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Emergency Supply Control from the Perspectives of Peacetime and Wartime: A System Dynamics Simulation

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Abstract: The supply of emergency materials is the fundament of emergency rescues. In view of the demand for emergency materials in major calamities, in this paper, a system dynamics model of emergency materials is constructed from the perspectives of wartime and peacetime. By setting and controlling the relevant parameters and variables, the influence of a variable on the demand and supply of emergency materials and the influence of government strategies on the quantity and provision of emergency material supply are analyzed. We explore the measures that can better ensure the supply to stabilize the social and economic security of the country. The results show that the emergency degree of an event will lead to increases in the amount of government expenditures and in the duration of such expenditures. Meanwhile, the increase in emergency cases will increase the variation range of the supply and demand deviation curve, lengthen the response time to demand, and fasten the growth trend of material supply. The Chinese government adopts comprehensive regulation and control mode, which make the supply and demand reach the equilibrium state more than twice as fast as other control methods. In addition, the promotion of publicity will improve the number of civil materials. A high inflation rate will lead to high imports of government materials, which will consequently affect the supply of emergency materials. The above research findings have important reference significance for the government's emergency materials management.

Key words: peacetime and wartime; system dynamics; emergency supplies

1 Introduction

In emergency management, the combination of peacetime and wartime implies that the government should take the coordinated development of national defense construction and economic construction as the guideline in crisis management. We should consider wartime and peacetime needs so that we can quickly integrate all kinds of mobilized resources in major events to ensure national and public security. From the combined perspective of peacetime and wartime, there is a certain amount of material demands in peacetime, and there is a larger amount of material demands in wartime when major events occur, such as masks, ventilators, protective clothing, fire extinguishers, cotton-padded clothes, and quilts. If the market economy mode is adopted for this kind of material, then it may only meet the daily needs and cannot meet the large wartime needs under major events. Therefore, the supply and regulation of such materials need the government's participation and planning.

The outbreak of COVID-19 in December of 2019 caused a great increase in the demand for medical protective materials. By only relying on the government's reserves, the demand could not be quickly met. Moreover, the serious shortage of materials caused individual enterprises to drive up prices and make huge profits, which has caused

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extremely bad effects. This problem also made politicians and scholars more concerned about the planning and regulation of emergency materials. The problems caused by COVID-19 indicate the urgency of establishing a set of emergency control systems for peacetime and wartime integration. Therefore, at this stage, it is of far-reaching significance to study a series of issues, such as the regulation of emergency supplies from the combined perspective of peacetime and wartime.

2 Literature Review

At present, most studies on emergency management are based on operational researches and related prediction theories to solve the problems of single-objective or multi-objective decision-making, single-factor or multi-factor optimization, and combinatorial optimization. As regards the aspect of using operations research as a tool to solve problems, Zhang[1] proposed that the government and local enterprises should cooperate to reserve materials so as to improve the compliance to the emergency demand and put forward the optimal reserve allocation strategy of local government authorities using the scenario-based integer programming method. Feng et al.[2] proposed a mathematical model for emergency material warehouse location by considering practical factors and designed a variable weighting algorithm to solve the model according to the theory and method of solving multi-objective optimization problems in operational research. Zhou and Olsen[3] considered the perishable nature of latex gloves and other products, studied the joint rotation and ordering strategy, and found that the optimal strategy structure was well preserved when it was extended to the scheme with capacity constraints and multiple planning ranges.

As regards prediction data and other aspects, Guan et al.[4] considered earthquake emergency rescue and the time sequence characteristics of logistics, the division of earthquake emergency rescue, and the coverage threshold of logistical material. Based on the amount and type of inventory items, considering the time series characteristics, a material warehouse location model was established to optimize aseismic goods and material warehouse set covering problem. Lin et al.[5] proposed a dynamic estimation model of disaster relief supply and demand based on big data, which combines the dynamic population distribution of Baidu big data with the multilayer perceptron neural network, and can accurately estimate the disaster relief supply and demand when urban floods occur. Onuma et al.[6] used regression analysis to measure the impact of disaster experience on emergency material category preparedness. The results show that the experience of disaster destruction increases disaster preparedness, but the degree of impact varies with the project category. Guo et al.[7] combined the development of a risk avoidance stochastic model with the material replacement strategy, designed and developed an airport vulnerable emergency material inventory system, and found that the airport achieved significant benefits using the proposed replacement strategy.

Although considerable studies on emergency management have been performed, traditional operational research and other methods cannot solve the problems of emergency material allocation and supervision involving time delay and dynamic changes. Since the 1950s, Forrester, a professor from the Massachusetts Institute of Technology, has applied computer science and feedback control theory to solve dynamic problems[8] and has achieved good results. By the 1970s, system dynamics had gradually developed into a research method to understand human dynamic complex systems. It is an applied discipline that closely combines system science theory with computer simulation and studies feedback mechanisms and behaviors. It can analyze complex systems and perform long-term dynamic simulations. The advantages of system dynamics have enabled scholars to apply it to medical treatments[9, 10], architecture[11], agriculture[12], and other fields. It is also used to solve different problems, such as water resources management[13, 14], power resources management[15], battery solid recovery[16] and energy emissions[17], population and housing issues[18], urban development[19], research on the influencing factors of strategic materials[20], and research on the influencing factors of transportation[21].

