Research on the Dynamic Evolution Mechanism of Airline Operation Support Capabilities in the Post-Pandemic Era

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ABSTRACT

To tackle the evolving dynamics of operational support capabilities for airlines in the post-pandemic landscape and to effectively improve these capabilities, a system dynamics model was devised to delineate the intricate interplay among internal factors affecting aviation operational support. This model acts as the groundwork for understanding the dynamic evolution of these capabilities. Following the model's analysis and development, case studies from S Airlines were incorporated and tested, confirming that insufficient operational support capabilities restrict airline growth. Four investment plans designed to boost airline operational support were comparatively evaluated to ensure airlines can scale while accommodating new support requirements. VENSIM software was utilized to simulate and assess these models, selecting the investment strategy offering the greatest overall return to enhance operational support for airlines.

Keywords: Airlines, Operation support capability, Dynamic evolution mechanism, System dynamics, Operational support demands, Civil aviation

1. Introduction

Since the deployment of the "Fourteenth Five-Year Plan" and proficient management of pandemic responses, China's civil aviation sector has progressively surmounted substantial challenges and achieved growth in recovery. The civil aviation market has consistently recovered, showing a positive trajectory for the sector. This resurgence is a notable turnaround for the global civil aviation industry [1,2].

In the post-pandemic period, prospects for consistent growth in aviation logistics supply are promising [3]. Nonetheless, this sector contends with intense competition from other transportation modes, such as highways and railways [4]. Additionally, external influences like economic shifts, oil price instability, and exchange rate variations further compound the challenges for the industry [5]. To pursue "reasonable growth in quantity and effective enhancement," airlines must overcome these challenges to sustain operational support capability [6]. The Civil Aviation Administration of China, in its “Special Scheme for the Development of Aviation Logistics of the Fourteenth Five-Year Plan,” underscores that tackling the complexities of internal and external factors remains a significant challenge in China’s aviation logistics field [7,8]. Immediate attention is needed to resolve structural contradictions and institutional hurdles to foster sustainable growth [9]. As market demand slowly increases, airlines are faced with both opportunities and challenges in boosting their operational capabilities to satisfy the rising demands for passenger and cargo services [10,11].

At present, research on the operational support capability in the aviation industry, both domestically and internationally, is relatively sparse. Research specifically targeting the operational support capability of airlines is almost non-existent. In existing research on operational support capabilities, Yuan Jiang employed the DEMATEL analysis method to pinpoint the essential components of operational support capability at small and medium-sized airports [12]. Cao Kui, using the practical processes at GAMESO company, summarized approaches to strengthen the operational support capability of Chinese-made civil aircraft [13]. System dynamics is a scientific field that integrates system management theory with computer simulation to explore system feedback mechanisms and behaviors [14]. Based on the outlined research background, this paper primarily focuses on airlines and selects China’s S Airlines for a detailed case study. Starting from actual operational conditions, this study provides a comprehensive analysis of S Airlines’ operational resilience. It aims to develop a research framework for operational resilience at small and medium-sized airports and a system dynamics model that elucidates the complex relationships among internal factors impacting airlines’ operational support capabilities [15]. This model will lay the groundwork for grasping the dynamic evolution of airlines’ operational capabilities. Moreover, based on the analysis stemming from the constructed model, policy recommendations are offered to support airlines’ operational support capabilities, ensuring they can effectively meet the changing demands of transportation services and serve as guidance for airline operational management and decision-making.

2. Analysis of the Dynamic Evolution System of Airlines’ Operational Support Capabilities

The operational support of an airline functions as a dynamic system that impacts the management of numerous factors [16]. This article introduces two subsystems to examine the dynamic evolution mechanism influencing airline operation support capabilities: the airline operating subsystems and the airline operation support subsystems. Due to the influence of various internal and external factors, this article defines the system boundaries necessary to address the issues of airline operation support. It categorizes the following influencing factors as endogenous variables: fleet size, flight volume, passenger satisfaction, passenger rate, operating income, operating costs, profit, operational security capabilities, latent risks, and flight delays; and exogenous variables include policies, demands of civil aviation passengers, and per capita GDP.

2.1 Airline Operations Subsystem

The operations development subsystem maps an airline's scale and progression. At its core, it features a crucial linkage among passenger revenue, profitability, fleet size, flight volume, and passenger volume. This subsystem is depicted through a causal diagram, as shown in Figure 1, incorporating 5 external factors, 20 internal factors, and 3 causal loops.

Causal Loop 1: Increases in passenger revenue enhance profitability, which supports aircraft acquisition in line with profit-driven schemes, leading to fleet expansion and increased flight volume and passenger numbers. The rise in passenger numbers boosts passenger turnover and revenue.

Negative Causal Loop 2: Higher passenger revenue results in increased taxes, which decrease profitability. Despite this, aircraft acquisition continues based on profit-driven schemes, facilitating growth in fleet and flight operations.

Negative Causal Loop 3: Elevated operating costs and the pandemic's detrimental effects on profits influence aircraft acquisition and limit fleet expansion. Figure 1 also elucidates significant causal chains involving external factors, particularly how the growth rate of per capita GDP impacts air passenger demand, leading to aircraft acquisition. This analysis, along with Loop 1, shows a positive trend: as GDP per capita grows, it drives air travel demand, leading to fleet expansion, which in turn enhances crew and flight operations, boosting passenger traffic and revenue, thereby increasing profitability. This encourages more aircraft acquisitions, promoting continuous fleet growth.

