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Airport classification in Chinese multi-airport regions: An interaction network perspective between aviation and high-speed rail

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The agglomeration of airports into multi-airport regions (MARs) has become one of the salient features of the worldwide air transport system in the last decades. Meanwhile, in China, the development of HSR is growing quickly, and is both competitive to and cooperative with the aviation network. To date some research has focused on the airport classification with aviation network properties within the specific MARs. However, little research comprehensively integrates complementary transport systems (such as civil aviation versus high-speed rail (HSR)) into the analytical framework for airport classification. The purpose of this paper is to identify the unique nature of component airports and their distribution in MARs in China from multiple perspectives by accounting for the influence of the HSR system. Airports are classified along multiple dimensions including

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competitive concentrations, the interaction between air transport and HSR, and airport community structure, among others. The results produce distinct partitions of the component airports in Chinese MARs, and provide insights into Chinese airport functionality and impacts of the HSR network on the distribution of different types of airports. The conclusions provide a more comprehensive assessment of airports' spatial arrangement in the unique Chinese MAR context. Although this paper did not derive the market share allocation and co-opetition relationship between a specific airport and HSR, it proposed a basic framework for future research.

Keywords: *airport classification, multi-airport region, interaction network, cluster analysis, high-speed rail, China.*

1. Introduction

Airport classification is a basis for analyzing the composition of aviation markets and their development. The categorization of airports by attribute, function, and region permits a better understanding of complex aviation markets, transport networks, and the nexus between place and mobility. The operating characteristics of an airport, geographic location, and the density of other co-located modes of transport in the surrounding area will have varying degrees of impact on how airports are organized. In China, the rapid development and planned future construction of high-speed rail (HSR) create a particularly multifaceted system for domestic travel that significantly impacts air networks. The aviation market, which traditionally has advantages on mid- and long-distance routes is undergoing a major test of both competition and cooperation from HSR. It is now evident that air transport is inseparable from the practical impact of HSR and that additional research to understand the role of airports in this evolving environment is required.

Discussions of the classification of airports appeared in a series of early Air Transport Research Society research reports (ATRS 2002) (ATRS Global Airport Benchmarking Research Report, 2002). The importance of classifying airports was reflected in numerous studies on the productivity, performance, and operational efficiency of airports as the 21st century began (Gillen and Lall, 1997; Janic and Reggiani, 2002; Lin and Hong, 2006; Oum et al., 2003; Sarkis and Talluri, 2004; S. Zhang et al., 2014). These articles were influential in the subsequent selection of classification criteria in research that followed. Organizations such as the International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) continue to use similar measures – such as airport size, function and ownership in their reporting. There are many possible indicators on which to base airport classification, including airlines' airport-based seat capacity, passengers, destinations and other operational data. At the same time, with the gradual formation and recognition of multi-airport regions (MARs) around the world (de Neufville, 1995), the classification of airports has necessarily become more refined and diverse. Scholars have reflected this diversity in the functionality of airports based both on standard measures and those that reflect on the idiosyncrasies of MARs in different regions (Malighetti et al., 2008; Rodríguez-Déniz et al., 2013; Fuellhart and O'Connor, 2019).

The rapid development of the aviation industry in China over the past several decades has resulted in a spatial configuration of airports in which MARs figure prominently. In particular, the massive growth in the demand for transport services in China, combined with growing incomes and greater regional integration requires approaches to understanding air transport that is sensitive to the complex Chinese context. The operation of the airline network in China differs from other countries (for example, minimal low-cost carrier impacts) as well as in aviation management (e.g., relatively high levels of regulation). This paper formulates a classification of airports in Chinese MARs that is explicitly sensitive to high-speed rail (HSR) which has developed with government-backing alongside aviation. The strong impact of HSR on the aviation market has given rise to new driving factors for the evolution of China's MARs. The competition and collaboration between Air-HSR has become an important research concern and often involves cost-benefit analysis, assessments of the impact on air transport market structure, and overall welfare implications (Adler et al., 2010; Jiang et al., 2017; Takebayashi, 2016; Xia and Zhang, 2017; Yang et al., 2020; A. Zhang et al., 2019). However, less work has been accomplished on the exploration of distinctive new groupings of airports and the distribution of various airport combinations in MARs taking into account the interactions of Air-HSR.

In view of China's unique background of aviation development and the concomitant expansion of a substantial HSR network, this paper proposes a new methodology to classify airports in Chinese MARs. The focus is to establish a basis point for future research by assessing the classification of airports in 2014 – a period just prior to the most recent spate of HSR development. By establishing the impact of HSR on airport operations and function at that time, a more complete understanding of the evolution of the nature of Air-HSR interaction may be possible.

Functional framework design is also one of the key points of government aviation network planning in the context of MARs (Malighetti et al., 2009a). In the future, for the basic classification analysis of airport functional division in China, it is inevitable that HSR must be considered. Therefore, three core questions are at the foundation of the research:

(1) Considering the interaction of Air-HSR, how can Chinese airports best be classified considering these dual modes of transport?

(2) To what extent does the new airport classification reflect the existing categorization apposed (issued) by the government or other authorities?

(3) What does airport classification under the existing multi-airport regional division in China imply for current and future transport in China?

The remainder of this article is organized in the following way. Section 2 gives a brief overview of the three core concerns of the research: airport classification, MARs, and the competition and collaboration between air transport and HSR (Air-HSR). Section 3 is concerned with the data used, and Section 4 describes the methodologies. The comparative results of the analyses are presented in Section 5, and Section 6 provides concluding thoughts and points to avenues for future research.

2. Literature Review

2.1 Air-HSR

With the increase and diversification of traffic demand, interaction between different transport modes is apparent. In particular, in some parts of the world, aviation and HSR have increased the extent of their overlap in recent years resulting in networks that have characteristics of substitution, complementarity, and competition coexisting at the same time. This has led to increasing interest in the empirical assessments between Air and HSR in different regional environments.

Due to the continuous development of HSR, its advantages (such as convenience and cheaper fares in some market lengths) have gradually made it a high-quality alternative for air passengers, and the competition between Air and HSR is becoming more pronounced. This has resulted in the research on the relationships between air transport and HSR to deepen over the past decade and incorporate more nuanced approaches. Much prior work about the Air-HSR relationship focused on passenger choice and the topics of substitution and competition. González-Savignat (2004) studied the potential competitiveness of HSR on the aviation market by analyzing passenger preferences under the assumption that some yet-to-be-built high-speed rail lines actually existed.