Some scholars have also combined the advantages of system dynamics to solve complex systems with other methods to solve problems. Fair et al.[22] used system dynamics modeling and combined it with computer experimental design and statistical analysis to provide relevant decision support for COVID-19. Zhu et al.[23] adopted the method of combining evolutionary game and system dynamics to conduct theoretical modeling and simulation analysis on the interaction of behavioral strategies of three participants (government departments, restaurants, and waste treatment companies) of urban kitchen waste. Zhang et al.[24]

used the Malmquist data envelopment analysis index to evaluate the differences in the ecological footprints of different marine pastures in China and then simulated the evolution trend of ecological efficiency under different policy scenarios using system dynamics from official data. Huang et al.[25] combined the spatial layout evaluation module, system dynamics, and multi-agent system to establish a rural residential renovation model and performed relevant empirical research.

The existing research focuses more on the issues of post-disaster or post-event material scheduling, temporary transit points, and location planning of warehouses. The solutions and treatments of related problems are inclined to the establishment of quantitative mathematical models to solve multi-objective problems. From the combined perspective of peacetime and wartime, a few studies have been performed on constructing system models by combining different factors, such as government reserve planning and material scheduling. Accordingly, in this study, the influencing factors of the emergency material supply and relevant process under the government regulation are comprehensively considered, and the relevant factors affecting emergency materials from the perspectives of peacetime and wartime are analyzed. The system dynamics method is used to establish a peacetime and wartime emergency material allocation model. Moreover, relevant parameters are set to analyze the government's related measures on the number of emergency supplies, and the supply and demand of the security situation, to explore measures that can better ensure the supply, and provide a certain reference for the government in emergency material management.

3 Model Framework

3.1 Model assumptions

From the combined perspective of peacetime and wartime, emergency supplies refer to materials produced by enterprises authorized by the government, which have certain peacetime and wartime demands in major events (e.g., wars, epidemic situations, and disasters), such as masks, medical materials, food, and clothing. Considering that the government's "peacetime and wartime combination" emergency supply allocation can play the role of private forces in emergency production and procurement, we can entrust enterprises to store materials, increase subsidies to enhance the enterprise production capacity, and transfer civil materials to meet peacetime and wartime needs. Accordingly, this study formulates the following model assumptions.

(1) After emergency events, the government will take out materials from a self-built warehouse for rescue. Based on the deviations in the supply and demand, we can control the cost of reserve expenditure to control the proportion of government reserve supply. The government can allocate the supply of emergency supplies in many ways, such as entrusting enterprises to reserve, collecting and transferring civil materials, and subsidizing enterprises to quickly switch production.

(2) Production and reserve strategies for enterprises are formulated to meet the requirements of the government. Enterprises have a certain amount of material reserves. When the government increases subsidies to enterprises, the proportion of reserve material expenditure will increase.

(3) In the material production process, the government will provide enterprises funds to subsidize raw materials, production capacity, and equipments to increase their production capacity and to help enterprises rapidly produce.

(4) The government can also raise emergency supplies through importing. Particularly, the ability to import goods and materials is affected by the import price impact index and other factors.

(5) Because the research is based on the perspective of the government, this study takes government-related expenditure costs into account in the model, mainly through the government expenditure costs to control the system. The costs include expenditure cost of government reserves, expenditure cost of enterprises reserves, government expenditure cost of enterprise production, government import expenditure cost, and government transfer cost.

3.2 System boundary analysis

Based on the means and research purposes of emergency material regulation from the perspectives of peacetime and wartime, this study divides the regulation system into five subsystems: government reserve subsystem, enterprise reserve subsystem, enterprise production subsystem, the government imported material subsystem, and government requisition civil material subsystem. Through these five subsystems, the supply of materials is guaranteed. The border of the material supervision system during wartime is shown in Fig. 1.

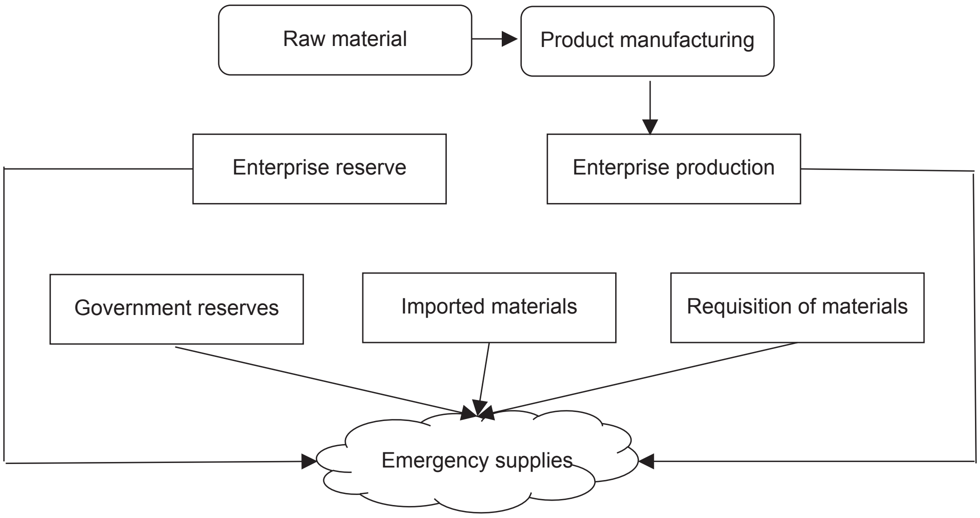

Fig. 1 Border map of the peacetime and wartime material supervision system.

3.3 Causal loop diagram

Based on the system boundary diagram presented in Section 3.2, this study presents a causal loop diagram of the emergency material control system from the perspectives of peacetime and wartime. The causal loop diagram is derived from the internal relationships of the five subsystems, as shown in Fig. 2.

(1) **Government reserve module.** This module includes a negative feedback loop: government reserve supply ratio → government reserve supply quantity → supply quantity → supply and demand deviation → expenditure cost of government reserves → reserve supply ratio.

