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Article

A Simulation Study of General Aviation Cargo Policy in China: A System Dynamics Perspective

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Abstract: Currently, addressing the imbalances in the development of domestic general air freight and public aviation freight formats, as well as the imperfections in policies, regulations, and systems, is crucial. This study employs system dynamics theory as its research method to con-struct a dynamic model of China's general aviation freight system. By examining the supply side, demand side, and the general aviation freight industry chain, the study illustrates the feedback relationships within general aviation freight and establishes an indicator system. Using Ven sim PLE software, the research creates causal relationship diagrams of the main subsystems and an overall system flow diagram. The model is quantitatively specified through historical and sensitivity testing. The findings indicate that varying levels of financial in-vestment and tax preferential policies significantly enhance the economic benefits of navigation and freight in China. Additionally, increased investment in scientific research funding is expected to advance the technical level of navigation operations. Therefore, it is recommended to boost investment in general air freight, implement preferential tax policies for air-craft manufacturing enterprises, navigation operating enterprises, and infrastructure support units, increase investment in R&D for the general cargo transport industry, and focus on the training and incentivization of navigation professionals.

Keywords: general aviation cargo; system elements; system dynamics; policy

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1. Introduction

With the rapid growth of the Chinese national economy and the expansion of the aviation market, the volume of goods transported in the civil aviation industry has continued to increase. By December 2023, the industry had handled 7.354 million tons of goods. While the growth rate has slightly slowed from the peak levels seen during the epidemic period, it has rebounded to 97% of the levels observed in 2019. The rise of e-commerce and modern logistics underscores the increasing importance of air freight, meeting extensive industrial and market demands. Despite its relatively limited coverage currently, general aviation freight plays an indispensable role in China's air freight sector. However, compared to research on air freight, both domestically and internationally, there has been comparatively less focus on general aviation freight.

In recent years, China has seen significant advancements in short-distance transportation and drone logistics. However, policies, regulations, and industry standards pertaining to general aviation freight are still underdeveloped. The “General Aviation Management License Management Regulations“ implemented from 01 January 2021, marked the initial inclusion of “General Aviation Freight” in regulatory frameworks. Despite these steps, the existing models for cargo transportation do not adequately align with those for general air freight.

According to the plan of the Civil Aviation Administration, the merger and revision of 275 international freight rules into 274 rules, now renamed as the "Regulations on the Management of Public Airlines Fortune Transportation” is expected to have a significant impact. At the national strategic level, it was emphasized in September 2020 that building a modern circulation system is a fundamental task for the national economy.

In this context, “building a high-quality civil aviation powerhouse and contributing to Chinese-style modernization” has emerged as a new mission for the civil aviation industry. As an emerging strategic sector, General Aviation plays a crucial role in socioeconomic development and is pivotal for the high-quality advancement of aviation. During the COVID-19 pandemic, General Air Cargo demonstrated its unique social value, such as the flexible deployment of SF drones in epidemic prevention and control, providing crucial support for transporting emergency medical supplies. However, the unregulated growth of the market and the inseparableness of the logistics system may lead to safety incidents and pose significant negative impacts on the air freight market.

In light of this, in-depth research on general air freight policies is particularly necessary. The main methods currently adopted by the Institute of General Aviation Freight have been significantly affected by temporal factors, which greatly weaken their effectiveness in policy research. To address these deficiencies, a more effective method must be developed to tackle the development of general air freight under the influence of various complex factors. This approach should provide decision-making support, offer a scientific basis for studying the standards and regulations of general aviation freight, and promote the healthy, efficient, and sustainable development of the general aviation freight industry. System dynamics can effectively quantify the interrelationships between various influencing factors. By establishing a system dynamics model, we can study the current status of China's general air freight development and analyze the impacts of policy adjustments in this sector. This method will facilitate a comprehensive understanding of the dynamics at play and support the formulation of robust policies and regulations to foster the growth of general air freight in China.

2. Literature Review

Many scholars have studied the development of air cargo transportation and there are many findings. Kupfer explores the impact of air cargo yields and oil prices in modeling global air cargo development [1]. This study offers insights into the future development of air cargo, with forecasts extending to 2023 based on air cargo demand and various scenarios. Chu summarizes and analyzes the development of the air cargo industry by comparing changes in indices such as CTK (Cargo Tonne Kilometers) and CLF (Cargo Load Factor), providing an overview of the air cargo industry’s recovery and operational adjustments post-pandemic [2]. This work highlights the development of both the global and domestic air cargo industries in 2020 and briefly examines trends for 2021. Wang explores the current state of China’s aviation industry, focusing on the opportunities and challenges in sustainable green investment in the air cargo sector [3]. Gong analyzes the business structure of China’s air cargo industry, summarizing its overall development characteristics and proposing strategies to leverage economic growth momentum during the pandemic for high-quality development in the air cargo sector [4].

Maintaining good social traffic order and formulating and implementing transport policies are key to ensuring social traffic order and realizing the Government's management of transport. An in-depth study of transportation policy helps to analyze the link between policy and the development of air cargo transportation. Wang describes the current situation and prospects of China’s air cargo industry, detailing current policies and the future direction, with a particular focus on green investing and sustainable transportation in the air cargo sector [5]. Yamaguchi examines the impact of transportation policies, such as the opening up of airspace, on trade and analyzes U.S. air cargo policy by using the number of air cargo exports as a metric [6]. Hu emphasizes the close relationship between air cargo development and national economic development, noting that China’s air cargo industry is still in its early stages and providing policy recommendations to accelerate its growth [7]. Domingues studied the air cargo security policies and regulations of

ICAO, the United States, and the European Union, assessing their effectiveness in ensuring safety in global air cargo transportation [8]. Liang analyzes the challenges of air cargo integration in the Yangtze River Delta, combining the region's actual freight transport situation with policy and development strategies [9]. Most scholars study air cargo in terms of the cargo market and its development, route network structure, cargo products, and benchmarking against high-speed rail cargo, among other areas. However, there are fewer studies focused on related policies. While there are some scattered studies on air cargo security policies, there are very few studies specifically related to general aviation cargo policies.