Despite this, loops concerning costs and taxes moderate this expansion. As fleets grow, operating costs rise, and heightened revenue leads to higher taxes, both of which restrain profitability and thus limit fleet expansion. However, typically, revenue outweighs costs and taxes, thus favoring the positive loop at a micro level.

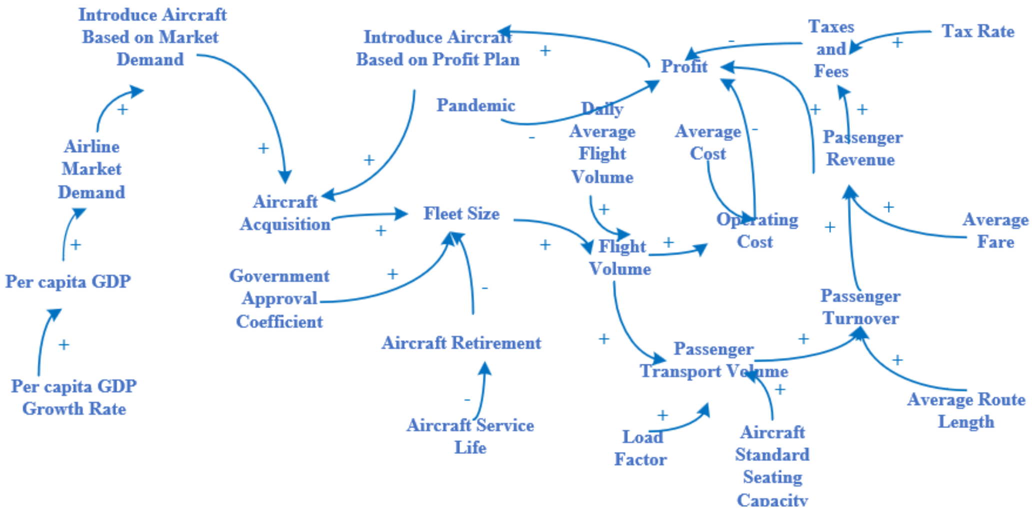

Figure 1. Cause-and-effect diagram of the airline operations development subsystem

Source: By authors.

2.2 Airline Operation Support Subsystem

The operational support system details an airline's internal framework, aimed at ensuring smooth flight operations. This subsystem utilizes the company's internal resources to support flight operations, reduce safety risks, and uphold cabin service standards. The operational support subsystem, Causality 2, includes 23 interconnected factors with 21 internal factors, 2 external factors, and 6 causal loops.

Causal Loop 1: Passenger revenue leads to investment in operational support, enhancing the support capability and level. Decreases in unnecessary delays reduce economic losses and maintain passenger revenue.

Causal Loop 2: Passenger revenue encourages investments in operational support, which increases the support capability and level, lowers the control rate of hazards, reducing safety risks. Decreased risks minimize accidents and losses, potentially lowering passenger revenue.

Causal Loop 3: Passenger revenue motivates investments in operational support, boosting support capabilities and levels, reducing flight delays, and enhancing passenger satisfaction. Increased satisfaction may increase passenger turnover, potentially reducing revenue.

Causal Loop 4: Passenger revenue initiates investments in operational support, enhancing support capabilities and levels, increasing hazard control rates, reducing safety risks. Lower risks may decrease passenger satisfaction and visitation but increase turnover, impacting revenue.

Causal Loop 5: Passenger revenue drives investments in operational support, boosting support capabilities and cabin service levels, enhancing passenger satisfaction and retention. Increased satisfaction and retention may raise passenger turnover, positively impacting revenue.

Negative Causal Loop 1: The pandemic has reduced the number of flights, affecting the demand for operational support capacity and subsequently operational support capabilities.

Negative Causal Loop 2: Enhanced cabin service levels increase passenger satisfaction and rates. Higher satisfaction and rates may increase passenger turnover and demand for cabin services. This increased demand may overextend service levels, potentially lowering overall satisfaction. These dynamics show that increased passenger revenue fosters investment in operational support, leading to reduced economic losses and improved passenger satisfaction, ultimately boosting revenue. Conversely, negative loops indicate that while enhancing cabin service levels initially increases passenger transport volume, it could later strain service levels and decrease overall satisfaction.

