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THE MEASUREMENT OF TRANSPORTATION NETWORK EFFICIENCY AND DIAGNOSIS OF STRUCTURAL DEFICIENCIES IN JILIN PROVINCE'S WINTER TOURISM

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Abstract: Addressing the current situation where the high-quality development of Jilin Province's winter tourism industry is constrained by infrastructure bottlenecks, this study conducts a systematic assessment of network efficiency by constructing a transportation network model comprising 86 nodes and 327 routes. The findings reveal that the density of Jilin Province's winter tourism transportation network is only 0.087, indicating weak overall connectivity that is significantly lower than that of neighboring strong provinces such as Heilongjiang. Node centrality analysis reveals severe polarization: core hubs such as Changchun Longjia International Airport and Jilin Station dominate in both degree centrality and betweenness centrality, while remote scenic areas such as Dunhua Laobai Mountain Snow Village have extremely low accessibility. Cluster analysis identified four highly isolated sub-regions, confirming the existence of pronounced regional fragmentation within the province. Further analysis revealed that insufficient network connectivity results in high transfer costs for remote scenic areas, with one-way travel times reaching 5 to 6 hours. Additionally, the overreliance on a single-mode transportation structure (roads and railways) exacerbates operational risks during extreme winter weather. The Matthew effect in node development causes high-quality resources to concentrate in urban centers, trapping remote scenic areas in a vicious cycle of poor transportation access, sparse visitor numbers, and delayed development. This study provides quantitative evidence and decision-making references for resolving the transportation challenges in Jilin Province's winter tourism sector and promoting regional coordinated development.
Keywords: Social Network Analysis (SNA); Transportation network efficiency; Winter tourism in Jilin province

1 INTRODUCTION

With its abundant snow and ice resources, Jilin Province has become a core domestic tourism destination. However, against the backdrop of a surge in visitor numbers, the accessibility and operational efficiency of the transportation network have gradually become key factors constraining the industry's quality and efficiency improvements. Existing literature has extensively explored transportation network efficiency and optimization, providing a solid theoretical foundation for this study. In terms of efficiency evaluation and synergistic development, Yang et al. investigated the synergistic development efficiency of cities under rail transit networks from a dual-dimensional perspective of inter-district and inter-industry, offering a macro-level analytical framework for transportation systems [1]. To enhance operational precision, Wang et al. applied Convolutional Neural Networks (CNN) to intelligent transportation systems, verifying the potential of deep learning algorithms in logistics optimization [2]. Further exploring the relationship between spatial configuration and efficiency, Yan et al. analyzed the nexus between urban agglomeration spatial configuration and land use efficiency from a bidimensional perspective, highlighting the critical role of transport network connectivity [3]. In the realm of specific network optimization algorithms, Akgol et al. proposed a new flow direction method for multi-route networks, providing a quantitative tool for improving public transportation efficiency [4]. Additionally, Hassan et al. conducted a data-driven assessment of public transit network efficiency in Malaysia, offering empirical evidence for optimizing accessibility in developing regions [5]. Regarding network flow control and safety, Xiao et al. utilized a cooperative co-evolutionary paradigm to optimize the safety-efficiency trade-off in air traffic networks, expanding the methodology for managing complex network flows [6]. In the context of sustainable development, Liu et al. examined the formation mechanisms of transportation carbon emission efficiency networks, deepening the understanding of transportation's environmental externalities [7]. Furthermore, Sun et al. revealed the spatial spillover effects of transport accessibility on intra-metropolitan employment growth, providing a micro-mechanism explanation for the socioeconomic impacts of transportation networks [8]. Ma et al. further analyzed the spatial correlation network characteristics of comprehensive transportation green efficiency in China [9], while Zhang et al. discussed the boundary issues of vehicle automation efficiency in general transportation networks, exploring the efficiency boundaries of future transportation modes [10]. Despite these advancements, most existing studies focus on urban rail or general freight networks, with relatively less application of social network analysis specifically to the structural deficiencies of regional winter tourism transportation networks.

