Hindawi
Journal of Advanced Transportation
Volume 2022, Article ID 3224485, 11 pages
https://doi.org/10.1155/2022/3224485

Research Article

A Study on the Utility Measurements and Influencing Factors of High-Speed Rail and Air Passenger Travel

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Received 30 December 2021; Revised 12 February 2022; Accepted 18 February 2022; Published 16 March 2022

Academic Editor: Luigi Dell'Olio

The increase in travel mode options has led to changes in the travel decision-making behaviors of passengers and differences in spatial patterns of the markets of high-speed rail and air travel. Taking China's central cities as the research subject, we analyze the spatial differentiation characteristics of high-speed rail and air transportation markets from a geographic perspective based on the passenger travel utility function. We analyze the influence on passenger travel decision-making behavior from the perspectives of the socioeconomic level and fare structure. The findings show that in the central city transportation market, passengers have a stronger preference for air travel. However, there are differences between regions, with high-speed rail dominating more in the partial north and air focusing on the partial south. As the value of time per capita increases, the dominant range of air travel gradually increases, while the dominant range of high-speed rail travel is compressed to some extent. An increase in fares does not cause a significant decrease in air demand; however, a reduction in fares leads to an increase in air passenger travel satisfaction.

1. Introduction

Since Beijing-Tianjin-Hebei intercity high-speed railway opened in August 2008, the scale of China's high-speed rail network has gradually expanded. By the end of 2020, there were about 38,000 km of high-speed rail in operation, serving more than 90% of China's population. The high-speed rail network is gradually moving from four north-south vertical and four east-west horizontal trunk networks toward a planned "eight horizontal and eight vertical" network, expanding from the eastern coastal areas to the western marginal areas. China's air passenger traffic has been growing rapidly, at an average annual rate of 12% since 2008 (excluding the years affected by COVID-19 travel restrictions), and the network has also expanded, initially forming a well-connected air transportation network centered on core cities such as Beijing, Shanghai, and Guangzhou. Therefore, the rapid development of high-speed rail and air has increased the travel options of passengers in the overlapping transportation market, especially in central cities (municipality, provincial capital, and subprovincial cities) with high population densities and high levels of economic development. Data show that the air passenger throughput of China's central cities accounted for about 70% of the total national air passenger throughput in 2020. Meanwhile, the high-speed rail network has achieved full coverage of central cities. On the one hand, the compression of space-time distance has increased the frequency of interaction with neighboring cities and accelerated the process of "co-location," while the radiation and the agglomeration capacity of central cities have been further strengthened and the regional core competitiveness has been improved. On the other hand, the competition between high-speed rail and air has become more intense, and this has led to some negative impacts on the air transport industry [1–5]. From the perspective of the supply side, high-speed rail has increased capacity and provided a more convenient way to travel compared to air. From the demand side, the choice of a variety of travel modes for passengers has led to the transportation market gradually forming a new pattern, with passengers in the dominant position. The competition for passenger resources has become an important tool for the development of the transportation market. Thus, for high-speed rail and air transportation service providers, analyzing the travel decision-making behavior of passengers is of great practical significance for subsequent resource allocation and strategic development in order to facilitate the formation of a new pattern of coordinated development of the transportation market.

Previous research has considered passenger travel preferences from the perspectives of passenger characteristics, transportation characteristics, and the external environment. "Utility theory," revealed preference surveys, stated preference surveys, and other survey methods have been used to obtain data on passengers' actual travel and choice preferences, and to build a non-set model to analyze passengers' travel mode decision-making behavior based on passenger characteristics [6–9]. Feng and Li [10] studied the travel decision-making mechanism of passengers in terms of their travel characteristics, and modeled the market share of different transportation modes using agent theory. Koohathongsumrit and Meethom [11] used a new hybrid multicriteria decision-making approach for route selection in multimodal supply chains to provide an effective decision support tool for decision-makers. Transport characteristics of different modes of transport have been analyzed in terms of safety, economy, comfort, and convenience in order to infer travelers' choice preferences [12, 13]. Roman and Martin [14] measured a range of service quality attributes of different modes of transport to explore the willingness-to-pay values of travelers under different transportation characteristics and found that reducing connection times is critical. Behrens and Pels [15] used a multinomial and mixed logit model to examine the actual travel behavior of passengers through a sample of passengers traveling from London to Paris. They concluded that travel time and the frequency of service are the main determinants of travel choice. From the external environment role perspective, Chai et al. [16] considered the regional economic development level to analyze the impact of high-speed rail development on air transport, finding that high-speed rail made a positive contribution to the development of air transport in regions with higher economic levels. Multiple economic agents [17] and natural environmental factors [18] were included in the unified analysis to explore the competitive relationship between high-speed rail and civil aviation. Wang et al. [19] studied the competition between high-speed rail and airlines in duplicating service hinterlands from a geographical perspective and found that both high-speed rail and airlines tend to serve areas with high population density and developed economy. Research on the competition between China's high-speed railway and the civil aviation industry has shown that the impact of high-speed railway on aviation peaked at the transportation distance of 650–755 miles, and that this impact decreased gradually as the transportation distance increased [16]. Research has shown that when a high-speed railway is opened, the passenger volume of flights along the line gradually decreases. For example, air travel declined by approximately 45% and 34% after the commencement of the Wuhan-Guangzhou and Beijing-Shanghai high-speed railways, respectively [20]. Jiang and Zhang [21] discussed the long-term benefits of high-speed rail competition on air transportation and found that the intervention of high-speed rail has continuously optimized the air transportation market. However, most research focused on the mode of transportation and studied the competitive relationship between high-speed rail and aviation and ignored the market competitive relationship formed by passenger preference. In view of this, the current paper analyzes the spatial differentiation characteristics of the high-speed railway and air transportation market formed by passenger preference from the perspectives of passenger characteristics (income, working hours), vehicle attributes (ticket price, travel distance, travel hours, and safety), external environment (urban infrastructure construction), and urban geography. The study also identifies the travel distance passengers prefer with regard to high-speed railway and aviation under different values of time per capita, and identifies the price- and time-sensitive characteristics of passengers in different cities by analyzing the change of passenger travel utility caused by fare adjustment. The relationship between passengers and transportation modes described in the study is conducive to the rational allocation of subsequent transportation resources. At the same time, the differences between transportation modes can provide a development focus for transportation enterprises so that they can achieve coordinated development between passengers and transportation modes.