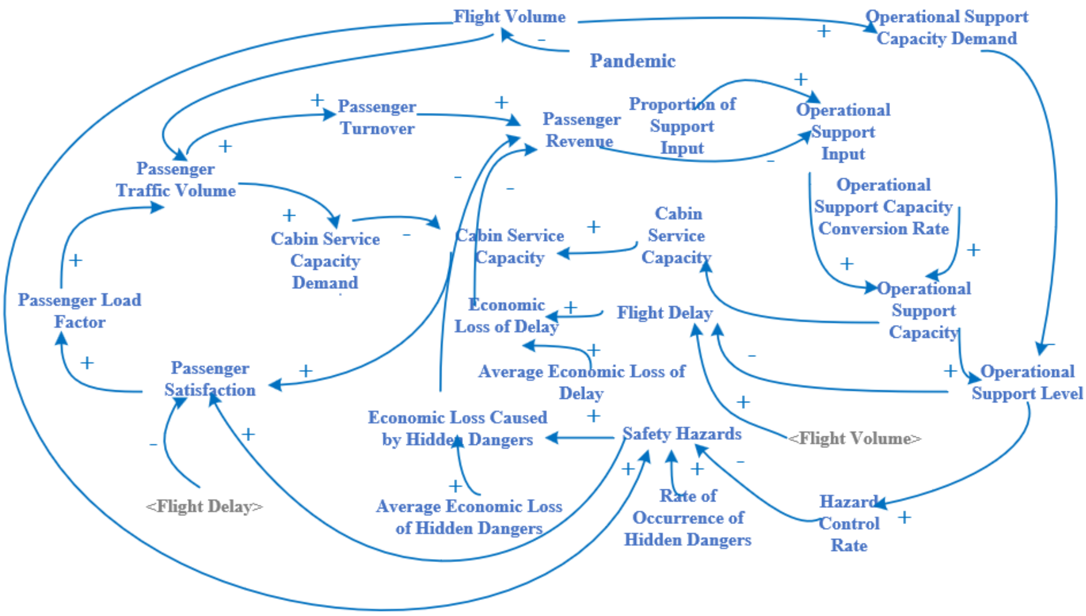

Figure 2. Causality diagram of the airline running support subsystem
Source: By authors.

3. Dynamic Simulation of the Airline Operation Support Capabilities System

3.1 Variable Selection

A dynamic evolution system diagram for airline operation support capability is established, encompassing the airline operation development subsystem and transportation support subsystem. The diagram categorizes variables into three distinct types: speed variables, auxiliary variables, and constants [17]. The dynamic evolution mechanism of the stock flow for the airline's operation support capability is illustrated in Figure 3, highlighting the complex interactions between the airline's operational development, transportation support, and the broader mechanisms that drive its evolution.

The variables in this diagram are classified based on different characteristics:

- State variables (3): per capita GDP, fleet size, and operation support capabilities.
- Rate variables (4): growth in per capita GDP, aircraft introduction, aircraft retirement, and increases in operation support capacity.
- Auxiliary variables (27): flight operations, passenger income, passenger transport volume, passenger turnover, operating costs, operation support investment, equipment budget allocation, operation support level, cabin support capacity, cabin support demand, cabin service level, control rates for potential risks, safety hazards, guest rates, economic losses from delays, accident-related economic losses, profits, taxes, flight market demand, aircraft market demand, transformation in operation support, strategies for market-driven aircraft introduction, profitability-based aircraft introduction, passenger numbers, passenger recognition of airline services, flight delays, and pandemic impacts on aircraft market demand.

- Constants (15): purchasing coefficients, government approval coefficients, growth rate of per capita GDP, tax rates, operation support investment coefficients, aircraft pricing, aircraft lifespan, average cost per flight, daily average seat capacity, average number of routes, and various averages related to route levels, fares, delays, and the economic impacts of accidents and potential risks.
- Table functions (4): capacity increases, airline recognition by passengers, flight delays, and aircraft market demands.

3.2 Model Equation Establishment

The model equation is designed to quantitatively clarify the causal feedback relationships among the variables. Within the system flow diagram, crucial equations are categorized into state variable equations, rate variable equations, auxiliary variable equations, and table functions [18]. Following the system's causality analysis and the construction of the stock flow diagram, initial values and equations for the system's stock flow are set up to simulate the model. Table 1 presents the primary model equations.