The system dynamics (SD) approach seeks to identify the root causes of problems from the internal structure of the system by studying the causal relationships between its constituent elements. This method describes the interaction and dynamic trajectory of these elements, making it particularly suitable for addressing complex socio-economic problems that span long time periods, suffer from insufficient data, and have low precision requirements. Wang investigates solid waste management using the SD classification policy [10]. Rees et al. applied the SD model to explain the causal relationships proposed by the Delphi method in the study of global transportation transformation, focusing on factors that drive business as usual and those that create barriers [11]. Vega and Bautista-Rodriguez developed a system dynamics model to predict the link between landfill capacity and recycling efficiency, considering demographic, economic, and waste recycling perspectives, using Singapore as a case study [12]. The development of the aviation industry is a complex and interactive process, and system dynamics modeling plays an important role in studying various impacts on civil aviation. Gavra et al. used the SD model to construct a game model for general aviation safety regulation, performing simulation analysis under static and dynamic strategies [13]. Liu Hang established an SD model of the air cargo service system at Zhengzhou Airport, providing a basis for the establishment of a comprehensive customer feedback system through empirical simulation [14]. Ghadge et al. analyzed the causal relationship between the traditional aviation spare parts supply chain and the supply chain after the introduction of 3D printing technology, using system dynamics to assess its impact [15]. He constructed a system dynamics model of both the traditional and 3D printing supply chains to conduct simulations and analyze the main influencing elements of the entire system. System dynamics has seen growing application in the aviation sector, focusing primarily on enhancing the performance and optimization of aviation engines, improving the efficiency and stability of aviation network structures, assessing risks related to aviation safety, and optimizing the management of aviation spare parts supply chains. However, research into the application of system dynamics in general aviation cargo remains in its nascent stages, lacking systematic and thorough exploration. Studies in the field of general aviation cargo are crucial for enhancing operational efficiency and reducing enterprise operating costs.

3. Methods

The rapid development of China's general aviation market and the government's increasing emphasis on this sector — evidenced by increased subsidies and the construction of new general-purpose airports — along with continuous advancements in manufacturing, operations, and support services, contribute to the dynamic complexity of China's general aviation freight industry. These influencing factors form interconnected feedback systems, necessitating the formulation of a comprehensive, systematic framework to study the complexity of China's general air freight system. System dynamics modeling is a widely used method for understanding dynamically complex systems governed by feedback loops. By applying system dynamics, we can effectively analyze and quantify the interrelationships among the various factors influencing general aviation freight, thereby gaining insights into the development of this sector and supporting informed decision-making.

Therefore, we use system dynamics methods to simulate the dynamics of general aviation freight systems. By analyzing both supply and demand sides, we decompose the general aviation freight system based on specific points within the aviation industry chain, addressing the balance and synergy of general aviation freight supply and demand. The general aviation freight system is a complex socio-technical system. A problem-oriented approach helps to identify and solve key challenges within this system, while a process-oriented approach aids in understanding the organization and relationships of different processes or activities. Focusing on the supply and demand of the research objects provides a powerful analytical framework for an in-depth understanding and improvement of the general aviation freight system. However, comprehensively covering the system's multi-dimensional characteristics remains challenging. Therefore, we combine the principles of problem-oriented and process-oriented approaches to systematically analyze and divide the system.

3.1. Causal Loop Diagram

The causal loop diagram (CLD) is an important tool for system feedback analysis. The diagram contains multiple influencing factors, each connected by arrows that indicate their causal relationships [16]. This visual representation helps to analyze the dynamic effects between various variables in the system, providing a clear view of the system's structure. A CLD has four main components: Causal Relationships: Represented by arrows, showing the direction of influence between variables; Variables: The elements that are affected within the system; Loop Polarity: Indicated by positive (+) or negative (-) symbols, showing whether the change in one variable causes an increase or decrease in another variable; Loop Identification: The process of identifying and labeling feedback loops within the diagram. These components collectively help in understanding and visualizing the interdependencies and feedback mechanisms within a system.

In this section, we use the causal loop diagram (CLD) to explore the causal relationships between various variables. Regional economy, domestic trade, general aviation freight supply capacity, and general air freight demand are interconnected influencing factors. These factors establish a dynamic and complex system. Figure 1 shows the causal loop diagram of General Aviation Freight. The CLD represents the causal relationships between variables, and we have identified four feedback loops within the system:

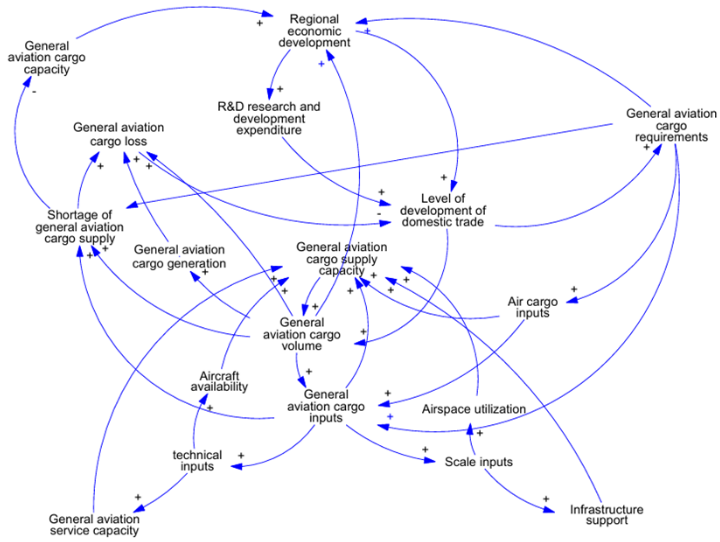

Figure 1. general air cargo causal loop diagram.

