural areas in Yangzhou City has been growing rapidly, and there is a strong demand for rural logistics network construction. Yangzhou Postal Logistics Branch is also actively exploring the construction of a rural logistics network at the village-town-city level, providing logistics services for urban industrial consumer goods going to the countryside and agricultural products such as Gaoyou duck eggs, Yizheng blackberries and Guangling vegetables going to the city. However, the Yangzhou Postal Logistics Branch in the rural logistics network operation process still exists in rural courier delivery costs are still high, the delivery timely delivery rate is low, the parcel loss rate is high and so on, there is an urgent need to further reduce costs and increase efficiency.

In summary, this paper takes the Yangzhou Branch of China Postal Express & Logistics Corporation as an example of the parameter assignment for the rural logistics network operation system, which has good representativeness and feasibility. At the same time, Yangzhou City is also the location of the author's work, through field interviews with the company's employees and access to financial statements and other information to obtain the relevant parameter values, and set the model simulation cycle for January–December, a unified number of kilograms as the unit, the amount of money in thousands of dollars as the unit, the time in months as the unit. Specifically include.

The main constants and state variable parameter values

Table 2 – Constant and state variable values

Parameter name	Description	Value and unit
Cargo category factor	A 0-1 variable that distinguishes the cargo category, with a value of 0 for industrial products and a value of 1 for fresh agricultural products	0 or 1
Unit cost of logistics shortage	Monthly cost of industrial goods storage and time occupation per box due to logistics shortage	0.265, ¥ 1,000/month/box
Additional unit cost of fresh agricultural products logistics shortage	Unit logistics shortage cost of fresh agricultural products higher than industrial products	0.085, ¥ 1,000/month/box
Demand-side satisfaction contribution factor	The extent to which demand-side satisfaction helps the Yangzhou Postal Logistics Branch expand its market share	0.005
Influence factor of network service level	Strength of influence of rural logistics network service level on demand-side logistics service satisfaction	0.86
Share of marketing investment	Share of marketing investment in total investment	5%
Share of demand-side relationship maintenance investment	Share of demand-side relationship maintenance investment in total investment	5%
Processing time	Time interval for network operation simulation	1, month
Discount on transportation volume	Discount on transportation rates when the transportation volume reaches a certain value	0.75
Hub discount	Discount on transportation rates for transportation through hub nodes	0.45
Ratio of cargo loss at a single hub	Ratio of cargo loss of fresh agricultural products in a single loading and unloading operation	2.5%

[4] https://www.ems.com.cn/companyintroduction
[5] http://www.chinapost.com.cn/xhtml1/category/2205/9803-1.htm

Parameter name	Description	Value and unit
Carbon tax rate	Tax rate for logistics carbon emission tax	0.00001, ￥1,000/kg
Carbon coefficient	Carbon emission per unit transportation volume of industrial products	1.58, kg/box/km
Carbon coefficient emissions from fresh agricultural products	Additional coefficient carbon emissions per unit of transportation of fresh agricultural products	0.25, kg/box/km
Unit cost of node construction	Cost of building a hub node	9.11, ￥1,000
Number of hub nodes	Number of hub nodes in the network	2, piece
Transportation rate	Transportation price per kilometre per box of industrial products for road transportation	U(0.00015, 0.00025), ￥1,000 /box/km
Surcharge rate for transportation of fresh agricultural products	Transportation rate of fresh agricultural products is higher than the part of industrial products	U(0.00035, 0.00045), ￥1,000 /box/km
Other operating costs	Costs incurred in operating the rural logistics network other than transportation costs, node construction costs, etc.	U(10, 20), ￥1,000
Logistics volume to be processed in rural logistics networks	Number of commodities awaiting logistics services from rural logistics networks	0, box
Enterprise market share	The volume ratio of the Yangzhou Postal Logistics Branch in Yangzhou to the total market	15%
Corporate assets	Economic resources measured in monetary terms owned or controlled by the Yangzhou Postal Logistics Branch	500, ￥1,000
Marketing investment	Expenditure on corporate image promotion, e.g. advertising cost	8, ￥1,000
Customer relationship maintenance investment	Investment in maintaining partnerships with customer	8, ￥1,000
Information technology investment	Enterprise's investment in the development, introduction or adoption of IT	10, ￥1,000
Intelligent equipment investment	Costs of purchasing intelligent equipment	10, ￥1,000

It should be noted that: first, the unit cost of node construction is based on a 15-year depreciation period to average the construction cost of a single hub node into 180 months. Second, the carbon tax rate is a reference to the linear carbon tax rate of 10 yuan/ton in European countries [31]. Third, according to the law of the market, the transportation rate and other operating costs fluctuate in the simulation time period of network operation, and only the approximate range of their changes can be obtained, so their values are represented by the uniform distribution function. The uniform distribution, denoted U(a,b), indicates that the parameter takes on a range of values between [a,b] and that the probability of all values in this interval is uniform. Fourth, the last five variables in the table are state variables, and only the initial value of the state variables is given here, and subsequently the value will change with the model simulation.

Table function

When there is a nonlinear relationship between two variables, a table function should be used to fit it. The main table functions in this model are as follows:

1) Equipment investment delay and the degree of equipment intelligence, information technology investment delay and the level of network informatisation, customer relationship investment delay and customer relationship, marketing investment delay and the amount of enterprise market share increase.
   In reality, the more intelligent the device, the more expensive it is, and then the enterprise needs to pay more investment in equipment, so the two have a positive relationship. When the degree of intelligence of the equipment reaches a certain value, the effect of equipment investment on its enhancement will become lower and lower. Similarly, there is a similar positive correlation between information technology

investment delay and network informatisation level, customer relationship investment delay and customer relationship, marketing investment delay and enterprise market share increase.

2) Network operation efficiency and network service level
Generally speaking, the higher the operating efficiency of the logistics network, the higher the service level of the network, and there is a strong positive correlation between the two. Similarly, when the network operation efficiency reaches a high level, the enhancement of the network service level will become smaller and smaller.

3) Network scheduling level, network operation level and network operation efficiency
There is also a positive correlation between rural logistics network scheduling level, network operation level and network operation efficiency. Network operation efficiency increases with the increase of scheduling level and operation level, and the magnitude of the increase decreases.

The curve trend of the above table function is roughly shown in *Figure 4*.

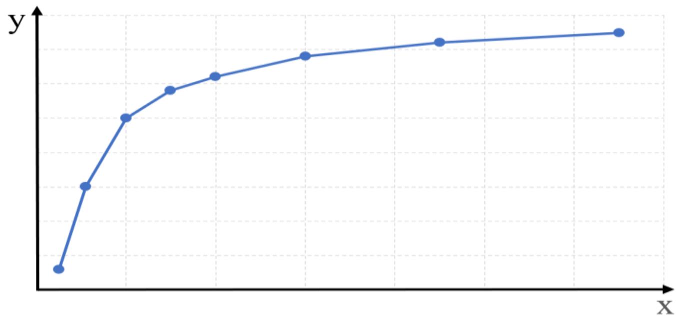


Figure 4 – Schematic of the direction of the curve of the marginal decreasing table function

3.5 Model check

Before conducting a simulation, it is necessary to check whether the constructed model can correctly reflect the behavioural characteristics and laws of the actual system so that the conclusions obtained from simulation and policy simulation are meaningful conclusions. Specifically, first of all, the simulation results of this model are in line with logic and reality and pass the structural test. Secondly, taking enterprise market share as an example, when the simulation interval is changed from 0.25 months to 0.5 months and then to 1 month, the values of enterprise market share under the two scenarios of rural logistics network handling general commodities and fresh agricultural products are basically the same, which indicates that the model is running stably and passes the sensitivity test. Finally, taking enterprise assets as an example, the simulation results of enterprise assets are in line with the realistic development trend of decreasing and then increasing, and pass the parameter test.