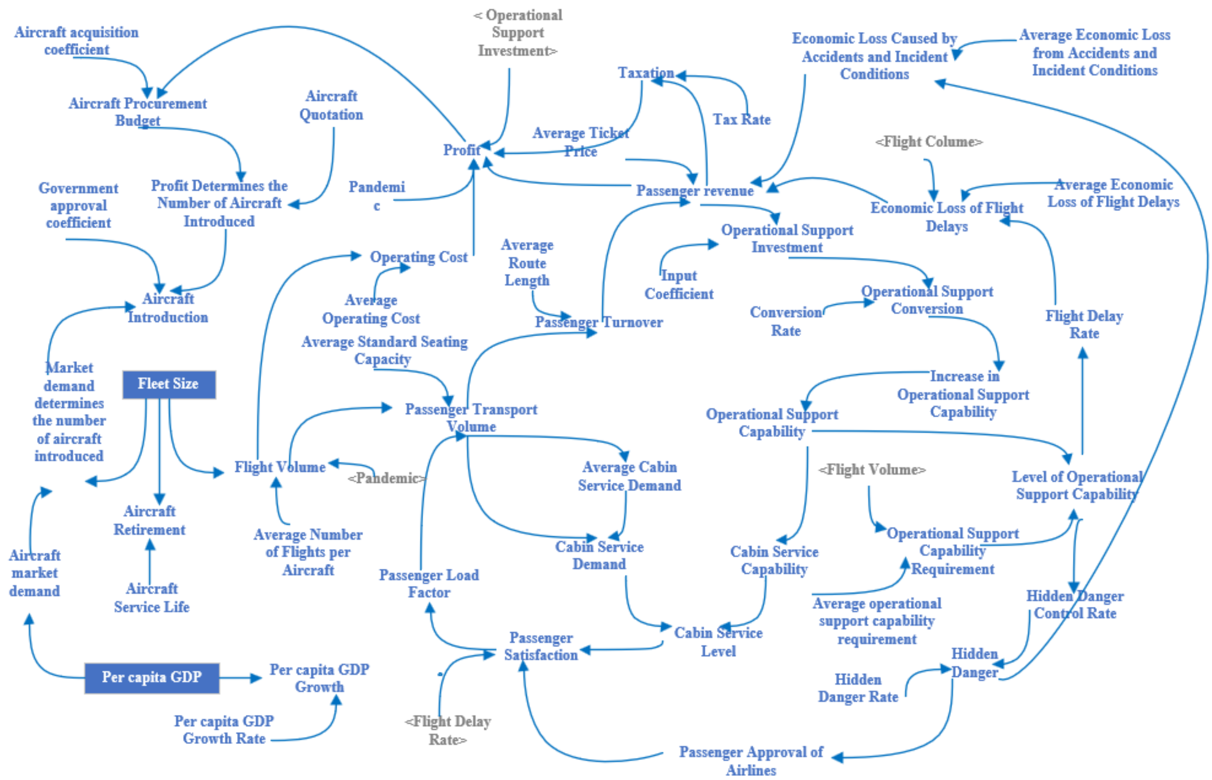

Figure 3. Dynamic evolution system stock flow of airlines running support capabilities

Source: By authors.

Table 1. Variable equation

Variable	Equation
Fleet Size	INTEG (Aircraft Introduction-Aircraft Retirement, Initial Value)
Operational Support Capability	INTEG (Increase in Operational Support Capability, Initial Value)

Per Capita GDP	INTEG (Increase in Per Capita GDP, Initial Value)
Aircraft Acquisition	INTEG (Government Approval Coefficient * MIN (Profit Determines Number of Aircraft Purchase or Lease, Market Demand Determines Aircraft Addition))
Aircraft Retirement	INTEG (Fleet Size/Aircraft Lifespan)
Per Capita GDP Growth	Per Capita GDP * Per Capita GDP Growth Rate
Flight Volume	Average Daily Number of Flights * Fleet Size * 365
Passenger Transport Volume	Load Factor * Average Standard Seats * Number of Flights
Passenger Traffic Volume	Passenger Transport Volume * Average Route Length
Operating Costs	Average Flight Cost * Number of Flights
Economic Loss from Delays	Flight Delay Rate * Average Delay Economic Loss * Number of Flights
Passenger Revenue	Average Ticket Price * Passenger Traffic Volume - Accident and Incident Economic Loss – Flight Delay Economic Loss
Profit	Passenger Revenue - Taxes and Fees - Operating Costs - Operational Support Investment
Taxes and Fees	Passenger Revenue * Tax Rate
Schemed Aircraft Introductions Based on Air Passenger Market Demand	IF THEN ELSE (Market Demand Aircraft - Fleet Size >= 0, Market Demand Aircraft - Fleet Size, 0)

Source: By authors.

3.3 Case Analysis

To confirm the model's effectiveness, it is simulated using Vensim software. S Airlines, based in S City, China, is a medium-sized airline that has maintained profitability for several years prior to the pandemic. Statistical data reveal that S Airlines achieves a high aircraft utilization rate, averaging 8.5 flights per aircraft per day with an availability rate of 99.5%. The airline emphasizes safety, invests substantially in operational support, and upholds a strong operational support system.

Before simulating the operations of S Airlines, model parameters are estimated using existing data from S Airlines and relevant data from the "China Civil Aviation Industry Development Statistical Bulletin" [19]. The parameters include the initial values of state variables, relevant constants, and table functions. Tools such as SPSS and Excel are utilized to estimate model parameters based on historical data, and some table functions are determined through expert consultations. Alternatively, some parameters are set based on the overall conditions within the civil aviation industry. The specific values of these parameters are detailed in Table 2.

Table 2. Airline operational support capability system model parameter values

Parameter Name	Value	Unit
Aircraft Quotation	15,000	Ten thousand Yuan
Aircraft Service Life	20	Years
Average Daily Flights per Aircraft	5.7	Units
Standard Seating Capacity	170	Seats
Average Route Length	1,200	Kilometers
Fleet Size	46	Aircraft
Average Ticket Price	0.000075	Ten thousand

		Yuan/passenger/kilometer
Average Delay Loss	3	Ten thousand Yuan
Average Accident and Incident Loss	10	Ten thousand Yuan
Per Capita GDP	4.4737	Ten thousand Yuan
Operational Support Capability	80	-
Operational Support Investment Coefficient	0.03	-
Government Approval Coefficient	0.8	-
Aircraft Acquisition Investment Ratio	0.85	-
Tax Rate	0.03	-
Per Capita GDP Growth Rate	0.086	-

Source: By authors.

The values for the function are obtained from the following equations: The growth in operational support capability is assessed by specialists drawing from their knowledge of S Airlines and their scholarly proficiency, with the operational support investment measured in tens of thousands of yuan. The airline's recognition by passengers is evaluated based on the frequency of safety hazards in S Airlines. However, this function table does not include the intermediate variable concerning the levels of accidents and incidents. Flight Market Demand: This value is calculated using a mathematical formula that utilizes historical data on per capita GDP (in ten thousand yuan) and civil aviation passenger volume (in ten thousand persons) from 2017 to 2023, analyzed through regression. The precise formula used is Flight Market Demand = (15464 * Ln (natural logarithm)(Per Capita GDP * 10000) - 13349) * 10000. Flight Delay Rate: This rate is established based on the average delay rate within China's civil aviation sector from 2017 to 2023, alongside delays linked to the airlines. The respective formula is Flight Delay Rate = 0.2 * (0.6 + 0.4/Operational Support Level), and the function table for the flight delay rate is created by plotting coordinates using this formula.