From the perspective of demand, they considered HSR as a competitor of air transport, indicating that air passengers began to switch modal choice during this period. Román et al. (2007) used Madrid–Barcelona as a case study to explore the underlying Air-HSR competition relationship by willingness-to-pay estimate and comparison of travel time saving between two modes of transport. To analyze the potential competition of Air-HSR in Trans-European high-speed rail network (TEN) projects, Adler and other authors (Adler et al., 2010) applied an updated game methodology for evaluating the cost-profit of different modes with the investment from the European Union. Dobruszkes (2011) implemented a supply-side comparison between HSR and air transport in Western Europe. Some aviation carriers changed their supply-side strategies for more efficient competition, such as reductions in seats and increases in flight frequency. The study shows that the services and development strategies provided by one transport supplier will also become an important factor in multi-supplier competition. Behrens and Pels (2012) also showed the intermodal and intramodal competition of Air-HSR in the London–Paris passenger market over six years from 2003. By exploring the extent and condition of substitution of HSR to air transport, they found two important factors for determining travel choice, travel time and frequency.

It is clear that the overlapping networks of HSR and air transport have been well-established as multifaceted and complex, especially in Europe and Asia. Yet while European studies into Air-HSR dominated earlier research, China, which has only rapidly developed HSR in recent years, has become the geographic focus of a new round of case studies. Yang and Zhang (2012) conducted an investigation of the influence of the Air-HSR competition effects on prices, profits and welfare under the assumption of maximizing profits of airlines, taking Chinese data as an example. Their research shows that the focuses on the Air-HSR competition from European and Chinese perspectives are different. Europe, for example, is much more mature in its identification of important factors that will drive the co-evolution of the Air-HSR relationship in coming years. China on the other hand – especially given the current rapid expansion of HSR – requires substantially more study on the social and economic impact of the competition between the two modes and to make certain that planning studies and hypothetical predictions for future HSR construction plans are coordinated in a reasonable, efficient and equitable way. All of this suggests that diverse, regionally-sensitive perspectives must be taken in assessing the Air-HSR relationship. For example, Wang et al. (2020) focused on the ‘temporal dimension’ and applied a time window method to assess Chinese city-pair operation between aviation and HSR. They found that there is a co-existence of competition and cooperation in the Air- HSR market, especially in the category of complementary city-pairs, highlighting the simultaneity competition and cooperation.

With the need for regional sensitivity in mind, a range of perspectives have been utilized to capture the specific nature of HSR and Air. Givoni and Banister (2006) began to search for the possibility of intermodal integration in the competition between different modes of transport. In their model, the service provided by HSR was used as a special spark in the aviation network to act in a role of complementarity or substitution. The free slots and modal convenience had significant benefits to airlines, lower environmental impacts, and smaller construction costs that promoted reasonable social resource allocation. Derudder et al. (2010) pointed out, looking at Bay Area Rapid Transit (BART) in the San Francisco / Oakland region, that besides competition, measures to improve complementarity between component airports in multi-airport cities (MAC) and traffic integration/integration are crucial. Jiang and Zhang (2014) focused on the effect of Air-HSR carriers' collaboration under hub capacity constraints. When the substitutability of Air-HSR is high, hub capacity becomes one of the most important factors in determining the contribution or reduction of the cooperation between two modes.

The influence of different airport categories on the Air-HSR relationship has also begun to be highlighted. Albalate et al. (2015) applied an empirical analysis from the supply-side of aviation to observe the distinction under different environments of Air-HSR service in some European metropolitan areas considering particular features of airports. Therefore, the attributes and characteristics of airports themselves are now becoming a main focus Air-HSR interactions and the future development strategy of both.

It can be seen that the impact of HSR on air transport is multifaceted, and different geographical characteristics and research biases influence results and interpretations. Our analysis is more inclined to regard the HSR as a cooperator with air transport rather than just a competitor and proposes that the two will become intermodal partners within the Chinese transport network. Research has used generalized measures of air transport and of HSR to capture these relationships. For example, Zhang et al. (2018) quantitatively compared the complementary and substitute effects of Air-HSR by the means of DID (difference-in-difference) method and compared the results between East Asia and Central European markets. Elsewhere, the HSR impact on air transport market structure and welfare has also been investigated (Jiang et al., 2017; Takebayashi, 2016; Xia and Zhang, 2017). A summary of approaches can be found in Table 1.

Table 1. Summary of Indexes from Air-HSR interaction analysis

Literature	Region	Index from aviation	Index from HSR
Dobruszkes (2011)	Five city-pairs in Western Europe	The number of seats and the number of flights	The routes of HSR
Behrens and Pels (2012)	London-Paris	The number of passengers Market share	The number of passengers Market share
Fu et al. (2012)	China	The location of airports; total travel time and cost efficiency of airline service	The location of HSR stations; total travel time and cost efficiency of HSR service
Yang and Zhang (2012)	China	Airfare	HSR fare
Fu et al. (2015)	China	LCCs	HSR service
Albalate et al. (2015)	EU 27 countries	Air service frequencies and seats	The location of HSR stations
Wan et al. (2016)	Northeast Asia	Airlines' domestic available seats on affected routes	HSR routes
Jiang and Zhang (2016)	China	Air traffic	HSR traffic
Zhang and Zhang (2016)	China	Air passenger flow	HSR service
Chen (2017)	China	Passengers, flights and seat capacity of air service	HSR routes
Zhang et al. (2017)	China	Airfare	HSR frequency
Wang et al. (2017)	China	Airline routes	HSR routes
Wang et al. (2018)	China	Air traffic	HSR speed
Su et al. (2020)	China	FSCs, LCCs	HSR service

As the table shows, the key indices of HSR are mainly based on routes, fare and location. On the other hand, the indexes from the aviation aspect are related to the factors of flights, flows, and capacity. Yang et al. (2020) selected HSR travel speed and the number of HSR stations as HSR-related variables in their evaluation model to reflect the impact of HSR on the aviation market. Other literature on the Air-HSR relationship has focused on the positive or negative impact of the entry of HSR on the relevant routes (Li et al., 2019; Su et al., 2020). Most of the articles using city-pair data and the variables of HSR routes and flights for analysis usually highlight the impact of HSR on air passengers or airlines, but fewer of them focus on the potential HSR effects from the perspective of airports. Considering the importance of both the number of and location of HSR stations, this article takes the approach that the number of HSR stations within specific buffer zones of airports is a key variable reflecting potential Air-HSR interaction.