(2) **Enterprise reserve module.** This module includes a negative feedback loop: proportion of enterprise reserve supply → amount of enterprise reserve supply→ amount of supply → supply and demand deviation → enterprises' reserve cost of government expenditure → proportion of enterprise reserve supply.

(3) **Enterprise production module.** This module includes two feedback loops. The positive feedback loop is raw material productivity → raw material inventory → transformed material productivity → enterprise output → supply quantity → supply and demand deviation → enterprise production cost of government expenditure → raw material productivity.

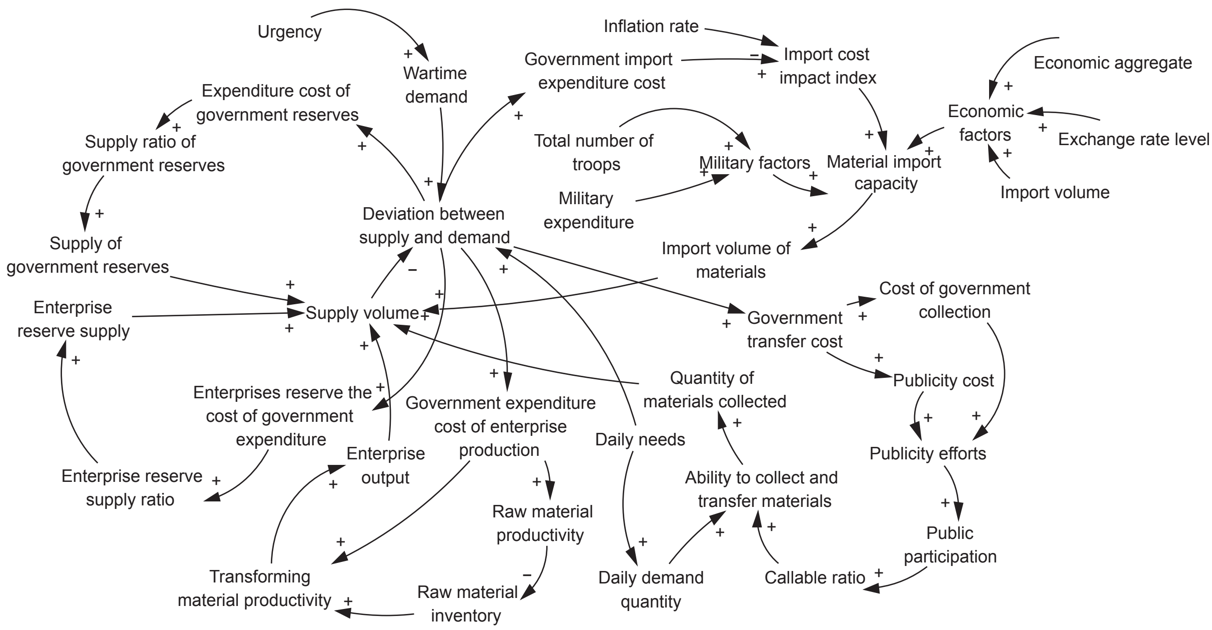

Fig. 2 Cause-and-effect loop diagram of the peacetime and wartime material control system.

The negative feedback loop is transforming material productivity → enterprise output → supply quantity → supply and demand deviation → government expenditure cost of enterprise production → transforming material productivity.

(4) **Government imported material module.** This module has a negative feedback loop: material import capacity → material import volume → supply volume → supply and demand deviation → government import expenditure cost → import cost impact index → material import capacity.

(5) **Module of civil material collection and transfer by the government.** This module includes a negative feedback loop: government's ability to collect and transfer civil materials → total amount of civil materials collected and transferred by the government → supply quantity → supply and demand deviation → government transfer cost → propaganda strength → propaganda strength → public participation degree → callable proportion → government's ability to collect and transfer civil materials.

3.4 Inventory flow diagram and main equations of the model

Referring to the existing literature, this study uses Vensim PLE software to draw the data flow diagram of the emergency material regulation system from the combined perspective of peacetime and wartime, as shown in Fig. 3. The key to setting the emergency material regulation model is to determine the relationship among various indicators. This study also uses measurement analysis and statistical analysis methods to determine the relationship between the indicators. In the system flow diagram, six state variables are used: government reserve supply (*ZFCBGJ*), enterprise reserve supply (*QYCBGJ*), raw material inventory (*CLKC*), enterprise output (*QYCL*), material import volume (*WZJK*), and the total amount of government-regulated civil materials (*ZFZD*). The flow diagram is composed of five modules: government reserve capacity submodule, enterprise reserve capacity module, enterprise production capacity module, government import material capacity module, and government requisition civil material capacity module.

(1) Government reserve module

The supply of government reserves (*ZFGJ*) is affected by the supply ratio of government reserves (*ZFGJBL*), the supply of government reserves (*ZFGJ*) affects the supply (*GJL*), the supply and demand deviation (*GXPC*) determines the expenditure cost of government reserves (*ZFCBCB*), and the expenditure cost of government reserves (*ZFCBCB*) affects the supply ratio of government reserves (*ZFGJBL*).