3.4 Model Verification

The model's initial configuration sets the timeline from 2017 to 2028. Before commencing the simulation, tests for dimensional consistency and validation were conducted using the Units Check and Check Model in Vensim® Personal Learning Edition (PLE).[20,21,22]. Both tests were passed successfully.

This was followed by an initial simulation to explore the dynamic evolution of the system dynamics model for an airline's operational support capability. This included a comparison with actual data from S Airlines to evaluate the model's accuracy, with fleet size from 2017 to 2023 as the validation parameter. The effectiveness of the model, as shown in Figure 4 and detailed in Table 3, confirms its reliability and the correctness of its outcomes.

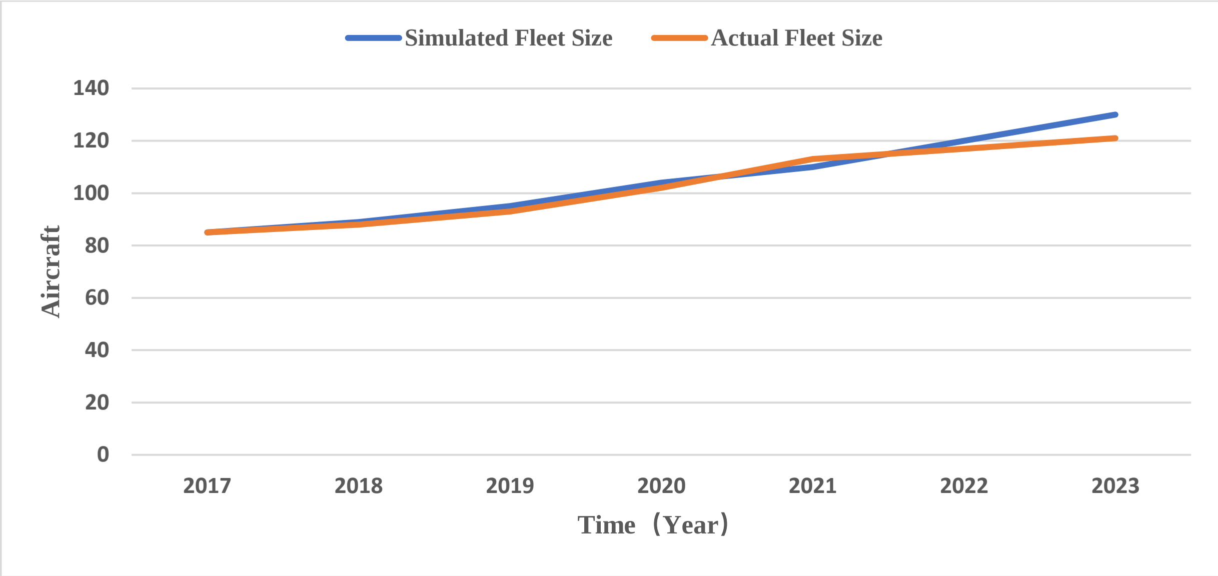

Figure 4. The fleet size effectiveness validation

Source: By authors.

Table 3. The fleet size effectiveness validation

Year	Simulated Fleet Size	Actual Fleet Size	Absolute Relative Error
2017	85	85	0
2018	89	88	0.011
2019	95	93	0.021
2020	104	102	0.020
2021	110	113	0.027
2022	120	117	0.024
2023	130	121	0.074
		Average Relative Error	0.025

Source: By authors.

After this comparison, the model demonstrated a strong correlation between the simulated and actual data, showing an average error of 2.5% in fleet size simulations. This validation underscores the model's precision and effectiveness, confirming its aptness for simulating the dynamic development of an airline's operational support capability.

3.5 Model Simulation and Policy Design

The simulation phase of the model aims to predict the operational condition of the airline. During this phase, the variable parameters of the model are altered to produce various scenario outcomes. A suitable scenario is then selected to form the basis of airline policy-making. Indicators such as fleet size, operational support level, and profitability are chosen to represent the dynamic progression of the airline's operational support capability.