Passengers primarily travel from an origin to the departure station mainly via road transportation (private cars, buses, etc.) or urban rail transportation (subway, light rail, etc.). The time for passengers to reach an airport or high-speed rail station varies somewhat due to the differences in infrastructure between cities. In view of this, the current paper considers the articulated travel mode as the city infrastructure construction situation, which is summarized into the perspective of external environment influencing factors.

The paper is structured as follows: Section 1 is the introduction, which introduced the research background and significance of this paper and summarized the current research status and shortcomings. Section 2 briefly introduced the technical methods required for the research problem. Section 3 analyzed the differences in passenger travel utility of high-speed rail and air in the central city passenger transportation market and the spatial differentiation characteristics of the two markets. Section 4 analyzed several factors that influence the travel decision-making behavior of passengers. Section 5 concluded the study.

2. Methods

2.1. Combined Utility Function. Passenger travel utility is the maximum satisfaction obtained via a certain mode of transportation. It is the comprehensive embodiment of a certain mode of transportation in terms of economy, rapidity, comfort, convenience, and safety. By establishing the combined utility function of high-speed rail and air, we can effectively quantify the degree of travel satisfaction of passengers from three perspectives: their own characteristics, attributes of the means of transportation, and the external environment. The combination of the above indicators can be carried out via the addition rule and the multiplication rule. Since safety indicators are relatively independent, when safety is poor, even if other indicators are in a better state, the overall travel utility will be poor. Therefore, the combined utility function model is designed by combining the additive and multiplicative methods, as shown in the following equation:

$$U_{ijk} = \left(\alpha E_{ijk}^{-1} + \beta Q_{ijk}^{-1} + \gamma M_{ijk}^{-1}\right) \times \varepsilon S_{ijk}^{-1}. \tag{1}$$

U_{ijk} is the combined utility value of the passengers' choice of mode (K) when traveling from city i to city j. The larger the value of U_{ijk}, the greater the satisfaction obtained by the travelers. E_{iik}, Q_{ijk}, M_{ijk}, F_{ijk}, and S_{ijk} are the indicators of economy, rapidity, comfort, convenience, and safety of passengers' choice of travel mode (K) on the travel route from city i to city j, respectively. α, β, γ, δ, and ε are the weights of each indicator obtained using the maximum likelihood estimation method.

The economy indicator is the product of the unit distance fare and the travel distance. This paper sets high-speed rail and air fares based on the pricing standards in the civil aviation domestic fare reform program. The air fare is 0.75 RMB per kilometer, and the fare for high-speed rail is 0.48 RMB per kilometer. The economic index (E) is shown as follows:

$$E = I \times D. \tag{2}$$

The rapidity indicator is the product of travel time in transit and the value of time per passenger. Passenger travel time consists of two components: total travel time (t) from the origin to the departure station and the destination to the end station, and travel time between stations (T). The total travel time (t) is obtained by analyzing the traveler's reachability time to reach the station through the shortest path analysis module in a geographic information system, and the interstation travel time (T) is obtained from the timetable. The value of time per capita (A) is measured using the income approach in economics as the ratio of the gross domestic product (GDP) per capita to the annual working hours. The rapidity indicator (Q) can be represented by

$$Q = (T + t) \times A. \tag{3}$$

The comfort indicator measurement method has been relatively well-developed: J is the ultimate recovery fatigue period, obtained by the travel recovery fatigue curve measurement, a and b are the hysteresis coefficients, and M is the comfort index as shown in the following equation:

$$M = \frac{J \times A}{1 + a \times e^{-b \times T}}. \tag{4}$$

The convenience indicator is the product of the time consumed taken up by the processes of ticketing, security check, and waiting for trains and the value of time per capita.

The safety indicator is taken to be 1 due to the low accident rate of high-speed rail and air.

