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A SYSTEM DYNAMICS-BASED SIMULATION MODEL FOR CROSS-BORDER LOGISTICS RISK TRANSMISSION

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Abstract
Logistical risks are now significantly more acute due to epidemics, economic recession and local political turmoil. Cross-border logistics risks are particularly prevalent given the large number of participants and the long transport distances involved. This paper develops a system dynamics model to analyse the key factors of cross-border logistics risk. In previous studies, people usually consider the risk factors as many independent individuals. But actually, there is a causal relationship as well as conduction effects between risk factors. Therefore, this paper analyses the relationship between risk factors through qualitative analysis and establishes a system dynamics model to indicate the direction of risk transmission. The rate of risk transmission was analysed using quantitative methods. Finally, this paper conducts simulations using survey data of cross-border e-commerce enterprises in Chengdu, indicating that the industry currently has more prominent customs risks, process risks, and cooperation risks. For these more serious risks, this paper proposes corresponding prevention and control measures.
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Key Words: Logistics Risks, System Dynamics, Cross-Border E-Commerce

1. INTRODUCTION

With the rapid development of international trade, China's cross-border e-commerce has achieved steady development. The spread of an epidemic, the global economic recession, and local political turbulence all contribute to the rapid growth of cross-border e-commerce in China. After the outbreak of the COVID-19 pandemic at the end of 2019, the Internet industry robbed some traditional industries of the market share. The unique "no-touch" mode of e-commerce is favoured by consumers around the world. People are accelerated to get into the habit of online consumption. As the world's largest manufacturing power, China quickly recovered production capacity because of its strong pandemic control capacity, which can meet the demand for goods in foreign countries where manufacturing recovery is blocked. That is the reason that China's cross-border e-commerce export business is still showing a steady growth trend with logistics blocked during pandemic outbreaks. In 2022, China's cross-border e-commerce import and export transaction volume reached 305 billion dollars which up by 9.8 %. Respectively, export amount reached 224 billion dollars which up by 11.7 %, and import amount reached 81 billion dollars, up 4.9 %. The average annual rate of export transaction volume increase during the years 2019-2021 was approximately 19 %.

With the rapid development of cross-border e-commerce, the risks that affecting the efficiency and quality of cross-border e-commerce operation have raised concerns. Among the many risks, logistics risks are more prominent, and it can be said that the epidemic has both highlighted and challenged the key role of logistics in business operations [1]. Compared with traditional logistics, cross-border e-commerce logistics has long transportation time and long distance, and the differences in national conditions and logistics infrastructure lead to significantly more uncertainties than within the country. In addition, the intermediate links such as customs clearance, commodity inspection, tax refund and foreign exchange settlement, and overseas storage are added, resulting in a significant increase of logistics cost and the decrease of logistics efficiency and logistics service quality. It is widely believed that logistics systems are vulnerable and open to many sources of threats [2]. For example, political conflicts could create market disruptions which result in heavy loss to the involved supply chain members [3]. The popular business measures such as logistics services outsourcing and strategic alliance also bring new cooperative risks to logistics systems [4]. The occurrence of disasters and pandemic, such as the Japan magnitude-9 earthquake in 2011 and COVID-19 pandemic bring disruption risk to logistics systems. Therefore, it's necessary to identify and manage logistics risks. Cross-border e-commerce logistics service providers carry out robust strategies which can help to enhance reliability of logistics services [5].

In this study, a system dynamics (SD) model will be developed to assess the risk transmission effects of cross-border logistics. Based on the constructed SD model, a series of risk transmission processes will be simulated and the sensitivity of various risks in cross-border logistics will be analysed. Finally, we can get the risk factors with high sensitivity in cross-border logistics through system dynamics simulation, and puts forward some targeted prevention and control measures.

2. LITERATURE REVIEW

Researchers have examined the current state of development and the contributing variables that limit cross-border logistics, and they have presented related recommendations and solutions from many angles [6-8]. For example, Wang et al. designed three kinds of O2O, O2D and D2D cross-border logistics models and analysed the product turnaround rate and the optimal order quantity of retailers under each model to implement their marketing strategies [9]. Giuffrida et al. investigated how firms cope with logistics uncertainty in cross-border logistics and whether different types of uncertainty affect the risk management strategies adopted by firms [10]. Liu et al. analysed the problems of cross-border e-commerce logistics from the perspective of cross-border development of China's e-commerce logistics, and then analysed the problems of cross-border e-commerce logistics from the macro level of cross-border e-commerce [11]. Ma et al. used the cross-border e-commerce hosting service database of BizArk to construct an index for China's export e-commerce prosperity and magnitude of risk which revealed a drastic fluctuation in customs facilitation [12]. To sum up, scholars in the field propose to develop multimodal transportation, strengthen the construction of logistics infrastructure, improve the logistics and distribution network, issue relevant laws, regulations and policies, build a smart logistics cloud platform, promote information resource sharing, and promote the construction of overseas warehouses to provide possible solutions to cross-border logistics.