The CLD represents the causal relationships between variables, and we have identified four feedback loops within the system:

1) Economic-Domestic Trade and General Air Freight: This loop illustrates how economic factors influence domestic trade and general air freight.
2) Economy-Domestic Trade and General Air Freight Demand: This loop shows the relationship between economic conditions, domestic trade, and the demand for general air freight.
3) Economic and General Aviation Freight Supply and Demand: This loop represents the interaction between economic factors and the balance of supply and demand in general aviation freight.
4) Economy and General Aviation Freight Supply Capacity: This loop highlights how economic factors affect the supply capacity of general aviation freight.

Through these feedback loops, the CLD provides a clear visualization of the interdependencies and dynamic interactions within the general aviation freight system.

1) Causal Loop Diagram 1: Economy - Domestic Trade and General Air Cargo

The diagram illustrates the feedback relationship between regional economic development, domestic trade, and general air cargo supply. As regional economic development increases, it stimulates the growth of domestic trade, which in turn accelerates the demand for general air freight. This increased demand necessitates a rise in supply; however, when supply is limited, the imbalance between supply and demand can reduce the capacity for general aviation cargo. This reduction in capacity negatively impacts regional economic development, thus completing the feedback loop. Furthermore, improvements in general aviation freight capacity can, to some extent, stimulate further economic growth.

2) Causal Loop Diagram 2: Economy - Domestic Trade and General Aviation Cargo Demand Capacity

This diagram highlights the feedback relationship between regional economic development, domestic trade, and general aviation cargo demand capacity. As regional economic development increases, it leads to higher investments in and outputs from high-tech industries, enhancing domestic trade. As both domestic trade and high-tech industries grow, the demand for aviation cargo transportation rises, which further stimulates regional economic development.

3) Causal Loop Diagram 3: Economy and General Aviation Cargo Supply and Demand

This diagram illustrates the feedback relationship between regional economic development, general aviation cargo requirements, and air cargo supply and demand. As regional economic development increases, it raises general aviation cargo requirements, which subsequently increases air cargo and general aviation cargo inputs. These increased inputs enhance the general aviation cargo supply capacity, which in turn boosts cargo volume. The higher cargo volume supports continued regional economic growth.

Investment in air freight, driven by regional economic growth, positively influences the supply capacity of general aviation cargo. As certain transport airports accommodate both commercial and general aviation aircraft, investments in both sectors contribute to an increased supply capacity for general aviation freight. This creates a positive correlation between investment and supply capacity: the greater the supply capacity, the higher the volume of air freight, which ultimately supports continued economic growth.

4) Causal Loop Diagram 4: Economy and General Aviation Cargo Supply Capacity

This diagram emphasizes the feedback relationships influencing the supply capacity of general aviation cargo. As supply capacity increases, cargo volume rises, leading to higher general aviation cargo inputs. These inputs then enhance technical inputs and improve service capacity, which reinforces cargo supply capacity, creating a positive feedback loop.

The diagram also shows how higher cargo supply capacity leads to a greater volume, which further increases cargo inputs. These inputs drive an expansion of operational scale, supported by infrastructure improvements. As infrastructure grows, it further boosts the supply capacity, reinforcing the system.

This process is driven by two primary investments: technological and scale-related. Investments in airport infrastructure and operational scale enhance the supply capacity of general air freight by expanding airport capabilities. Larger operations promote more take-offs and landings of cargo aircraft. Meanwhile, technological investments enhance the service capabilities of general aviation operators and improve air freight infrastructure efficiency, fostering further growth in the general aviation cargo sector.

3.2. Stock and Flow Diagram

The Stock-flow Diagram (SFD) captures mathematical relationships between variables. A stock and flow diagram provide the framework for model simulations. Figure 2 illustrates the Stock-Flow Diagram (SFD) that represents the model. Model variables are categorised as stock, flow, and auxiliary. A rectangular box symbolises stockvariables, whereas a valve symbol represents flow variables, and no symbol is used for auxiliary variables. A stock variable represents the level or inventory value at a given time. The flow variable expresses the rate of quantities changes to or from a given stock. It is always expressed as a function of time. Stock variables are changed based on variations in flow variable values. Clouds outside the model boundary represent the source or sink of the flow variable.

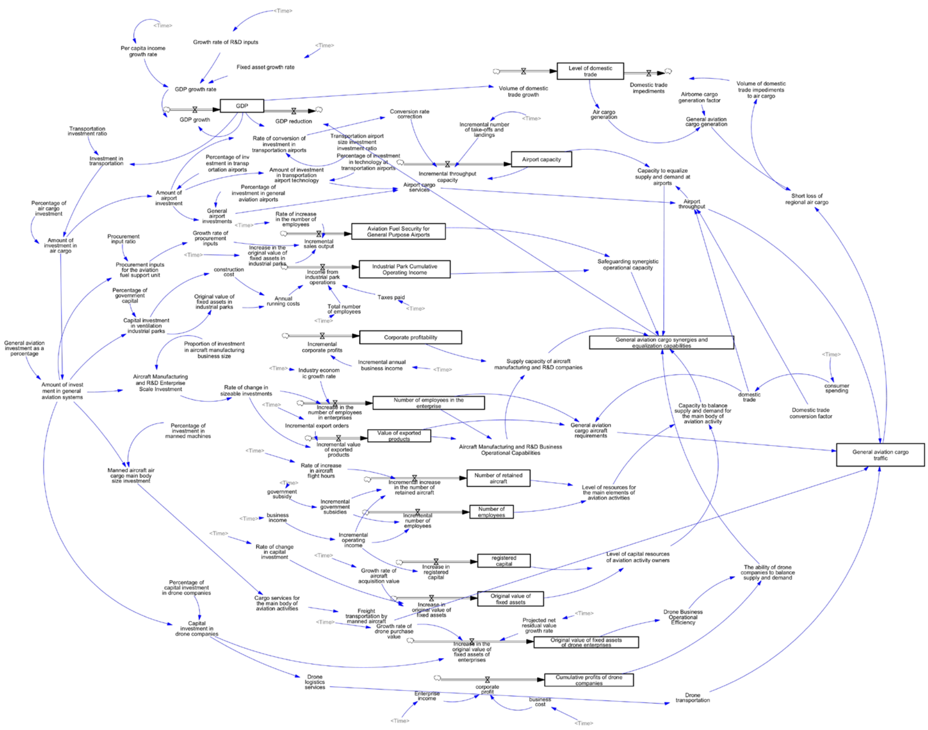

Figure 2. Stock-flow diagram.