4. SIMULATION OF RURAL LOGISTICS NETWORK OPERATION AND SIMULATION OF COST REDUCTION AND EFFICIENCY ENHANCEMENT STRATEGIES

4.1 Analysis of simulation results of rural logistics network operation

Operation efficiency of rural logistics network

As shown in *Figure 5* and *Table 3*, the rural logistics network is functioning well when handling general goods. The operation efficiency has continued to increase except for January–February (there is a lag in the investment effect), and the speed has gradually slowed down. On the other hand, the curve of the volume of goods to be handled in the rural logistics network shows a fluctuating state, which rises and falls throughout the operating cycle. The rising state indicates that the logistics supply is smaller than the logistics demand, there is a logistics shortage, and the logistics volume to be processed reaches the highest value in June, indicating that the logistics shortage has accumulated for six months to reach the maximum gap of about 133 boxes. The falling state after June indicates that with the improvement of the network operation efficiency, the logistics supply begins to be larger than the logistics demand, and the gap of the shortage of logistics is narrowing. However, there is another wave of rise in November–December, indicating that the logistics demand in November–December increases sharply, and exceeds the existing logistics supply capacity of the network, which is consistent with the promotional activities of enterprises in November. From *Figure 6* and *Table 4*, it can be found that similar to the simulation results in the general commodity scenario, the operating efficiency of the rural logistics network when handling fresh agricultural products is also on an upward trend (except for January–February), but the magnitude of the increase and the maximum operating efficiency are lower than those in the general commodity scenario. In addition, the fluctuation range of the logistics volume to be handled is bigger than that of the general commodity scenario, and the overall trend is upward, with the maximum shortfall reaching about 298 boxes, so it is clear that the logistics shortage of the rural logistics network is more serious when handling fresh agricultural products.

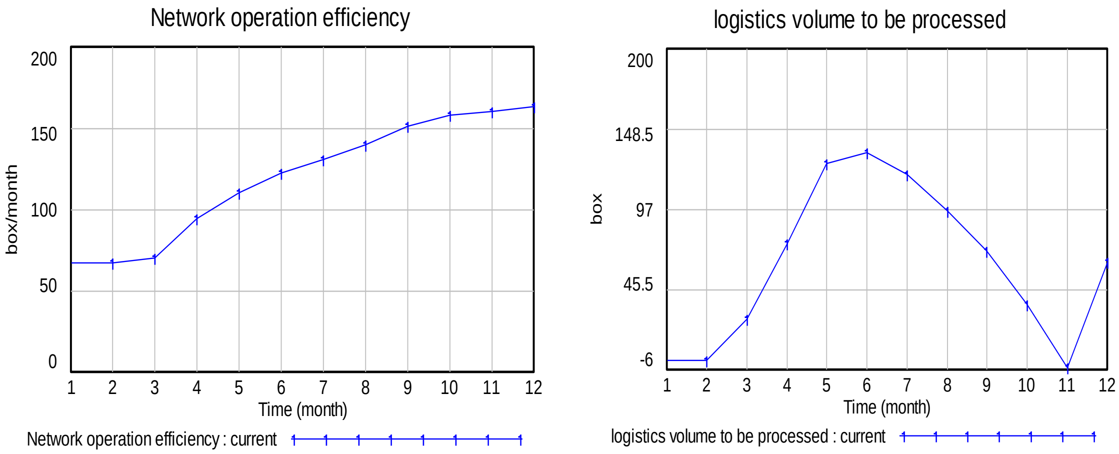


Figure 5 – Network operational efficiencies in the general commodities scenario

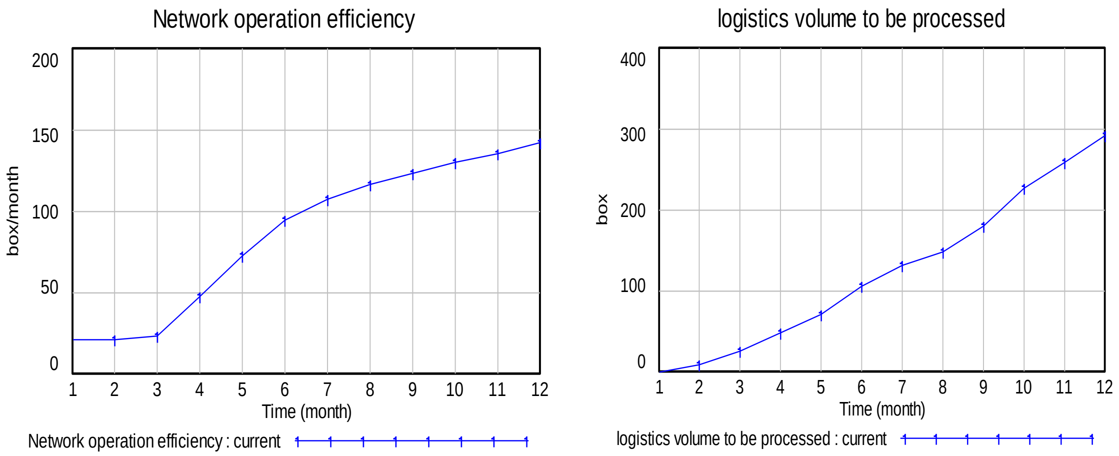


Figure 6 – Network operational efficiency in the fresh agricultural products scenario

Table 3 – Data of network operation efficiency and logistics volume to be processed in the general commodities scenario

Month	1	2	3	4	5	6	7	8	9	10	11	12
network operation efficiency	67	67	70	94	110	122	131	140	151	158	160	163
logistics volume to be processed	0	0	26	75	126	133	119	96	70	36	-6	63

Table 4 – Data of network operation efficiency and logistics volume to be processed in the fresh agricultural produce scenario

Month	1	2	3	4	5	6	7	8	9	10	11	12
network operation efficiency	21	21	23	47	72	94	107	116	124	130	135	141
logistics volume to be processed	0	16	32	54	78	113	138	155	186	233	265	298

Operating cost of rural logistics network

Enterprises should not blindly pursue the lowest cost when conducting logistics cost control, and the optimal logistics cost should be at the balance of minimising cost and high logistics service level. As shown in *Figures 7 and 8*, *Tables 5 and 6*, the logistics service levels of the rural logistics network when handling general commodities and fresh agricultural products are both on an increasing trend after March and gradually slow down. This is consistent with the curve of network operation efficiency, indicating that under the influence of network operation efficiency, the network service level is also gradually increased. At this level of logistics service, the logistics cost curve rises and falls, and is consistent with the curve trend of the logistics volume to be handled, indicating that when the network operating efficiency is low, the logistics shortage cost accounts for a larger share of the operating cost of the rural logistics network. In addition, the logistics cost in the scenario of fresh agricultural products is integrally higher than that in the scenario of general commodities, which is related to the additional cost of cargo damage incurred by loading, unloading and transporting fresh agricultural products, and the need to incur more transport and environmental cost due to the cold chain transport.