However, risks associated with cross-border logistics have not been thoroughly studied. Although there have been studies on stock market risks, traffic safety risks and quality risk in supply chain [13-17], only a few scholars used a combination of qualitative and quantitative analysis to study the risk assessment of cross-border logistics from a practical point of view, and established a risk assessment system and assessment methods. For example, Zhang et al. argued that there are many drawbacks and risks in China's e-commerce logistics industry at present, and it is necessary to conduct an in-depth analysis of its management defects and take measures to improve them so as to build an e-commerce logistics management system with Chinese characteristics [18]. Zhou et al. combined the fitness model with the local world model to simulate the risk transmission of the B2C cross-border e-commerce supply chain [19]. Yang and Zhang solved the complex problem of logistics capacity assessment in e-commerce environment and established a model of logistics capacity evaluation index system based on fuzzy-AHP method [20]. Chhibber et al. reviewed critically the existing methods to obtain the solution of different types of fuzzy transportation problem and analysed their benefits and drawbacks [21].

Existing studies on cross-border logistics risks are still relatively few, and they are all based on methods such as AHP, without considering the correlation between risk factors. This paper constructs a system dynamics model to derive the key influencing factors of B2C cross-border logistics risks through sensitivity analysis, which helps enterprises to identify and prevent logistics risks in the actual operation and management of cross-border e-commerce. On the other hand, this paper extends the scope of application of system dynamics modelling studies.

3. MODEL DESCRIPTION

3.1 Risk identification

Based on the content of literature mining and expert interviews, the paper identifies 38 cross-border logistics risk factors, divided into seven risk subsystems of process risk, employee operational risk, information risk, operations management risk, clearance risk, cooperation risk and environmental risk. The risk factors contained in each risk subsystem and the source presented in Table I.

Table I: Cross-border logistics risk list.

Risk Subsystem	No.	Risk Factors	Source
Process Risk A1	1	Shipping Delays	Literature Identification
	2	Lost goods	Literature Identification
	3	Product Breakage	Literature Identification
	4	Low distribution efficiency	Literature Identification
	5	Poor logistics infrastructure	Literature Identification
	6	Unscientific transportation system	Literature Identification
	7	Risk of backlog and stagnation of goods in storage	Literature Identification
Employee Operational Risk A2	8	Staff misses to send out less and wrong	Literature Identification
	9	Employees entering wrong information	Literature Identification
	10	Low level of staff packaging standardization	Experts add
	11	Low security awareness among warehouse managers	Literature Identification
Information Risk A3	12	Logistics information not updated in time	Literature Identification
	13	Inaccurate logistics information	Literature Identification
	14	Customers leave wrong information	Literature Identification
	15	Market information not updated in time	Experts add
Operations Management Risk A4	16	Unreasonable system	Literature Identification
	17	Organizational Decision Mistakes	Literature Identification
	18	Fast turnover of employees	Experts add
	19	Poor professionalism of employees	Literature Identification
	20	Product does not meet delivery requirements	Literature Identification
	21	High rate of product returns and exchanges	Literature Identification
	22	Cross-border payment risks	Literature Identification
Clearance Risk A5	23	Low efficiency of customs clearance	Literature Identification
	24	Low level of commercial inspection	Literature Identification
	25	Customs product quality inspection does not pass	Literature Identification
	26	Weak risk awareness among customs officers	Literature Identification
	27	Risk of imperfect customs monitoring system	Literature Identification
Cooperation Risk A6	28	Partner selection risk	Literature Identification
	29	Risk of uneven distribution of benefits among partners	Literature Identification
	30	Risk of partner mistrust	Literature Identification
	31	Risk of self-interested behaviour of partners	Literature Identification
	32	Risk of evasion of obligations by partners	Literature Identification
Environmental Risk A7	33	Cultural Differences	Literature Identification
	34	Natural Disasters	Literature Identification
	35	Exchange rate fluctuations	Literature Identification
	36	Policy Changes	Literature Identification
	37	Macroeconomic fluctuations	Literature Identification
	38	Highly fluctuating market demand	Literature Identification

3.2 Causality analysis

For cross-border logistics risk system, there are not only risk transmission effects between each risk subsystem internally, but also numerous causal transmission effects of risk factors between different subsystems.