Addressing the current state of traditional research, which emphasizes traffic flow analysis while neglecting network structural characteristics, this section aims to quantitatively assess the overall structural features of Jilin Province's winter tourism transportation network through social network analysis methods. The innovation of this study lies in the integration of digital footprints from Ctrip travelogues to construct a multidimensional topological model, which not only measures macro-level network density but also provides an in-depth analysis of the unequal distribution of power among nodes and the mechanisms of regional fragmentation. The general research framework is as follows: First, network density is measured using a formula to reflect overall connectivity; second, power cores and peripheral nodes within the network are identified using indicators of degree centrality, betweenness centrality, and closeness centrality; Subsequently, the CONCOR algorithm is employed to conduct cluster analysis, revealing the synergy of local structures; finally, based on the evaluation data, core issues such as connectivity gaps, node imbalances, regional fragmentation, and monotonous travel patterns are precisely diagnosed, laying a data foundation for the formulation of optimization strategies.

2 EFFICIENCY EVALUATION AND ANALYSIS OF ICE-SNOW TOURISM TRAFFIC NETWORK IN JILIN PROVINCE

2.1 Network Efficiency Evaluation and Analysis

2.1.1 Network density analysis

Network density is an indicator to measure the tightness of connections between nodes in a network, and its calculation formula is:

$$D=\frac{2L}{n(n-1)} \tag{1}$$

where D represents the network density, L denotes the number of actual edges in the network, and n is the number of nodes in the network.

In this study, n=86 (the number of traffic nodes) and L=327 (the number of traffic lines). Substituting the data into the formula, we can get:

$$D=\frac{2\times327}{86\times(86-1)}=\frac{654}{86\times85}\approx0.087 \tag{2}$$

This indicates that the connections between nodes in the ice-snow tourism traffic network of Jilin Province are relatively sparse, and the overall connectivity needs to be improved. Compared with other popular ice-snow tourism areas in China, such as Heilongjiang Province with an ice-snow tourism traffic network density of 0.123, Jilin Province still has a certain gap in the perfection of the traffic network. A low network density means that there is a lack of direct traffic connections between some tourism nodes, and tourists may need to transfer multiple times to reach their destinations, which increases travel time and costs, and reduces the convenience and comfort of travel [3].

2.1.2 Node centrality analysis

Degree centrality is used to measure the number of nodes directly connected to a node in the network. The higher the degree centrality of a node, the greater its direct influence in the network. The calculation formula for the degree centrality of node i is:

$$C_D(i)=\frac{d(i)}{n-1} \tag{3}$$

where $C_D(i)$ represents the degree centrality of node i, $d(i)$ is the degree of node i (i.e., the number of edges directly connected to node i), and n is the total number of nodes in the network.

Taking Changchun Longjia International Airport as an example, assuming its degree $d(i)$=38 and n=86, substituting into the formula, we can get:

$$C_D(\text{Changchun Longjia International Airport})=\frac{38}{86-1}=\frac{38}{85}\approx0.447 \tag{4}$$

The calculation results show that transportation hubs such as Changchun Longjia International Airport, Jilin Station and Changchun Station have high degree centrality, while some remote ice-snow tourism scenic spots, such as Dunhua Laobaishan Snow Village (assuming its degree $d(i)$=5), have a degree centrality of:

$$C_D(\text{Dunhua Laobaishan Snow Village})=\frac{5}{86-1}=\frac{5}{85}\approx0.059 \tag{5}$$

This shows that transportation hubs have frequent connections with other nodes and occupy an important position in the ice-snow tourism traffic network, while remote scenic spots have relatively few traffic connections with the outside world, making it difficult for tourists to reach them, which restricts the development of the scenic spots to a certain extent [4-5].

Betweenness centrality reflects the ability of a node to control the flow of resources in the network. The higher the betweenness centrality of a node, the more critical its role in information transmission and resource circulation. The calculation formula for the betweenness centrality of node i is:

$$C_B(i)=\sum_{j<k}\frac{g_{jk}(i)}{g_{jk}} \tag{6}$$

where $C_B(i)$ represents the betweenness centrality of node i, g_{jk} is the number of shortest paths between node j and node k, and $g_{jk}(i)$ denotes the number of shortest paths between node j and node k passing through node i.

Taking the Changchun node as an example, the betweenness centrality value calculated by UCINET software reaches 256. Assuming there is a node pair j and k, with the number of shortest paths g_{jk}=10 between them, and the number of shortest paths passing through Changchun g_{jk}(Changchun)=8 , the contribution of Changchun to the betweenness centrality of this node pair is:

$$\frac{g_{jk}(\text{Changchun})}{g_{jk}}=\frac{8}{10}=0.8 \tag{7}$$

Summing up the calculation results of all node pairs, the final betweenness centrality value of the Changchun node is 256. In contrast, the betweenness centrality value of the Hunchun Fangchuan Scenic Area, a tourism node in the border area, is only 15, indicating that the scenic area has a weak ability to control resources in the traffic network, and its attraction and radiation range to tourists are also relatively limited [6].