2.2. Standard Deviation Ellipse. The standard deviation ellipse, as a classical method of analysis of directional characteristics of spatial distribution [22], plays an important role in characterizing the layout of high-speed rail and air transportation markets in space and in correctly understanding the development focus. The standard deviation ellipse has the following basic elements: center point, long semi-axis, short semi-axis, and azimuthal angle. The specific implementation steps are as follows.

The center of the ellipse is determined by the arithmetic mean center. This is calculated by

$$\begin{cases} \mathrm{SDE}_x = \sqrt{\dfrac{\sum_{i=1}^{n} \left(x_i - X\right)^2}{n}}, \\[2ex] \mathrm{SDE}_y = \sqrt{\dfrac{\sum_{i=1}^{n} \left(y_i - Y\right)^2}{n}}. \end{cases} \tag{5}$$

SDE_x and SDE_y are the variance of the ellipse. This determines the spreading range of high-speed rail and air markets in geographic space. x_i and y_i are the spatial location coordinates of city i. X and Y are the arithmetic mean centers, and n is the number of cities.

The direction of the ellipse can be determined by taking the x-axis as the prevailing axis and the positive north as 0°. This is calculated in the following equation, where $\widetilde{x}_i$ and $\widetilde{y}_i$ are the differences between the mean center and the x- and y-axes' coordinates.

$$\tan\theta = \frac{\left(\sum_{i=1}^{n} \widetilde{x}_i^{\,2} - \sum_{i=1}^{n} \widetilde{y}_i^{\,2}\right) + \sqrt{\left(\sum_{i=1}^{n} \widetilde{x}_i^{\,2} - \sum_{i=1}^{n} \widetilde{y}_i^{\,2}\right) + 4\left(\sum_{i=1}^{n} \widetilde{x}_i^{\,2}\widetilde{y}_i^{\,2}\right)^2}}{2\sum_{i=1}^{n} \widetilde{x}_i^{\,2}\widetilde{y}_i^{\,2}}. \tag{6}$$

The lengths of the x- and y-axes are determined as shown in the following equation:

$$\begin{cases} \sigma_x = \sqrt{2}\sqrt{\dfrac{\sum_{i=1}^{n}\left(\tilde{x}_i \cos\theta - \tilde{y}_i \sin\theta\right)^2}{n}}, \\ \sigma_y = \sqrt{2}\sqrt{\dfrac{\sum_{i=1}^{n}\left(\tilde{x}_i \sin\theta + \tilde{y}_i \cos\theta\right)^2}{n}}. \end{cases} \tag{7}$$

σ_x and σ_y are the standard deviations of x- and y-axes, respectively. The difference between the long and short semi-axes determines the flatness of the ellipse. The larger the difference, the flatter the ellipse, and the more obvious the directionality of the characterized element data. The shorter the short semi-axis, the stronger the centripetal force of the characterized element data, and the greater the dispersion of the element data.

2.3. Passenger Selection Probability of Travel Mode. For city node i with multiple transportation options, it is assumed that the passenger has k options on the travel route from i to j. The mode k travel utility is U_{ik}, the probability of the travel mode k being selected is P_{ik}, which is calculated as follows:

$$\begin{cases} P_{ik} = \dfrac{e^{U_{ik}}}{\sum_{k=1}^{2} e^{U_{ik}}}, \\ U_{ik} = \sum_{j=1}^{n} U_{ijk}. \end{cases} \tag{8}$$

3. Measurement of High-Speed Railway and Air Travel Utility and Market Patterns in Central Cities

The variability among passenger characteristics, transportation characteristics, and external environment makes the combined quantified utility values of passengers choosing high-speed rail and air travel in the central city passenger transportation market vary somewhat. This section analyzes the differences between high-speed rail and air travel by measuring the utility values of passenger travel in the central city passenger market in a macroscopic comparison, and further verifies the rationality of the combined utility function through the standard deviation ellipse.

3.1. Utility Value Measurement of High-Speed Railway and Air Passengers in Central Cities. With the presence of both high-speed rail and air operations, travelers have several choices with regard to modes of travel. As a result, passengers often choose the mode of travel that maximizes their own interests. The level of satisfaction offered by different means of transport determines the willingness of passengers to reuse them, thus creating competitiveness in the transport market.

Analysis of the economy, rapidity, comfort, convenience, and safety of high-speed rail and air travel in 33 central cities shows that the utility values are in the range of 0.17–2.25 and 0.26–3.07, respectively, as shown in Table 1. For central cities, the satisfaction of passengers choosing high-speed rail travel is lower than those choosing air, indicating that passengers prefer air travel in a transportation market composed of central cities as nodes. The travel utility values vary widely between cities under the same transportation mode. In terms of high-speed rail travel, the utility value of passenger travel in Beijing and Shanghai is 2.25, while the utility value of passenger travel in marginal areas such as Hohhot, Changchun, and Urumqi is less than 0.3. In terms of air travel, the utility value of passenger travel in Beijing and Shanghai is greater than 3, while the utility value of passenger travel in marginal areas such as Hohhot, Changchun, and Urumqi is only around 0.3. As shown in Figure 1, a visual analysis of the distribution pattern of linkages constituted by central cities shows that Beijing, Shanghai, Guangzhou, and Chengdu-Chongqing areas are densely connected, forming a network structure of greater scale, making these areas more accessible to travelers, in contrast to other areas, with obvious imbalance, forming a core-edge characteristic. There are also differences in the degree of satisfaction of passengers from different modes of transportation within the same city. A total of 57.6% of central cities have a difference of 0.5 or more between the utility values of high-speed rail and air travel. For cities with more obvious core status, the difference between the utility values of high-speed rail and air travel is larger, while marginal areas are relatively neutral in their choice of travel modes.