(2) Enterprise reserve module

Enterprise reserve supply (*QYGJ*) is affected by the enterprise reserve supply ratio (*QYGJBL*), the enterprise reserve supply (*QYGJ*) affects the supply (*GJL*), supply and demand deviation (*GXPC*) determines the enterprises' reserve cost of government expenditure (*QYCBZFZC*), and enterprises' reserve

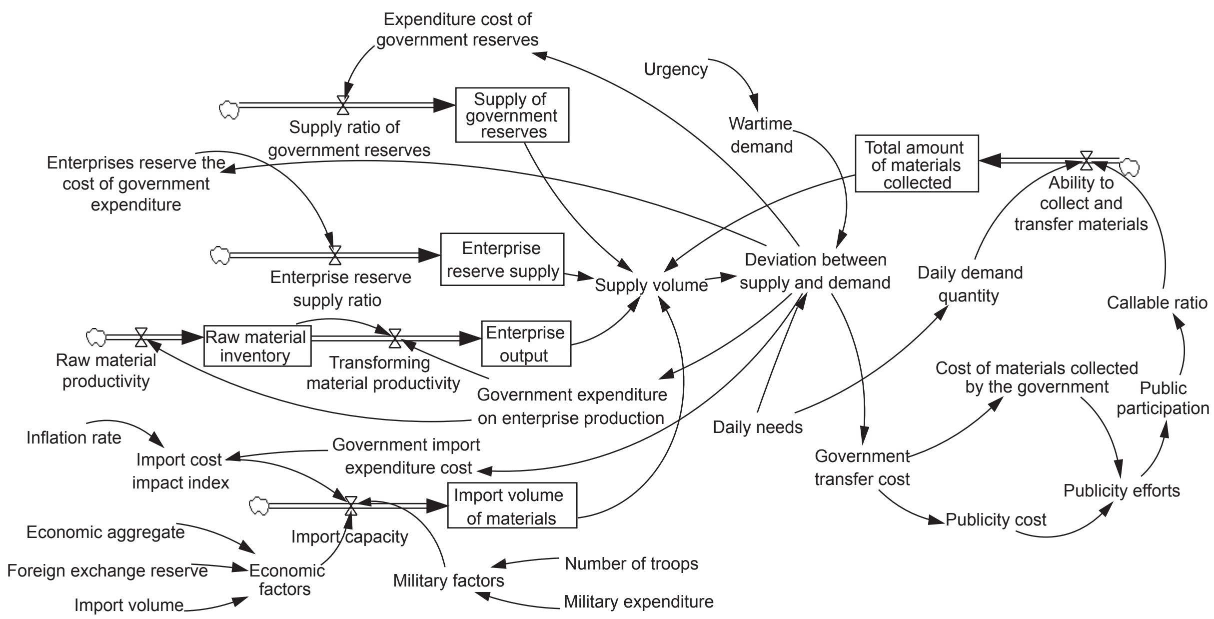

Fig. 3 Flow chart of the emergency material control system in peacetime and wartime.

cost of government expenditure (*QYCBZFZC*) affects the enterprise reserve supply ratio (*QYGJBL*).

(3) Enterprise production module

The production activities of enterprises will have a raw material inventory (*YCLKC*), and the raw material inventory (*YCLKC*) is determined by the raw material productivity (*CLSCL*) and conversion material productivity (*ZHSCL*). The output of the enterprises (*QYCL*) is affected by the productivity of transformed materials (*ZHSCL*), and the output (*QYCL*) of the enterprises affects the supply (*GJL*). The supply and demand deviation (*GXPC*) determines the government expenditure cost of enterprise production (*QYSCZFZC*) and then affects the raw material productivity (*CLSCL*) and transformation material productivity (*ZHSCL*).

(4) Government import module

Material import capacity (*JKNL*) affects the material import volume (*WZJKL*), material import volume (*WZJKL*) affects the supply volume (*GJL*), the supply and demand deviation (*GXPC*) determines the government's import expenditure cost (*ZFJKZC*), and the government's import expenditure cost (*ZFJKZC*) and inflation rate (*THPZL*) determine the import cost impact index (*JKCBZS*). The influence index of the import cost (*JKCBZS*), economic factors (*JJYS*), and military factors (*JSYS*) affect the material import capacity (*JKNL*).

In this module, economic and military factors are unobservable variables. Inspired by the structural equation model, this study uses a structural model to count unobservable variables (military and economic factors), that is, some important observable variables related to the unobservable variables.

Figure 4 shows the structural model of the economic factor (*JJYS*) and military factor (*JSYS*). The two factors are measured separately by the following observable variables. In the statistics of military factors, the important observable variables are as follows: number of troops (*JDSL*) and military expenditure (*JFKZ*). Among the economic factors, the total economic aggregate (*JJZL*), national foreign exchange reserves (*WHCB*), and foreign trade imports (*WMJKL*) are used as observable variables.

(5) Government material requisition module

The total amount of civil materials collected by the government (*ZFZDWZ*) is affected by the ability of the government to collect civil materials (*ZFZDNL*). The total amount of civil materials collected by the government (*ZFZDWZ*) affects the supply (*GJL*). The supply and demand deviation (*GXPC*) determines the government transfer cost (*ZFDYCB*). The government transfer cost (*ZFDYCB*) includes the cost of demand (*ZDPSCB*) and the cost of publicity (*XCCB*). These costs affect the intensity of publicity (*XCLD*), publicity cost affects public participation (*MZCYD*), public participation (*MZCYD*) affects callable proportion (*DYBL*), and callable proportion (*DYBL*) affects the government's ability to collect civil materials (*ZFZDNL*).

The five parts mentioned above are the five modules in the system dynamics model. The output of the emergency supplies of the five modules constitutes the supply of emergency supplies in the model. The supply should meet not only the peacetime demand, but also the wartime demand. At this time, there will be a supply and demand deviation. In this study, based on the corresponding supply and demand deviation, we determine and adjust the output of each module in government spending. The main equations of each subsystem are shown in Table 1.