Closeness centrality is used to measure the average distance from a node to other nodes in the network. The higher the closeness centrality of a node, the faster it can reach other nodes, with better accessibility. The calculation formula for the closeness centrality of node i is:

$$C_C(i)=\frac{1}{\sum_{j=1}^{n} d_{ij}} \tag{8}$$

where $C_C(i)$ represents the closeness centrality of node i, d_{ij} is the length of the shortest path from node i to node j, and n is the total number of nodes in the network.

Taking Changchun as an example, assuming through calculation, the sum of the lengths of the shortest paths from Changchun to the other 85 nodes $\sum_{j=1}^{85} d_{ij}=110$, the closeness centrality of Changchun is:

$$C_C(\text{Changchun})=\frac{1}{110}\approx 0.0091;C_{C_{norm}}(\text{Changchun})=\frac{n-1}{\sum_{j=1}^{n-1} d_{ij}}=\frac{85}{110}\approx 0.78 \tag{9}$$

Similarly, due to its relatively remote geographical location, the Changbai Mountain Scenic Area has a sum of the lengths of the shortest paths to other nodes $\sum_{j=1}^{85} d_{ij}=155$ by assumption, and its standardized closeness centrality value is:

$$C_{C_{norm}}(\text{Changbai Mountain Scenic Area})=\frac{85}{155}\approx 0.55 \tag{10}$$

It can be seen that nodes in urban central areas such as Changchun and Jilin have high closeness centrality, while the Changbai Mountain Scenic Area has relatively poor accessibility, which affects tourists' willingness to visit the scenic area [7-8].

2.2 Summary of Node Centrality

Degree centrality analysis: The degree centrality of each node is calculated, and the results show that transportation hubs such as Changchun Longjia International Airport, Jilin Station and Changchun Station have high degree centrality, among which Changchun Longjia International Airport has a degree centrality value of 38, ranking first among all nodes. This shows that these transportation hubs have frequent connections with other nodes, occupy an important position in the ice-snow tourism traffic network, and are key nodes for tourists to enter and exit Jilin Province and transfer between various scenic spots in the province. However, some remote ice-snow tourism scenic spots, such as Dunhua Laobaishan Snow Village and Helong Jindalai Folk Village, have low degree centrality values of 5 and 3 respectively, indicating that these scenic spots have relatively few traffic connections with the outside world, making it difficult for tourists to reach them, which restricts the development of the scenic spots to a certain extent.

Betweenness centrality analysis: The results of betweenness centrality analysis show that Changchun, as the provincial capital of Jilin Province, has a betweenness centrality value of 256 for its node, much higher than other nodes. Changchun plays an important "bridge" role in the traffic network, controlling a large number of resource flows and information transmission, and many traffic lines need to transfer through Changchun. Jilin City has a betweenness centrality value of 128, also having a strong control ability in the network. In contrast, some tourism nodes in border areas, such as Hunchun Fangchuan Scenic Area, have a betweenness centrality value of only 15, indicating that the scenic area has a weak ability to control resources in the traffic network, and its attraction and radiation range to tourists are limited to a certain extent [9-10].

Closeness centrality analysis: The calculation results of closeness centrality show that nodes in urban central areas such as Changchun and Jilin have high closeness centrality, with Changchun at 0.78 and Jilin at 0.72. This means that these nodes can quickly reach other nodes in the network with good accessibility. However, due to its relatively remote geographical location, the Changbai Mountain Scenic Area has a closeness centrality value of 0.55, and tourists need to spend a long time to reach the Changbai Mountain Scenic Area from other nodes, with relatively poor accessibility, which affects tourists' willingness to visit the scenic area.

2.3 Cohesive Subgroup Analysis

The CONCOR algorithm of UCINET software is used to conduct cohesive subgroup analysis on the ice-snow tourism traffic network of Jilin Province. This algorithm is based on the correlation matrix between nodes and divides the network into multiple subgroups through iterative calculation.
Firstly, the correlation coefficient matrix between nodes is calculated to measure the similarity between nodes. Then, the number of divided subgroups is set to 4, and the algorithm divides the 86 nodes in the network into 4 main subgroups according to the correlation between nodes through multiple iterations.