Risk causal transmission effects within each risk subsystem for example: In the process risk, the unscientific transportation system can easily lead to transportation delays or low distribution efficiency. In operation management risk, low employee satisfaction with the system can lead to rapid employee turnover, which in turn can lead to low professional quality of employees or can lead to the risk of some operational errors.

And there are causal transmission effects of risk factors between different subsystems. For example: High fluctuation of market demand which can easily lead to backlog and stagnation risk of warehouse goods; Product breakage prone to high product return and exchange rate.

In this paper, based on the causal relationship between all of risk factors, system dynamics model for cross-border logistics risk is constructed as shown in Fig. 1.

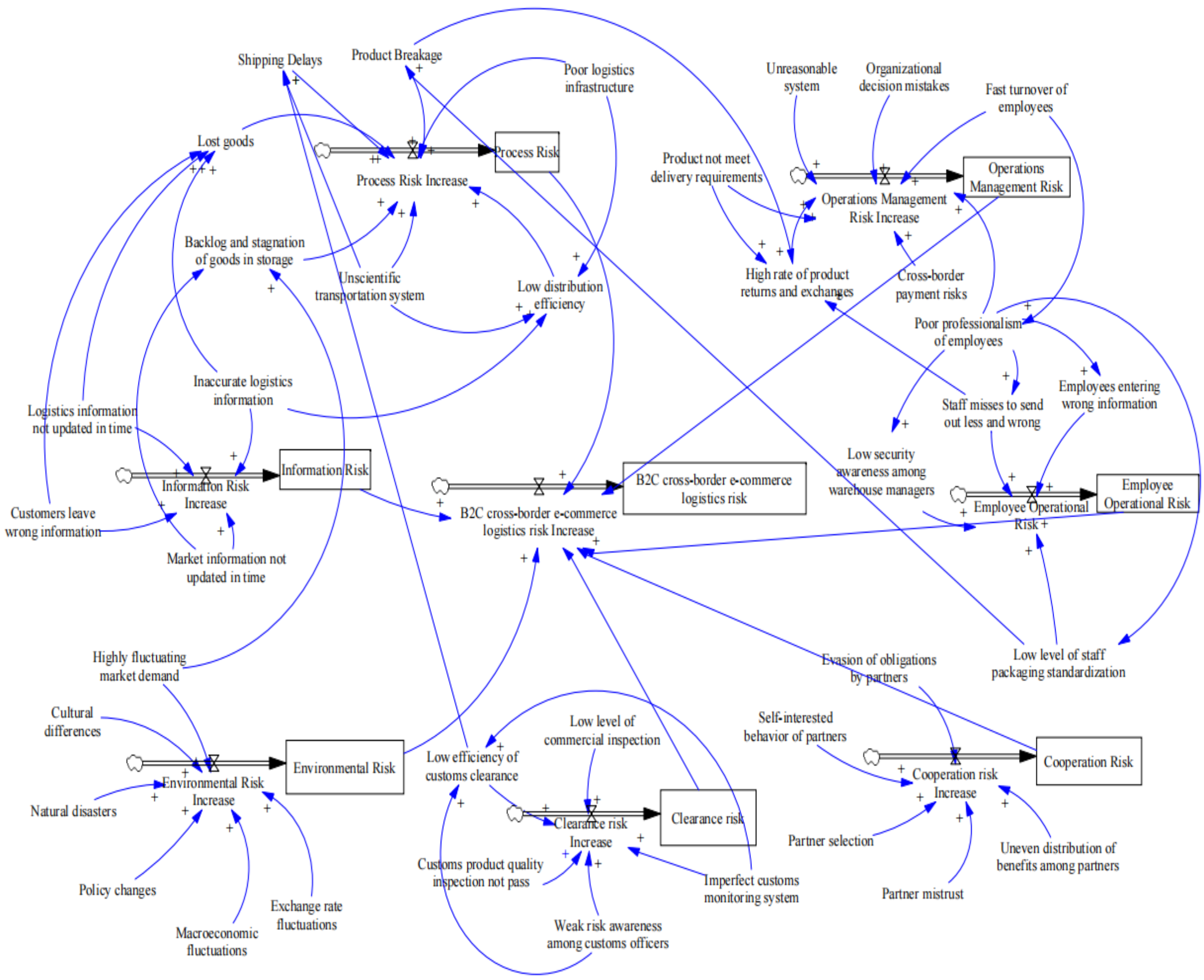

Figure 1: System dynamics framework for Cross-border logistics risk.