The application of 'buffer zones' in airport research is mostly employed in terms of noise, ecology and economic market areas. The meaning of the buffer zone proposed in this article is closer to the definition of a special catchment area. Many papers emphasize the importance of 'catchment area' for airport research, which can reflect the attributes and traffic characteristics of airports from multiple perspectives (Fuellhart, 2007; Lieshout, 2012; Paliska et al., 2016; Sun et al., 2021; Teixeira and Derudder, 2021). The catchment area is an important index for measuring airport competitiveness from a geographical angle. This paper uses the ‘special catchment area’ to reflect potential attractiveness of the airport as a center for HSR stations.

2.2 *Airport classification*

Airport classification studies are diverse, which is not unexpected given the varied geographical and geopolitical locations in which they have been constructed. Depending upon the objectives of the research, classification studies have usually fallen into three general categories. First, some studies utilize single or single type indicators such as degree, hubbing function (Derudder et al., 2007), etc. Other studies employ airport properties conjointly, combing multiple indicators and geographical factors (such as co-located airports). A third technique is to develop a synthetic cross-network indicator system that incorporates aspects of both previous techniques, but also explicitly includes other modes of transport.

When airport classification is only used as a partition of research objects, it usually appears in the form of individual clustering. Simple classifications are usually based on only one criterion, such as the passenger traffic of airports, geographic factors, the type of airport activities (US Federal Aviation Administration, 2021), or airport functionality. A summary of this approach is shown in Table 2.

Table 2. Summary of airport classifications in different reports and articles

Author, Year	Airport classification
Civil Aviation Administration of China (CAAC), 2008	In terms of airport functionality: the portal composite hub, the regional hub, and others
Bonnefoy et al., 2010	In terms of the portion of passenger traffic: primary (>20%), secondary (1~20%) based on passenger traffic
Derudder et al., 2010	In terms of geographical scale: national, regional, international airports In terms of airports' specific role: hub, dominant airports
Brueckner et al., 2014	Identifying the metro area's primary' airports based on the largest number of domestic OD passengers; Categorizing the metro area's other airports into 'core' and 'fringe' categories based on the distance to the primary airports.
Sun et al., 2017	In terms of the number of passenger traffic: primary (>2 million), secondary (0.1~2 million), tertiary airports (<0.1 million)
US Federal Aviation Administration (FAA), 2021	In terms of the type of activities: commercial service, primary, cargo service, reliever, and general aviation airports

Among many basic airport classifications studies, the single evaluation index most widely used is the number of passengers or the attributes of specific - service. This type of classification generally only reflects airport passenger volumes or airport service types.

Classification results obtained by a single index tend to be broad but lack nuance. Increasingly, it is clear that these types of classification schemes cannot satisfy the growing complexity of multi-dimensional airport research. More complex classifications of airports have utilized more diverse combinations of factors in their algorithms, including recognition of overlapping market areas, functional distinctions between facilities, financial information, and passenger characteristics. Postorino and Versaci (2014) designed a fuzzy-based procedure to implement airport clustering in terms of geometric points. This geographical airport classification method recognizes the functional identification of airports in the aviation network. Adikariwattage et al. (2012) refined the categorization criteria to include passenger characteristics and terminal size to compare similar airport categories that had not been subdivided previously. Vogel and Graham (2013) applied cluster analysis to discuss the importance and necessity of airport categories from financial perspectives. In addition to the combination of simple indicators, geographical factors and regional economic influence have also become new features of airport classification research.

With the increase of airport density (in some regions, like China) and development of aviation networks (almost everywhere), a special geographical feature of air transport location, MARs, gradually became recognized in various regions around the world. As of 2015, conservatively there are at least 53 major multi-airport areas in the world (O'Connor and Fuellhart, 2016). Therefore, multi-dimensional index systems to analyze airport location have become more common. Malighetti et al. (2008) showed the detailed functions of component MAR airports in the European aviation network using simulated annealing and found parallel networks arising as of low-cost airlines rose in prominence in Europe. Low-Cost Carriers (LCCs) are a typical feature of the European aviation market, especially in the context of MARs (and which, interestingly, is largely absent from the Chinese market). For assessing government decision-making and fund allocation under the context of the National Plan of Integrated Airport Systems (NPIASs) of the US, Rodríguez-Déniz and Voltes-Dorta (2014) proposed an innovative measurement of airport connectivity based upon centrality and role in the aviation network. Here, the importance of mining the network characteristics of airport nodes is emphasized. Fuellhart and O'Connor (2019) integrated and optimized supply-side indicators of airport classification and the results provided an overview of the diversity of global commercial aviation regions by focusing on the functional role of airports amid changing markets. In view of the MAR context, the multi-dimensional airport classification reflects the characteristics and trends of the airport itself and the setting of the aviation industry where the MARs are located.

Given the somewhat unique circumstances of Air-HSR in China, this paper adds to the geographic study of Air-HSR interactions by incorporating an HSR indicator to create a multi-dimensional airport classification scheme. The research highlights the increasing complex mix of airport and rail functions within Chinese MARs.

To develop the scheme, we employ hierarchical clustering analysis, which has been frequently used in related research (Burghouwt and Hakfoort, 2001; Galle et al., 2010; Jessop, 2012; Madas and Zografos, 2008; Malighetti et al., 2009b; Rodríguez-Déniz and Voltes-Dorta, 2014; Sarkis and Talluri, 2004). In addition, we add to the method by studying the topological characteristics of network nodes through community detection (X. Chen et al., 2020; Gegov et al., 2013; Guimerà et al., 2005; Gurtner et al., 2014; Wu et al., 2019).

3. Data and Methodology

The data onto airport properties (such as the number of passengers, carriers and destinations) in this study is from mainland China from 2014 and is available from Official Aviation Guide of the Airways (OAG). 2014 is an essential benchmark year before the explosive growth of HSR in China. By 2014, though China already had reached an astounding scale of HSR construction, it was not truly countrywide coverage. Therefore, in terms of Air-HSR interaction, 2014 data displays the impact of HSR on airport classification at the preliminary cooperation-competition stage with the aviation industry. Three data sets describing Chinese airport properties in 2014 were selected for this study:

- DS1 (basic airport properties data),
- DS2a (Air-HSR interaction in 50km zone), and
- DS2b (Air-HSR interaction in 90km zone).

The flight data is mainly based on Chinese domestic routes and administration divisions. The data exclude Hong Kong, Taiwan, and Macau.