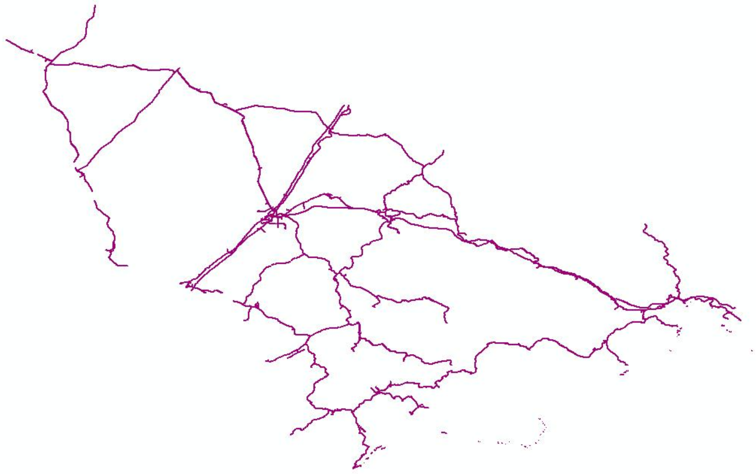

Figure 1 Railway Network Map of Jilin Province
Source: http://bzdt.ch.mnr.gov.cn

Railway Network Map of Jilin Province is shown in Figure 1.

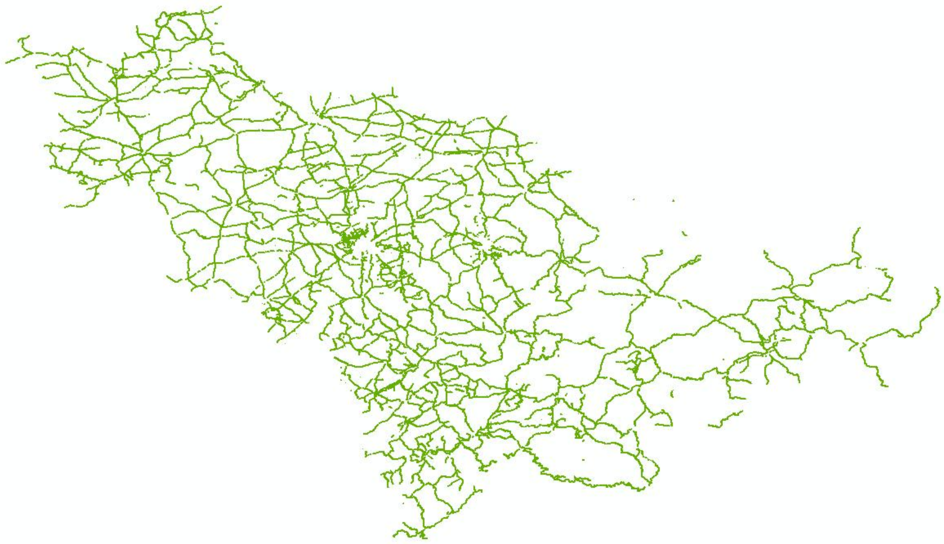

Figure 2 Highway Network Map of Jilin Province
Source: http://bzdt.ch.mnr.gov.cn

Highway Network Map of Jilin Province is shown in Figure 2.
The first subgroup is centered on Changchun, including tourist attractions and transportation hubs around Changchun, such as Changchun Jingyuetan National Forest Park and Changchun Lianhuashan Ski Resort. The internal traffic connections of this subgroup are close, forming a relatively independent traffic network area; the second subgroup is centered on Jilin City, covering scenic spots such as Songhua Lake Resort and Beishan Park, as well as transportation hubs such as Jilin Station, with relatively complete traffic lines within the subgroup; the third subgroup is centered on the Changbai Mountain Scenic Area, including scenic spots such as the North Slope and West Slope of Changbai Mountain, and surrounding traffic nodes, but the connections between this subgroup and other subgroups are relatively few; the fourth subgroup is composed of tourism nodes in Yanbian Prefecture, such as Yanji Maoershan National Forest Park and Tumen Port. The internal traffic network of the subgroup has certain uniqueness, but its external connections are relatively weak. The results of cohesive subgroup analysis show that there is an obvious phenomenon of regional segmentation in the ice-snow tourism traffic network of Jilin Province, and the traffic connections between each

subgroup are not close enough, which is not conducive to the integration and coordinated development of tourism resources.