3.3 Data source

The relevant data in this paper are mainly from the questionnaire survey, and a total of 20 experts were invited, including 4 experts from Chengdu cross-border e-commerce association, 8 Chengdu cross-border e-commerce staff and 8 Chengdu cross-border logistics enterprise staff. Each risk factor was scored by the experts in two dimensions, namely the degree of possibility and the degree of harm. The likelihood of occurrence and hazard were divided into five levels, and scored from 1 to 5, and higher scores indicated higher likelihood of occurrence or greater hazard, and the scoring criteria are shown in Table II.

Table II: Risk factor scoring criteria.

Possibilities	Score	Harmfulness	Score
Highly probable	5	Serious	5
More likely	4	Larger	4
Medium likelihood	3	General	3
Less likely	2	Minor	2
Very unlikely	1	Almost no effect	1

3.4 System dynamics formula

The system dynamics model constructed in this paper includes three kinds of variables, auxiliary variables; rate variables; and state variables. Firstly, the system dynamics model of auxiliary variables is constructed by other auxiliary variables related with this auxiliary variable and the relative coefficients. The relative coefficients that reflecting mutual influence relationship between each auxiliary variable, are derived by multiple linear regression analysis in SPSS. Secondly, the rate variable means the risk-increasing value of each subsystem. The system dynamics model of rate variable is constructed by auxiliary variables and absolute coefficient. The absolute coefficient is derived by a multiple linear regression of the combined score values of the subsystem. Finally, the state variables are jointly determined by the corresponding rate variables as well as the initial value of state variable. The following are the systematic equations for these three kinds of variables:

Auxiliary variables = ∑(related auxiliary variables × relative coefficients)

Rate variable = ∑(auxiliary variable × absolute coefficient)

State variable = INTEG (corresponding to the rate variable, the initial value of state variable).

(1) Calculation of auxiliary variable values

Based on the established system dynamics equations, it can be seen that there are one state variable and one rate variable in each of the seven subsystems, and the risk factors in each subsystem are the corresponding auxiliary variables. The expert scoring method is used to assign values to the parameters, and the expert scoring in this paper not only scores the hazard degree of the risk factors, but also includes the likelihood of occurrence of the influencing factors in the evaluation index. In the calculation, to further reduce the error, a combination of arithmetic and geometric averaging methods were considered to measure the risk factors (auxiliary variables). Then the two methods were averaged. The calculation formula is as follows.

$$A_{ij} = \left(\sqrt{P_{ij} * I_{ij}} + \frac{P_{ij}+I_{ij}}{2}\right)/2 \tag{1}$$

Among them:

A_{ij}: the composite score of the j^{th} expert on the risk magnitude of the i^{th} risk factor.

P_{ij}: the composite score of the j^{th} expert on the likelihood magnitude of the i^{th} risk factor.

I_{ij}: the combined score of the j^{th} expert on the magnitude of the hazard of the i^{th} risk factor.

(2) Calculation of relative coefficients

According to the system dynamics equation derived in the first step, it can be found that the relationship between risk factors is complex, and many risk factors are influenced by the action and influence of more than one other factor. This makes the equation not simply monotonic and there may be situations where one dependent variable corresponds to more than one independent variable. For such a relational equation, the thesis calculates the coefficients based on the data obtained from the questionnaire and uses SPSS software to perform multiple linear regression to obtain the coefficients and the expression of the relational equation. The relationship equation between the independent variable and the dependent variable is shown in the following expressions:

$$Y=\beta_0+X_1\beta_1+X_2\beta_2+\cdots+X_t\beta_t+\varepsilon \tag{2}$$

Among them:

β_0: a constant.

X_t: the t^{th} independent variable (other auxiliary variables that influence the dependent variable).

β_t: the relative coefficient of the t^{th} independent variable.

Y: the dependent variable (an affected auxiliary variable).

ε: the random error.

(3) Calculation of absolute coefficients

By calculating Eq. (1), we obtain the composite score of each expert for each risk factor. And we can obtain the composite score of the expert on the risk magnitude of the risk subsystem according to the calculation formula is as follows:

$$A_j=\sum_{i=1}^{m} A_{ij} \tag{3}$$

Among them:

m: the number of the risk factors in the risk subsystem.

