

Research on the Belt and Road International Network Optimization Initiative Based on Deep Learning

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Keywords: Leaf area index, Hyperspectral, PROSAIL, Uncertainty

Abstract: The research aims to optimize the international air transport network under the "the Belt and Road" initiative through improved gravity model and in-depth learning technology. By constructing a comprehensive index system for civil aviation transportation, using principal component analysis to screen key indicators, and combining deep learning to predict route opening. The results show that the accuracy rate of the model prediction reaches 85%, and it can basically identify the potential of opening routes between China and countries along the "the Belt and Road". The research provides scientific basis for route planning and policy formulation, which helps to improve air transportation efficiency and promote regional economic development.

1. Introduction

In this context, it is crucial to plan the existing air transportation network, scientifically evaluate the market development potential, and accurately promote the construction of the "Air Silk Road".

China's civil aviation development plan has a clear goal, that is, by the end of the "14th Five Year Plan" period, there will be no less than 50 countries sailing with countries along the "the Belt and Road". The plan also proposes an international air route network layout of "one circle, six corridors, and five channels", aiming to optimize and expand the "Air Silk Road"^[1].

During this period, the European Organization for Aviation Navigation Planning (EUROControl) was the first to propose the ARN trunk route network planning plan, aimed at optimizing and integrating Europe's high-altitude route systems. At the same time, the Federal Aviation Administration (FAA) of the United States launched the ambitious National Airspace Restructuring Program (NAR) in 2001, which aimed to address the growing demand for air transportation and enhance aviation safety and environmental sustainability by redesigning and integrating the US airspace structure. In 1973, Siddique proposed an innovative method of optimizing the layout of the air route network using a quantitative mathematical model. This method provided a new theoretical tool and analytical framework for subsequent air route network planning. In 2000, Mehadhebi pioneered an innovative route network redesign and optimization strategy, which was subsequently applied to the route system renovation in France, achieving structural optimization and service improvement of the route network. In addition, Duong et al. employed a multi-stage dynamic network flow planning technique to effectively solve the problems of route selection and flight altitude layer

configuration, improving the operational efficiency and security of the route network^[2-3].

This paper optimizes the international air transport network under the "the Belt and Road" initiative through the improved gravity model and in-depth learning technology. (Data source: World Economic Organization, Civil Aviation Administration of China)

2. Gravity Model Analysis

2.1 The Frontiers of Gravitational Models

At the beginning of the 20th century, Albert Einstein proposed the revolutionary theory of general relativity, which completely changed our traditional understanding of gravity. In Einstein's theory, gravity is no longer seen as a mysterious force, but as the natural motion trajectory of objects in the curvature of spacetime. This theory not only predicted shocking phenomena such as time dilation and gravitational waves, but was also experimentally validated through observations of a solar eclipse in 1919, thus establishing the scientific status of Einstein's theory^[4], as shown in Fig 1.

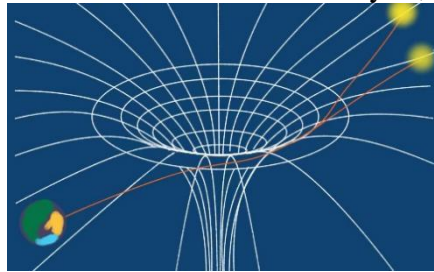


Figure 1: Diagram of special relativity

In modern times, experts from various industries continue to explore the study of gravitational field models, attempting to quantify them in daily life in order to achieve deeper theoretical breakthroughs.

2.2 Analysis of Gravity Field Model in Civil Aviation

When exploring the complexity of civil aviation transportation networks, we can draw inspiration from the gravitational field theory in general relativity to construct an innovative civil aviation gravitational field model. This model views cities as nodes in the airline network, and the comprehensive strength of civil aviation transportation at each node is analogized to the mass in general relativity^[5]. Just as the mass between celestial bodies affects the structure of the universe through gravitational interactions, the strength of civil aviation transportation between cities also shapes the formation and development of airline networks through similar gravitational interactions.