4 Model Simulation Analysis

4.1 Scenario setting

In this section, we present the regulation of emergency supplies from the perspectives of peacetime and

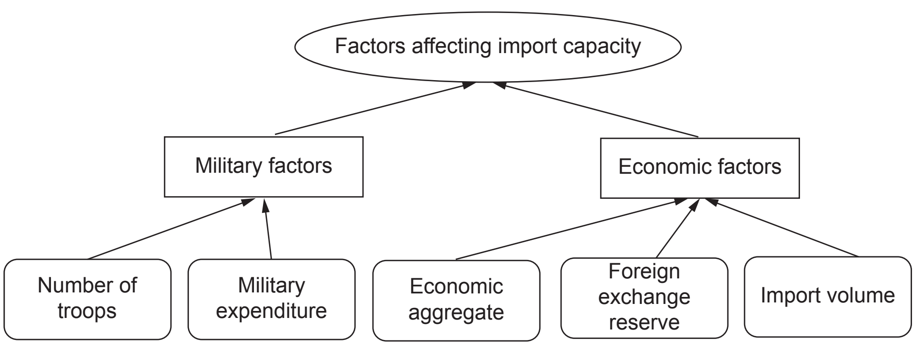

Fig. 4 Structural model of international relations with material-exporting countries.

Table 1 Main equations of each subsystem.

Subsystem	Variable name	Calculation formula
Government reserves	Supply of government reserves	$ZFGJ.K = ZFGJ.J + ZFGJBL.JK \times DT$
	Supply ratio of government reserves	$ZFGHBL = ZFCBCB/250$
	Expenditure cost of government reserves	$ZFCBCB = ABS(GXPC \times 0.3)$
Enterprise reserve	Enterprise reserve supply	$QYGJ.K = QYGJ.J + QYGJBL.JK \times DT$
	Enterprise reserve supply ratio	$QYCGJBL = QYCBZFZC/300$
	Enterprises reserve the cost of government expenditure	$QYCBZFZC = ABS(GXPC \times 0.2)$
Enterprise production	Raw material inventory	$YCLKC.K = YCLKC.J + (ZHSCL.JK - CLSCL.JK) \times DT$
	Enterprise output	$QYCL.K = QYCL.J + QYSCZFZC.JK \times DT$
	Raw material productivity	$CLSCL = QYSCZFZC/100$
	Transforming material productivity	$ZHSCL = \min(QYSCZFZC/200, YCLKC)$
	Government expenditure cost of enterprise production	$QYSCZFZC = ABS(GXPC \times 0.25)$
Imported materials	Import volume of materials	$WZJKL.K = WZJKL.J + JKNL.JK \times DT$
	Material import capacity	$JKNL = (JJYS + JSYS + JKCBZS)/10000$
	Government import expenditure cost	$ZFJKZC = ABS(GXPC \times 0.15)$
	Economic factors	$JJYS = a \times JJZL + b \times WHCB + c \times WMJKL$
	Military factors	$JSYS = d \times JDSL + e \times JFKZ$
Requisition supplies	Total amount of materials collected by the government	$ZFZDWZ.K = ZFZDWZ.J + ZFZDNL.JK \times DT$
	Government's ability of recruitment	$ZFZDNL = PSXQSL \times DYBL$
	Government transfer cost	$ZFDYCB = ABS(GXPC \times 0.1)$
	Deviation between supply and demand	$GXPC = GJL - PSXQ - ZSXQ$

wartime. First, the correctness and applicability of the emergency supply regulation system model are tested by setting corresponding demand scenarios. Second, the reality of the model is tested. The data experiment part of the emergency supplies to the ventilator is taken as an example. The main data of the experiment were derived from the website of the National Bureau of Statistics, SIPRI Yearbook 2020, government official website, and other documents.

4.2 Data processing and setting

For available data, this study uses the average method and proportion method, among others, to obtain representative values. For data that cannot be consulted, the expert consultation method is used. Combined with the emergency level, four scenarios of material demand are set up: emergency level 1, emergency level 2, economic level 3, and emergency level 4. The normal demand of these scenarios remains unchanged, so the normal demand value of emergency materials is set as a fixed value in this study. The wartime demand varies according to the degree of emergency, and the higher the degree of emergency, the greater the wartime demand.

The setting of other relevant parameters in this model is shown in Table 2, which includes real data. Taking the data of 2020 as the research point, the simulation and analysis are performed. There is no clear data on China's military expenditure in 2020. Nonetheless, based on SIPRI Yearbook 2020, the military expenditure in 2019 is 261 billion US dollars, which is converted into approximately 1800.2 billion yuan. The number of troops is approximately 2 million (according to the Department of Veterans Affairs). According to the data released on the website of the National Bureau of Statistics, the national foreign exchange reserve in 2020 was about 3216.5 billion US dollars. According to the annual average exchange rate of RMB (1 US dollar = 6.8974 yuan), the total amount will be approximately 22185.4 billion RMB.

Table 2 Reference table of parameters in the model.

Variable name	Numerical value
Inflation rate	0.037
Economic aggregate	1.015986×10^{14}
State foreign exchange reserves	2.21854×10^{13}
Foreign trade import volume	1.42231×10^{13}
Tax revenue	1.54310×10^{13}
Number of troops	2×10^{6}
Military expenditure	1.8002×10^{12}

4.3 Model checking and simulation analysis

To test the feasibility and authenticity of the model, this study sets relevant parameters to examine whether the model is practical under extreme conditions. The values and formulas of relevant variables and the values of some stock are set to observe the changes in the government reserve supply, enterprise reserve supply, enterprise output, material import volume, and the total amount of civilian materials added by the government over time. The results are shown in Fig. 5. In Fig. 5, the supply of materials for the five modules is all 0, which is in line with the actual situation. This study also tests other variables, which all pass the test. Due to space constraints, we will not discuss each variable here.