In China's General Aviation Cargo SFD Model, the feedback loop primarily manifests from the perspective of supply and demand. It encompasses three main subsystems: the economic subsystem, domestic trading subsystem, and the general aviation industry chain subsystem. Within the industrial chain-oriented framework, the general aviation industry chain subsystem is further divided into aircraft manufacturing, general aviation operations, and infrastructure support subsystems. For a detailed explanation of model variables, please refer to Appendix A.

4. Results and Discussion

We use Vensim Software to develop the model that is simulated for 15 years with INITIAL TIME = 2015, FINAL TIME = 2029, and step being 1 year. This section explores the impact of external factors on supply and demand perspectives through scenario analysis in China's general aviation freight system. It examines how external factors influence aircraft manufacturing, drone enterprises, and airport operations through simulations involving demand, funding, and technology-oriented policies. The analysis identifies distinct effects of various policy types and proposes relevant policy recommendations based on simulation outcomes, aiming to guide policymakers towards more targeted policy optimizations.

4.1. Model Validation

The testing and analysis of the model comprise a systematic quantitative consistency test and a behavioral test. The consistency test was conducted using Vensim software, focusing on measuring model coherence. Subsequently, the behavioral test was divided into two parts: a historicity test and a sensitivity test.

4.1.1. Historicity Test: GDP Test

While the accuracy of system dynamics forecasting is limited, it provides an intuitive reflection of the overall system's development trends. Therefore, it is validated against historical national GDP data, with verification typically falling within an acceptable range (usually less than 15%). This demonstrates consistency between the GDP data and historical trends, confirming the validity of the model. Table 1 presents the main evaluation indicators and simulation results of the model.

Table 1. GDP Historical Test.

Year	GDP in real terms (billions of dollars)	GDP simulation (billions of dollars)	inaccuracies
2015	685,571	685,571	0.000
2016	742,694	729,005	0.018
2017	830,945	779,060	0.078
2018	915,243	855,128	0.066
2019	983,751	921,064	0.064
2020	1,005,451	993,224	0.012
2021	1,141,231	1,008,030	0.117
2022	1,197,250	1,149,860	0.040

Given that general aviation freight is still in its early stages of development, its stability is relatively low, resulting in significant discrepancies between actual values and predicted values. However, the overall trend is roughly consistent, indicating that the simulation results are applicable to real-world scenarios. For specific inspection results, refer to Table 2.

Table 2. Aircraft Quantity Tests for Owned Aircraft.

Year	Actual number of aircraft	Simulated values for the number of aircraft	inaccuracies
2015	13	13	0.000
2016	31	34	0.097
2017	41	54	0.317
2018	59	72	0.220
2019	135	90	0.333
2020	104	109	0.048

2021	160	129	0.193
2022	177	166	0.062

4.1.2. Sensitivity Test

We conducted a sensitivity test on GDP as a behavioral variable by analyzing its impact under extreme conditions. Specifically, we simulated scenarios where the GDP growth rate is set to 0 and compared it with simulations using conventional growth rates, as depicted in Figure 3. When the GDP growth rate is set to 0, the regional economy exhibits a gradually declining linear trend, whereas historical growth rate settings result in a curved shape. This simulation validates that the system behaves as expected under sensitivity testing.

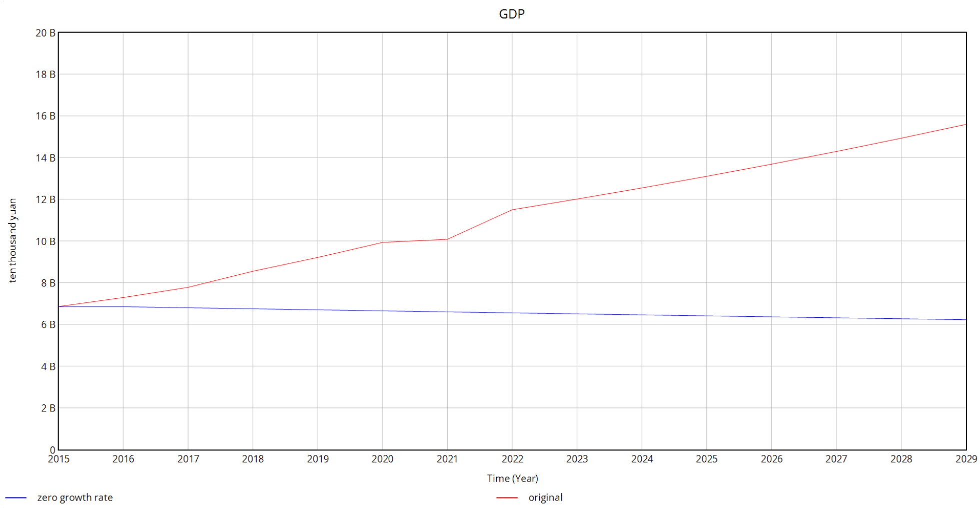

Figure 3. Simulation of GDP sensitivity test.

On the basis of the dynamic model and inspection of the Chinese General Air Cargo System built above, we conduct system simulation results analysis, and then combine the simulation analysis results to complete policy simulation through different scenarios.

