Key Factors of Overseas Aftermarket Aircraft Spare Parts Supply Logistics

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Abstract. The demand for aftermarket aircraft spare parts (ASPs) is different from that for aftermarket general-equipment spare parts in terms of supplier quantity, supply process, and supply conditions. These differences in demand characteristics lead to changes in supply logistics. This study investigates the key factors affecting the aftermarket ASP supply.

Keywords: aftermarket aircraft spare parts, performance improvement, Chinese-made civil aircraft.

1 Introduction

In spare parts supply logistics, aftermarket aircraft spare part (ASP) supply logistics is unique. Aftermarket ASP suppliers are not centralized, the value of aftermarket ASPs is different, and the supply cycle is sometimes limited to the loss of aircraft on ground (AOG).

On December 18, 2022, an ARJ21 was delivered to its first overseas customer, Indonesian Air Asia, marking the first time Chinese-made civil aircraft (CCA) was purchased in the overseas market. After selling CCA abroad, operational support services become key to market competitiveness. Aftermarket service is the source of competitiveness in overseas sales. In the entire life cycle of an aircraft, the cost of aftermarket ASP maintenance accounts for 10%–20% of the airline's direct operating costs [1]. Therefore, research on aftermarket ASPs for CCA should be based on aftermarket maintenance costs. To our knowledge, no study has systematically investigated the issues related to overseas aftermarket ASPs for CCA.

Research on aftermarket spare parts supply logistics has focused on the following six areas: (1) aftermarket spare parts supply chain management [2], including order processing, transportation, and distribution; (2) aftermarket spare parts demand forecasting [3], exploring how to accurately predict demand for spare parts to promptly replenish and allocate inventory, thus avoiding inventory surplus or shortage problems; (3) supplier management and cooperation [4], studying how to select and manage suitable spare

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parts suppliers, establish stable cooperative relationships, and ensure the quality and timely delivery of spare parts; (4) spare parts inventory management [5], analyzing how to manage spare parts inventory, including determining appropriate inventory levels, optimizing warehouse layout, and implementing regular inventory and maintenance measures to ensure part availability and reduce costs; (5) aftermarket logistics network design [6], focusing on how to design an efficient aftermarket logistics network, including selecting suitable warehouse and logistics center locations and optimizing transportation routes and modes to meet the demand for fast delivery; and (6) technical support and maintenance services [7], exploring how to provide high-quality technical support and maintenance services, including using remote fault diagnosis, training support, and maintenance manual management to improve equipment utilization.

ASP management research has mainly focused on spare parts maintenance strategies [8], demand variability [9], and inventory control [10]. ASP demand is a type of intermittent demand [11], and research should select methods based on the specific operational scenario [12]. Studies have shown that ASP maintenance quality has a significant effect on its demand [9]. For an aircraft maintenance service provider, improving maintenance quality control can enhance the reliability of ASPs [13]. Existing studies highlight the need for further research on ASP supply. At the same time, there are relatively few studies conducted from the perspective of suppliers regarding ASPs.

Thus, to coordinate the manufacturing and maintenance of CCA, it is necessary to design an overseas supply mode for aftermarket ASPs.

2 Aftermarket ASP Demand Concerns

After the 1990s, with the emphasis on the construction of assessment index systems for aviation manufacturing enterprises, research started to focus on ways to better evaluate the quality and reliability of aftermarket ASPs. This topic tends to receive more attention when major emergencies occur, aiming to find more effective evaluation index systems. Current methods for designing evaluation index systems for aviation manufacturing suppliers are mainly based on statistics in the literature and a small amount of field investigation. Based on the abundance of recent literature, we summarize the representative evaluation indicators for aircraft manufacturing suppliers and briefly analyze the construction of indicator systems [14–16].

The quality–cost–delivery–service (QCDS) mode is an interrelated “four-dimensional” mode adopted by Toyota in its just-in-time manufacturing. This mode is popular and applies to both organizations and manufacturing activities. QCDS can be used to explore the demand features of airlines in the aftermarket for aircraft, especially aftermarket ASPs (Figure 1).

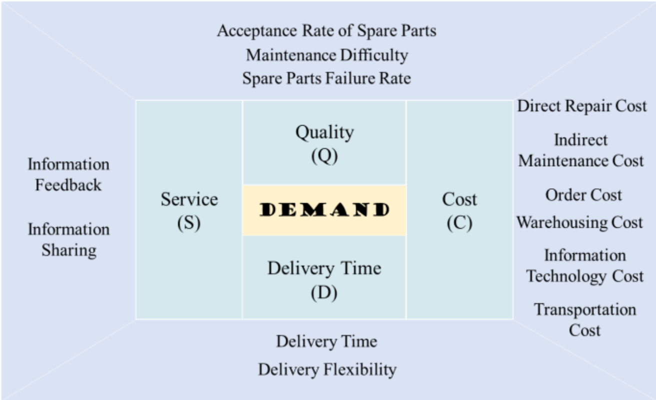

Fig. 1. Quality–cost–delivery–service mode for airlines' aftermarket ASP demand.