There are 31 provincial-level administrative regions in mainland China, including 22 provinces, 5 autonomous regions, and 4 municipalities directly under the central government. In 2014, there were 202 civil aviation airports, handling about 73.26 million passengers in our research area. Based on the established economic belts and transport connections, we identify five major airport groups: (1) Beijing-Tianjin-Hebei, (2) Yangtze River Delta, (3) Pearl River Delta, (4) the middle reaches of the Yangtze River, and, (5) Chengyu. These divisions are justified as they correspond to the five important national-level city clusters of China. However, these five major airport clusters do not cover all civil transport airports in mainland China; this requires a more comprehensive partition.

For the completeness and objectivity of airport classification, we adopt the airport groups proposed by CAAC (Civil Aviation Administration of China) in the 'National Civil Airport Layout Planning' (2008). The distribution of provincial-level administrative regions and domestic air passengers in these five multi-airport regions are presented in Table 3.

Table 3. Multi-airport regions from CAAC

No.	multi-airport regions	provincial-level administrative regions included	the number of airports	the proportion of domestic passenger throughput in 2014
1	Northern China	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang	51	22.30%
2	Eastern China	Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong	43	28.90%
3	Middle South China	Guangdong, Guangxi, Hainan, Henan, Hubei, Hunan	31	24.30%
4	Southwestern China	Chongqing, Sichuan, Yunnan, Guizhou, Xizang	42	16.20%
5	Northwestern China	Shanxi, Gansu, Qinghai, Ningxia, Xinjiang	35	8.30%

(source: 2014 National Airport Production Statistics Bulletin)

Due to the differences in the geographical environment between east and west China, along with highly uneven economic development, the official classification of multi-airport regions does not correspond exactly to the existing large city clusters. It is important to recognize that while the major city clusters are all located in eastern China, MARs in western China also occupy an important position in the network. Meanwhile, the development of aviation in China is affected and guided by certain policy which influences the geographical-based division factors chosen by the CAAC (J. Wang et al., 2019; A. Zhang and Chen, 2003).

Two linked methods are utilized to classify airports across multiple dimensions in Chinese MARs: hierarchical cluster analysis (Rodríguez-Déniz and Voltes-Dorta, 2014) and the Fast Newman algorithm for community structure detection (Fan et al., 2019). These are discussed in detail next.

3.1 Hierarchical cluster analysis

There are two types of hierarchical clustering: divisive (top-down) and agglomerative (bottom-up) (Brian S. Everitt et al., 2011). To have an overview of the comprehensive strength and position in the market, the agglomerative hierarchical clustering (AHC) with average-linkage were applied for the background of China's aviation. Given the less limitation and no need to pre-determined the number of clusters, the applicability and popularity of AHC for airport classification has been proven by a lot of literature (Rodríguez-Déniz & Voltes-Dorta, 2014; Suau-Sanchez et al., 2015). Average-linkage is one of the wide-used metrics of agglomerative clustering, where the distance between each pair of observations in each cluster is added up and divided by the number of pairs to get an average inter-cluster distance. Compared with other methods, average-linkage has good monotonicity and its degree of spatial expansion and concentration is moderate, that is, the distance range of the class and the sensitivity of distinguishing the class is moderate.[5] The selected calculation of similarity distance between airports is the Squared Euclidean distance from this study because it better reflects the performance of the algorithm and enhances the long-distance impact on the cluster analysis (Spencer, 2013). For determining the optimal number of clusters, we used the NbClust package in R to predefine and dendrogram for final decision. The NbClust provides 30 functional indices for assessment and offers the final frequency among all indices corresponding to different numbers of clusters. In addition to the results of the NbClust package, we also observed the dendrogram and the clustering progress and compared the differences of the mean of the relevant parameters of the airports in each category on each step, then finally determined the number of clusters.

Given the MARs research background and comprehensive variable selection, some variables from Fuellhart and O'Connor (2019) were chosen for this clustering. Six variables were employed in the model after a preliminary variable screening[6], as shown in Table 4 (see (Fuellhart and O'Connor, 2019) for additional details on calculation). DS1 consists of Chinese airport data related to these six variables in 2014.

Table 4. Basic properties of airports

Variables		Roles
TS	total seats available	TS reflects the scale and service level of the airport and has often been used as an important measurement index.
TC	total carriers	TC reflects the business scope of the airport and the dissimilarity of service diversity of carriers between airports.
EC	effective airport competitors	EC represents the concentration of the aviation industry and airline competition at the airport and implies the market controls of airlines.
SR	significant routes	SR reflects the distribution characteristics of airport routes by measuring the concentration of passengers on air transport links.
PSR	percentage of significant routes	PSR reflects the level of the routes concentration on the airport by computing the proportion of significant routes.
TD	total destinations	TD represents the geographical scope of the aviation services provided by the airport.

The added data of the Air-HSR variable in DS2a and DS2b is mainly based on the longitude and latitude information on airports and HSR stations in China. We conceived HSR stations as the auxiliary transport infrastructure of the airports. To reflect the Air- HSR interaction, a count of the HSR stations in the specific 'catchment area' of airports was employed as a new variable in the classification analysis. In addition, the 'catchment area' here is not for passengers but HSR stations, that is, how many HSR stations were co-located in an airport's 'catchment area'. Referring to the set of inter-airport spatial distance from previous literature (Hansen and Weidner, 1995; Sun et al., 2017), we selected 50km and 90km respectively as the buffer thresholds of airports in Chinese aviation network. As of 2014, when the size of the buffer zone reaches 90km, it covers all the HSR

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[5] The average-linkage clustering was implemented by SPSS (Yim & Ramdeen, 2015).

[6] Multi-dimension variables on carriers and routes were used on variable screening. After blind selection of variables and preliminary clustering with average-linkage algorithm, the variable screening based on the differences in the mean of each variable in different clusters was completed. Variables with small differences in means were filtered out in terms of the multi-mean graphs of 2014.

stations in China with no large-area buffer overlap. When the size of the buffer zone exceeds 90km, the overlapping phenomenon of the buffer zones causes some HSR stations to be counted over 2 times which affects the integrity of the results. Figure 1 shows Chinese airports and their 50km buffer zones.

