Structural Behavioral Study on the General Aviation Network Based on Complex Network

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Abstract. The general aviation system is an open and dissipative system with complex structures and behavioral features. This paper has established the system model and network model for general aviation. We have analyzed integral attributes and individual attributes by applying the complex network theory and concluded that the general aviation network has influential enterprise factors and node relations. We have checked whether the network has small world effect, scale-free property and network centrality property which a complex network should have by applying degree distribution of functions and proved that the general aviation network system is a complex network. Therefore, we propose to achieve the evolution process of the general aviation industrial chain to collaborative innovation cluster of advanced-form industries by strengthening network multiplication effect, stimulating innovation performance and spanning the structural hole path.

1. Introduction  
General aviation (GA) covers secondary and tertiary industries. With remarkable driving effect towards economic development and consumption upgrading, it is an industry with dense capital and technology, high correlation and a long industrial chain. It can serve transforming and upgrading of production, transportation and consumption modes and so has become a potential industrial option for China’s economic transition and upgrading.

As a general method of abstraction and description for large-scale and complex systems, and as an abstraction structural morphology for systems, complex network can be used to study any complex systems. It emphasizes and focuses on topological features of a system structure and so gives in-depth knowledge about system structures and structural evolution [1-3]. To study sprawl of the general aviation network by applying the complex network theory, is in essence to focus on changes in network structures and network features caused by changes in network nodes and edges. By constituting a general aviation network model based on complex network, studying integral structural attributes of the network and judging whether it has small world effect and scale-free property[4-7], we can know about development path, sprawl method and sprawl stage of general aviation and their features and influence factors to sprawl and analyze general laws of dynamic development of general
aviation under the economic model of “new normal” as well as interactive mechanism of activities. This has laid a solid theoretical foundation for modeling and simulation of industrial evolution.

2. Constitution of the General Aviation Network System

Key nodes of the innovation network are determined based on theory of social network relation and principle of embeddedness and with core enterprises in the general aviation industrial chain (GAIN) as the structural embeddedness. With value chain, supply chain, information sharing behavior, credit and trust as relational embeddedness, we have constituted the innovation network \( G(S,P) \) for the general aviation industrial chain, where \( S \) refers to the set of all nodes of the general aviation enterprises and \( P \) refers to the set of relational nodes of the general aviation enterprises. The adjacent matrix \( A \) can be defined as the set of general aviation enterprises \( S = \{s_1,s_2,\ldots,s_n\} \), so the element \( a_{ij} \) in the \( n \times n \) matrix \( A \).

\[
a_{ij} = \begin{cases} 1, & \text{if } s_i \text{ affects } s_j \\ 0, & \text{else} \end{cases}
\]

(1)

In the network study, the matrix for relations between network factors is set as a 0-1 matrix, that is, when the factor \( s_i \) is correlative to another factor \( s_j \), then the matrix value is 1, otherwise, the matrix value is 0. Eventually, we get the 0-1 matrix \( A \) for the general aviation network.

\[
A = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
a_{21} & a_{22} & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}
\]

(2)

3. Analysis of Complex Network Property of the General Aviation Industry

Based on different positions of industrial chains and starting from relations between main bodies, this study abstracts the cluster network model for general aviation into nodes of three types including enterprises, governments and research institutions, selects 27 large-scale enterprises and scientific and technological research institutions from the core enterprise network and establishes a 27*27 matrix.

![Network Topology of GAIN](image)

Figure 1. Network Topology of GAIN

3.1. Integral Attribute Analysis of the General Aviation Network

The integral attribute analysis of the network is an analysis towards the general aviation network from the perspective of affinity and resource efficiency. The density of the general aviation network is 0.246<0.5, which shows that there are no direct correlations between many nodes, that enterprise
cooperation and communication are not enough, and that network contacting frequency and strength are low. Therefore, in the future development strategies, we should consciously strengthen cooperation and communication between enterprises, cooperation and communication between enterprises and scientific and technological institutions and cooperation and communication of enterprises in industrial chain and cooperation and communication in technological information in order to promote flux of information, knowledge and technology, strengthen interaction in industrial chain and enhance network density of clusters.

Table 1. Structure Attributes of GAIN.

| Index          | Data          | Index              | Data          |
|----------------|---------------|--------------------|---------------|
| Nodes          | 26            | Arcs               | 160           |
| Density        | 0.246         | Clustering coefficient | 0.582         |
| Average distance | 1.966         | Maximum distance   | 5             |

3.2. Analysis of Resource Allocation Issues in the General Aviation Network

The resource allocation capacity of the general aviation cluster can be derived from the network centrality analysis, in which centrality of network node reveals leadership position and ability of communication of an enterprise in the whole network. Mediating capability of network node is determined by the value of distance centrality.