Next, this study tests the reality of the model. Four kinds of emergency situations are simulated, and the emergency events are divided into four levels to study the change in emergency material production from the perspectives of peacetime and wartime. The model duration is 24 weeks, and the time step is set to 1. The corresponding simulation results and analysis are shown below.

4.3.1 Analysis of the influence of emergency degree on various factors

First, this study examines the change law of the total cost of government expenditure under different emergency degrees. The emergency degree is divided into four levels: emergency level 1, emergency level 2, emergency level 3, and emergency level 4. The higher the value, the higher the degree. As shown in Fig. 6, the expenditure cost of the government generally follows this rule: the higher the emergency degree of the event, the higher the expenditure cost of the government, and the longer the expenditure time. However, the expenditure cost of the government gradually decreases with time and finally tends to reach zero. The government expenditure of emergency level 1 is the lowest, and its expenditure is Extreme condition test result 0 in the 7th week. The government

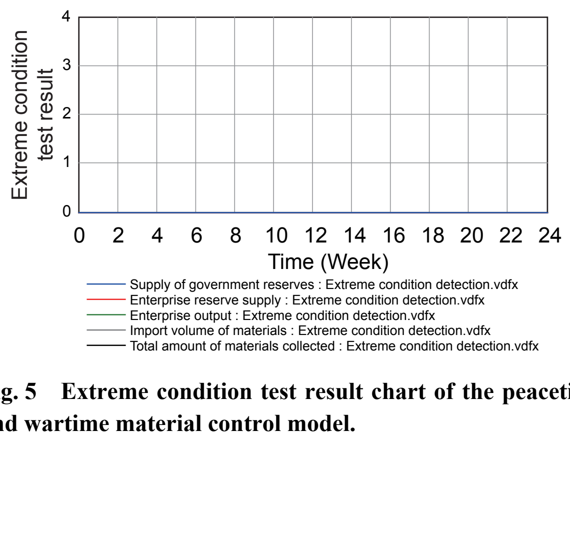

Fig. 5 Extreme condition test result chart of the peacetime and wartime material control model.

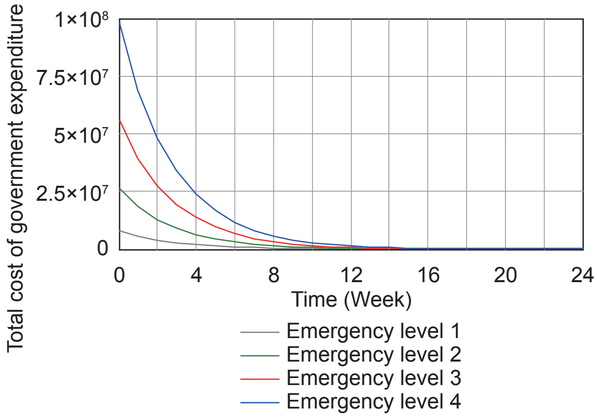

Fig. 6 Total cost of government expenditure under different emergency degrees.

expenditure of emergency level 4 is the highest, which is approximately ten times that of emergency level 1 at the beginning, and the time when the expenditure curve reaches 0 greatly increases in the 13th week.

In reality, the lower the emergency level, the lesser the total demand will be in response to the war. With the increase in time, the increase in supply capacity will lead to less supply and demand deviation and less expenditure adopted by the government, and the corresponding demand will be met faster. Similarly, the higher the emergency, the higher the total wartime demand, and the government will increase the cost expenditure ratio from the beginning to enhance the supply capacity to meet the demand. Essentially, the higher the emergency level of the event, the longer the expenditure lasts. Therefore, the government should adjust the expenditure according to the emergency degree of the event, increase the spending intensity in the early stage, and continuously improve the supply capacity to quickly meet the demand.

Next, we study the law of supply and demand deviation of materials under different emergency degrees. As shown in Fig. 7, in the beginning, the supply and demand deviation under the four emergency degrees is quite different. Moreover, the supply and demand deviation of emergency level 4 is up to one million. This finding indicates that under this event degree, the demand during the war is very great, and the supply of materials cannot be quickly and timely corresponding. Conversely, there is little deviation between the supply and demand in emergency level 4, which indicates that the wartime demand is relatively small, and the demand can be easily met. In addition, the time for the supply and demand deviation to reach 0 under emergency levels 1, 2, 3, and 4 is the 7th, 10th,

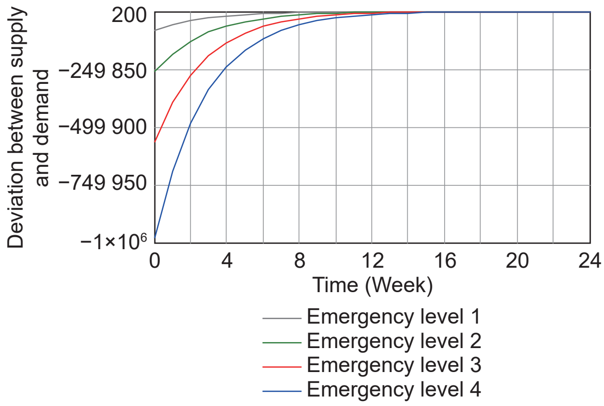

Fig. 7 Deviation of material supply and demand under different emergency degrees.