In this model, the comprehensive strength of civil aviation transportation in a city represents positive quality, which symbolizes the growth and development potential of the city. With the continuous expansion of cities and the improvement of civil aviation infrastructure, these positive masses will gradually increase, thereby generating stronger influence in the gravitational field of civil aviation. However, unlike the pure mass in general relativity, our model also introduces the concept of negative mass to represent factors that hinder the development of civil aviation transportation, such as high operating costs and competition from other modes of transportation. The greater the negative mass of a city, the weaker its attractiveness in the civil aviation gravity field, which may lead to its marginalization in the airline network^[6].

Each city node emits particles to other nodes in the network, symbolizing the potential for opening air routes between cities. When the comprehensive strength of two cities is strong, the particle motion acceleration between them is greater, reflecting the greater potential for establishing direct flight

routes between them. At the same time, the interaction between cities is not only about attraction, but also includes impedance force. The magnitude of this impedance force is closely related to the operating costs and competitiveness of cities, which in turn affects the opening and maintenance of air routes^[7].

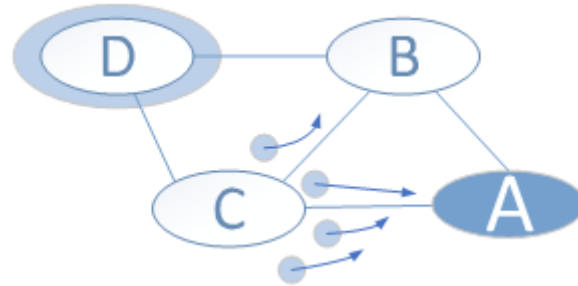


Figure 2: Schematic diagram of civil aviation gravity field

As shown in the schematic diagram of the civil aviation gravity field in Fig 2, assuming there are four airports A, B, C, and D in the gravity field, the four airports form a parallelogram, and there is an $AB=AC$ relationship. Each airport emits particles to another airport. The darker the color of the four airports A, B, C, and D, the greater the positive mass, where the D shape is surrounded by negative mass. Each airport emits particles to another airport, and the relationship between the particle's acceleration is AAA . This directly reflects the greater potential for establishing a direct flight route between A and C.

Due to the large positive mass of A, when the distance from C to A and B is equal, most of the particles emitted by C run towards A, with a small portion running towards B. Due to the presence of negative mass around D, it is difficult to generate particle motion between C and D. The larger the negative mass of a city, the weaker its attraction in the civil aviation gravity field, which may lead to its marginalization in the airline network.

Through the civil aviation gravity field model, it is possible to analyze and predict the development trend of the route network in more depth, help airlines and policy makers identify potential opportunities and challenges in the market, and thus formulate more effective route planning and development strategies.

2.3 Introduction to Gravity Field Models

The gravity model was originally proposed based on Newton's law of universal gravitation, used to describe the mutual attraction between objects. In the 1960s, Dutch economist Jan Tinbergen and Finnish economist Poyhonen introduced this concept into the field of economics and developed a spatial interaction model for analyzing trade flows between two economies, known as the Economic Gravity Model.

The basic form of the economic gravity model is a synonymous replacement of Newton's universal gravity formula, replacing the "mass" of an economy with economic indicators such as Gross Domestic Product (GDP) or population size, while "distance" can be a representation of actual geographical distance or transportation costs. The basic formula of the model is as follows:

$$I_{ij} = K \frac{M_i M_j}{D_{ij}^\alpha} \quad (1)$$

Among them:

I_{ij} represents the trade flow between country (or region) i and country j ;

M_i and M_j respectively represent the economic moduli of two countries (usually GDP or population);

D_{ij} represents the distance between country i and country j , which can be the actual geographical distance or an agent for transportation costs;

K is a constant used to adjust the scale of the model;

Since its introduction into economics, the gravity model has been validated in empirical research by numerous scholars, and its application scope is constantly expanding. In addition to the initial analysis of trade flow, this model has also been widely applied in various fields such as spatial layout, tourism, and population migration. This article improves the gravity model based on the existing theoretical foundation and takes into account the characteristics of international air transportation^[8].