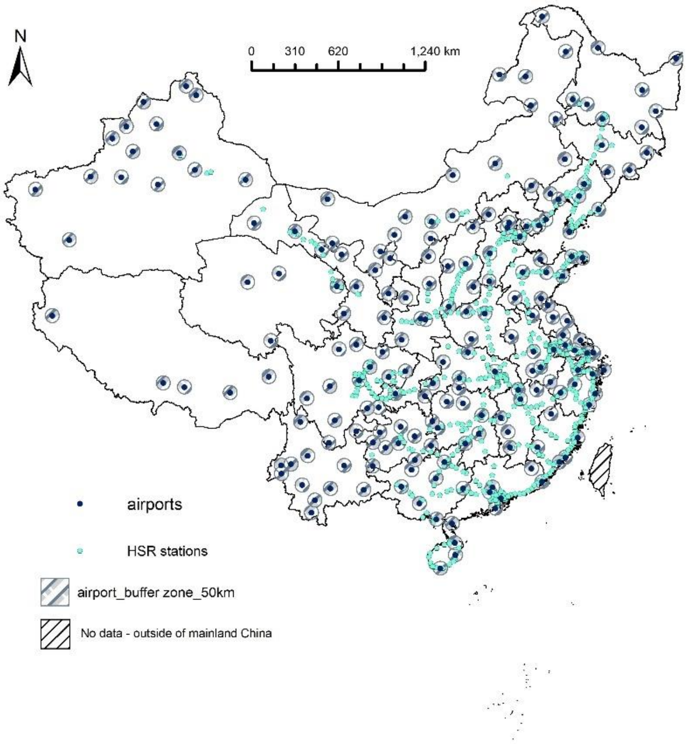

Figure 1. Airports with 50km buffer zone and HSR stations in China

3.2 *Community structure detection*

Analyzing the distribution of airports in the Chinese aviation network from the perspective of topological structure is another dimension of this research. In contrast to the airport classification established on the basic attributes described above, topology research based on airport flight data reflects the status and the role of airports in the context of this complex network of China. To examine this methodology, we selected the Fast Newman algorithm (Newman, 2004) and modularity to explore the airport topological distribution across the entire Chinese aviation network.

The Fast Newman (FN) algorithm is an improved Girvan Newman (GN) (Girvan & Newman, 2002) technique based on a new optimization principle with the introduction to the 'greedy' algorithm, which effectively solves problems involving complex and small networks in an efficient time frame. Modularity Q was designed to measure the strength of the division of a network into modules (communities) (Newman, 2004). Community refers to a group of nodes in the network, where the links within the community are stronger than those between the link with the outside world. Based on this definition, modularity measures the pros and cons of segmentation by comparing the internal and external connections of the community. The hierarchy of the largest Q value is selected to obtain the final community structure. The three centrality indicators (degree centrality, closeness centrality and betweenness centrality) were measured to seek the potential characteristics of each airport community (Neal, 2012). The value of centralities of each community was the mean of the centrality of component airports which obtained by igraph package in R.

4. Results

For comprehensive airport classification in Chinese MARs, three results comprised of two analytical methods were calculated: (1) airport classification with only airport properties, and airport classifications with the introduction of Air-HSR interaction at 50km and 90km buffer zones, (2) airport communities under topology structure and (3) some partitions in the Chinese MARs. The similarities and differences between the results reveal a number of key findings.

4.1 Airport classification without and with the Air-HSR interaction

First, we clustered airports without and with Air-HSR interaction. This analysis with fundamental airport properties serves as a benchmark for subsequent analyses, as Table 5 shows. To explore the effect of Air-HSR interaction on airport categorization, we employed hierarchical analysis with new Air-HSR variables. After delimiting the buffer zone between the airport and the HSR stations, the calculation of the number of HSR stations was reflective of the airport's attractiveness to HSR.

Table 5. Three airport partitions of hierarchical clustering analysis

Data set	Results of the Airport Clusters (N)				
Basic properties	Regional airports (156)	Super airport (1)	Network connectors (45)		
		PEK			
50km buffer zone	Regional airports (156)	Gateway hubs (3)	Major regional hubs (38)	**Air-HSR hubs** (3)	**Competitive air hubs** (2)
		CAN, PEK, PVG		*CTU, SHA, SZX*	*KMG, XIY*
90km buffer zone	Regional airports (156)	Super airport (1)	Major regional hubs (36)	**Air-HSR hubs** (7)	**Competitive air hubs** (2)
		PEK		*CAN, CTU, NKG, PVG, SHA, SZX, WUH*	*KMG, XIY*

Baseline clusters: 3 clusters

The analysis utilizing only basic airport properties serves as a benchmark for subsequent analyses. Some descriptive statistics of airport clusters and the comparison of results were used as the basis of cluster naming, such as the mean of variables. Three basic airport clusters appeared in this step.

In the benchmark analysis, Cluster 1 accounted for over 60% of the total number of airports and has the lowest value of the five attributes among these clusters, especially the 'TS' (total seats available) which is one or two orders of magnitude lower from the other clusters. Interestingly, the airports in this cluster did not have many significant routes, but their routes were relatively concentrated. The number of total carriers and total destinations was more indicative of the limited scope of airport services. Due to the geographical and market constraints on such airports, we term this cluster **regional airports**.

The second-largest cluster is **network connectors**. Based upon the two high values of 'TC' (total carriers) and 'EC' (effective airport competitors), these airports have active market competition. Given only about 30% of the 'SRP' (significant routes percentage), the resources of these airports were not completely concentrated on just a few thick routes, and the route coverage was wider. In most cases, they provided diversified services to multiple regions and were highly competitive in the market.

Interestingly, Beijing Capital International Airport (PEK) formed its own cluster and we designated it a **super airport**. Owing to the political and economic status of Beijing, along with its development history and uniqueness as the initial development center of the Chinese aviation network was unique among Chinese airports. Its lower EC value indicates market competition environment in PEK had gradually become stable and conservative. From these observations, PEK undertook the position of an absolute hub with a relatively unchanged market state.

Introduction of Air-HSR effects

To distinguish and identify these airport clusters, we measured the means of six variables in these five clusters. Representative results of the 50km buffer zone situation are shown in Table 6. These descriptive statistics of airport clusters and the comparison of results were used as the groundwork of cluster naming.

Table 6. Mean of variables between clusters in the dataset of 50km buffer zone

Cluster	TS	TC	EC	SR	SRP	TD	HSR 50km	N
1.Regional airports	435504	4.57	2.80	5.85	61.78%	10.22	0.94	156
2.Major regional hubs	7831321	18.47	7.19	39.69	32.77%	57.45	4.03	38
3.Gateway hubs	43555994	18.67	4.44	42.52	22.02%	134.33	5.67	3
4.Air-HSR hubs	25340332	20.33	5.57	30.92	17.86%	109.67	16.67	3
5.Competitive air hubs	23137548	24.50	6.10	102.08	28.03%	107.50	1.00	2

Red: Max, Blue: Colmax (Second Max), Green: Min

When the Air-HSR variable of 50km buffer zone was added, the highest-level airport cluster became three airports: PEK as well as CAN (Guangzhou) and PVG (Shanghai-Pudong) in eastern China. We refer to these as **gateway hubs**.