A_{ij}: the composite score of the j^{th} expert on the risk magnitude of the i^{th} risk factor.

A_j: the composite score of the j^{th} expert on the risk magnitude of the risk subsystem.

The composite score of the expert on the risk magnitude of the risk subsystem calculated according to Eq. (3) are again subjected to regression analysis to obtain absolute coefficients.

(4) Calculation of the initial value of the state variable

According to Eq. (3), the composite score of the experts on the rate variable is calculated, and the average of all the experts' scores on the state variable is taken as the initial value of the state variable. The calculation formula is as follows:

$$A=\frac{1}{n}\sum_{i=1}^{m} A_j \tag{4}$$

Among them:

m: the number of the risk factors in the risk subsystem.

n: the number of experts.

A_j: the rating of the j^{th} expert on the magnitude of the rate variable to which such risk factor belongs.

A: the initial value of the state variable.

3.5 Equation construction

According to the equations in section 3.4, data processing was performed to obtain the combined scores of each expert for each risk factor. Then the system dynamics equations for the auxiliary variables, rate variable and state variables are constructed as follows:

(1) System dynamics equation for the auxiliary variables

If the auxiliary variable has other variables that affect himself, the system dynamics model of the auxiliary variables is constructed by first calculating the specific values of each auxiliary variable separately, based on multiple linear regression analysis, and deriving the relative coefficients reflecting the mutual influence relationship between each auxiliary variable, as shown in Eq. (2), for example:

Shipping Delays = 1.931 + 0.171 × unscientific transportation system + 0.321 × low efficiency of customs clearance

If the auxiliary variable does not affect his own other variables, the system dynamics equation of the auxiliary variable is equal to the initial value of that auxiliary variable, for example:

Poor logistics infrastructure = 2.732

(2) System dynamics equation of the rate variable

The rate variable is the risk increase value of each subsystem is calculated by the value of the comprehensive score of the subsystem, that is, the value obtained from Eq. (3) as the independent variable, the specific value of each auxiliary variable under the subsystem as the dependent variable for multiple linear regression analysis, the absolute coefficient of the interaction between the rate variable and each auxiliary variable under the subsystem, for example:

Process factor subsystem risk increase = 0.747 × shipping delays + 0.630 × lost goods + 0.651 × product breakage + 0.783 × low distribution efficiency + 0.733 × poor logistics infrastructure + 0.703 × unscientific transportation system + 0.752 × risk of backlog and stagnation of goods in storage

(3) System dynamics equation of state variables

The system dynamics equation of state variables is composed of INTEG function in Vensim PLE software, which is determined by the increased value of subsystem risk and the initial value of state variables, for example:

Process factor subsystem risk state value = INTEG (process factor subsystem risk increase value, 3.003)

According to the above calculation steps, the system dynamics equations of all auxiliary variables, rate variables, and state variables are obtained, and the above system dynamics equations, initial trial state values and other parameters are substituted into the already drawn stock flow diagram to complete the SD model construction.

4. SIMULATION ANALYSIS AND DISCUSSION

The above system dynamics equations and parameters are entered in the model of the system dynamics stock flow diagram that has been drawn. The Vensim PLE software is used to perform sensitivity analysis on the risk factors (auxiliary variables) in each system model, so that the importance of each risk factor in the transmission of risk in B2C export cross-border e-commerce logistics can be studied in more detail and identified. The sensitivity analysis in the thesis is based on keeping the initial state of other risk factors, changing individual factors in turn, and simulating the model with the changed initial values in again, repeating the operation several times, and finally obtaining the sensitivity analysis graph, so as to determine the relative sensitivity of each risk factor in the risk transmission system, and the analysis results are shown in Figs. 2 to 9.

4.1 Cross-border logistics risk sensitivity analysis

Through sensitivity analysis, the following conclusion was drawn: "Clearance risk" > "Process risk" > "Cooperation risk" > " Employee operational risk" > "Operational management risk" > "Environmental risk" > "Information risk", as shown in Fig. 2.