Based on the characteristics of aviation manufacturing, the advantages of existing supplier evaluation indicators, and the demand for overseas aftermarket ASPs, we can deduce the demand for aftermarket ASPs and establish a QCDS-based index system. Then, based on the actual aftermarket ASP operation and maintenance, the first-level indicators are divided into 10 second-level indicators (Table 1).

Table 1. Indicators related to the demand for aftermarket ASPs for operation and maintenance.

Indicator level		Description
First	Second	
Quality	Aftermarket ASP compliance (AC)	Whether it receives design, production, maintenance, airworthiness, and installation approval from the related authorities, the manufacturing country, and so on
	Failure impact (FI)	Aftermarket ASPs returned to the factory for repair; whether the number of failures is high and the degree of impact is high
Delivery	On-time delivery (DT)	Whether it can be delivered on time and whether the on-time delivery rate is high
	Delivery flexibility (DF)	When the delivery time and quantity are changed, whether it can be adjusted in time
Price	Price economy (PE)	Are aftermarket ASPs sold at an economical price?
	Transportation economics (TE)	Whether aftermarket ASP transportation prices, labor costs, road transportation management fees, customs taxes, etc., are low
	Payment flexibility (PF)	Are the payment methods and terms flexible?
Service	Aftermarket guarantee (AG)	Includes aftermarket problem-solving, training, communication, etc.
	AOG guarantee (AOG)	Whether high-quality AOG aftermarket ASPs support services are provided

3 Key Factor Analysis

Interpretative structural modelling (ISM) is a kind of structural modeling technology. The main function of ISM is to analyze the factors of certain complex systems with many factors, but it cannot express the main degree between factors. The decision-making trial and evaluation laboratory (DEMATEL) is a method for analyzing and solving difficult, complex, multilevel problems. DEMATEL mainly evaluates the strength of the relationships between factors in the system and screens out the main complex factors. DEMATEL-ISM can not only identify a clear hierarchical structure in the system affected by many complex factors but also deduce several key factors in the structure. Thus, DEMATEL-ISM is used to find the top three key factors (Table 2).

To determine the relationships among various factors, we designed an expert scoring table for the factors and invited five researchers and experts in the field of aftermarket ASPs, as well as some staff related to aftermarket ASPs, to participate in scoring. These experts and staff came from airlines, aircraft manufacturers (COMAC), aftermarket ASPs suppliers, and so on. We use the five-level (0, 1, 2, 3, 4) scoring rule, where influence gradually increases from small to large.

First, we use DEMATEL to calculate the direct influence matrix, the comprehensive influence matrix T, and the weight of the factors.

The calculation steps are as follows:

Step 1: Determine the influencing factors of the system, $S_1, S_2, ...S_n, S_i \in (i = 1, 2, ..., n)$ where n is the number of influencing factors and S is the set of influencing factors.

Step 2: Establish the direct impact matrix R. This paper follows the five-level scoring rule of (0, 1, 2, 3, 4), from small to large, the impact gradually increases, such as the impact of spare parts compliance on failure impact is level 1, and the impact of delivery punctuality on delivery flexibility is level 4. According to the Delphi method, the direct impact matrix between factors is obtained, $R = \left[r_{ij} \right]_{n \times n}$, r_{ij} represents the degree of influence of the influencing factor S_i on S_j, without considering the influence of the factor on itself.

Step 3: Normalize the direct impact matrix R to obtain the normalized impact matrix.

$$R^* = \left[r_{ij}^* \right]_{n \times n} = \frac{R}{\max_{1 \le i \le n} \sum_{j=1}^{n} r_{ij}} \tag{1}$$

Step 4: Construct the comprehensive impact matrix T. The comprehensive impact matrix represents the comprehensive impact of each factor on the system, which is used to determine the impact of each factor relative to the highest factor in the system.

$$T = R^* \frac{I}{I - R^*} = R^*(I - R^*)^{-1} \tag{2}$$

Step 5: Calculate the influence degree f_i and influence degree e_i of each factor.

$$f_i = \sum_{j=1}^{n} t_{ij}, i = 1, 2, ..., n \tag{3}$$

$$e_i = \sum_{i=1}^{n} t_{ij}, \mathrm{j} = 1, 2, ..., n \tag{4}$$

Step 6: Calculate the centrality M_i and the causal degree N_i.

$$M_i = f_i + e_i, i = 1, 2, ..., \mathrm{n} \tag{5}$$

$$N_i = f_i + e_i, i = 1, 2, ..., \mathrm{n} \tag{6}$$

Step 7: Calculate the overall influence matrix $H(H = \left[h_{ij}\right]_{\mathrm{n}\times\mathrm{n}})$.

$$H = T + I \tag{7}$$

Step 8: Calculate the reachability matrix $K(K = \left[k_{ij}\right]_{\mathrm{n}\times\mathrm{n}})$,Where λ is the threshold, $\lambda \in [0,1], k_{ij}$ is the association value from node i to node j, and $k_{ij} = 1$ means that node i and node j are associated.