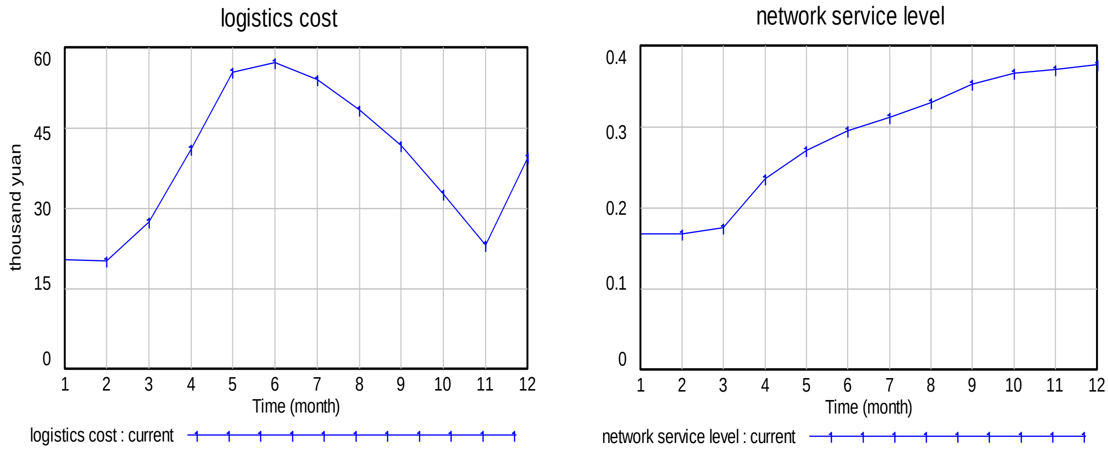


Figure 7 – Network operating cost in the general commodities scenario

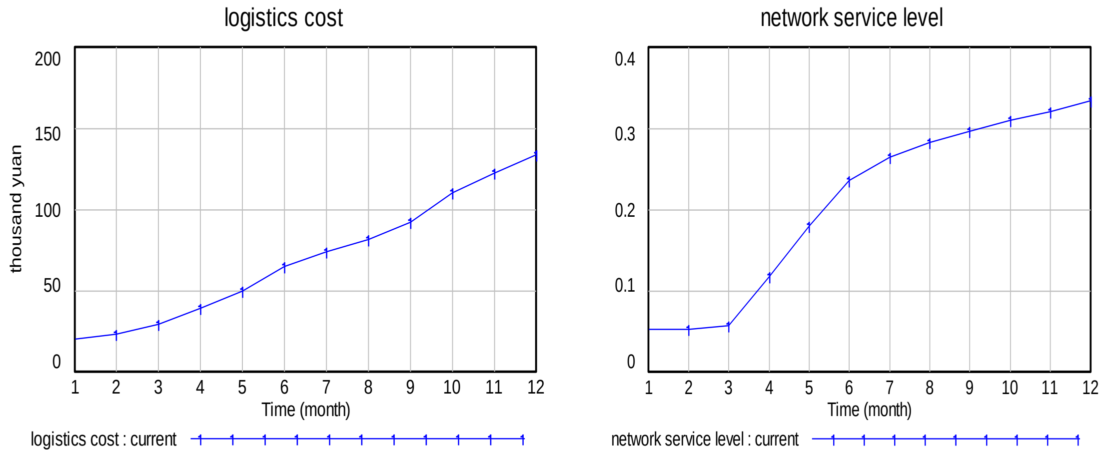


Figure 8 – Network operating cost in the fresh agricultural products scenario

Table 5 – Data of network operation cost in the general commodities scenario

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
logistics cost	20.3	20.2	27.4	40.9	55.4	57.2	53.9	48.2	41.6	32.6	23.1	39.5
network service level	0.17	0.17	0.18	0.24	0.27	0.29	0.31	0.33	0.35	0.37	0.37	0.38

Table 6 – Data of network operation cost in the fresh agricultural produce scenario.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
logistics cost	20.2	25.8	31.7	41.5	52.4	66.9	76.7	83.7	94.9	112.3	124.2	136.1
network service level	0.05	0.05	0.06	0.12	0.18	0.24	0.26	0.28	0.30	0.31	0.32	0.33

Operational benefits of rural logistics network

Figure 9, *Figure 10*, *Table 7* and *Table 8* show that the market share of the firms in both scenarios is on an upward trend. However, the corporate assets show a trend of first falling and then rising. It shows that in the initial stage of enterprise development, various types of investment and operating expenses are relatively large, but the income is small; as network operation efficiency and network service levels improve, enterprise logistics costs are reduced and market share is expanding, and enterprises will gradually recover their initial investment and move toward profitability. Comparing the operating efficiency of rural logistics networks dealing with general commodities and fresh agricultural products, it is found that the rising trend of enterprise assets in dealing with fresh agricultural products is relatively flat, which is related to the lower operating efficiency of the network for fresh agricultural products and higher logistics cost, and also indicates that enterprises dealing with fresh agricultural products will need a long period of time to recover their capital and make profits, which is consistent with the realities of the long return on investment in fresh agricultural products and the high risks involved.

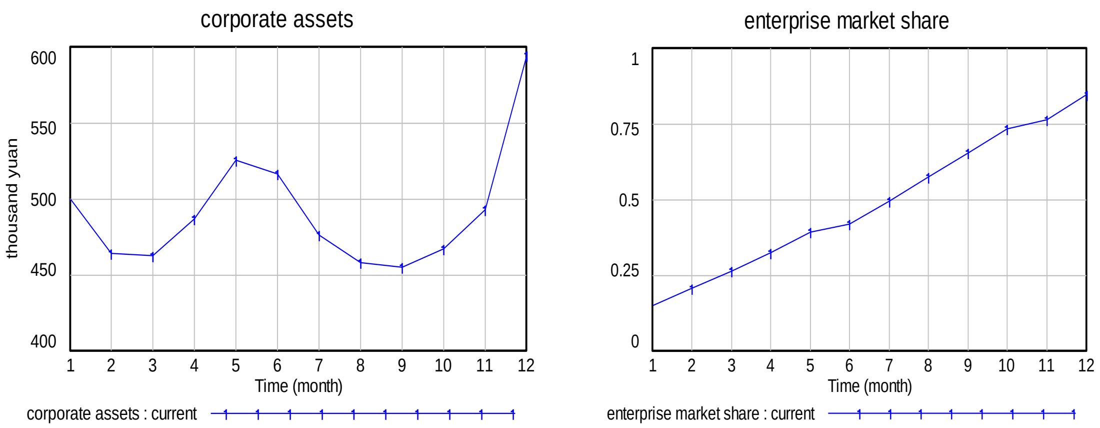


Figure 9 – Network operational benefits under the general commodities scenario

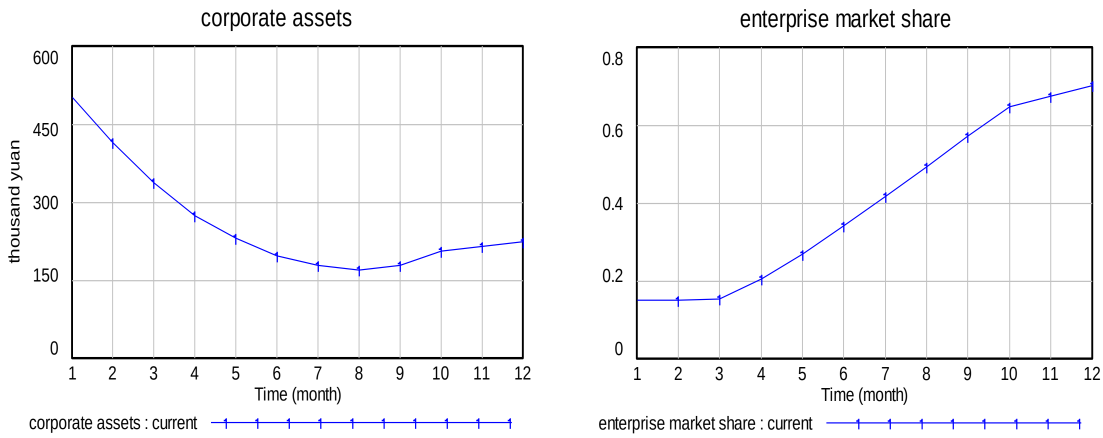


Figure 10 – Network operational benefits under the fresh agricultural products scenario