4.2. Policy Needs Analysis Design

When designing a comprehensive air freight policy, the primary focus should be on ensuring policy quantification and data acquisition, which form the basis for effective policy formulation. The main impacts of policies can be categorized into aircraft manufacturing and research and development enterprises, infrastructure providers, general aviation operators, and customers. The needs and feedback from these groups directly influence policy formation and adjustments.

For enterprises, policies should prioritize economic benefits, technical advancements, and operational management improvements. This can be achieved through measures such as financial subsidies and support for research and development, aimed at enhancing service capabilities and market competitiveness.

For customers, policy design should ensure price competitiveness and high service quality to enhance customer satisfaction.

To streamline policy direction and implementation, policies can be categorized into three types: economy-oriented, focused on meeting specific market demands; fund-oriented, aimed at easing economic pressures on enterprises; and technology-oriented, geared towards promoting technological advancements and sustainable development.

This classification enables policymakers to address industry-specific challenges effectively, ensuring policies are tailored to meet diverse needs and promote overall industry growth.

One of the critical functions of system dynamics is conducting policy simulations. This process entails adjusting key input variables within the model to simulate the potential impacts of policy changes represented by these variables on other output variables within the system. In this section, Vensim software is utilized to perform simulation analyses, exploring how various policy changes influence the operational effectiveness of China's general aviation cargo system.

4.2.1. Demand-Oriented Policy Impact Simulation

Demand-oriented policies primarily focus on stimulating market demand and influencing customer preferences. These policies aim to directly increase market demand for products and services, thereby promoting market expansion and consumer acceptance. By enhancing product appeal and marketing efforts, these policies can directly impact the sales and market share of enterprises. Additionally, increasing the competitiveness of export products can expand market share and enhance the export value of enterprises.

In this study, market demand factors are primarily reflected in the economic environment, such as the operating income of the General Aviation Industrial Park. By adjusting system parameters and keeping other variables constant, control variables are modified to reflect changes in demand. For policy impact objects, such as aircraft manufacturing enterprises and industrial parks, the value of export products can be adjusted to reflect incremental changes, while the operating income of the General Aviation Industrial Park can be adjusted to reflect changes in the number of employees and taxes paid.

The design of demand-oriented policies includes two scenarios: one without policy intervention and one with the implementation of demand-oriented policies. By comparing the economic benefits of aircraft manufacturing enterprises and General Aviation Industrial Parks in both scenarios, the effectiveness of demand-oriented policies can be evaluated.

Scenario 1: The subsidy ratio for export orders is 2%.

Scenario 2: Employee subsidies, where the number of enterprise employees increases by 20%, and the subsidy ratio increases by 2%.

Scenario 3: Tax subsidies, where enterprises pay 20% more in taxes, and the subsidy ratio increases by 2%.

As shown in Figure 4 during the simulation period, it can be observed that both the employee subsidy and tax subsidy scenarios have a significant impact on the economic benefits of the General Aviation Industrial Park. The implementation of demand-oriented policies can enhance the economic benefits of the Aviation Industrial Park. In particular, these policies help improve economic outcomes within the park and stabilize market conditions. By 2023, the economic benefits under these policies reach a steady state, which is higher than those under current policies.

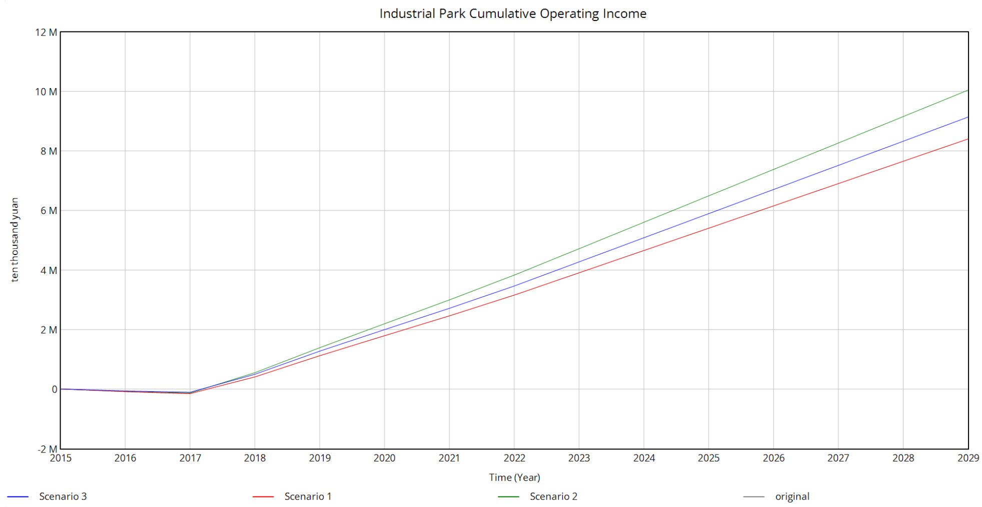

Figure 4. Simulation Results of Operating Revenues of the General Aviation Industrial Park under Demand-Oriented Policies.

4.2.2. Simulation of the Impact of Fund-Oriented Policies

Fund-oriented policies provide direct economic support to help enterprises optimize their cost structures and increase investment, thereby improving profitability and market development capabilities. These policies support the capital needs and financial requirements of enterprises through financial incentives, such as increased investment, ensuring financial stability.

We focus on the impact of changes in general aviation cargo input funds on the economic benefits of Chinese aircraft manufacturing and general aviation operating enterprises (including traditional aviation activity subjects and drone companies). This impact is reflected in the system regulation parameters, with other variable parameters held constant while adjusting the control variable.