From the perspective of different transportation distances, passengers' travel preferences for high-speed rail and aviation show different characteristics in the distance distribution law. As shown in Figure 2, the distribution of air passenger flow does not conform to the distance attenuation law but shows a skewed distribution. Within the air transportation range of 200–1,000 km, the air passenger flow increases with distance, and then fluctuates and attenuates. High-speed railway transportation shows a particularly obvious law of distance attenuation beyond 200 km. In terms of medium- and short-distance transportation distance, high-speed rail maintains a dominant position in the comprehensive transportation system with its technical advantages, which also reflected that passengers prefer high-speed rail for short-distance travel. With the increase in distance, the technical advantages of high-speed rail gradually weaken, and the advantages of air transportation gradually highlight and occupy a dominant position, making air travel more popular for passengers traveling medium and long distances.

3.2. Spatial Patterns of High-Speed Railway and Air Market Based on Utility Value. The passenger travel utility was determined to verify whether the spatial pattern of the transportation market formed by passenger preferences fits the actual spatial pattern of the high-speed rail and air market. The probability of travel choice of high-speed rail and air was measured using passenger travel utility value as the weighted value and high-speed rail frequency and flight frequency as the original value. The consistency analysis of the weighted and original values using the standard deviation ellipse is shown in Table 2.

Table 1: Travel utility value of high-speed rail (HSR) and air in central cities.

City	U_i		X	City	U_i		X
	HSR	Air			HSR	Air	
Beijing	2.25	3.06	0.81	Qingdao	1.4	1.95	0.55
Shanghai	2.25	3.07	0.82	Hangzhou	1.3	1.83	0.53
Chengdu	1.7	2.51	0.81	Nanchang	1.16	1.64	0.48
Chongqing	1.81	2.56	0.75	Nanjing	1.13	1.58	0.45
Guangzhou	1.84	2.55	0.71	Ningbo	1.14	1.59	0.45
Xian	1.79	2.49	0.7	Tianjin	1.12	1.54	0.42
Lanzhou	1.43	2.11	0.68	Jinan	0.86	1.21	0.35
Wuhan	1.68	2.33	0.65	Shenyang	0.78	1.09	0.31
Xiamen	1.49	2.12	0.63	Hefei	0.63	0.88	0.25
Zhengzhou	1.51	2.13	0.62	Shijiazhuang	0.52	0.74	0.22
Kunming	1.35	1.97	0.62	Harbin	0.63	0.84	0.21
Guiyang	1.36	1.98	0.62	Dalian	0.44	0.61	0.17
Taiyuan	1.29	1.89	0.6	Xining	0.35	0.51	0.16
Fuzhou	1.4	1.99	0.59	Hohhot	0.17	0.28	0.11
Nanning	1.26	1.84	0.58	Changchun	0.26	0.36	0.1
Changsha	1.43	2	0.57	Urumqi	0.17	0.26	0.9
Shenzhen	1.39	1.95	0.56				

Note. X represents the difference of passenger travel utility between HSR and air.

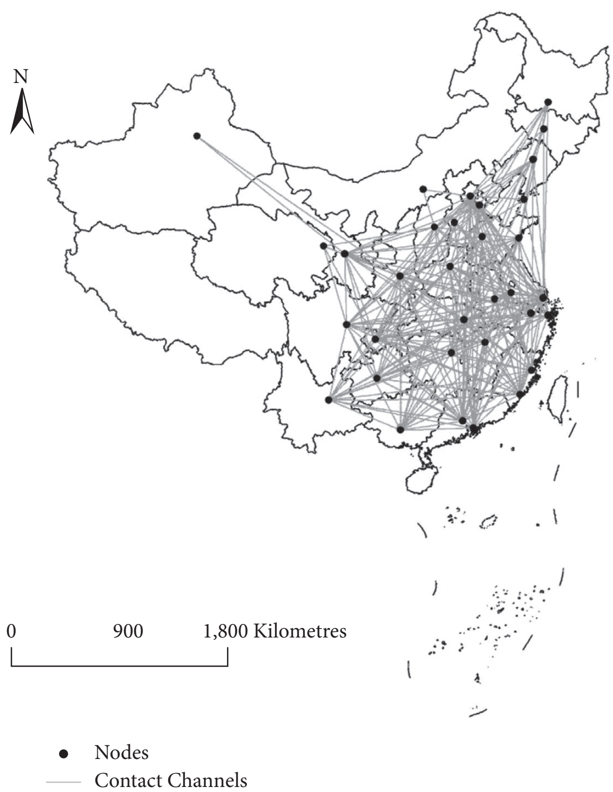

Figure 1: Distribution pattern of contact channels. Note: Nodes: Central cities with both high-speed railway stations and airports. Contact Channels: Passenger travel routes with both high-speed rail and air transport services. The figure intuitively reflects the range layout of passengers who can choose both high-speed rail travel and air travel.