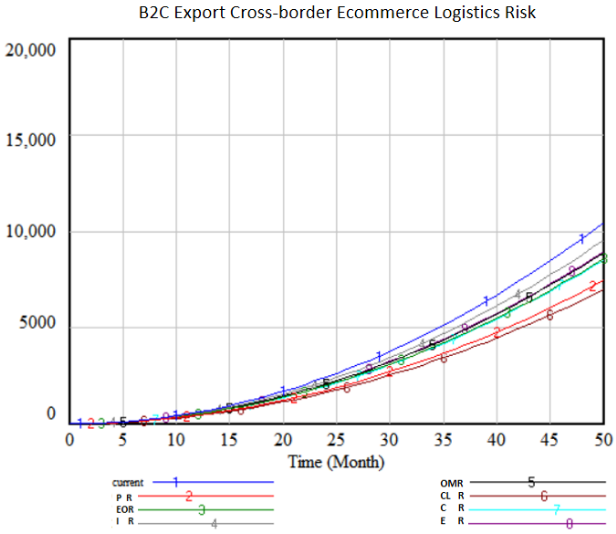

Figure 2: B2C cross-border e-commerce logistics risk sensitivity analysis.

From the risk transmission process, clearance risk has the highest sensitivity. Generally, it takes 1-3 days to clear customs, and the clearance time during the epidemic is 3-5 days longer than usual, and since the survey data of this thesis is carried out during the epidemic, the clearance time will be extended, so the customs clearance risk is more prominent. Second is the process risk, the factors are the most complex, uncertainty factors, cross-border e-commerce logistics of the long transport distance, the number of transit, so the process risk is also more prominent. The third is the cooperation risk, this data from B2C cross-border e-commerce enterprises, logistics services mostly with third-party logistics companies, so the cooperation risk is also an important risk in the logistics of B2C cross-border e-commerce enterprises.

4.2 Risk sensitivity analysis for each subsystem

From Fig. 3, we can see that, process risk sensitivity in descending order: "Unscientific transportation system" > "Low distribution efficiency" > "Shipping delays" > "Product breakage" > "Lost goods" > "Risk of backlog and stagnation of goods in storage".

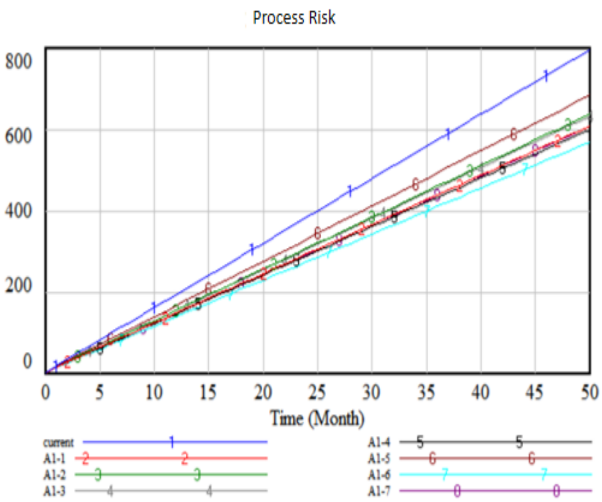

Figure 3: Process risk sensitivity analysis.

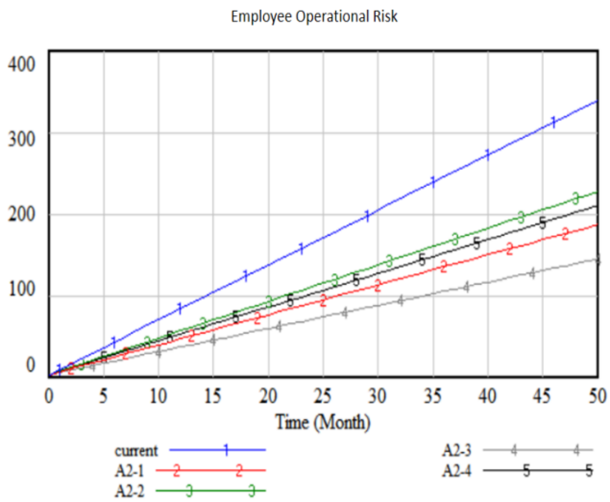

Figure 4: Employee operational risk sensitivity analysis.

From Fig. 4, we can see that, employee operational sensitivity in descending order: "Low level of staff packaging standardization" > "Staff misses to send out less and wrong" >

"Employees entering wrong information" > "Low security awareness among warehouse managers".

From Fig. 5, we can see that, information risk sensitivity in descending order: "Inaccurate logistics information" > "Logistics information not updated in time" > "Market information not updated in time" > "Customers leave wrong information".