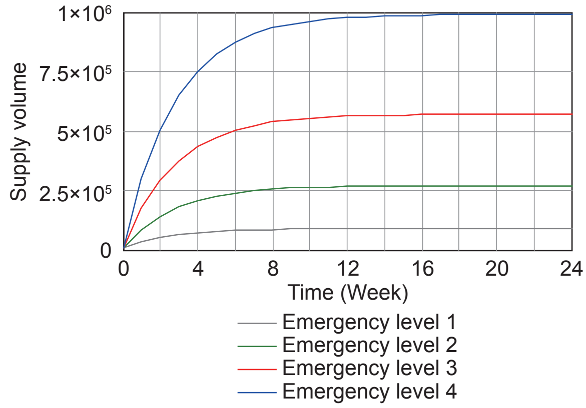

Fig. 8 Material supply quantity under different emergency degrees.

11th, and 13th weeks, respectively.

The supply and demand deviation increases with the degree of emergency. Particularly, the supply and demand deviation is the smallest in emergency level 1. This finding indicates that the government's response to the relevant demand has the most rapid and timely manner when the degree of emergency is lower and the demand is the easiest to be satisfied. The higher the degree of the event, the more time the government needs to respond to the relevant needs. In the later stage, the deviation of supply and demand in various degrees is shrinking, approaching the balance of supply and demand. For example, when the degree of emergency is low, the government expenditure can be reduced in the medium term to achieve a balance between supply and demand. When the emergency degree of the event is high, we can appropriately extend the duration of expenditure cost or expand the proportion of expenditure in the early stage. When the emergency degree is in the middle, the supply is far greater than the demand, and the expenditure can be reduced in the middle and later periods. On the one hand, the supply and demand are close to the balance, and on the other hand, the cost of the government can be saved to the greatest extent.

Then, the impact of different emergency levels on supply is discussed, and the simulation results are shown in Fig. 8. The abscissa of Fig. 8 represents the days of dispatching and regulating materials. The blue, red, green, and gray lines represent the curves of supply volume under government regulation and control with time under emergency levels 4, 3, 2, and 1, respectively. When the emergency level was 4, the supply showed a rapid upward trend until it reached the maximum value around the 14th week and entered a stable state. In emergency level 3, the supply showed an upward trend and reached the maximum value around the 12th week and entered a stable state. The growth rate of emergency levels 2 and 1 was slower than that of emergency levels 3 and 4 and reached the maximum value in the 11th and 8th weeks, respectively. The results show that supply increases with the level of emergency. A high level of emergency fastens the growth trend of supply.

In practice, when the emergency degree of the event is low, the government can increase its expenditure cost and proportion in the early stage of dispatching to quickly respond to the demand and stabilize the situation. With a high degree of emergency, we can increase the cost and proportion of expenditure in the medium-term scheduling, so that the medium-term supply growth rate is the same as that in the early stage, and shorten the time for the supply to reach balance to quickly increase the supply to meet the demand.

4.3.2 Analysis of the influence of different government regulation strategies on the supply and demand deviation

Focusing on the influence of different government regulation strategies on the supply and demand deviation, this study sets five strategies in the experimental part to observe and compare the change in the deviation curve between the supply and demand, and the results are shown in Fig. 9. The blue line in Fig. 9 shows the deviation curve of the supply and demand under the comprehensive strategy adopted by the government under emergency level 3. The comprehensive control strategies include government reserves, the government entrusted enterprise reserves, enterprise production, government import, and private collection of materials. Red line indicates that the

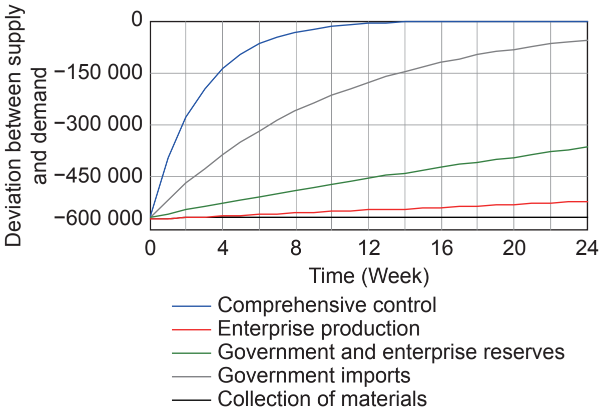

Fig. 9 Comparison of the supply and demand deviation under different control strategies.

government only adopts the deviation curve of the supply and demand under the production policy of enterprises. Green line indicates the deviation curve of the supply and demand under the strategy of the government reserve and entrusted enterprise reserve. Gray line and black line indicate the supply and demand deviation curve under the government's import policy and civil goods policy, respectively. The variation of the supply and demand deviation was the fastest under comprehensive control, and the supply and demand balance was reached in the 12th week. However, the supply and demand deviation under other separate control policies did not reach the equilibrium state in the 12th week or even at the end of the experimental period. Among them, the supply under the government's call policy was the slowest, followed by the production of enterprises, the reserve of enterprises entrusted by the government, and finally the import by the government.

The above phenomena show the importance of adopting comprehensive policies to regulate and control the supply and demand of goods and materials. To raise and reserve goods and materials, entrusted enterprise reserves and imports from other countries can greatly reduce the time to reach the balance of supply and demand. However, only adopting a single policy will slow down the response time and speed of demand. The comprehensive control policy will make the supply and demand balance more than twice as fast as other single control policies. During peacetime, relevant government departments need to plan material reserves to meet the peacetime and wartime demands more quickly in case of emergencies. In addition, the production and supply of enterprises are important material supply channels. During wartime, we can increase the subsidies to enterprises and subsidize their ability to change production and raw material procurement or production capacity.