Output variable selection: drone cargo volume, general aviation cargo volume

The current proportion of state financial investment in general aviation cargo is low, accounting for only 0.01% of air cargo transportation. Therefore, the investment in general aviation cargo will be increased by 1%, 2%, and 3% on the original basis. By comparing the development trends of UAV cargo volume and general aviation cargo volume under the four scenarios — no increase in investment, and increases in investment proportion by 1%, 2%, and 3% — the simulation results are shown in Figure 5 to Figure 6.

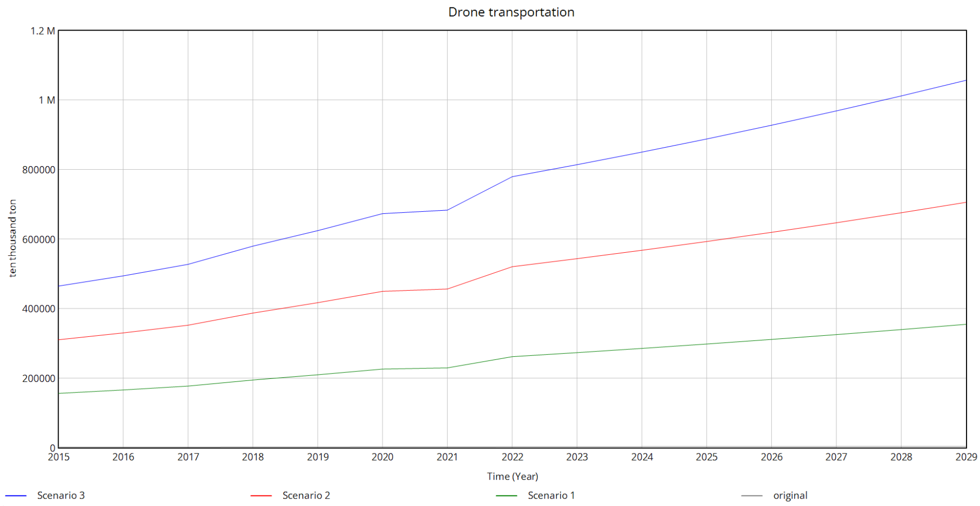

Figure 5. Cumulative simulation results of drone freight traffic under the subsidy policy.

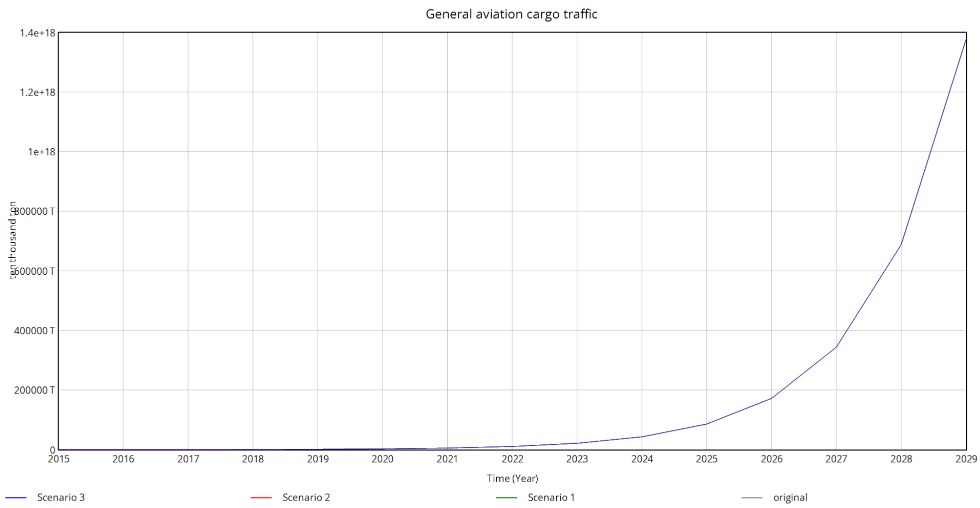

Figure 6. Simulation results of general aviation cargo volume under subsidy policy.

According to the simulation results from Figure 5 to Figure 6, maintaining unchanged parameters shows that the proportion of investment in general aviation freight has a minor impact on the total shipping volume of general aviation but significantly boosts development. Specifically, increasing the investment in general aviation freight policy has amplified the volume of freight handled by drones, thereby fostering the growth of drone logistics in China. This underscores that a judicious increase in the general aviation freight investment policy is an effective strategy to propel the development of the general aviation freight industry.

4.2.3. Technology-Oriented Policy Impact Simulation

The technical-oriented policy focuses on the impact of research and development (R&D) funding on the technological advancement and operational efficiency of airports and general aviation operating companies. Given that funding for airport and general aviation development primarily comes from government sources, the amount of R&D funding becomes a critical control variable in the model. In this context, government funding injections are the main influencing factors affecting R&D funding levels.

Based on current statistics, the government's annual growth rate for airport and general aviation development is set at a specific percentage. Therefore, this study establishes two scenarios to investigate the potential impact of different levels of government support on technology and operational capabilities:

Scenario 1: Increase R&D funding by 5%.

Scenario 2: Increase R&D funding by 10%.

Comparing these scenarios with the baseline case (no increase in R&D funds), the simulation examines how these funding increases affect the technological and operational capabilities of airports and general aviation operating enterprises.

The selected output variables include general aviation cargo generation, aviation fuel assurance at general airports, and collaborative operational capabilities. These indicators are crucial for comprehensively evaluating the effects of increased scientific research funding on the operation and assurance capabilities of the general aviation freight system. This evaluation aims to provide a scientific basis for policy formulation.

Figure 7 shows that technical-oriented policies positively impact universal air freight production volumes, particularly with a 10% increase in technology investment leading to significant growth. In Figure 8, current policies indicate a slow growth in aviation oil assurance levels. Implementing technical-oriented policies, especially with a 10% increase in R&D funding, significantly improves oil assurance levels. Figure 9 reveals that excessive R&D investment may hinder coordinated operational capabilities in general air freight assurance. This underscores the importance of balancing technical investments to effectively manage aviation oil supply shortages. In summary, these simulation results emphasize the role of technical-oriented policies in enhancing operational capabilities and infrastructure within the general aviation sector. They highlight the need for targeted technological investments to foster industry growth and efficiency, emphasizing the importance of maintaining a balanced approach to investment.