2.4 Improvement of Gravity Field Model

In the original gravity model, M_i and M_j correspond to economic variables in different regions respectively; When studying the gravity value of China and countries along the the Belt and Road, the variable M_j can be made a constant variable, that is, it always represents China's economic modulus. On the basis of the original gravity model, the gravity model can be changed to:

$$I_{ij} = KM_j X \quad (2)$$

At this point, the gravity model can be viewed as a linear function about X , where $X = \frac{M_i}{D_{ij}}$.

In this formula, because M_j is a fixed value and K is a constant, the gravity value is independent of M_j , so the gravity model of China and countries along the the Belt and Road is only affected by variables other than M, at this time, the gravity model can be simplified as:

$$I_{ij} = \frac{M_i}{D_{ij}} \quad (3)$$

In the practical application of gravity models, although simplifying M to GDP or population is a convenient method, this approach cannot fully capture the complexity that affects the interactions between economies. Economic interaction is a multidimensional phenomenon that is not only influenced by factors such as market diversity, but also involves the complexity of economic activities and their dynamic changes over time. Therefore, in order to improve the description and prediction ability of the model, it is necessary to construct M as a comprehensive economic modulus, covering as many economic interaction factors as possible. Therefore, here we define M_i as the comprehensive thrust index of civil aviation transportation, and D_{ij} as the comprehensive resistance index of civil aviation transportation. M_i includes eight indicators: per capita GDP, total GDP, trade as a percentage of GDP, total domestic population, world competitiveness index, CPI, HDI, and TTCI of country LL, while D_{ij} includes two indicators: range and time value.

This article obtains M_i as $f(GDP, MGDP, TGDP, POP, WCI, CPI, HDI, TTCI)$ and D_{ij} as $g(d_i, t_i)$ (where TT is the time cost function), and the final improved gravity model obtained is:

$$I_{ij} = \frac{f(GDP, MGDP, TGDP, POP, WCI, CPI, HDI, TTCI)}{g(d_i, t_i)} \quad (4)$$

For the convenience of subsequent calculations, we will convert $\frac{1}{g(d_i, t_i)}$ to $g(d_i, t_i)^{-1}$ to obtain the final improved gravity model:

$$I_{ij} = f(GDP, MGDP, TGDP, POP, WCI, CPI, HDI, TTCI)g(d_i, t_i)^{-1} \quad (5)$$

Namely:

$$I_{ij} = G(GDP, MGDP, TGDP, POP, WCI, CPI, HDI, TTCI, d_i, t_i) \quad (6)$$

This article names all coefficients related to gravity as the Civil Aviation Transport Composite Index.

3. Establishment of a comprehensive index system for civil aviation transportation

3.1 Establishment of Comprehensive Resistance Index for Civil Aviation Transportation

When analyzing the impedance effect of civil aviation transportation routes between cities, travel cost and travel duration are two key factors. The cost of travel is usually proportional to the distance traveled, as longer distances mean higher fuel consumption and operating costs. The travel time can be converted into economic costs by considering the time value of passengers, that is, the time cost of passengers. In other words, the longer a traveler spends on their trip, the greater their implied economic losses, which can be seen as additional expenses from the perspective of time value. Therefore, when evaluating the impedance of civil aviation transportation routes, we need to comprehensively consider the two main factors of direct cost brought by flight distance and passenger time cost^[9]. Therefore, establish a time cost function:

$$t_i = a + cd_i + vt \quad (7)$$

In the formula, c represents the unit mileage cost. According to the 2019 Civil Aviation Industry Development Statistics Bulletin of the Civil Aviation Administration of China, the unit mileage cost of international routes is 0.7 yuan/km, therefore it is set at 0.7. For the distance between China and the country, due to political needs, the first route opened between the two countries is usually the capital route, so the distance between the two capitals is calculated through Google Maps. The time value coefficient is calculated as follows: first, take the per capita GDP of the country as the benchmark value. Then, divide the value by the number of days in a year (365 days) to obtain the daily per capita GDP. Next, divide the daily per capita GDP by the number of hours per day (24 hours) to obtain the time value coefficient, where v represents the hourly economic activity value of national citizens. According to ICAO statistics, the average speed of international scheduled flights is 0.57M, so the average speed is 700km/h, which is the ratio to the average speed. The majority of overseas travelers choose to take a plane, so the ignored impact is 0. Obtain a new practical cost function:

$$t_i = cd_i + vt \quad (8)$$

By using the formula of the practical cost function, the time cost required by the country can be calculated.