Table 7 – Data of network operation benefits in the general commodities scenario

Month	1	2	3	4	5	6	7	8	9	10	11	12
corporate assets	500	464	463	487	525	517	476	458	455	467	493	594
enterprise market share	0.15	0.21	0.27	0.32	0.39	0.42	0.49	0.57	0.65	0.73	0.76	0.84

Table 8 – Data of network operation benefits in the fresh agricultural produce scenario

Month	1	2	3	4	5	6	7	8	9	10	11	12
corporate assets	500	421	348	285	240	203	179	167	170	187	189	193
enterprise market share	0.15	0.15	0.15	0.21	0.27	0.34	0.42	0.49	0.57	0.65	0.68	0.70

To sum up, the existing rural logistics network of the enterprise operation efficiency has low operation efficiency and cannot meet the demand. Whether it deals with general commodities or fresh agricultural products, there is a shortage of logistics, which increases the cost of enterprise logistics and impedes the accumulation of enterprise assets. In the long run, the development of the enterprise and the social economy are bound to be adversely affected. For this reason, rational enterprises and the government should pay attention to the construction of rural logistics networks, and actively take measures to improve the operational efficiency of rural logistics networks to reduce costs and increase efficiency.

4.2 Simulation of cost reduction and efficiency improvement strategies in rural logistics network

Here, the strategy simulation is mainly carried out from both endogenous and exogenous aspects. Endogenous refers to the operation and management measures that enterprises can control and improve, while exogenous is the optimisation of the general environment of rural logistics network operation, i.e. the simulation of relevant government policies. It should be noted that the scenario of network processing of general commodities is taken as an example, and the simulation results of the scenario of processing fresh agricultural products have the same trend, so we will not go into details again.

Rural logistics network operation programme

The operation programme refers to a series of operation and management measures adopted by the enterprise for rural logistics networks and the low working level and scheduling level caused by the special characteristics of rural logistics are the main reasons for the high cost and low efficiency of rural logistics networks. For this reason, the operation and management of the rural logistics network by the enterprise should be based on the networked operation mode, coordinated organisational mechanism and intelligent link management, and here is a simulation experiment on the effectiveness of such an operation programme. The specific design is to observe the corresponding changes in logistics cost and enterprise assets by controlling the proportion of investment in information technology and intelligent equipment corresponding to the different values of the three constants of operation mode, coordination mechanism and intelligent link management method, the degree of improvement in customer and node relationship, and the degree of improvement in network working level.

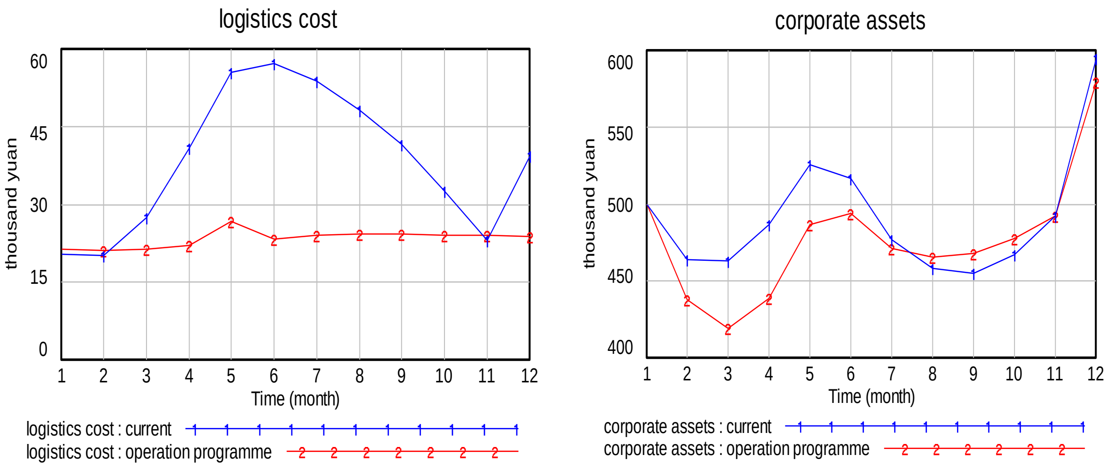
The results are shown in *Figure 11* and *Table 9*. When a company implements operational management of its rural logistics network, it can achieve a significant reduction in logistics cost (*Figure 11a*) and a slow increase in corporate assets (*Figure 11b*).

Rural logistics land use policy

Node construction unit cost refers to the cost that an enterprise needs to pay to build a hub node, of which the largest proportion is the land cost required to build a hub node, and it is closely related to the government's rural logistics land use policy. This paper reduces the unit cost of node construction by 15% and 25% respectively from 91,100 yuan, and conducts rural logistics network operation simulations to observe the direction and intensity of the impact of the logistics land policy represented by the unit cost of node construction on logistics cost and corporate assets. That is, it is divided into two policy simulation scenarios:

RLLU Policy 1: 15% reduction in the unit cost of node construction;

RLLU Policy 2: 25% reduction in the unit cost of node construction.

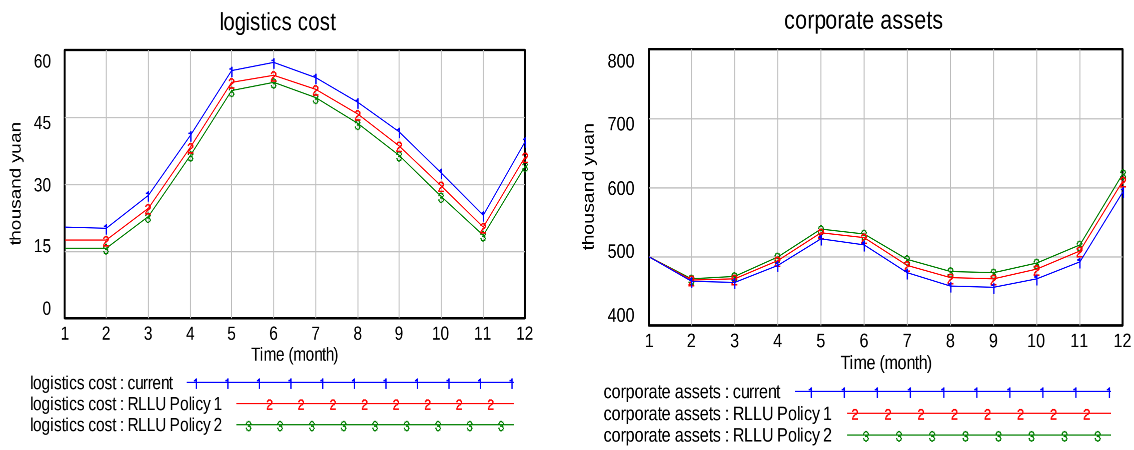


(a) *(b)*

Figure 11 – a) Changes in logistics costs for adopting operation programmes; b) Changes in corporate assets for adopting operation programmes