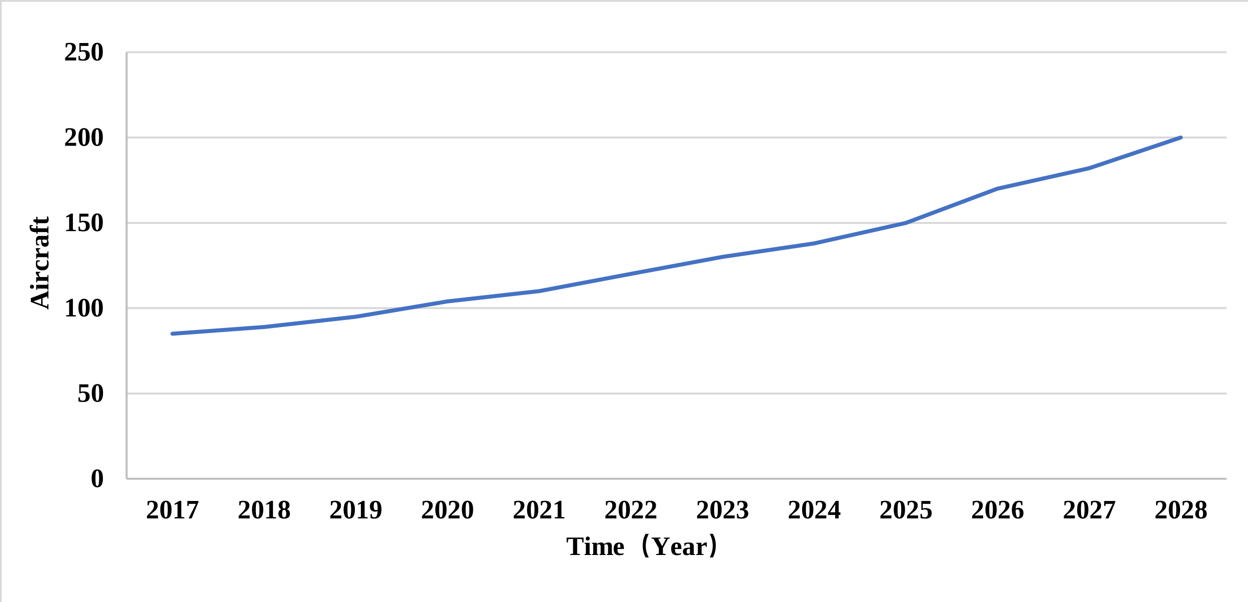

Figure 5. Initial simulation values for fleet size

Source: By authors.

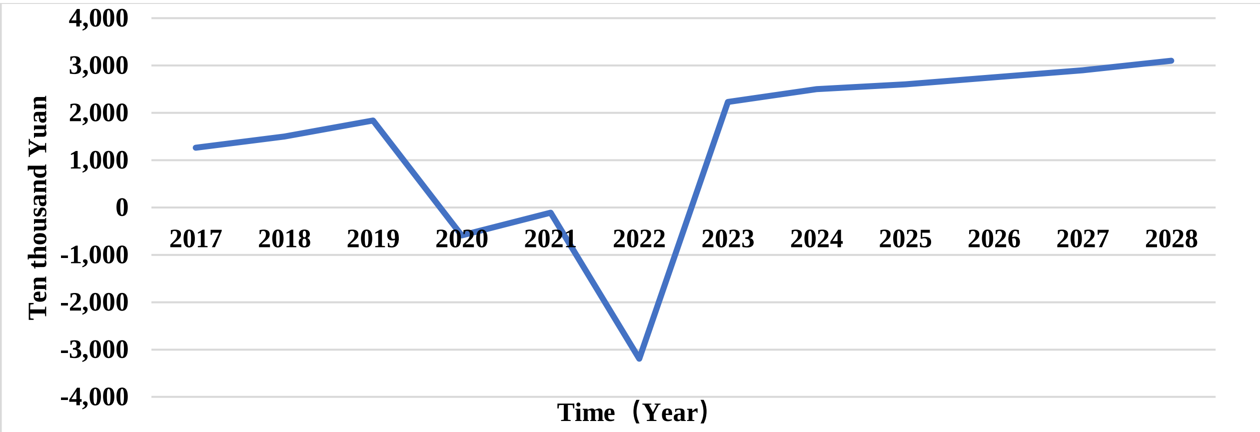

Figure 6. Initial simulation values for profit

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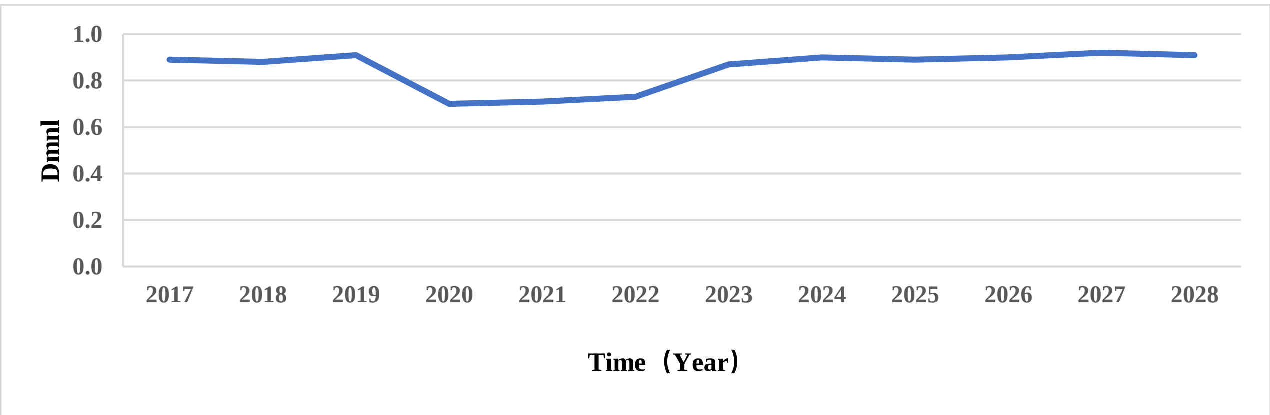

Figure 7. Initial simulation graph for the operational support level

Source: By authors.

As depicted in Figure 5, the airline's fleet size is on a consistent growth trajectory, projected to reach 150 aircraft by 2025. Despite the challenges of the post-pandemic era and the influences of profitability and market demands, the airline continues to experience strong growth. The expansion in fleet size is expected to accelerate post-2023.

According to Figure 6, S Airlines experienced a notable decline in profits from 2020 to 2022, compared to prior years, but post-2023, a resurgence in profit growth is anticipated. Aside from the years impacted by the pandemic, the growth trends in fleet size closely reflect those in net profits, with variations during this period due to pandemic-related factors and inadequate operational support capabilities.