3.2 Comprehensive thrust index of civil aviation transportation

In order to reduce the problem of large economic volume caused by a country's large population, the average GDP indicator has been added on the basis of only GDP and population as the indicator, to weaken the advantage of countries with large population and total GDP in the comprehensive thrust index of civil aviation transportation. On this basis, in order to increase the dimension of the comprehensive thrust index of civil aviation transportation, five indicators including TGDP, WCI, CPI, HDI, and TCI were added according to the World Economic Forum (WEF) "2019 Tourism Competitiveness Report" and "2019 Global Competitiveness Report" to enhance the dimension.

3.3 Normalization of indicators

According to different data characteristics and application scenarios, various normalization strategies such as Min Max normalization, Z-score normalization, and logarithmic normalization can be selected. Due to the strong correlation between these selected indicators, we choose Min Max normalization here. In order to eliminate the disadvantage of smaller normalized results due to large differences in certain indicators, we will multiply the normalized values by one hundred to amplify the normalized values for easy observation. Namely:

$$X' = \frac{X - MIN}{MAX - MIN} \times 100 \tag{9}$$

To achieve optimal data processing results and lay the foundation for subsequent principal component analysis and deep learning.

3.4 Analysis and Results of Principal Component Analysis

Principal Component Analysis (PCA) is a technique in multivariate statistical analysis that is based on the core concept of dimensionality reduction. It integrates multiple interrelated indicators into several representative comprehensive indicators through linear transformation. This method not only effectively extracts and displays the key characteristics of the research object, but also eliminates redundant information in the data, thereby simplifying the analysis process and avoiding unnecessary duplicate operations^[10].

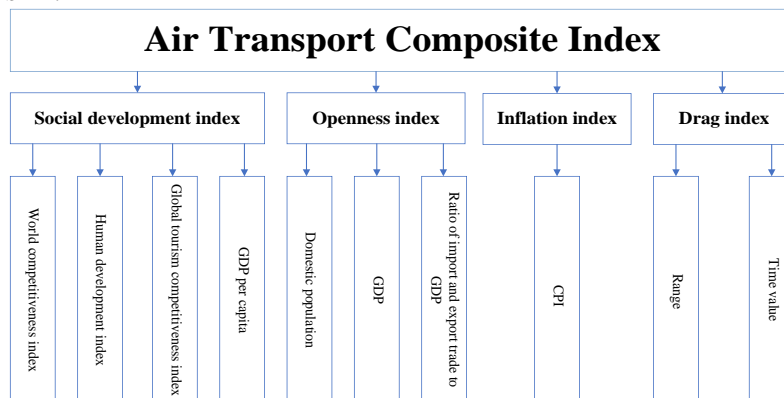


Figure 3: National Civil Aviation Transport Comprehensive Index System

This article uses SPSS 29 The 0 statistical software processes the above 10 indicators and uses principal component analysis to select the following principal components. Principal component factors are extracted based on the principle of eigenvalues greater than 1, and the score for each indicator is given at the end. The established evaluation index system is shown in Fig 3.

4. Route construction of countries along the the Belt and Road

4.1 Data Processing

Before conducting deep learning, preprocessing data is an important step, which includes encoding categorical features. When dealing with issues related to the direct flight status of a country, there are several reasons to code the direct flight country as 1 and the non direct flight country as 0^[11]:

(1) Data format consistency: Deep learning models, especially neural networks, typically require numerical inputs. Converting categorical features into numerical data can ensure that the input data format of the model is consistent, making it easier for the model to process.

(2) Model understanding: The model cannot directly understand the text category, such as "yes" or "no". By converting these categories into binary values (0 and 1), the model can more easily learn the relationship between features and target variables.

(3) Computational simplification: Because deep learning is capable of implementing logistic regression and supporting vector machines, encoding features into binary values can simplify the calculation process and improve the operational efficiency of the model.