(1) The center-of-gravity point is consistent. From the perspective of weighted values, the center of gravity of the high-speed rail market layout is located at (113.9° E, 33.8° N), and the center of gravity of the air market layout is located at (113.8° E, 32.9° N). In terms of raw values, the center of gravity of the high-speed rail market layout is located at (114.3° E, 33.4° N), and the center of gravity of the air market layout is located at (113.5° E, 33.2° N). Both favor the spatial development pattern with Zhengzhou as the center-of-gravity point.

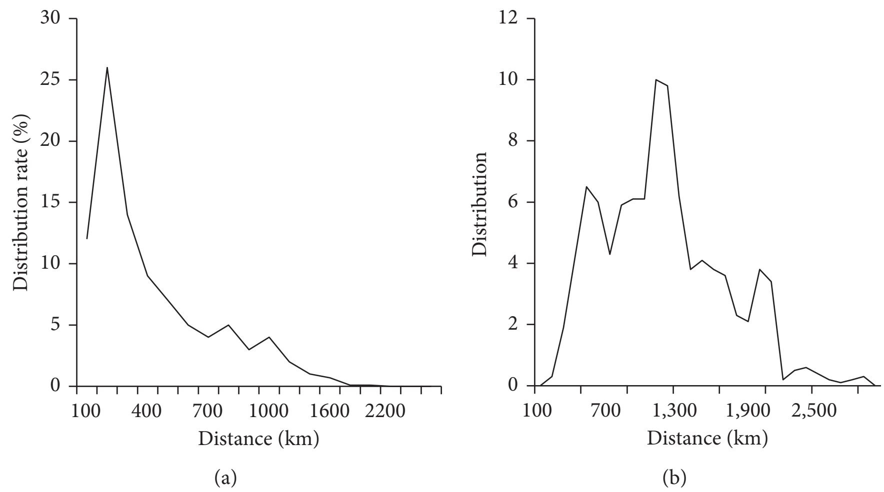

Figure 2: Travel preference of high-speed rail and air under different transportation distances. (a) HSR. (b) Aviation

Table 2: Estimated value of ellipse elements of high-speed rail and air.

	Center	Rotation (degree)	Axial length	
			x	y
HSR				
Weighted value	(113.9° E, 33.8° N)	78.83°	11.88	9.17
Raw value	(114.3° E, 33.4° N)	70.61°	10.87	8.58
Air				
Weighted value	(113.8° E, 32.9° N)	72.47°	11.05	8.77
Raw value	(113.5° E, 33.2° N)	78.09°	11.75	9.22

(2) The spatial layout range is also consistent. From the spatial layout range of the ellipse, the difference (u) of both long and short semi-axes lies within the interval of 2.28–2.71, while the rotation angle lies within the interval of 72°–79°, and the direction axes are all pointing northeast-southwest.

These results show that the market pattern of high-speed rail and airline based on passenger travel utility value can effectively portray the actual market, indicating that factors such as economy, rapidity, comfort, convenience, and safety have a degree of influence on passenger travel decision-making behavior.

The high-speed rail and air market patterns measured based on the combined utility function of passenger travel are visualized in Figure 3. An analysis of the spatial distribution differences between the two transportation markets shows that:

(1) The market expansion direction of high-speed rail and air is different. The layout of the air market is biased to the south, while the layout of high-speed rail is more concentrated to the north. In the central city transportation market, a fierce competition zone is formed with Zhengzhou as the center, while the market scope of each relative advantage is formed in the partial north and the partial south.

(2) The degree of equilibrium in the development of the air market is more perfect compared to that of the high-speed rail market. The smaller the difference between the long and short semi-axes of the ellipse, the flatter the shape, making the ellipse closer to a circle. The difference between the long and short semi-axes of high-speed rail is 2.71, while the difference for air is 2.28. This indicates that the directionality of high-speed rail is more obvious compared with air, while the development of air is better balanced.

(3) The layout of the high-speed rail market has a larger scope. The ellipse area of high-speed rail is 342.56 km^2, and the ellipse area of air is 304.60 km^2. Characterizing the scope of the market layout by the ellipse area, it is found that the scope of high-speed rail market is larger than that of the aviation market, and it is located on the north side, forming a relative competition gap area.

A comparative analysis of the market layout of high-speed rail and air reveals that the two transportation markets are based on comprehensive factors that have different spatial characteristics. The market layout of high-speed rail is larger in scope compared with the air market, but the development is less balanced. Both form a competitive pattern