With the introduction to a new Air-HSR variable, the number of airport clusters changed from three to five, and the network connectors in the baseline clusters were split into three distinct categories.

Airports designated as **major regional hubs** had lower values on several factors. The high EC values implied that the market competition among airlines at these airports was still very strong and there were many alternative services at such nodes after the introduction of the Air-HSR variable. It further appears that the airlines had relatively lower market power in their market. With the second-highest value of SRP, these airports provided regional services in a targeted manner. At the same time, the relatively large percentage of non-thick routes reflected that the airports played an important role in minor routes to smaller destinations, creating a wider coverage functions as the hub.

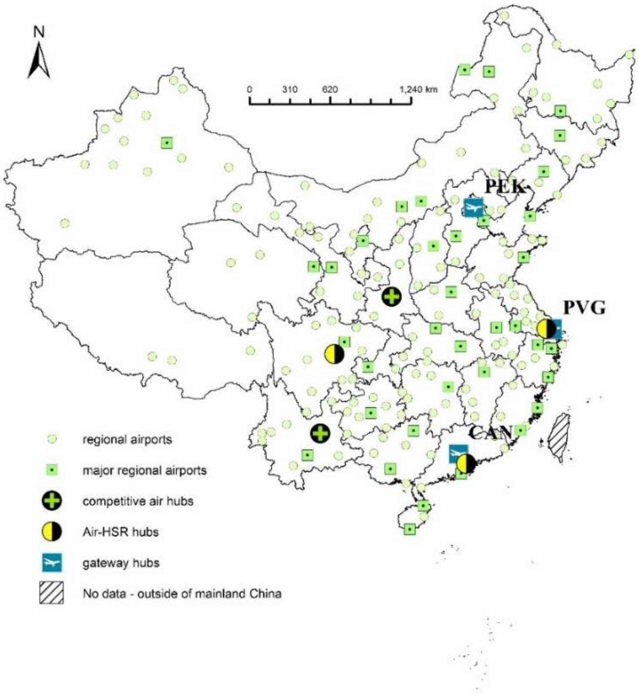

Figure 2. Airport partition with Air-HSR interaction in the 50km buffer zone

According to the highest number of HSR stations in the buffer zone (Cluster 4), these airports were designated as **Air-HSR hubs**. Their most prominent feature was the close integration with HSR, which reflected the Air-HSR interactive development models. Two airports were clustered into Cluster 5 (KMG (Kunming), XIY (Xi'an)). The highest value of TC expresses that such airports attract many airlines and their market competition was active. Many significant routes, many destinations, and diverse services were also important features. However, the low number of HSR stations in the buffer zone indicated that the development of HSR construction surrounding airports was not substantial. This type of airport is a competitive hub airport in regions focused more on aviation services. Due to their geographical location and development strategy, they were more inclined to develop into a higher-level gateway hub from the perspective of aviation services instead of increasing airport passengers through the interaction with HSR like Air-HSR hub airports. We refer to them as **competitive air hubs**. From the characteristics of these two new clusters, adding HSR-related variables indeed affects the results of airport classification and also strengthens the role of some individual hub airports in the network.

Expansion of airport buffer zone

After increasing the scope of the buffer zone to 90km, there was an average of 24 HSR stations around each airport in the cluster **Air-HSR hubs**. Surprisingly, NKG (Nanjing) and WUH (Wuhan) transferred from the major regional hubs to the higher-level cluster (Air-HSR hubs) after the scope of the buffer zone was expanded. The HSR stations that interacted with these two airports were all HSR stations with a wide catchment area.

The construction of HSR has different impacts on different categories of airports in diverse geographical locations, especially for Air-HSR hubs. After the expansion of the buffer zone, the number of HSR stations surrounding major regional hubs was still only a quarter of that of Air-HSR hubs, even if the number increased. The results of the 50km and 90km buffer zone implied that national hub airports had more interaction with HSR than major regional airports.

The two new airport clusters showed their development potential of different trends based on these variables, more prominent in Air-HSR complementarity or more competitive in air transport.

Air-HSR hubs: These include NKG and WUH, which are Nanjing Lukou Airport and Wuhan Tianhe Airport. Nanjing and Wuhan are both major rail hubs in eastern China. Nanjing Railway Station is the largest transport hub of East China, and Wuhan is one of the six largest railway passenger transport centers in all of China. This traffic background provides basic convenience and effective planning ideas for the development of the two airports into Air-HSR hub airports. At the same time, Nanjing and Wuhan are important provincial capitals in China, and they have certain administrative advantages in construction and planning.

Two **competitive air hubs** emerged: KMG (Kunming Changshui Airport) and XIY (Xi'an Xianyang Airport). Kunming is one of the most important tourist cities in China. Its city airport, KMG, had more than 30 million passengers in 2014. More interestingly, a total of six airlines have established their bases at KMG airport, which shows its competitiveness among airlines. XIY is rated as a four-star airport in the world by Skytrax. Although Xi'an North Station is a top HSR station in China, the geographical location of the city Xi'an determines the vitality and competitiveness of XIY airport in China's aviation network. As the only international airport in the Guanzhong city-regions, it has five base airlines.

4.2 Airport classification under the topological structure

The above-mentioned classifications based on airport properties lack the route information of the airports without analyzing the classification and distribution of component airports from the background of the Chinese airline network. For more analytical comprehensiveness, this subsection reveals the results of community detection (based on route data) and of the hierarchical cluster analysis with the Air-HSR variable in the 50km buffer zone. The results of community detection of the Chinese aviation network were presented in Fig. 3.