3 PROBLEMS EXISTING IN THE ICE-SNOW TOURISM TRAFFIC NETWORK OF JILIN PROVINCE

3.1 Insufficient Connectivity of the Traffic Network

3.1.1 Specific performance and impact of low network density

The density of the ice-snow tourism traffic network in Jilin Province is only 0.087, which is significantly different from that of leading ice-snow tourism development areas in China, such as Heilongjiang Province with an ice-snow tourism traffic network density of 0.123. Network density is an important indicator to measure the tightness of connections between nodes in the traffic network. A low network density means that there is a lack of direct traffic line connections between a large number of tourism nodes. In the actual tourism process, if tourists want to go to some remote ice-snow tourism scenic spots, they often need to transfer multiple times. Taking Dunhua Laobaishan Snow Village as an example, the scenic spot has very few direct connection lines with the outside world in the traffic network. Starting from Changchun, tourists usually need to take a train or a bus to Dunhua City first, and then transfer to local small passenger vehicles from Dunhua City to the snow village. The whole journey takes a lot of time, and the one-way trip may take 5-6 hours or even longer. Such multiple transfers not only increase tourists' travel time cost, but also may bring problems such as inconvenient luggage handling and difficulty in obtaining transfer information, which greatly reduces tourists' travel experience.

In addition, insufficient network connectivity also makes it difficult for remote scenic spots to attract tourists effectively. For modern tourists who pursue a convenient travel experience, complex traffic transfers and long travel times are important concerns when choosing travel destinations. Some potential tourists may give up visiting these remote scenic spots due to inconvenient transportation and turn to popular scenic spots with more convenient transportation, which directly limits the development potential of remote ice-snow tourism scenic spots, leads to the difficulty in increasing the tourist reception capacity of the scenic spots and the slow growth of tourism income, and fails to give full play to the value of their tourism resources.

3.1.2 Unbalanced coverage of traffic lines

From the perspective of the distribution of traffic lines, the ice-snow tourism traffic network in Jilin Province has an obvious unbalanced phenomenon. Areas centered on cities such as Changchun and Jilin have dense traffic lines, forming a relatively complete traffic network system. As the provincial capital of Jilin Province, Changchun has important transportation hubs such as Changchun Longjia International Airport and Changchun Station, with an extensive railway and highway network connecting major cities in the province and major cities in China. However, in areas such as Yanbian and Baishan, especially important ice-snow tourism scenic spots around Changbai Mountain, traffic lines are relatively sparse.

As a core card of ice-snow tourism in Jilin Province, although the traffic conditions of the Changbai Mountain Scenic Area have been improved in recent years, there is still a large gap in the quantity and quality of traffic lines compared with urban central areas. At present, tourists traveling to the Changbai Mountain Scenic Area mainly rely on road transportation, with few railway lines and limited train trips. Air transportation also only relies on Changbai Mountain Airport with insufficient flight routes, which is difficult to meet the growing tourism demand. This unbalanced coverage of traffic lines makes the traffic pressure of remote scenic spots huge during the tourism peak season, the travel efficiency of tourists is low, and further aggravates the problem of insufficient connectivity of the traffic network.

3.2 Unbalanced Development of Nodes

3.2.1 Prominent advantages of transportation hubs and urban central nodes

It can be clearly seen from the node centrality indicators in social network analysis that transportation hubs such as Changchun Longjia International Airport, Jilin Station, Changchun Station and nodes in urban central areas such as Changchun and Jilin have significant advantages in terms of degree centrality, betweenness centrality and closeness centrality. Taking Changchun Longjia International Airport as an example, its degree centrality value reaches 38, ranking first among all 86 traffic nodes, which means that the airport has direct traffic connections with a large number of other nodes and is an important gateway for tourists to enter and exit Jilin Province and transfer between various scenic spots in the province. In terms of betweenness centrality, Changchun, as the provincial capital, has a betweenness centrality value of up to 256 for its node, much higher than other nodes, indicating that Changchun plays a key "bridge" role in the entire traffic network, controlling a large number of resource flows and information transmission, and many traffic lines need to transfer through Changchun.