Table 9 – Changes in adopting operation programmes

Month	Logistics cost			Corporate assets		
	Before adoption	**After adoption**	**Rate of change**	**Before adoption**	**After adoption**	**Rate of change**
1	20.329	21.242	4.49%	500	500	0
2	20.209	21.070	4.26%	463.803	437.89	5.59%
3	27.367	21.380	21.88%	462.615	419.273	9.37%
4	40.933	22.145	45.90%	486.676	438.832	9.83%
5	55.416	26.624	51.96%	525.386	486.763	7.35%
6	57.197	23.328	59.21%	516.651	493.781	4.43%
7	53.872	23.940	55.56%	476.441	470.73	1.20%
8	48.248	24.315	49.60%	457.734	465.233	1.64%
9	41.597	24.294	41.60%	455.015	467.885	2.83%
10	32.615	24.120	26.05%	467.151	477.771	2.27%
11	23.071	24.072	4.34%	492.522	492.449	0.01%
12	39.507	23.686	40.05%	594.479	579.575	2.51%



(a) *(b)*

Figure 12 – a) Changes in logistics costs for adjusting RLLU policies; b) Changes in enterprise assets for adjusting RLLU policies

Table 10 – Changes in operational results of adjusting RLLU policies

Month	Logistics cost				
	Current	**RLLU Policy 1**	**Rate of change**	**RLLU Policy 2**	**Rate of change**
1	20.329	17.596	13.44%	15.774	22.41%
2	20.209	17.476	13.52%	15.654	22.54%
3	27.367	24.634	9.99%	22.812	16.64%
4	40.933	38.200	6.68%	36.378	11.13%
5	55.416	52.683	4.93%	50.861	8.22%
6	57.197	54.464	4.78%	52.642	7.96%
7	53.872	51.139	5.07%	49.348	8.40%
8	48.248	45.548	5.60%	43.461	9.92%
9	41.597	38.599	7.21%	36.544	12.15%
10	32.615	29.617	9.19%	27.265	16.40%
11	23.071	20.368	11.71%	18.546	19.61%
12	39.507	36.244	8.26%	34.157	13.54%
Month	**Corporate assets**				
	Current	**RLLU Policy 1**	**Rate of change**	**RLLU Policy 2**	**Rate of change**
1	500	500	0.00%	500	0.00%
2	463.803	466.536	0.59%	468.358	0.98%
3	462.615	467.644	1.09%	470.996	1.81%
4	486.676	493.633	1.43%	498.271	2.38%
5	525.386	533.963	1.63%	539.681	2.72%
6	516.651	526.588	1.92%	533.214	3.21%
7	476.441	487.522	2.33%	494.909	3.88%
8	457.734	469.775	2.63%	477.771	4.38%
9	455.015	467.83	2.82%	476.633	4.75%
10	467.151	480.913	2.95%	490.363	4.97%
11	492.522	507.08	2.96%	517.37	5.05%
12	594.479	609.411	2.51%	620.856	4.44%

As shown in *Figure 12* and *Table 10*, when RLLU policies were adopted, the node construction cost was significantly reduced, resulting in a reduction in logistics cost. At the same time, the logistics service level of the network does not change, corporate assets increase, and RLLU Policy 2 results in a greater reduction in logistics cost and a greater increase in corporate assets than RLLU Policy 1. It means that the relevant enterprises have a higher sensitivity to the rural logistics land use policy then the government can regulate the development of the relevant enterprises and even the relevant industries by controlling the logistics land cost or loosening or tightening the logistics land use index and other logistics land use policies. At present, the chaotic logistics land management is also one of the reasons restricting the extension of the urban logistics network to the countryside, which should attract the attention of the relevant departments.

Rural road traffic management policy

In reality, there are various obstacles in the logistics corridor between the city and the countryside, and the construction of roads in rural areas is also relatively backward, so the corresponding transport rates of rural logistics remain high. In order to observe the real impact of rural road traffic management policies on logistics costs and enterprise assets, the transport rates are reduced by 25% and 45%, respectively. That is, it is divided into two policy simulation scenarios:

RRTM Policy 1: 25% reduction in the transportation rates;

RRTM Policy 2: 45% reduction in the transportation rates.

As shown in *Figure 13a*, firstly, when the RRTM policies were adopted, there was a small reduction in logistics costs. Secondly, as shown in *Figure 13b*, corporate assets are almost unchanged in January–June, but there is a small increase in June–December, while January–June is a period of decline in enterprise assets and June–December is a period of growth, which indicates that the reduction of transport rates is more effective in the maturity period of enterprises. That is, when the construction and operation of rural logistics networks of enterprises are more mature when the network operation efficiency rises, the network handling volume and transport volume increase accordingly, and the proportion of transport cost and logistics cost in the decrease of enterprise assets increases, the effect of reducing transport cost and logistics costs on the increase of enterprise assets will be more significant. Accordingly, rural road transport management policies are also one of the ways to achieve "cost reduction and efficiency improvement" for enterprises, but not the main way. It should be implemented for enterprises with more mature logistics operations or at a mature stage in the operation of the enterprise's logistics network.

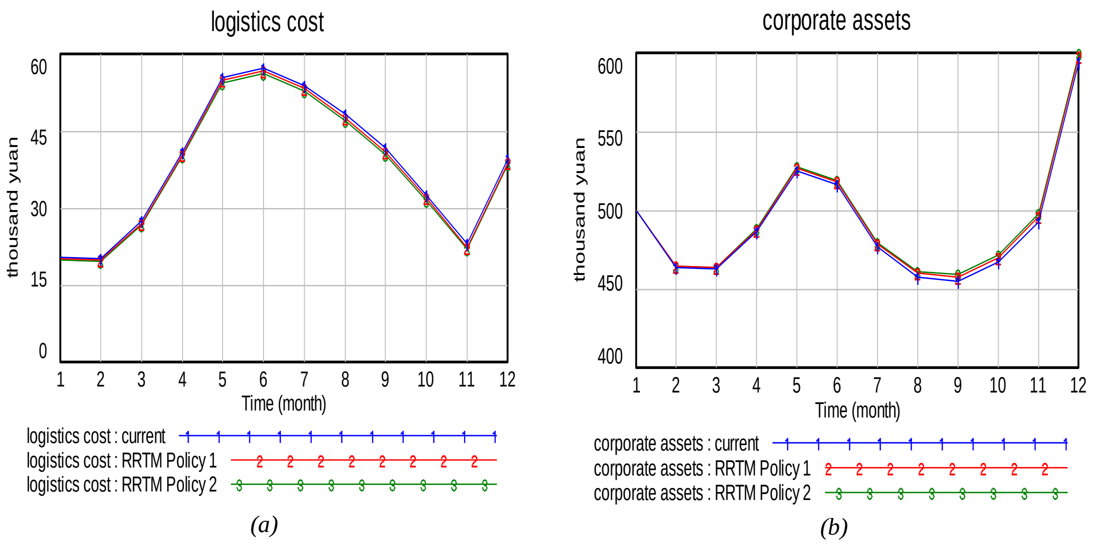


Figure 13 – a) Changes in logistics costs for adjusting RRTM policies; b) Changes in enterprise assets for adjusting RRTM policies

Table 11 – Changes in operational results of adjusting RRTM policies

Month	**Logistics cost**				
	Current	**RRTM Policy 1**	**Rate of change**	**RRTM Policy 2**	**Rate of change**
1	20.329	20.001	1.62%	19.803	2.59%
2	20.209	19.910	1.48%	19.731	2.37%
3	27.367	27.010	1.30%	26.796	2.09%
4	40.933	40.502	1.05%	40.243	1.68%
5	55.416	54.790	1.13%	54.415	1.81%
6	57.197	56.625	1.00%	56.282	1.60%
7	53.872	53.231	1.19%	52.846	1.90%
8	48.248	47.516	1.52%	47.076	2.43%
9	41.597	40.838	1.83%	40.382	2.92%
10	32.615	31.869	2.29%	31.422	3.66%
11	23.071	22.332	3.20%	21.889	5.12%
12	39.507	38.842	1.68%	38.443	2.69%