By analysing network-centrality-degree/betweenness, we have derived the result as is shown in Fig. 2 and 3. The analysis shows that both degree and betweenness of HKJD are the highest. As a general aviation enterprise management institution of government nature, it has established many ties with general aviation industries and become a bridge between enterprises and governments through its role as a communication medium, thus playing an important coordinating and stimulating role to government promotion of relevant policies and their effective execution by enterprises.

At the same time, XF, SF, XF and GJ rank the top four in degree, which shows that they are in the upstream of the general aviation industrial chain. With strong scientific research capacities and through their competitive diversified products such as business airplanes, regional airliners and small airplanes and good management ability, they have obtained a large quantity of relational linkages in the general aviation industrial cluster. Thus, they are influential in the cluster, play a pivotal role in resource allocation and integration and have become leading enterprises of resource reliance, coordination and control and organizational learning through their subcontracts with foreign aviation enterprises and by driving development of small and medium-sized enterprises in the upstream and downstream of the industrial chain.
From the perspective of betweenness, LY takes the second place and has the strongest capacity as a medium. Its key equipment project supporting plane development has produced match-production capacity. LY has become the structural hole node in the network. According to preferential attachment mechanism in the study of complex networks, its medium role has strengthened cooperative relationship between LY and many other enterprises in the cluster, thus enhancing affinity of network linkage.

4. Degree Distribution Function Tests
In this section, we will check whether the general aviation system has the features of a complex system through the degree distribution function.

4.1. Small World Effect Tests
According to the theory of small world effect, a network with a shorter average path and higher clustering coefficient is called a small world network. According to statistical properties of the small world network model, clustering coefficient of the WS small world network and the NW small world network can be expressed with Formula 3 and the average path length L(p) for the WS small world network model can be expressed with Formula 4, where N refers to number of network nodes, k refers to average degree and p refers to reconnection probability. A network with clustering coefficient C(p) > 0.1 and average path length L(p)<10 can be regarded as a small world network.

\[
C(p) = \frac{3(k-2)}{4(k-1)}(1-p)^3, \quad C(p) = \frac{3(k-2)}{4(k-1)+4kp(p+2)}
\]  
\[
L(p) = \frac{2N}{k} f\left(\frac{NKp}{2}\right)
\]

In this study, L(p)=4.252<10 and C(p)=0.561 > 0.1 for the general aviation network, so it has some features of small world effect. The underground mine fire network is a small world network.

4.2. Scale-Free Effect Tests
Exponential distribution has the same features as power-law distribution. Exponential distribution is suitable for analysis of a complex network with fewer nodes and greater node changes. According to the definition of degree distribution, the vertical axis shows occurring frequency of node degree P(k) and the horizontal axis shows node degree of the linear coordinate k.

The degree exponential distribution function for the general aviation network: 
\[ y = \lambda e^{-0.131x} = 0.913e^{-0.1094x} \] . The slope of the imitative straight line under the semi-logarithmic coordinate is -0.118 and the linear fitting R^2=0.9524.

\[ P(K > k) \sim e^{-0.118k}, (0 < k \leq 26) \]

**Figure 4.** Degree Centrality Distribution of GAIN

Through analysis and curve fitting, this author has found that degree distribution of the general aviation network conforms well to exponential distribution, that the slope λ of the degree distribution
fitting line is -0.118 and that both out-degree and in-degree of the underground mine fire network conform to exponential distribution. Therefore, it can be proved that the general aviation network is a scale-free network and that the general aviation system has scale-free property.

5. Conclusion
This paper has systematically studied topological property and inner mechanism of the general aviation network by comprehensively combining the system engineering theory and computer simulation, applying relevant theories about complex systems and following the procedure from empirical observation to theory construction. Starting from the complex evolution and coupling relations of the general aviation system, the general aviation network model has been established. This network has been analyzed through integral attribute study and individual attribute study. Through inspection of the degree distribution function, the general aviation system can be further proved to be a complex network. Therefore, we propose to achieve the evolution process of the general aviation industrial chain to collaborative innovation cluster of advanced-form industries by strengthening network multiplication effect, stimulating innovation performance and spanning the structural hole path.

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