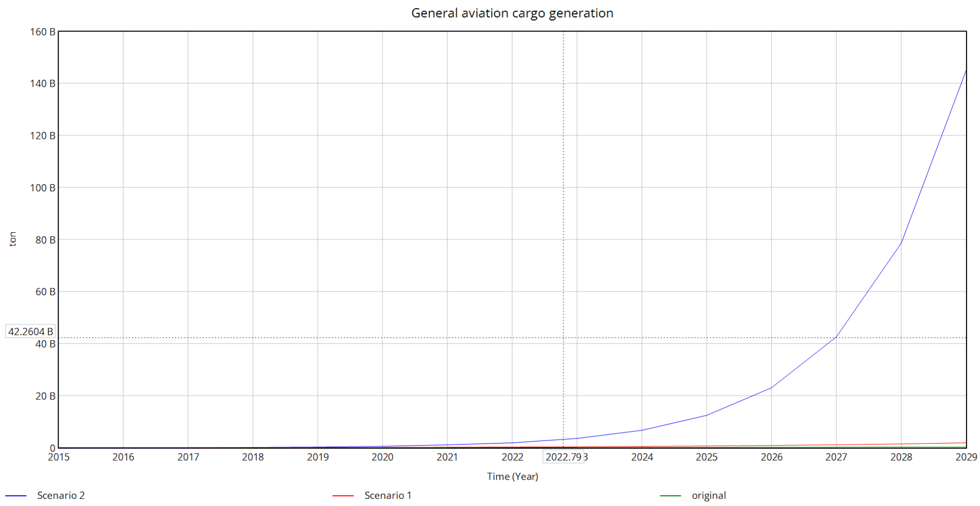

Figure 7. Simulation results of general aviation cargo generation under technology-oriented policies.

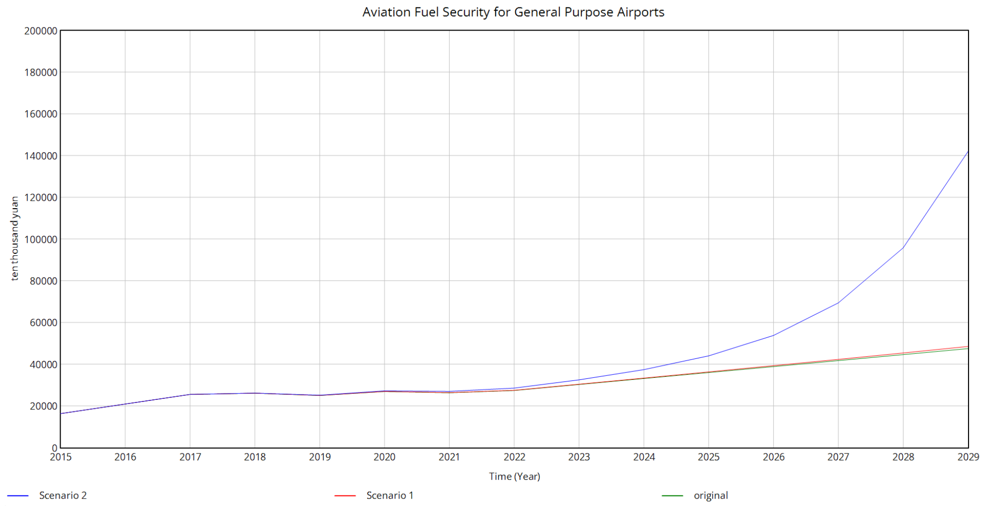

Figure 8. Simulation Results of Jet Fuel Security at General Purpose Airports under Technology-Oriented Policies.

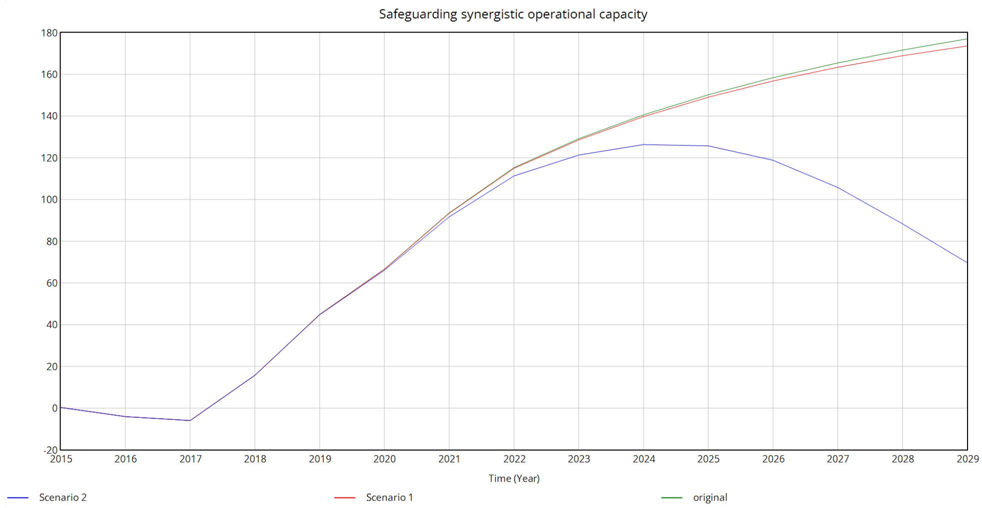

Figure 9. Results of the simulation of safeguards synergistic operational capacity under technology-oriented policies.