Month	Corporate assets				
	Current	**RRTM Policy 1**	**Rate of change**	**RRTM Policy 2**	**Rate of change**
1	500	500	0.00%	500	0.00%
2	463.803	464.132	0.07%	464.329	0.11%
3	462.615	463.19	0.12%	463.535	0.20%
4	486.676	487.516	0.17%	488.02	0.28%
5	525.386	526.522	0.22%	527.204	0.35%
6	516.651	518.231	0.31%	519.179	0.49%
7	476.441	478.34	0.40%	479.479	0.64%
8	457.734	459.97	0.49%	461.312	0.78%
9	455.015	457.626	0.57%	459.192	0.92%
10	467.151	470.103	0.63%	471.875	1.01%
11	492.522	495.747	0.65%	497.683	1.05%
12	594.479	598.927	0.75%	600.012	0.94%

Rural logistics carbon tax policy

In recent years, with the serious deterioration of air quality, carbon emission and environmental pollution have become a high concern both at home and abroad, and people from all walks of life have called for the introduction of a carbon tax policy to address the issue of carbon emission. The logistics industry is also a "big player" in carbon emissions, and China's logistics industry is still in the stage of rough development, with small and medium-sized logistics enterprises as the main form of organisation, and it is necessary to explore whether the levy of carbon tax will inhibit the development of the logistics industry and increase the burden on enterprises. Especially for rural logistics, the carbon emission of cold chain logistics of fresh agricultural products is higher, but the main body of logistics is weaker. In reality, China is still groping for the specific carbon tax mechanism and carbon tax rate, so the carbon tax policy in the above SD model refers to the linear carbon tax rate of 10 yuan/ton in European countries. Here, this paper sets the carbon tax rate at 5 yuan/ton, 2,000 yuan/ton (where the significant increase in the carbon tax rate is intended to make the changes in logistics costs and corporate assets larger for easy comparison) and 3,000 yuan/ton, respectively to find a reasonable range of carbon tax rate. That is, it is divided into three policy simulation scenarios:

RLCT Policy 1: carbon tax rate decreases to 5 yuan/ton;

RLCT Policy 2: carbon tax rate increases to 2,000 yuan/ton;

RLCT Policy 3: carbon tax rate increases to 3,000 yuan/ton.

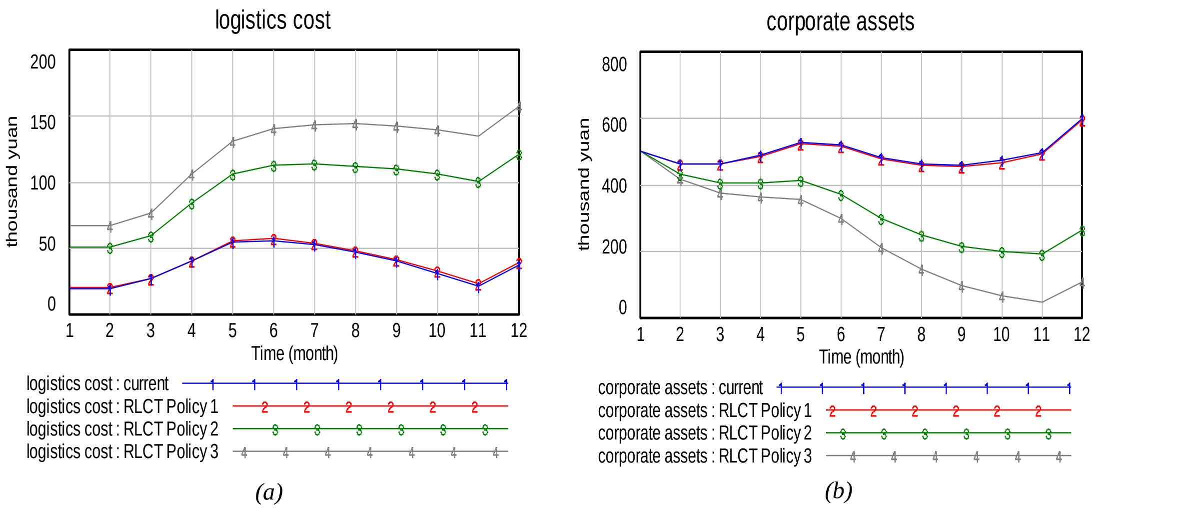


Figure 14 – a) Changes in logistics costs for adjusting RLCT policies. b) Changes in enterprise assets for adjusting RLCT policies

Table 12 – Changes in operational results of adjusting RLCT policies

Month	Logistics cost						
	Current	**RLCT Policy 1**	**Rate of change**	**RLCT Policy 2**	**Rate of change**	**RLCT Policy 3**	**Rate of change**
1	19.694	20.329	3.22%	51.293	152.31%	67.172	230.42%
2	19.574	20.209	3.24 %	51.173	153.22%	67.052	231.79%
3	26.703	27.367	2.49%	59.718	118.21%	76.308	178.83%
4	40.042	40.933	2.23%	84.375	106.13%	106.653	160.56%
5	54.373	55.416	1.92%	105.755	90.84%	130.855	136.13%
6	56.04	57.197	2.06%	112.858	97.32%	140.104	144.95%
7	52.63	53.872	2.36%	113.728	111.11%	143.398	166.18%
8	46.92	48.248	2.83%	112.064	132.27%	143.920	198.29%
9	40.17	41.597	3.55%	109.850	164.08%	142.434	242.41%
10	31.12	32.615	4.80%	106.006	225.02%	139.618	328.08%
11	21.55	23.071	7.06%	100.193	334.28%	134.858	484.53%
12	37.96	39.507	4.08%	121.701	208.05%	157.732	299.25%
Month	**Corporate assets**						
	Current	**RLCT Policy 1**	**Rate of change**	**RLCT Policy 2**	**Rate of change**	**RLCT Policy 3**	**Rate of change**
1	500	500	0.00%	500	0.00%	500	0.00%
2	464.438	463.803	0.14%	432.839	6.68%	416.96	10.10%
3	463.784	462.615	0.25%	405.641	12.32%	376.424	18.63%
4	488.321	486.676	0.34%	406.467	16.48%	365.335	24.93%
5	527.659	525.386	0.43%	414.568	21.09%	357.739	31.91%
6	519.603	516.651	0.57%	373.224	27.76%	300.388	41.86%
7	480.077	476.441	0.76%	300.301	36.97%	211.873	55.53%
8	462.031	457.734	0.93%	249.921	45.40%	145.972	68.11%
9	459.952	455.015	1.07%	216.636	52.39%	97.462	78.58%
10	472.729	467.151	1.18%	198.659	57.47%	65.969	85.88%
11	498.705	492.522	1.24%	193.598	60.69%	47.246	90.41%
12	601.19	594.479	1.12%	266.261	55.21%	107.681	81.89%

As shown in *Figure 14* and *Table 12*, first, as the carbon tax rate increases, logistics costs increase and enterprise assets decrease. Second, when the carbon tax rate is less than 2,000 yuan/ton (RLCT Policy 1), with the increase of the carbon tax rate, the overall change in logistics cost and corporate assets is not large. Third, when the carbon tax rate reaches 2,000 yuan/ton (RLCT Policy 2 and RLCT Policy 3), logistics costs increase and corporate assets fall sharply. Fourth, the negative effect of the increase in the carbon tax rate on corporate assets is expanding month by month.