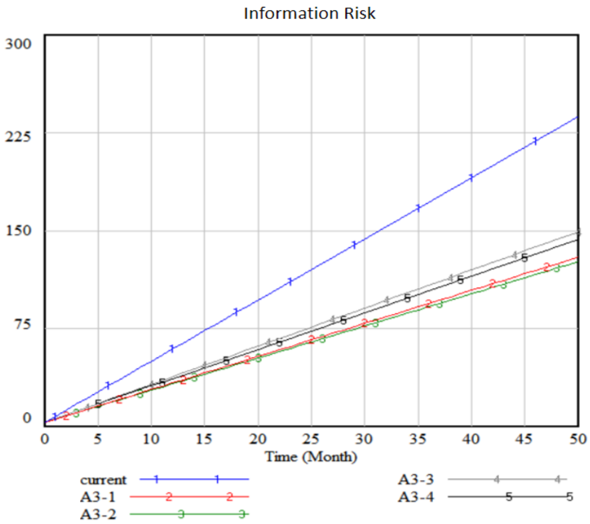

Figure 5: Information risk sensitivity analysis.

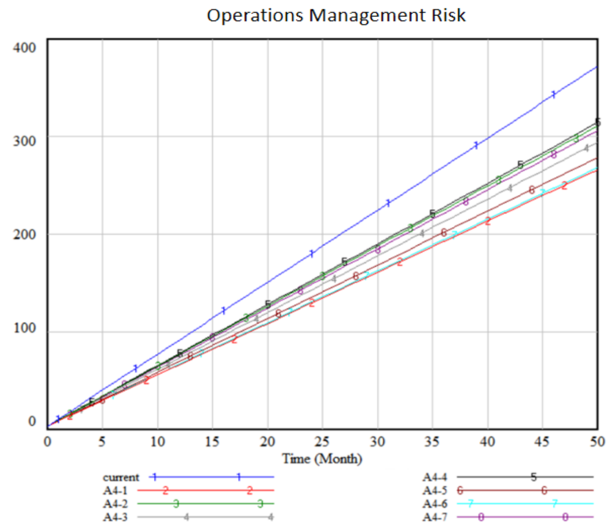

Figure 6: Operation management risk sensitivity analysis.

From Fig. 6, we can see that, operational management risk sensitivity in descending order: "Unreasonable system" > "High rate of product returns and exchanges" > "Product does not meet delivery requirements" > "Fast turnover of employees" > "Cross-border payment risks" > "Organizational decision mistakes" > "Poor professionalism of employees".

From Fig. 7, we can see that, clearance risk sensitivity in descending order: "Weak risk awareness of customs personnel" > "Low efficiency of customs clearance" > "Customs product quality inspection does not pass" > "Risk of imperfect customs monitoring system" > "Low level of commercial inspection".

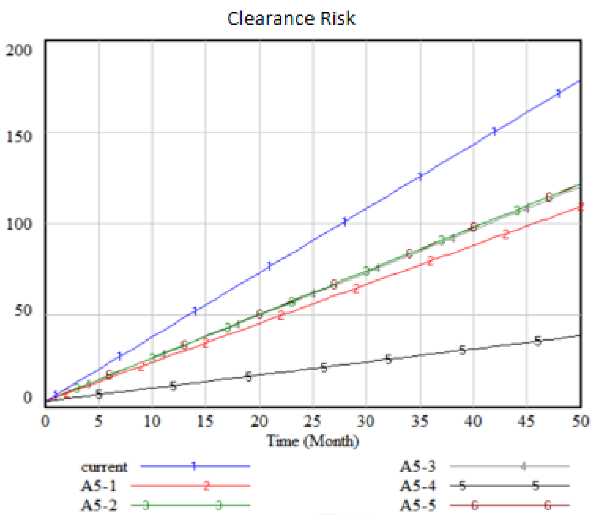

Figure 7: Clearance risk sensitivity analysis.

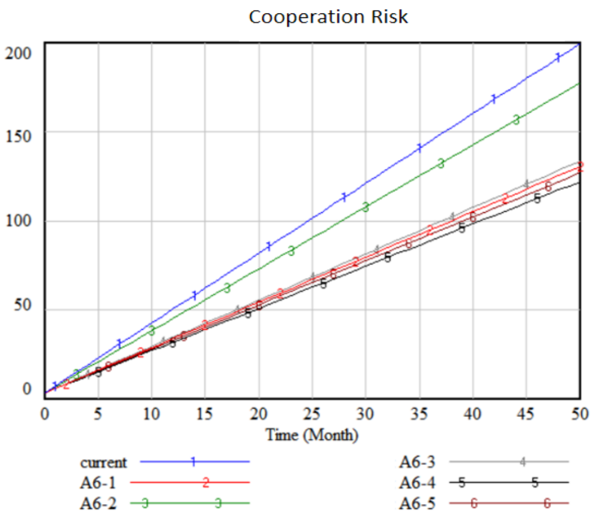

Figure 8: Cooperation risk sensitivity analysis.