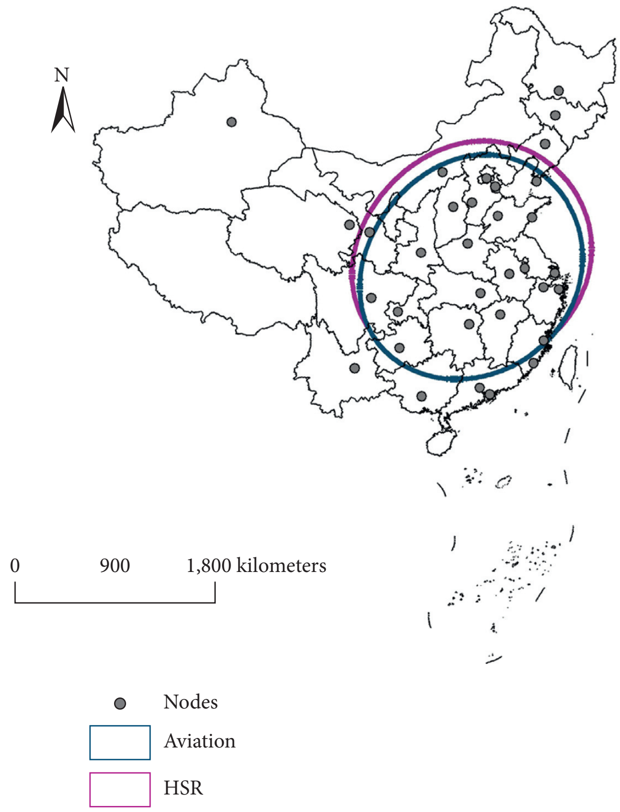

Figure 3: Spatial distribution pattern of the high-speed rail and air market based on utility value. Note: The ellipse marked in purple indicates the spatial layout of passengers' preference for high-speed rail travel in the passenger transport market of central cities; the ellipse marked in blue indicates the spatial layout of passengers' preference for air travel in the passenger transport market of central cities. The size, direction, and center point of the ellipse intuitively reflect the differences of passengers' preferences for high-speed rail and air travel in central cities.

with Zhengzhou as the center, as well as the respective relative advantage areas on the south and north sides.

4. Influencing Factors

Since passengers' preferences for high-speed rail and air show spatially differentiated characteristics in the overall central city transportation market, it is necessary to explore the mechanisms underlying the formation of intercity variability. In transportation market research, Mandel et al. [23] added socioeconomic variables to enrich the logit model. This can provide more reasonable results when compared with the traditional linear utility function. Therefore, this section investigates the differences in the value of time per capita caused by different levels of urban economic development and identifies the travel distance in travelers' preference for high-speed rail and air. At the same time, by analyzing the change pattern of travel utility values triggered by fare adjustment, the price and time sensitivity of travelers in different cities is discerned.

4.1. The Value of Time per Capita. Economic indicators such as GDP per capita, year-end savings deposits of residents, average wage of employees, disposable income, and retail sales of social consumer goods per capita were clustered to analyze 33 central cities, and the value of time per capita was measured using the income method. The value of time per capita was used to divide the central cities into four categories, as shown in Table 3.

To further analyze the influence of value of time per capita on urban residents' travel preferences, the dominant zones of high-speed rail and air under different values of time per capita are portrayed—i.e., passengers' preference for a certain travel mode is higher in that zone. The high-speed rail and air transportation markets are divided according to the sharing rate and categorized into an absolute dominance zone (sharing rate over 90%), a relative dominance zone (sharing rate 70–90%), and a competitive zone (30–70%), as shown in Table 4. High-speed rail and air passenger travel preferences show a certain distance effect. High-speed rail shows dominance at short and medium transport distances, while the dominance of aviation transport is mainly concentrated in the medium and long transport markets. With the growth of the value of time per capita, the dominant segment of high-speed rail gradually decreases, and the dominant segment of air gradually increases, i.e., the value of time per capita is inversely proportional to the dominant segment of high-speed rail and positively proportional to the dominant segment of air.

For cities with a value of time per capita of 52.90 RMB per hour, the dominant segment of high-speed rail is mainly

Table 3: The value of time per capita of central cities.

Category	Cities	Value of time per capita (RMB per hour)
1	Beijing, Shanghai, Tianjin	52.90
2	Nanjing, Hangzhou, Ningbo, Shenzhen, Jinan, Wuhan, Qingdao, Changchun, Chongqing, Dalian, Shenyang, Guangzhou	35.00
3	Harbin, Xining, Fuzhou, Xiamen, Zhengzhou, Hefei, Shijiazhuang, Nanchang, Changsha, Xian	28.00
4	Kunming, Lanzhou, Guiyang, Taiyuan, Nanning, Chengdu, Hohhot, Urumqi	17.63

Table 4: Division of market scope of high-speed rail and air.

Value of time per capita (RMB per hour	Absolute advantage section (km)		Highly competitive section (km)	Comparative advantage section (km)	
	HSR	Air		HSR	Air
52.90	<310	>1030	630–890	310–630	890–1030
35.00	<410	>1120	690–940	410–690	940–1120
28.00	<460	>1320	780–1110	460–780	1110–1320
17.63	<540	>1410	860–1250	540–860	1250–1410

the transportation market within 310 km, and the dominant segment of air is the transportation market beyond 1,030 km. As the value of time per capita decreases to 17.63 RMB per hour, the advantageous area of high-speed rail expands to the transportation market within 540 km, and the advantageous area of air shrinks to the transportation market beyond 1,410 km. This indicates that with the increase in the value of time per capita, the preference for high-speed rail travel gradually decreases, and the preference of air travel gradually increases—i.e., as the economic cost pressure of transportation travel gradually decreases, speed becomes an important consideration for travelers, reflecting that with the increase in the value of time per capita, the price sensitivity of travelers decreases, and the time sensitivity increases.