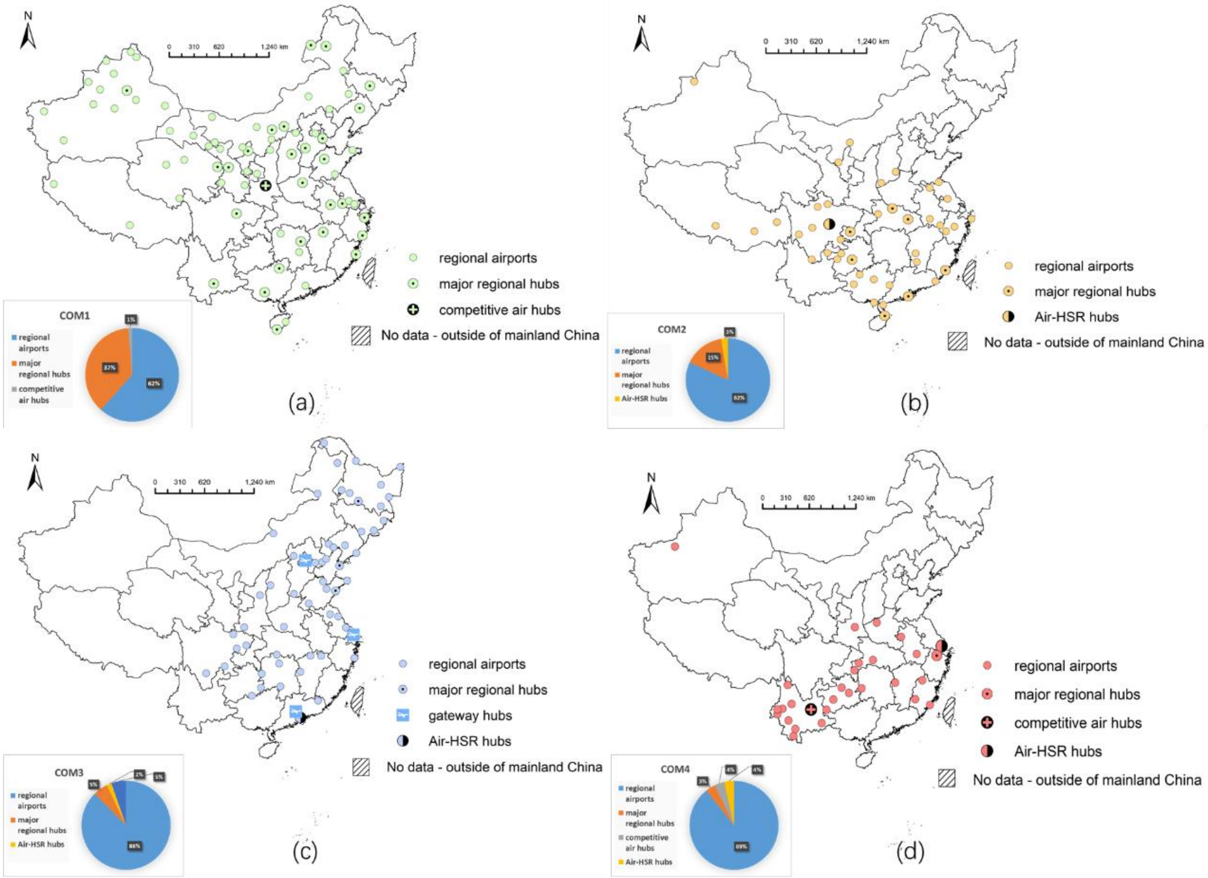

Figure 3. Airport clusters in the 4 airport communities in 2014: (a) Community 1, (b) Community 2, (c) Community 3, (d) Community 4

Taking into account topological structure, airport communities in China had significant differences in the spatial distribution of airport clusters in 2014. As a result of the FN algorithm, China's airports are divided into four airport communities.

Community 1 (COM1) is a single-center airport community composed of only one competitive air hub Xi'an Airport (XIY), major regional hubs and regional airports widely distributed across China, as shown in Fig.3(a). Spatially, it is the only community that covers most airports in northwest China. The most major regional hubs in eastern and central China have stronger connections with airports in northwestern China than other regions. In 2014, the air service from XIY airport covered all parts of the country, which may be related to its characteristics of airline base.

Interestingly, the two communities with similar geographic locations, COM2 and COM4, did not become one community (Fig. 3(b) and 3(d)). Community 2 (COM2) is also a single-center airport community including one Air-HSR hub Chengdu Airport (CTU), 7 major regional hubs and regional airports most located in southern China with weaker connections with northwestern China. Community 4 (COM4) is more like a small-scale functional community with a dual center of a competitive air hub (Kunming Airport, KMG) and an Air-HSR hub (Shanghai Airport, SHA). The formation of this association relates to the characteristics of high travel demand in Shanghai and high tourism demand in Yunnan Province.

Most of the airports in Community 3 (COM3) are located in eastern China, and the main components are three Chinese gateway-level airports, the three major regional hubs and regional airports. This shows that three Chinese gateway hubs have greater interactions with the eastern regional airports reflecting the demographic and economic advantages there.

Degree centrality usually reflects the characteristics of a node in a regional network, and closeness centrality and betweenness centrality reflect the characteristics of a node in the overall network. COM1 has the highest value of degree centrality and COM3 ranks 1 in closeness centrality and betweenness centrality. The variance in COM1 is higher because it covers more major regional hubs. COM3 is the most central community in the aviation network and shoulders important intermediary tasks in 2014. In addition, COM2 has the smallest value of closeness centrality with a big gap to other communities as its large proportion of regional airports from Fig. 3(b). Actually, until 2012, the spatial structure of MARs just emerged in China's aviation network (J. Wang et al., 2014). Although some rudiments of functional airport communities have appeared, the vague and less prominent functional features indicate that China's aviation network has not been completely systemized in 2014.

4.3 Airport classifications in the Chinese MARs

With the initial formation of Chinese MARs in 2014, an instructive perspective is to explore the distribution of airport classification in the context of MARs. According to the province where the airport was located, we categorized the airports into five airport groups (Fig. 4). We can derive an overview of the distribution of different types of airports in the Chinese MARs from Table 7.

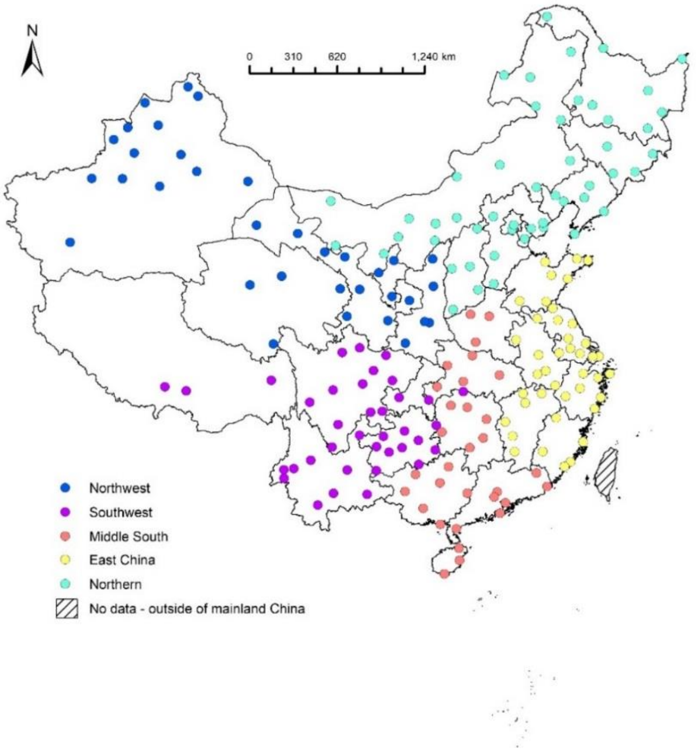

Figure 4. Distribution of multi-airport regions from CAAC

Table 7. Airport classifications under 50km and 90km buffer zones in the Chinese MARs