From Fig. 8, we can see that, cooperation risk sensitivity in descending order: "Risk of self-interested behaviour of partners" > "Risk of evasion of obligations by partners" > "Partner selection risk" > "Risk of partner mistrust" > "Risk of uneven distribution of benefits among partners".

From Fig. 9, we can see that, environmental risk sensitivity in descending order: "Exchange rate fluctuations" > "Policy changes" > "Macroeconomic fluctuations" > "Natural disasters" > "Cultural differences" > "Highly fluctuating market demand".

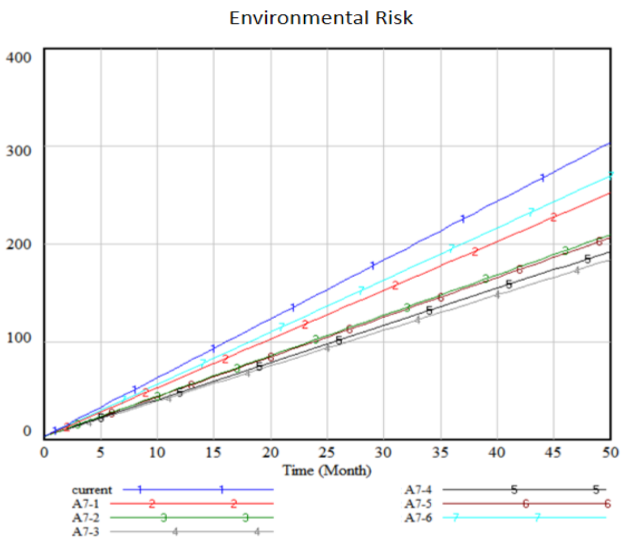

Figure 9: Environmental risk sensitivity analysis.

4.3 Discussion

As far as clearance risks are concerned, first of all, the government should keep a strict control on customs personnel. The government should recruit more customs talents and have a complete training process for customs personnel. Secondly, the government should study and learn from advanced foreign customs supervision system to establish a sound customs supervision system, streamline the customs clearance process, improve the efficiency of customs clearance, etc.

In terms of process risk, enterprises should improve their own risk awareness. On the one hand, we should strive to improve logistics infrastructure and information technology to reduce the risk of cargo damage and cargo loss. On the other hand, a special risk event recording system and abnormal reminder system should be developed in order to specifically analyse the root causes of risk events and take appropriate avoidance measures.

In terms of cooperation risk, when choosing partners, cross-border e-commerce enterprises should first fully understand the organizational background of cross-border logistics enterprises and make a comprehensive assessment of them to determine their stability and establish a credibility mechanism. The division of responsibilities between enterprises should be clearly defined, and the cooperation risks of the sector should be avoided or negotiated and shared in advance without affecting mutual cooperation and trust, so as to strive for the maximum benefits for the company.

5. CONCLUSIONS

This paper firstly identifies risk factors through literature combing combined with expert interviews to get a list of B2C cross-border e-commerce logistics risk factors and classifies them into seven categories, namely process risk, employee operation risk, information risk, operation management risk, customs clearance risk, cooperation risk, and environmental risk. Then the causal relationship between different risk factors is analysed, a system dynamics model of cross-border logistics risk is constructed, and simulation analysis is conducted using Vensim PLE software. Finally, the following conclusions are drawn:

(1) The nature of risk is uncertainty, and the level of risk in cross-border logistics is positively correlated with the predicted time horizon, i.e. the larger the time horizon, the higher the risk level, and the simulation results are in line with the actual situation.

(2) The highest sensitivity of cross-border logistics risk is customs clearance risk, followed by process risk and cooperation risk, and the lowest sensitivity of information risk.

(3) The background of data research in this paper is during the epidemic, the customs clearance time is delayed by 3-5 days compared with normal, so it is justified to be a key risk factor.

The paper provides a detailed analysis of the interactions between a total of 38 risk-influencing factors in seven categories of risk sources, but there is no detailed elaboration of the transmission medium between each risk factor and what stakes are mainly generated for which risk recipient, and these factors can be considered in the model for further research in the future.

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