However, there are still some potential markets that theoretically belong to the advantageous transportation range of high-speed rail and air to be expanded. Based on the absolute advantageous transportation range of high-speed rail and aviation in Table 4, Table 5 shows the potential markets that have not formed a competitive relationship to date. It can be seen that Lhasa's passenger transport market is relatively weak, with 10 cities not connected. Therefore, on the one hand, the development of potential markets can alleviate the fierce competition between high-speed rail and air, forming a balanced and coordinated transportation pattern. On the other hand, such development is conducive to the interaction between the two node cities, which would improve the travel utility of passengers in marginal areas.

4.2. Fare Structures. The different attributes of the means of transportation indicate that high-speed rail and air have different fare structures. The existence of certain social attributes of high-speed rail operations makes the fare structure relatively uniform. Statistical analysis of high-speed rail data shows that its fare level is about 0.48 RMB per kilometer. Air operations are shared by multiple airlines, and the fare structure is more complex than for high-speed rail. In order to curb airline competition and irregularities in the formulation of fares, the civil aviation domestic tariff reform program manages airline fares and adjusts the indirect management of air transport benchmark prices and fluctuation ranges, with the average social cost of air transport, market supply and demand conditions, and social affordability used to determine benchmark prices and fluctuation ranges. The benchmark price is set at an average of 0.75 RMB per kilometer; the maximum rate of fare increase must not exceed 25% of the benchmark price, and the rate of downward fluctuation must not exceed 45% of the benchmark price except for special routes. In view of this, the fare structure of domestic routes is shown in Table 6.

The coefficient of variation is used to analyze the dispersion of passenger travel utility values measured by the three types of fares. As shown in Table 7, based on the current average fare of 0.75 RMB per passenger kilometer on the route, increasing fares slightly reduce the gap in the utility values of passenger travel between cities within a certain range, with the coefficient of variation decreasing from 4.21 to 4.20, while decreasing fares maximize passengers' self-interest, with the coefficient of variation increasing from 4.21 to 4.31. Overall, the change in fare structure has a relatively low impact on passengers who choose to travel by air, further reflecting the reduced economic pressure of transportation travel and the increasing importance of speedy travel, i.e., air passengers are less price-sensitive and more time-sensitive to travel.

In order to study the impact of fare structure changes on the utility values of passenger travel, the utility values of air passenger travel measured by fare increases and fare decreases were compared with the utility values measured based on the base price, as shown in Table 8.

Table 5: Competitive gaps for high-speed rail and air.

City	Cities not connected	City	Cities not connected
Changsha	Lhasa, Shijiazhuang	Nanning	Xining
Changchun	Guiyang, Lhasa, Xining	Shenyang	Lhasa, Xining
Dalian	Lhasa, Xining, Yinchuan	Shijiazhuang	Changsha, Lhasa, Xining
Guiyang	Changchun	Taiyuan	Xining
Harbin	Lanzhou, Lhasa	Tianjin	Xining
Jinan	Lhasa	Urumqi	Lhasa, Ningbo
Lanzhou	Shijiazhuang	Xining	Dalian, Ningbo, Nanning, Shenyang, Shijiazhuang, Taiyuan, Tianjin
Nanchang	Changsha, Lhasa	Zhengzhou	Lhasa

Table 6: Fare structure of domestic routes.

Fare structure	Fare (RMB per passenger km)
Upper limits	0.94
Benchmark price	0.75
Lower limits	0.41

Table 7: Intergroup differences in different fares.

Fare	Standard deviation	Average value	Coefficient of variation
Upper limits	0.00522	0.12431	4.20
Benchmark price	0.00525	0.12445	4.21
Lower limits	0.00539	0.12501	4.31

Table 8: The change of utility value caused by fare adjustment.

City	Increase	Decrease	City	Increase	Decrease
Beijing			Qingdao		
Shanghai		+	Hangzhou	–	+
Chengdu		+	Nanchang		+
Chongqing		+	Nanjing		+
Guangzhou		+	Ningbo		+
Xian		+	Tianjin	–	
Lanzhou	–		Jinan		+
Wuhan		+	Shenyang		+
Xiamen		+	Hefei		+
Zhengzhou	–	+	Shijiazhuang	–	+
Kunming			Harbin		+
Guiyang		+	Dalian		+
Taiyuan	–	+	Xining	–	
Fuzhou			Hohhot		+
Nanning		+	Changchun		
Changsha			Urumqi	–	
Shenzhen	–				

Note. –Indicates that the utility value of urban passenger travel under a certain fare level is reduced compared with the utility value calculated at the benchmark price, +indicates an increase.

(1) The increase in air fares decreases the utility value of air travel in 9 cities, accounting for 27% of the sample, while a decrease in fares increases the utility value of air travel in 22 cities, accounting for 67% of the sample. It can be seen that the loss of air travelers caused by the increase in fares within a certain range is limited, but the demand for air travel by passengers can be increased significantly by the reduction of fares.

(2) The adjustment of fares has little impact for cities such as Beijing, Changchun, Changsha, Fuzhou, Kunming, and Qingdao. In these cities, passenger travel utility values are relatively unchanged and show low price sensitivity, while for cities such as Hangzhou, Shijiazhuang, Taiyuan, and Zhengzhou, whose passenger travel utility values are proportional to the fares, high price sensitivity is shown.