Airport numbers in airport groups	Regional airports		Major regional hubs		Gateway hubs	Super airport	**Air-HSR hubs**		**Competitive air hubs**	
	50km	90km	50km	90km	50km	90km	50km	90km	50km	90km
Northern	39	39	11	11	1	1	0	0	0	0
East China	31	31	10	9	1	0	**1**	**3**	0	0
Middle South	20	20	9	8	1	0	**1**	**3**	0	0
Southwest	36	36	4	4	0	0	**1**	**1**	**1**	**1**
Northwest	30	30	4	4	0	0	0	0	**1**	**1**

The distribution of regional airports in the airport groups was comparatively even. One exception was that the scale of the Middle South airport group was originally the smallest in all airport groups, it had only 20 regional airports. The numbers of major regional hubs reflect the character of China's important aviation nodes being dense in the east and sparse in the west.

By introducing the Air-HSR interaction, hub airports were subdivided. When the size of the Air-HSR buffer zone was set to 50km, the three eastern airport groups occupied nearly 80% of the major regional hubs and were equally divided among three gateway hubs. In 2014, the airport groups that developed the new airport categories were East China, Middle South, and Southwest. This result was in line with the fact that HSR was more densely focused and distributed in these regions. Competitive hubs emerged in the two western airport groups where no major hub airports controlled a large amount of aviation market share. To weaken the HSR effect, this cluster of airports chose to focus on how to gradually reinforce its market power in their regions.

Given the above results, there was substantial differentiation in airport classification across China, particularly between east and west. The airport system of the Northern airport group was relatively stable under a changeable external environment after the introduction of HSR, without two new airport classes from the Air-HSR interaction. With the cooperation-competition of Air-HSR, the Middle South and East China airport groups, which play a significant connecting role in the network, have the potential to take the lead in the development of inter-modal transport. As the relatively slow development of air and railway, the component airports of the western airport groups were more inclined to utilize their environmental advantage to enhance their competitiveness and gradually take the initiative in the aviation market.

5. Discussions and Conclusions

The present study provides a multi-dimensional overview of MARs in the special Chinese context. With the rapid development of the aviation industry in recent decades, China's air transport network has formed a distinct and evolving pattern of MARs. At the same time, the extensive network of HSR in China also complements and competes with air transport. Therefore, any study of Chinese MARs must consider the HSR effect.

We employed multi-dimensional airport classification for component airports in the MARs and compared the changes before and after the introduction of variables about the co-location of HSR stations to observe the dynamic evolution of China's multi-airport/ multi-modal regions in 2014.

The comparison of results showed that after introducing the Air-HSR interaction, airport classifications were refined. Not only were airport clusters expanded, but also two special airport clusters appeared: Air-HSR hubs and competitive air hubs. These were two airport clusters with completely different styles of development. One was to form a complementary model with HSR, and the other was more focused on competitiveness with the aviation market. Looking deeper, the Air-HSR hub will develop as a potential center in the evolution of Chinese MARs with its driving factor, HSR. This type of airport has a vested interest in the competition and cooperation between air transport and HSR since rail will provide access and egress to airports, while at the same time providing alternative transport choices to consumers. These hubs also provide potential test-cases for promoting inter-modal integration when facing the impact of other transport modes in the future.

The Northern airport group, with the capital Beijing as its center, was relatively stable in different classification results. Under the influence of HSR, the Air-HSR hubs, the new airport cluster, emerged in the East China, Middle South, and Southwest airport groups. When the attractiveness of airports for HSR increased, that is, the effect of Air-HSR cooperation increased, the number of Air- HSR airports increased in East China and Middle South airport groups. These two airport groups were more sensitive to the HSR effects. These results and geographical features of the Middle South airport group hinted at its potential transfer characteristic. The Southwest airport group was the only airport group that had two new types of airports evolve in the classification, which suggested that the Southwest airport group had a more market-oriented environment. The hub airports of the Northwest airport group were inclined to increase their market power in a less comprehensive multi-modal transport environment.

For community detection, COM 3, which has national-level airports and occupies the favorable terrain in the east, shows the highest closeness centrality and betweenness centrality in the network. The lowest closeness centrality is COM 2, which has a larger proportion of regional airports. In terms of topological characteristics, we found that the Chinese aviation network was not highly modularized, and the route distribution among airport groups did not reach a systematic level in 2014.

Given the conclusions from previous literature, the substitution may be stronger between regional airports and the HSR. We can reasonably infer that in 2014, compared with the competition between the two, the construction of domestic HSR was more inclined to promote the active cooperation between the national hub airports and the HSR. This kind of interaction can be drawn from the fact that there were more HSR stations in the zones of national hub airports.

For the MARs centered on regional hub airports, the traffic of secondary airports and regional airports is usually unstable with HSR influence. But this kind of instability is not a blind reduction in passenger flow that started with a competition. There are also cases where HSR brings passengers. Therefore, the future construction and planning can optimize the development of regional airports based on their specific characteristics and learn from the existing cases of the Air-HSR airport.

By the absence of a comprehensive study on airports in MARs, the construction of many new airports in China has caused some potential problems. For example, the passenger flow of new airports in the region is insufficient, and passenger flow distribution that does not meet market demands hinders the development of component airports of MARs to a high-quality multi-airport system. The competition and cooperation relationship with HSR is not handled properly, resulting in unhealthy interaction barriers. The article serves as basic research on the evolution of MARs and provides some references and ideas for formulating relevant policies in the future.

The research in this paper only used data of 2014. The subsequent analysis based on panel data will provide the evolution of a spatial view on the dynamic changes. However, we did not apply an indicator to measure market share or traffic flow between each airport and the HSR in this paper. The Air-HSR co-opetition relationship of the specific airport was not shown directly. The types, the level and the modes of collaboration and competition will be discussed in future research. Observing MARs only in China may produce inherent biases. In the future, we can use the methodology of this article to observe the interaction between airports and other transport modes in other countries' MARs. Interesting conclusions may be found in these comparisons.

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