In general, the implementation of the logistics carbon tax policy on enterprises will increase their logistics costs, thereby guiding enterprises to reduce logistics carbon emissions. However, the actual linear carbon tax rate should be formulated within a certain range, to achieve a balance between the carbon emission management effect and the development of enterprises. If the carbon tax rate is too high, it will increase the logistics cost of enterprises too much, which will limit the development of the enterprise and even lead to its bankruptcy. Such a carbon tax policy has a better effect on the governance of enterprises with relatively mature logistics businesses than that of the enterprises in the early stage of development of the logistics network. Carbon taxes should be levied based on the logistics development stages of enterprises.

5. DISCUSSION

The operation of the rural logistics network is related to the efficiency of the circulation of the production and living necessities of rural residents and even has a greater impact on commodity trade and sustainable economic development. However, scholars mostly study the optimisation of logistics networks under the regional perspectives of industries and cities, economic zones, etc. and pay little attention to rural logistics networks. This paper focuses on the problem of disordered construction and inadequate operation and management of rural logistics networks, and it is of great practical significance to study how to optimise the construction of rural logistics networks. The few studies on rural logistics networks mainly focus on the conceptual definition of rural logistics, the measurement of the development level and the construction of rural logistics network sites, and simply focus on the decision-making scheme of cost minimisation, with little research on the operation and management of the rural logistics network and the "efficiency enhancement". This paper explores the operation optimisation of rural logistics networks from the dual perspectives of cost reduction and efficiency enhancement, clarifies the interaction between logistics costs, network operation efficiency and enterprise development, and puts forward policy suggestions for cost reduction and efficiency enhancement. In terms of research methodology, existing studies are either theoretical analyses or based on operations research models. This paper introduces a system dynamics modelling and simulation methodology, which starts from the system as a whole, effectively combines quantitative and qualitative analyses, and constructs a nonlinear, multiple-feedback rural logistics network operation system to simulate the operation of the real rural logistics network and the effect of the implementation of policies such as land use, road traffic management and carbon tax.

The rural logistics network operating system defined and the SD model developed in this paper, although useful, have drawbacks and limitations. For example, the correct understanding and scientific treatment of logistics costs is related to the effectiveness of cost control, but the composition of logistics costs varies according to the changing requirements of logistics activities. This paper mainly considers the node construction cost of the rural logistics network, transport costs, fresh agricultural products, cargo damage costs, environmental costs and logistics shortage costs, and other scholars have to consider the cost of congestion, the psychological cost of the population and so on. In order to make the analyses of cost elements more accurate and refined, subsequent research work should more comprehensively examine the various costs in the operation of rural logistics networks, so that the research can be closer to reality.

6. CONCLUSIONS

Network operation efficiency, logistics shortage, logistics service level, logistics cost, enterprise development, network construction and network operation interact with each other and constrain each other, which together determine the operation status of a rural logistics network. Simulation results show that when the operation efficiency of a rural logistics network rises, the logistics shortages are reduced, the logistics service levels are improved, and the logistics cost shows a downward trend; accordingly, the market share of the network operating enterprises gradually expands, while the assets of the enterprises rebound and grow after the initial reduction of the network construction. However, on the whole, the existing rural logistics network of the enterprises has low operation efficiency and cannot meet the demand. There is a shortage of logistics whether it is handling general commodities or fresh agricultural products, which increases the logistics cost and hinders the accumulation of enterprise assets.

The policy simulation reveals that the rural logistics network operation programme, rural logistics land use policy and rural logistics carbon tax policy, which are mainly based on networking, organisation and intelligence, are the high-leverage measures for rural logistics networks to reduce cost and increase efficiency. This points out the construction direction of rural logistics networks for enterprises and the government. For enterprises, they should realise the value and significance of optimising the construction of rural logistics networks in terms of long-term development. They should actively play their role, introduce intelligent equipment, build information systems and coordinate organisational relationships, etc., and strive to improve the operational efficiency of rural logistics and take the road of sustainable development. For the government, it should realise that reducing the unit cost of logistics node construction and setting a reasonable carbon tax rate can further optimise the operating environment of rural logistics networks, and help enterprises better achieve the goal of reducing cost and increasing efficiency. We should focus on increasing support in terms of reducing and exempting relevant taxes and increasing the land use index for rural logistics and distribution centres.

The implementation of relevant programmes and policies should also pay attention to distinguishing the implementation stage and the attributes of the subject being implemented. Different policies should be implemented in phases. Logistics land use policies with the main content of reducing the unit cost of node construction should be implemented in the early stages of enterprise rural logistics network construction and operation and should be implemented in the mature stage to reduce rural transport rates. In addition, rural logistics networks show numerical differences in cost and benefits when serving commodities with different attributes, and relatively speaking, rural logistics networks are more costly, less efficient and less effective when handling fresh agricultural products. Therefore, attention should be paid to increasing policy incentives for fresh agricultural produce logistics enterprises.

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戴盼倩，陆成琳，徐静

综合考虑成本、效率和效益的农村物流网络运营策略研究

摘要
高成本、低效率和效益运转的农村物流网络是制约城乡之间商品流通和经济社会发展的瓶颈。鉴于此，本文首先运用系统动力学建模方法分析了农村物流网络运营系统的构成要素及其相互关系，并绘制了因果图；其次，用动力学方程量化因果图，建立存量和流量图；第三，设置相关参数，用 vensim 软件进行结构、参数和灵敏度测试；最后，针对处理一般商品和新鲜农产品的场景，对农村物流网络运营进行了模拟，揭示了网络运营效率、物流成本和运营企业效益之间的反馈机制，并从内生和外生层面模拟了不同运营策略的实施效果，探索如何构建高效、低成本、高效益的农村物流网络。结果表明：网络化、组织化与智能化的运作方案与物流用地政策、碳税政策是实现农村物流网络降本增效的高杠杆措施，但要注意区分实施阶段与被实施企业属性，在网络建设初期以降低物流用地成本为主，在网络运作成熟阶段征收物流碳税并注意降低运输费率，加大对生鲜农产品物流企业的政策优惠。

关键词
降本增效；农村物流网络；系统动力学

APPENDIX

This appendix provides the functional relationships of variables and the system dynamics equations in the stock and flow diagram (*Figure 2*). These equations are Dynamo language equations, run on Vensim software.