Table 9: Regression results of influencing factors on high-speed rail and air passenger travel utility.

Variable	High-speed rail		Air	
	Coefficient	Standard error	Coefficient	Standard error
In(DIS)	0.013***	0.005	−0.0051***	0.000
In(PRI)	−0.014***	0.004	−0.0001	0.000
In(VTPC)	0.022***	0.004	−0.0137***	0.000
Constant	−0.072***	0.022	0.2066***	0.002

Note: ***, **, and * indicate significance at the levels of 10%, 5%, and 1%, respectively.

4.3. Impact Analysis. By combining the potential impact of distance, the value of time per capita, and fare on passenger travel utility, the extent of the impact of each factor can be quantified. The data model is shown as follows:

$$\begin{aligned}\text{In}\left(\text{UV}_i\right) &= \beta_0 + \beta_1\text{In}\left(\text{DIS}_i\right) + \beta_2\text{In}\left(\text{PRI}_i\right) \\ &\quad + \beta_3\text{In}\left(\text{VTPC}_i\right) + \varepsilon_i.\end{aligned} \tag{9}$$

The interpreted variable (UV) is the passenger travel utility, and the explanatory variables are the travel distance (DIS), expressed in terms of distance between stations; fare (PRI), the price at which the ticket is purchased in accordance with regulations; and the value of time per capita (VTPC), expressed as a percentage of the GDP per capita to the annual working hours.

The specific analysis of the explanatory variables is shown in Table 9: (1) Distance has a positive and significant impact on the travel utility of high-speed rail, and has a negative significant impact on aviation. An increase in distance traveled leads to a decrease in the travel utility of high-speed rail passengers, but the travel utility of air passengers increases. This confirms that the passengers' preference for high-speed rail adheres to the law of distance attenuation. (2) The impact of fare on aviation is not significant, due to the low price sensitivity of air passengers. For these passengers, the pursuit of service quality is more important. (3) The value of time per capita has a positive impact on the utility of high-speed rail and a negative impact on air travel. The value of time per capita reflects the level of passenger consumption to a certain extent, and it can be seen that passengers in areas with higher economic level are more inclined to choose air as a mode of travel.

5. Conclusions

This paper studied sample data from cities where both high-speed rail and air operations exist. The results show that (1) air travel gives residents in central cities a higher sense of travel satisfaction when compared with high-speed rail travel. However, the gap between the two is narrowed in marginal cities, indicating that the dominance of air transportation is largely reflected in cities with core status. At the same time, because the peripheral cities are less connected to their neighbors, there is a considerable gap between the travel utility of the same mode of transportation in these areas and that of the core cities. (2) When the spatial distribution of travel preferences of high-speed rail and air passengers is analyzed by means of standard deviation ellipses, it is found that there are obvious geographical differences in the spatial orientation of passengers who prefer high-speed rail travel to air travel. In the north, the passenger preference for high-speed rail travel is clearer than that for air travel, but the development is less balanced than that of the air passenger market. Overall, the spatial distribution of passenger travel preference is centered on (113° E, 33° N) and expands in all directions. (3) Meanwhile, the value of time per capita is inversely proportional to the length of the dominant interval of high-speed rail and positively proportional to the dominant interval of air transportation. The time sensitivity of travelers gradually increases as the economic pressure of travel decreases. (4) The air fare structure is more complex compared to high-speed rail, and it was found that a move to lower fares caused the overall gap between cities to be widened, indicating that a single fare does not apply to all cities.

In view of the above results, the following countermeasures and suggestions are put forward. (1) Within the transportation scope of the absolute advantage of high-speed rail, some medium- and short-haul air routes should be appropriately compressed or eliminated so as to avoid the waste of aviation resources caused by the excessive concentration of a single transportation mode. (2) The price sensitivity of air passengers is lower than that of high-speed rail passengers. For the air transportation industry, practitioners should strengthen the quality of transportation services and match the ticket price with the passenger consumption level to avoid lost revenue opportunities. For high-speed rail, relevant parties should break through the bottleneck of the current unified fare and seek a better designated mode of floating fare to meet the travel needs of passengers under different transportation distances. (3) At present, in the transportation market of central cities, there are still markets suited to two modes of transportation. Therefore, potential markets should be explored to form a balanced and coordinated passenger transport market pattern. This requires the consideration of several factors. First, due to certain aspects of air transportation, such as ticket price fluctuation and uncertainty of punctuality rate, there is a gap between the actual utility of air passenger travel and expectation. Second, the market difference between high-speed rail and aviation caused by passenger travel preference provides a construction idea for the coordinated development of the two modes of transportation. In follow-up research, simulating the implementation path of the coordinated development of the two modes of transportation will be highly significant in building an integrated transportation market.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was partially supported by National Science Foundation of China (grant nos. U2033213 and U1733127). It was also supported by Fundamental Research Funds for Center Universities, China (grant no. J2021-063), and Independent Research Project of Key Laboratory of Civil Aviation Flight Technology and Flight Safety, China (grant no. FZ2021KF12).

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