4.3.3 Analysis of the influence of different parameters on the capacity and supply

We pay attention to the influence of publicity on the ability of the government to secure materials. The simulation results are shown in Fig. 10. The abscissa represents the days of dispatching and regulating materials, and the ordinate represents the capacity of increasing materials. The green, red, and blue lines in Fig. 10 represent the curves of the government's ability to recruit and transfer civilian materials with the time of material regulation when the publicity efforts are 0.1, 0.3, and 0.5 (effort 1, effort 2, and effort 3), respectively. Although the three curves of the government's ability to collect and transfer civil materials are from high to low, the time for the collection and transfer ability to flatten is different, and the initial values of the collection and transfer ability are also different. When the publicity effort is 0.5, the collection and transfer ability is the strongest, the initial value is the highest, and the time for the collection and transferability to flatten is around the 13th week. When the publicity effort is 0.1, the ability of recruitment is the weakest, and the initial value is the lowest. The ability of recruitment tends to be stable for approximately 11 weeks. In general, the larger the proportion of publicity cost, the stronger the government's ability to collect and transfer civil materials, and the stronger the sustainability of the ability. The results show that the publicity cost of the government to the public affects the ability of material collection and transfer and the time when the ability of material collection and transfer tends to be stable.

Then we study the impact of inflation rate on the

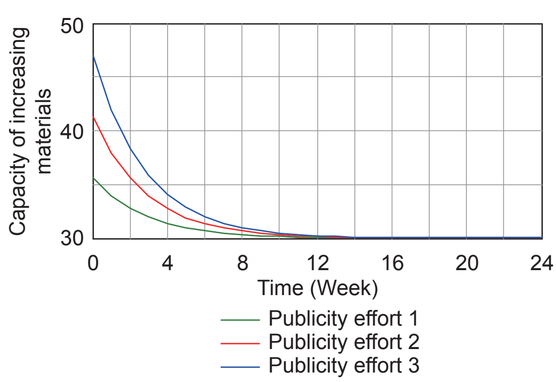

Fig. 10 Comparison of the government's ability to collect and transfer materials under different publicity costs.

import of goods and materials. Considering that the price rises rapidly when the emergency occurs, this paper divides the inflation rate into three levels, in which the corresponding inflation rate of inflation 1 is 0.037, which is the real data of 2020. The corresponding inflation rate of inflation 2 is 0.08. Inflation 3 corresponds to an inflation rate of 0.13. It can be seen in Fig. 11 that the change range of material import volume curve under inflation 1 is the smallest, and the time for it to stabilize is about the 18th week. The curve of import volume under inflation 3 has the largest change range, and it reaches the stable time in the sixth week or so. According to the phenomenon, we can find the following rules: the smaller the inflation rate is, the smaller the import volume will be, and the longer the curve of import volume will be stable. When the inflation is higher, the import volume will be larger, but its impact on the import volume will be weaker.

Undoubtedly, the inflation rate affects the imports of goods and materials. Inflation is conducive to import. Inflation makes domestic prices more expensive, so a country has more willingness to buy other countries' products. Therefore, when the government chooses to import materials from other countries, it should consider the impact of the inflation rate on its import volume at that time. When the inflation rate is low at the time of the event, relevant government departments should consider the production and reserve of materials through other channels and ways to make preparations and plans in advance to ensure an adequate supply of materials.

5 Conclusion

Considering the demand of emergency materials during major events, this study uses the theory of system dynamics to build a regulation model of emergency

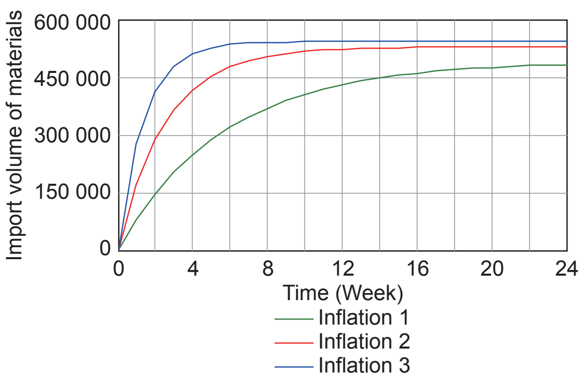

Fig. 11 Comparison of material imports under different inflation rates.

materials by considering the perspectives of peacetime and wartime. The model is based on five submodules: government reserve, enterprise reserve, enterprise production, government import, and government collection. Through the setting and regulation of relevant parameters, this study analyzes the impact of government measures on the quantity of emergency supplies and the impact of relevant parameters on the supply of emergency supplies from the combined perspective of peacetime and wartime.

Previous studies have only focused on the control of emergency supplies when an event occurs and on the emergency demand, ignoring the actual demands. Accordingly, from the perspectives of peacetime and wartime, the present study examines the scheduling problem of emergency materials, which focuses on the peacetime demand and wartime demand when an event occurs and the impact of a series of government preparations (including the establishment of government reserve warehouse and entrusted enterprise reserve) before an event.

Based on the results, we can formulate the following conclusions: (1) The higher the degree of emergency, the higher the cost of government expenditure, and the longer the duration of expenditure. At the same time, the higher the degree of emergency, the larger the deviation curve of material supply and demand, the longer the response time to demand, and the faster the growth trend of material supply. (2) It takes more than twice as long for the government to achieve the balance of supply and demand through a comprehensive regulation than other regulation methods. (3) The promotion of publicity will greatly increase the number of civil materials collected by the government. Therefore, in an event with a strong degree of emergency, relevant government departments can increase the publicity to increase the material supply of the additional module. (4) The higher the inflation rate, the higher the government's material imports, which will affect the supply of emergency materials. Therefore, the impact of inflation on the import submodule should be taken into account when regulating materials.

In future research, we can discuss more different attributes into the category of system characteristics and can study cross-regional material allocation from the perspectives of peacetime and wartime.

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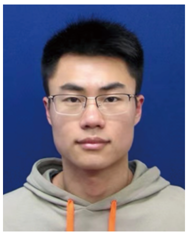

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