Figure 7 shows that outside of the pandemic-affected years, the level of operational support in S Airlines remains relatively stable, as per the initial simulation results. To align the investment ratio in operational support with the airline's operational progression, adjustments to the operational support investment ratio were made in the model for further simulations. Observations were made on the changing dynamics of the operational support capacity. Employing the operational support investment coefficient as a policy variable, four different approaches were devised and evaluated against the initial simulation outcomes.

Table 4. Scheme Table

Scheme	Investment Coefficients
Initial Simulation Results	0.03
Scheme 1	0.04
Scheme 2	0.05
Scheme 3	0.06
Scheme 4	0.07

Source: By authors.

Conclusions from Figures 8, 9, and 10: From 2017 to 2028, the growth trends of fleet sizes across all schemes remained consistent with the initial simulations, even for the three years affected by the pandemic. Moreover, an increase in the investment coefficient for operational support corresponds with an increase in fleet size. This highlights the positive impact of enhancing investments in operational support capacity on the airline's fleet expansion. A similar pattern is observed in operational support levels, reflecting trends in fleet size. However, profitability data reveal a potential challenge: Scheme 4 shows an excessive investment in operational support capacity, resulting in a notable profit decline in the post-pandemic era of 2028. This downturn could hinder the airline's future growth and expansion prospects. In contrast, Schemes 2 and 3 show significant improvements. While maintaining fleet sizes comparable to Scheme 4, both Schemes 2 and 3 achieve substantially higher profits by 2028, thereby facilitating the airline's further expansion. Furthermore, Scheme 3, with its slightly lower operational support level compared to Scheme 4 but significantly higher than Scheme 2, emerges as the preferred policy option.

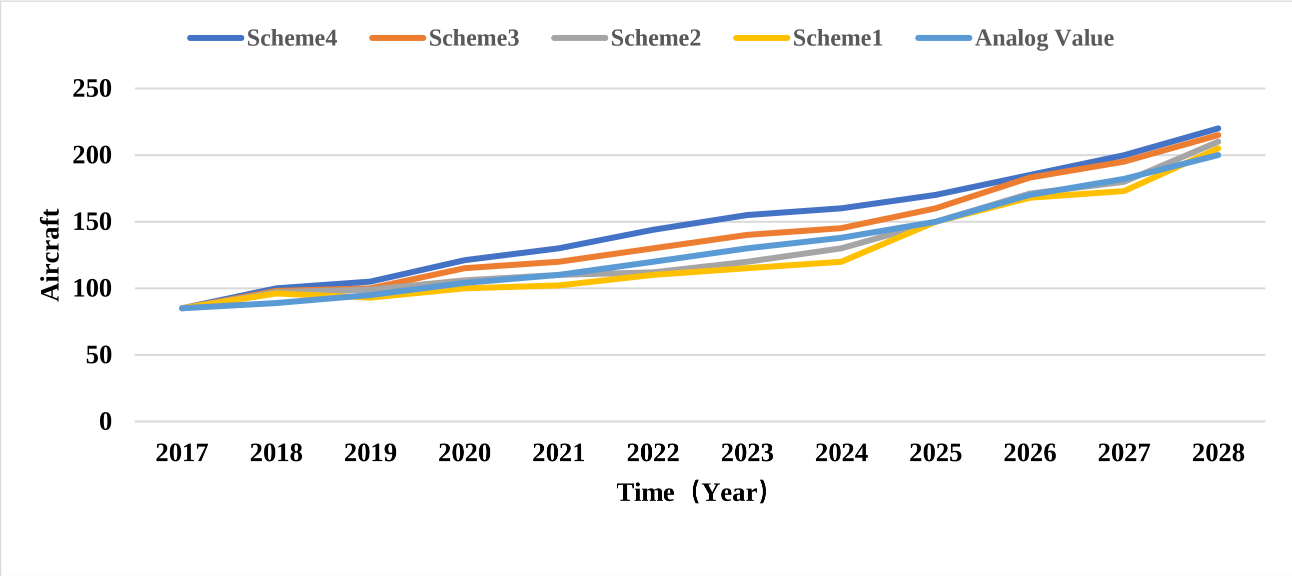

Figure 8. The fleet size chart for the different schemes

Source: By authors.