$$k_{ij} = \begin{cases} 1, h_{ij} \geq \lambda \\ 0, h_{ij} < \lambda \end{cases} (\mathrm{i}, \mathrm{j} = 1, 2, ..., \mathrm{n}) \tag{8}$$

Step 9: Establish antecedent set and reachable set.

$$A(\mathrm{S_i}) = \{\mathrm{s_j} \in \mathrm{S} \mid \mathrm{k_{ji}} = 1\} \tag{9}$$

$$\mathrm{R}(\mathrm{S_i}) = \{\mathrm{s_j} \in \mathrm{S} \mid \mathrm{k}_{ij} = 1\} \tag{10}$$

Step 10: Establish an explanatory structural model.

Then, we obtain the influence-influenced degree diagram and central-cause degree diagram, as shown in Figures 2 and 3, respectively.

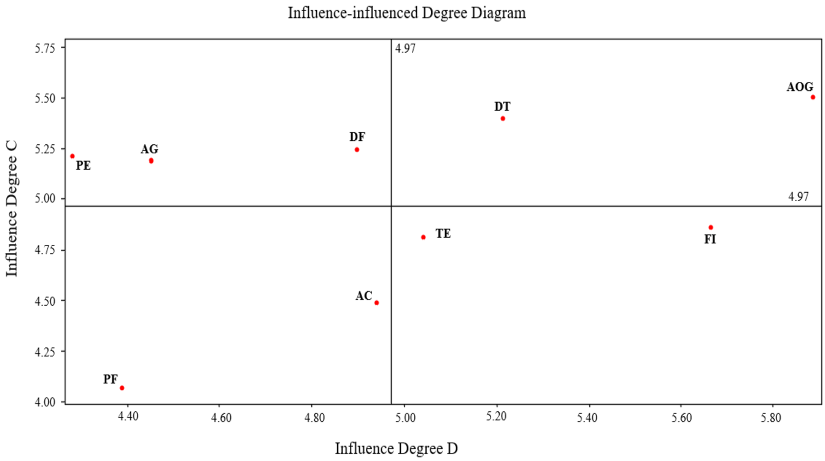

Fig. 2. Influence-influenced degree diagram.

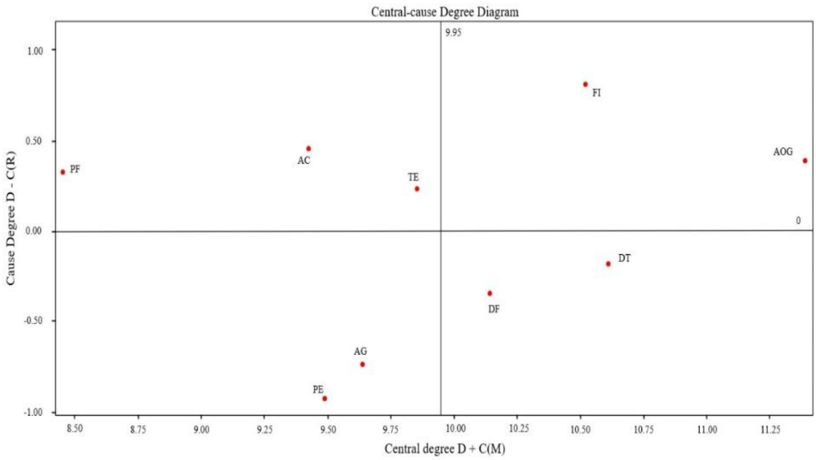

Fig. 3. Central-cause degree diagram.

Second, set a threshold value λ for comprehensive influence matrix T to eliminate redundant information in the system. If $t_{ij} > \lambda$, then $A_{ij} = 1$, while if $t_{ij} < \lambda$, then $A_{ij} = 0$. We use the related statistical data of the comprehensive influence matrix T to set λ. So, if the mean of T is x, and the standard deviation of T is σ, then $\lambda = x + \sigma$. We can calculate $\lambda = 0.635$ using MATLAB. Thus, we finally obtain the reachability matrix, with the hierarchical decomposition table as shown in Table 2.

Table 2. Hierarchical decomposition table.

Hierarchy	Factors
Upper	AC, DF, PE, PF, AG
Bottom	FI, DT, TE, AOG

From the hierarchical analysis table of the reachability matrix, we can see that aftermarket ASP compliance, delivery flexibility, price economy, payment flexibility, and aftermarket guarantee are the first-level factors, and the deeper factors are failure impact, delivery punctuality, transportation economy, and AOG security.

4 Conclusion

Using DEMATEL-ISM, AOG, DT, and FI are identified as the deep causes and also the cause factors, and centrality ranks high, ranking in the top three. Although transportation economics is the underlying cause, it ranks fifth in the centrality ranking and is not as important as AOG guarantee, delivery punctuality, and failure impact. Thus, AOG guarantee, delivery punctuality and failure impact are the three main influencing factors. The design of ASP supply model and logistics management in the future should focus more on key factors.

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