(4) Avoiding bias: If appropriate encoding is not performed, the model may assign different weights to category features, leading to bias in the learning process. By using binary encoding, it is ensured that the model processes all categories equally.

(5) Simplification of multi category problems: When dealing with problems with more than two categories, can be used to transform category features. But in the case of only two categories, a simple binary encoding (0 and 1) is sufficient to illustrate the category situation, making the results more concise.

4.2 Deep learning outcomes

From the heat map, it can be found that there is a correlation between GDP and TTCI, WCI, and HDI. There is a strong correlation between HDI and TTCI and WCI, and there is also a strong correlation between WCI and TTCI. This directly proves that this set of data can be used to predict the opening of routes through deep learning, as shown in Fig 4.

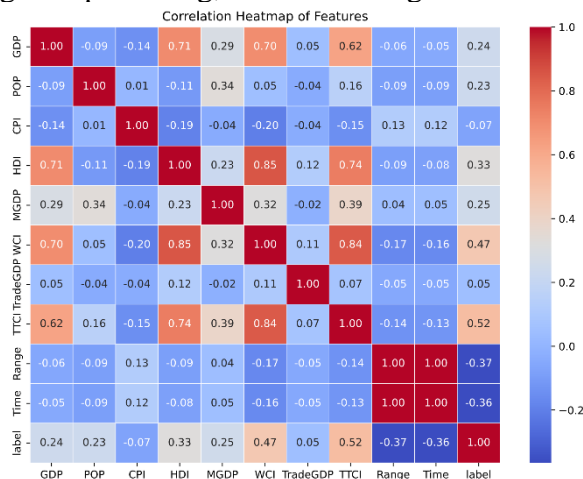


Figure 4: Correlation heatmap

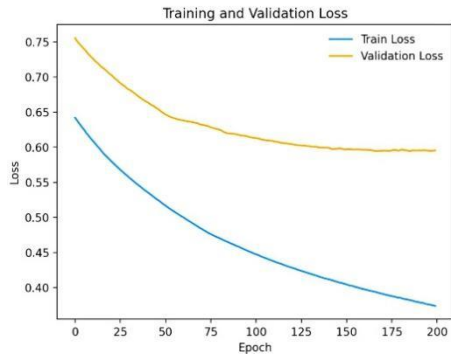


Figure 5: Loss rate

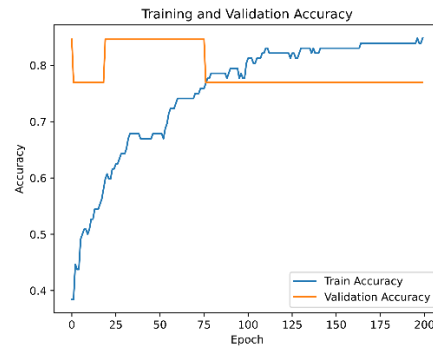


Figure 6: Accuracy

As shown in Fig 5 and 6, the loss rates of the training and validation sets decrease continuously with the increase of training cycles, indicating that the model is effectively learning from the training data. As the training progresses, the model's understanding of the data becomes deeper, and its predictive and generalization abilities gradually enhance, without any obvious overfitting phenomenon. At the end of training, the loss rate began to stabilize, indicating that the current model structure and hyperparameter settings matched the characteristics of the problem and could effectively capture patterns in the data. In the accuracy chart, the accuracy of the training set is constantly increasing. Although the accuracy of the validation set fluctuates, the accuracy of the validation set tends to stabilize and remains at a relatively high value in the final cycle, as shown in Fig 7 and 8. (Image source: Baidu Maps)



Figure 7: Initial Route



Figure 8: Optimized Route

5. Conclusion

This article uses an improved gravity model to predict the feasibility of route opening, and boldly predicts and optimizes the route network through optimization models; Finally, compare the actual direct flight chart with the predicted direct flight chart. The above phenomena indicate that the model selection is appropriate and can verify with high accuracy whether China and other countries have the conditions to open air routes.

This article only selected ten indicators for prediction, and some variables have low correlation, which directly prevents the loss rate from being within a very low range. In future research, we will select more variables for experimentation and continuously refine the model until it can be fully applied.

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