4.3. Policy Recommendations

Based on the simulation results, the implementation of demand-oriented, fund-oriented, and technical-oriented policies has a positive impact on Chinese General Air Cargo. In light of these findings and considering the current state of China's general aviation cargo industry, the following suggestions are proposed:

1) Demand-Oriented Policy:

Improve export product subsidy policies: Strengthen incentives within the General Aviation Industrial Park to provide a broader market-driven force. This will ensure that aircraft manufacturing and service companies can meet the evolving market demand.

Precise incentives: Utilize precise incentives to enable the General Aviation Industrial Park to fully leverage its role in resource integration and technological innovation.

2) Fund-Oriented Policy:

Increase subsidies: The state should continue to provide subsidies for general air freight and appropriately increase the support ratio.

Cost reduction and Investment Incentives: Lower corporate costs to encourage increased investment in innovation and improve the synergies within the general aviation freight system.

1) Technical-Oriented Policy:

Boost R&D investment: Increase technical research and development investment for airports and drone companies to maintain technological leadership.

Application of new technologies: Apply new technologies to sectors like aviation oil assurance to improve general aviation freight generation. This will enhance the technological competitiveness of the entire industry, resulting in higher benefits and service quality.

These recommendations aim to create a robust framework for the continued growth and efficiency of China's general aviation cargo industry by addressing market demand, financial support, and technological advancements.

5. Conclusions

This article presents the following main conclusions through the analysis of the general aviation industry mechanisms and the factors influencing freight.

5.1. Economic Development Driver

Economic development is the fundamental driving force for the development of general aviation freight systems. GDP growth has promoted investment in related infrastructure, forming a positive feedback cycle between economic development and general aviation systems.

5.2. System Structure

The General Air Cargo System consists of three main subsystems: economic, domestic trade, and the general aviation industry chain. The system causality and flow diagrams reveal the complex mutual dependence and promotion relationship between subsystems, emphasizing the importance of coordinated development.

5.3. Simulation Prediction

Through system dynamic simulation, the long-term development trend of general aviation freight systems is predicted, showing that key capability indicators will exhibit a growth trend, and the system will continue to optimize and develop.

5.4. Policy Impact

Simulation analysis shows that different policies significantly impact the system's development. The comprehensive implementation of economic, technical, operational, and management policies can improve transportation capacity, freight efficiency, and service quality. This holistic approach is crucial for the continued growth and efficiency of the general aviation freight industry.

These conclusions highlight the interconnectedness of economic growth, system structure, and policy impact in fostering a robust and efficient general aviation freight system.

5.5. Future Directions for Further Research and Improvement

Model Refinement and Complexity: Future research should aim to develop more complex and refined model structures to better capture subtle changes and dynamics within the system. This could involve incorporating additional subsystems and feedback loops to account for multidimensional policy types, thereby enhancing the model's robustness and accuracy.

Integration of Interdisciplinary Approaches: Combining the system dynamics approach with methodologies from other disciplines, such as economic analysis and sociological research, can provide a more comprehensive perspective and deeper insights. This interdisciplinary approach facilitates a better understanding of the multifaceted factors in complex systems and the interactions between them.

Appendix A. Model variables

According to the selected variables, we obtained data from the past 10 years from the China Statistical Yearbook and various China General Aviation enterprises. Using SPSS software, we fitted the data to derive the following formula:

$$GDP\ reduction = GDP \times (0.999 + 0.001 \times General\ aviation\ cargo\ synergies\ and\ equalization\ capabilities) \times 0.001 \tag{A1}$$

$$GDP\ growth = GDP \times GDP\ growth\ rate \tag{A2}$$

$$GDP\ growth\ rate = EXP(8.743) \times Fixed\ asset\ growth\ rate^{1.531} \times Growth\ rate\ of\ R\&D\ inputs^{4.069} \times Per\ capita\ income\ growth\ rate^{-0.747} \tag{A3}$$

$$Volume\ of\ domestic\ trade\ growth = 0.486 \times GDP - 6750.49 \tag{A4}$$

$$Domestic\ trade\ impediments = 0.01 \times Volume\ of\ domestic\ trade\ impediments\ to\ air\ cargo \tag{A5}$$

$$Incremental\ corporate\ profits = 0.192795 \times Incremental\ annual\ business\ income - 12682.2 \tag{A6}$$

$$Incremental\ value\ of\ exported\ products = 775{,}435 \times Rate\ of\ change\ in\ sizeable\ investments - 0.067436 \times Incremental\ export\ orders - 40{,}615.5 \tag{A7}$$

$$Airport\ cargo\ services = \big((Amount\ of\ investment\ in\ transportation\ airport\ technology + General\ airport\ investments) \times 3.619 \times 10{,}000 + 860{,}966\big) \times 0.2 \tag{A8}$$

$$Income\ from\ industrial\ park\ operations = 70.2804 \times Total\ number\ of\ employees + 48.9176 \times Taxes\ paid - 1328.13 \times Annual\ running\ costs + 563{,}972 \tag{A9}$$

$$Increase\ in\ the\ number\ of\ employees\ in\ enterprises = -30{,}443.7 \times Rate\ of\ change\ in\ sizeable\ investments + 64{,}969.6 \times Industry\ economic\ growth\ rate - 4996.41 \tag{A10}$$

$$Incremental\ increase\ in\ the\ number\ of\ retained\ aircraft = 0.022 \times Rate\ of\ increase\ in\ aircraft\ flight\ hours + 6.1e-05 \times Incremental\ operating\ income - 0.003 \times Incremental\ government\ subsidies + 16.536 \tag{A11}$$

$$Drone\ transportation = 365 \times 4 * 0.01 \times Drone\ logistics\ \frac{services}{10000} \tag{A12}$$

$$Incremental\ sales\ output = -11{,}719.8 \times Rate\ of\ increase\ in\ the\ number\ of\ employees + 2.16835 \times Increase\ in\ the\ original\ value\ of\ fixed\ assets\ in\ industrial\ parks + 4420.73 \times Growth\ rate\ of\ procurement\ inputs + 277.529 \tag{A13}$$

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