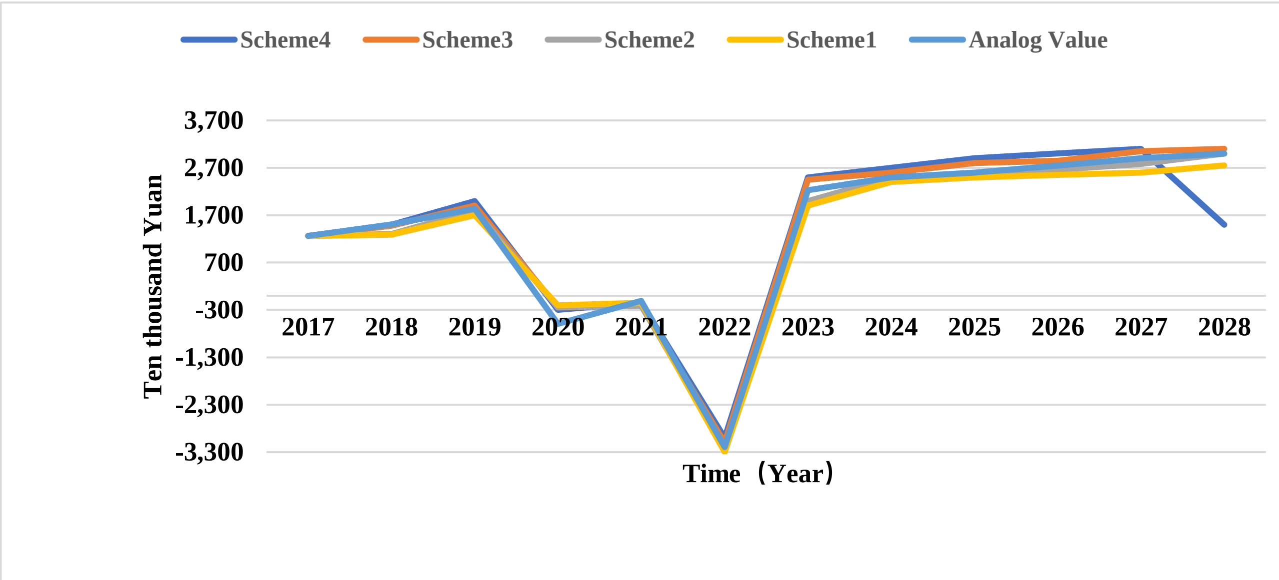

Figure 9. The profit chart under different schemes

Source: By authors.

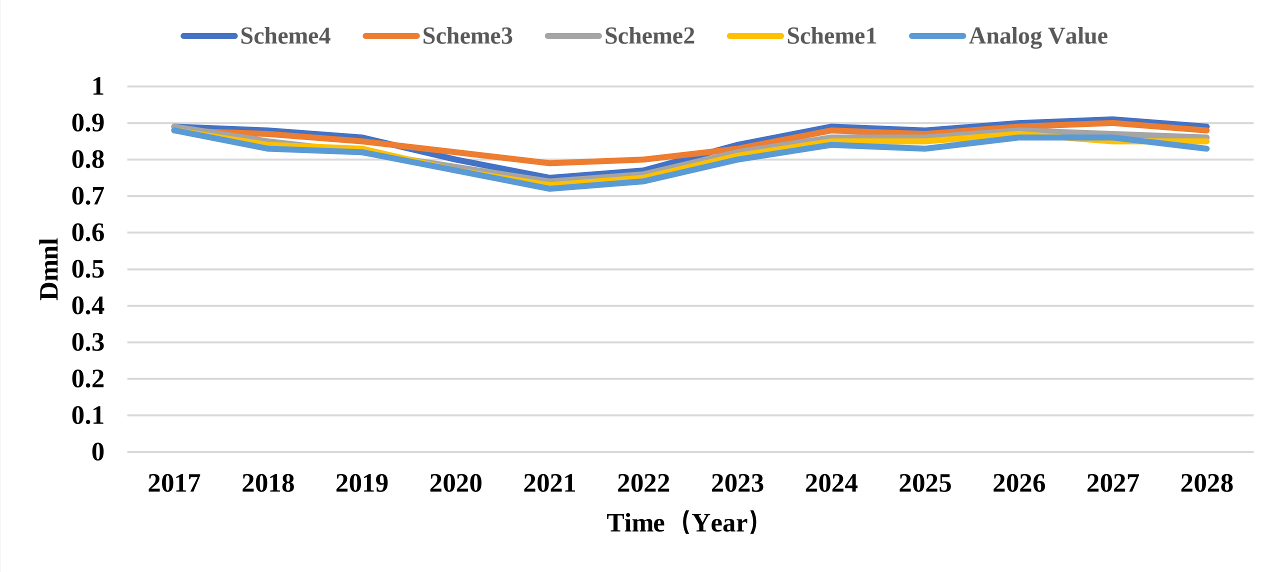

Figure 10. The operational support level chart under different schemes.
Source: By authors.

4. Conclusions

(1) This research utilizes system dynamics methodologies to examine the dynamic evolution of operational support capabilities in the airline industry. Variables were chosen through theoretical analysis to develop a model for assessing operational support capabilities. Initial simulations of the model used operational data from S Airlines. The equations, system constants, and initial values of the level variables in the flowchart were initially refined using data from S Airlines. Dimensional consistency checks, model validation, and effectiveness tests were followed, and all were successfully completed by the model. Generated charts showing fleet size, profit, and operational support level indicated that limited investment in operational support might restrict the airline’s further growth.

(2) After the initial simulations, four distinct schemes were developed. Following further simulation and comparative analysis in the post-pandemic period, it is recommended that airlines adopt Scheme 3, which involves an investment coefficient of 0.06, as the optimal improvement strategy to enhance operational support for airlines.

(3) The dynamic evolution system of an airline’s operational support capacity is intricate, involving numerous variables and complex interrelationships. Consideration was given to nonlinear fluctuations influenced by the pandemic. The complexity of the system may lead to an imperfect model structure, which poses challenges in accurately quantifying variable relationships. It is recommended that airlines continuously update their model structures using real-time operational data. Moreover, including factors such as increased operational support capacity, passenger satisfaction, flight delay rates, and aircraft market demand can significantly boost operational support levels.

(4) Future research directions primarily include the following: This study did not account for the influence of airports/airspace. Integrating studies with airports to explore the impact of different

airport management models on airlines' operational support capabilities and flight procedures is a potential next step. The evolution of general aviation, closely tied to airline operations and the opening of low-altitude airspace, is likely to escalate. Future research might explore the implications of general aviation and its integration with airline operation studies. Although focused on S Airlines, the methodologies used in this study are applicable to major airlines across the nation, providing a basis for decision-making and methodological support to enhance and develop airline operations.

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