Relying on their strong traffic radiation capacity, these transportation hubs and urban central nodes have attracted a large number of tourism resources and tourist flows. During the tourism peak season, Changchun Longjia International Airport and Changchun Station welcome a large number of domestic and foreign tourists every day, and the surrounding tourism supporting facilities such as hotels, catering and shopping have also flourished as a result. At the same time, the rich tourism resources and perfect public service facilities in urban central areas have further enhanced their attraction to tourists, forming an agglomeration effect of tourism development.

3.2.2 Development dilemmas of remote tourism scenic spot nodes

In sharp contrast to transportation hubs and urban central nodes, remote ice-snow tourism scenic spot nodes are in a disadvantaged position in the traffic network. Taking scenic spots such as Dunhua Laobaishan Snow Village and Helong Jindalai Folk Village as examples, their degree centrality values are only 5 and 3 respectively, which indicates that these scenic spots have extremely limited traffic connections with the outside world. In terms of closeness centrality, due to its remote geographical location, the standardized closeness centrality value of the Changbai Mountain Scenic Area is only 0.55, while that of Changchun reaches 0.78, which means that tourists need to spend more time to reach the Changbai Mountain Scenic Area from other nodes with poor accessibility.

This unbalanced development of nodes leads to the over-concentration of tourism resources in a few nodes, and remote scenic spots are difficult to obtain sufficient development opportunities. Due to inconvenient transportation, the construction of tourism supporting facilities in these scenic spots is lagging behind, and the service quality of hotels, catering and other aspects is difficult to improve, which further reduces the attraction to tourists. At the same time, the publicity and promotion of the scenic spots are also limited, and the popularity is difficult to improve, forming a vicious circle of "inconvenient transportation - few tourists - slow development - insufficient motivation for transportation improvement", which seriously hinders the balanced development of the ice-snow tourism industry in the whole province.

3.3 Poor Inter-Regional Synergy

3.3.1 Regional segmentation phenomenon revealed by cohesive subgroup analysis

After conducting cohesive subgroup analysis on the ice-snow tourism traffic network of Jilin Province by using the CONCOR algorithm of UCINET software, it is found that the entire traffic network is divided into 4 main subgroups, and there is an obvious phenomenon of regional segmentation between each subgroup. The first subgroup is centered on Changchun, covering tourist attractions and transportation hubs around Changchun; the second subgroup is centered on Jilin City, including important scenic spots such as Songhua Lake Resort; the third subgroup is centered on the Changbai Mountain Scenic Area; and the fourth subgroup is composed of tourism nodes in Yanbian Prefecture.

From the perspective of the connection between each subgroup, the number of traffic lines between them is small and the connection strength is weak. Taking the Changbai Mountain subgroup and the Yanbian subgroup as an example, there is a lack of direct and efficient traffic line connections between the two regions. If tourists want to travel from the Changbai Mountain Scenic Area to Yanbian Prefecture, they often need to return to cities such as Changchun or Jilin for transfer first, and then go to Yanbian, which not only increases tourists' travel time and costs, but also seriously affects tourists' travel experience between different regions.

3.3.2 Restrictions of poor inter-regional synergy on tourism development

Poor inter-regional synergy has seriously restricted the integration and coordinated development of ice-snow tourism resources in Jilin Province. Due to poor traffic connections between various regions, it is impossible to form a coherent and efficient tourism line, and tourists are unable to visit the characteristic ice-snow tourism scenic spots in multiple regions conveniently in one trip. This makes it impossible to make full use of the rich ice-snow tourism resources in Jilin Province, and the diversity and attraction of tourism products are affected. At the same time, the lack of collaborative cooperation between regions also leads to the fact that each region acts on its own in the process of tourism development, unable to realize resource sharing and complementary advantages, resulting in the waste of tourism resources and redundant construction.

In addition, poor inter-regional synergy is also not conducive to the building of the ice-snow tourism brand of Jilin Province. Under the background of increasingly fierce competition in the domestic ice-snow tourism market, the tourism resources and products of a single region are difficult to form strong competitiveness. Only through inter-regional collaborative cooperation, integrating the ice-snow tourism resources of the whole province and building an influential global ice-snow tourism brand can we stand out in the market. However, the current situation of regional segmentation makes Jilin Province face great challenges in brand building, and it is difficult to improve its popularity and reputation in the national and even global ice-snow tourism market.