(1) coordination mechanism table function = WITH LOOKUP (coordination mechanism, ([(0,0)-(10,10)],(0,0.25),(1,0.6)))
(2) corporate assets= INTEG (increase-decrease,500)
(3) customer relationship= 0.35*coordination mechanism table function+0.65*customer relationship maintenance investment delay table function
(4) customer relationship maintenance investment= INTEG (increase in customer relationship maintenance investment,8)
(5) customer relationship maintenance investment delay= DELAY FIXED(customer relationship maintenance investment,2, 6)
(6) customer relationship maintenance investment delay table function = WITH LOOKUP (customer relationship maintenance investment delay, ([(0,0)-(600,1)],(0,0),(5,0.25),(25,0.45),(55,0.65),(95,0.75),(145,0.8),(235,0.85),(355,0.9),(500,0.95)))
(7) customer satisfaction with logistics services= network service level*network service level impact factor
(8) decrease= other operating costs+logistics cost+increase in customer relationship maintenance investment +increase in intelligent equipment investment+increase in information technology investment +increase in marketing investment
(9) direct distance = WITH LOOKUP (transport routes, ([(0,0)-(22,80)],(1,0),(2,0),(3,0),(4,0),(5,0),(6,75),(7,75),(8,0),(9,0),(10,0),(11,9),(12,75),(13,75),(14,0),(15,0),(16,0),(17,75),(18,75),(19,75),(20,0),(21,0),(22,0))
(10) direct transport cost= transport volume*(transport fee rate+fresh agricultural produces transport surcharge rate*commodity category factor)*transport volume discount*direct distance*commodity category factor
(11) distance between hub nodes = WITH LOOKUP (transport routes,([(0,0)-(22,100)],(1,0),(2,100),(3,100),(4,100),(5,100),(6,100),(7,100),(8,100),(9,100),(10,100),(11,100),(12,100),(13,100),(14,0),(15,0),(16,0),(17,0),(18,0),(19,0),(20,0),(21,0),(22,0)))
(12) distance between non hub to hub nodes = WITH LOOKUP (transport routes,([(-1,0)-(22,200)],(1,80),(2,80),(3,130),(4,150),(5,120),(6,130),(7,120),(8,0),(9,50),(10,70),(11,40),(12,50),(13,40),(14,50),(15,40),(16,70),(17,50),(18,40),(19,0),(20,120),(21,90),(22,110)))
(13) enterprise market share= INTEG (expansion-reduction,0.15)
(14) environmental cost=transport volume*carbon tax rate*(carbon emission factor+additional factor of carbon emission for fresh agricultural products *commodity category factor)*(distance between hub nodes+distance between non hub to hub nodes+direct distance*commodity category factor)
(15) expansion=customer satisfaction with logistics services*customer logistics satisfaction contribution coefficient+marketing investment delay table function
(16) Fresh agricultural produce cost of cargo damage=transport volume*rate of cargo damage*unit cost of cargo damage*commodity category factor
(17) fresh agricultural produces transport surcharge rate= RANDOM UNIFORM(0.00035, 0.00045 , 0)
(18) increase in customer relationship maintenance investment=IF THEN ELSE(corporate assets<=0, 0 , corporate assets*share of customer relationship maintenance investment
(19) increase in information technology investment=IF THEN ELSE(corporate assets<=0, 0 , corporate assets*share of information technology investment)
(20) increase in intelligent equipment investment=IF THEN ELSE(corporate assets<=0 , 0 ,corporate assets*share of intelligent equipment investment)
(21) increase in marketing investment= IF THEN ELSE(corporate assets<=0, 0,corporate assets*share of marketing investment)
(22) increase=product sales price*volume of commodity sales
(23) information technology investment= INTEG (increase in information technology investment,10)
(24) information technology investment delay=DELAY FIXED(information technology investment ,2, 8)
(25) information technology investment delay table function = WITH LOOKUP (information technology investment delay, ([(0,0)-(600,1)],(0,0),(5,0.15),(25,0.35),(55,0.55),(95,0.65),(145,0.7),(205,0.75),(275,0.8),(355,0.85),(445,0.9),(545,0.95)))
(26) intelligent equipment investment= INTEG (increase in intelligent equipment investment,10)
(27) intelligent equipment investment delay=DELAY FIXED(intelligent equipment investment, 2 ,8)
(28) intelligent equipment investment delay table function = WITH LOOKUP (intelligent equipment investment delay, ([(0,0)-(500,1)],(0,0),(5,0.15),(35,0.35),(70,0.55),(110,0.75),(155,0.8),(205,0.85),(260,0.9),(320,0.95)))
(29) link management methods table function = WITH LOOKUP (link management methods,([(0,0)-(10,10)],(0,0.22),(1,0.52)))

(30) logistics cost=logistics shortage cost+Fresh agricultural produce cost of cargo damage+transport cost+environmental cost+node construction cost
(31) logistics shortage cost=IF THEN ELSE(logistics volume to be processed in rural logistics networks<0, 0,logistics volume to be processed in rural logistics networks*(logistics shortage unit cost+fresh agricultural produce logistics shortage unit additional cost*commodity category factor))
(32) logistics volume to be processed in rural logistics networks= INTEG (logistics demand volume-network handling volume,0)
(33) market volume = WITH LOOKUP (Time, ([(0,0)-(12,400)],(1,200),(2,200),(3,250),(4,300),(5,350),(6,300),(7,250),(8,250),(9,250),(10,200),(11,200),(12,200)))
(34) marketing investment= INTEG (increase in marketing investment,8)
(35) marketing investment delay=DELAY FIXED(marketing investment, 2, 6)
(36) marketing investment delay table function =WITH LOOKUP(marketing investment delay,([(0,0)-(3755,0.2)],(0,0),(5,0.1),(55,0.115),(155,0.1155),(355,0.1156),(655,0.1157),(1055,0.1158),(1555,0.11585),(2155,0.116),(2855,0.1161),(3755,0.1162)))
(37) network informatisation level=equipment intelligence level*0.45+information technology investment delay table function*0.55
(38) Network operation efficiency=INTEGER(0.5*network working level table function+0.5*network scheduling level table function)
(39) network organisation coordination degree= 0.6*customer relationship+0.4*node relationship
(40) network scheduling level= network organisation coordination degree*0.4+network informatisation level*0.6
(41) network scheduling level table function = WITH LOOKUP (network scheduling level,([(0,0)-(1,800)],(0,0),(0.15,5),(0.25,25),(0.35,55),(0.45,115),(0.55,145),(0.65,205),(0.75,305),(0.85,405),(0.95,505)))
(42) network service level = WITH LOOKUP (Network operation efficiency, ([(0,0)-(1000,1)],(0,0),(100,0.25),(200,0.45),(300,0.6),(400,0.7),(500,0.75),(600,0.775),(700,0.79),(800,0.8),(900,0.805),(1000,0.809)))
(43) network working level=equipment intelligence level*0.6+link management methods table function*0.4
(44) network working level table function = WITH LOOKUP (network working level,([(0,0)-(1,800)],(0,0),(0.1,10),(0.2,30),(0.3,60),(0.4,105),(0.5,155),(0.6,215),(0.7,285),(0.8,375),(0.9,475)))
(45) node relationship = WITH LOOKUP (coordination mechanism, ([(0,0)-(10,10)],(0,0.2),(1,0.65)))
(46) number of hubs passed through = WITH LOOKUP (transport routes, ([(1,0)-(22,2)],(1,1),(2,2),(3,2),(4,2),(5,2),(6,2),(7,2),(8,2),(9,2),(10,2),(11,2),(12,2),(12,2),(13,2),(14,1),(15,1),(16,1),(17,1), (18,1),(19,0),(20,1),(21,1),(22,1)))
(47) other operating costs=RANDOM UNIFORM(10,20 , 0)
(48) product sales price = WITH LOOKUP (Time, ([(0,0)-(12,2)],(1,0.98),(2,0.98),(3,0.88),(4,0.78),(5,0.68),(6,0.78),(7,0.88),(8,0.88),(9,0.88),(10,0.98),(11,0.98),(12,0.98)))
(49) reduction=IF THEN ELSE(product sales price-average market price>0, (product sales price-average market price)*0.645+0.05, 0.05)
(50) share of information technology investment = WITH LOOKUP (operation mode,([(0,0)-(10,10)],(0,0.03),(1,0.055)))
(51) share of intelligent equipment investment = WITH LOOKUP (operation mode,([(0,0)-(10,10)],(0,0.03),(1,0.055)))
(52) transport cost=transport cost between hubs+direct transport cost+transport cost from non hub to hub
(53) transport cost between hubs=(transport fee rate+fresh agricultural produces transport surcharge rate*commodity category factor)*hub discount*transport volume*distance between hub nodes
(54) transport cost from non hub to hub=(transport fee rate+fresh agricultural produces transport surcharge rate*commodity category factor)*transport volume*distance between non hub to hub nodes
(55) transport fee rate=RANDOM UNIFORM(0.00015, 0.00025 , 0)
(56) volume of commodity sales=INTEGER(enterprise market share*market volume)