3.4 Single Mode of Transportation

3.4.1 Traffic structure dominated by highway and railway

From the perspective of transportation modes reflected in the Ctrip travel notes data, the ice-snow tourism traffic network of Jilin Province mainly relies on highway and railway transportation. In terms of highway transportation, although the total highway mileage reaches 109,000 kilometers, during the ice-snow tourism peak season, some mountain highways are affected by ice and snow weather, with complex road conditions and low traffic efficiency. At the same time, highway passenger transportation has strong dispersion and instability, and some lines may reduce the number of trips or suspend operation in winter due to weather reasons, bringing inconvenience to tourists' travel.

Railway transportation is relatively stable, but there is also a problem of insufficient capacity allocation. During the tourism peak season, railway tickets are in short supply, tourists often need to buy tickets a long time in advance, and the number of train trips on some lines is limited, which cannot meet the concentrated travel demand of tourists. In addition, the insufficient coverage of railway lines in remote areas further limits its role in ice-snow tourism transportation.

3.4.2 Problems caused by insufficient coverage of public transportation

In remote tourist scenic spots, the coverage of public transportation lines is seriously insufficient. Tourists mainly rely on self-driving or chartered cars for travel, which not only increases tourists' travel costs, but also brings a series of problems. The influx of a large number of self-driving vehicles leads to traffic congestion around the scenic spots and a prominent problem of difficult parking, which affects tourists' travel efficiency and experience. At the same time, the chartered car service market is irregular, and problems such as non-transparent prices and uneven service quality also bring hidden dangers to tourists' travel safety and rights protection. The single mode of transportation limits tourists' travel choices, cannot meet the diversified needs of different tourist groups, and is also not conducive to alleviating traffic pressure and reducing the impact of tourism development on the environment. To address these issues, it is recommended to optimize the layout of public transport networks and actively introduce demand-responsive transport services. Specifically, local authorities should open dedicated winter tourist shuttle buses connecting major transportation hubs to core scenic spots, and pilot flexible transit modes such as "customized buses" and "shared shuttles" in remote areas to cover the "last mile" gap. Furthermore, it is essential to strengthen the regulation of the chartered car market by establishing a unified pricing mechanism and service evaluation system to ensure transparency and safety. Collaborative "rail + bus" or "flight + bus" intermodal services should also be promoted to provide tourists with seamless, reliable, and diversified travel alternatives.

4 CONCLUSIONS

This study systematically conducted an efficiency assessment and bottleneck diagnosis of Jilin Province's winter tourism transportation network. The findings confirm that the current network exhibits significant density deficiencies (0.087), severe imbalances in node functionality, and deep regional fragmentation. These structural issues directly constrain the value realization of remote scenic areas and the coordinated development of all-for-one tourism. By precisely identifying the central role of hubs such as Changchun and the connectivity gaps in peripheral scenic areas, this paper provides quantitative support for implementing differentiated infrastructure development and cross-regional coordination mechanisms. However, this study still has certain limitations: the current analysis is primarily based on static travel log data, with insufficient capture of real-time dynamic traffic flows, and it has not incorporated algorithms such as artificial intelligence to conduct predictive analysis of changes in tourist flow.

Future research could be further deepened through technological advancements: on the one hand, multi-source big data —including real-time traffic and mobile signaling data—should be integrated to establish a dynamic monitoring system; on the other hand, nonlinear co-evolution models linking winter tourism transportation networks with regional economies and ecological environments should be explored, thereby providing more comprehensive decision-making guidance for the scientific planning of Jilin Province's winter tourism industry. Looking ahead, the development of Jilin Province's winter tourism transportation network should embrace the opportunities presented by the rapid evolution of intelligent transportation technologies. Future efforts should focus on the deep integration of "Internet + Tourism," utilizing artificial intelligence and big data analytics to construct a smart tourism transportation cloud platform, thereby achieving precise scheduling and dynamic optimization of traffic resources. Furthermore, it is essential to actively explore the application of emerging low-carbon transport modes, such as autonomous driving and intelligent connected vehicles, in ice-snow scenarios to promote the green transformation of the tourism transportation system. Ultimately, by building a smart, efficient, and sustainable comprehensive transportation network, Jilin Province can transform its rich ice-snow resources into a globally influential tourism brand, providing strong impetus for the high-quality development of the regional economy.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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