

Spatiotemporal Behavior and Hotspot Analysis of Tourists in Yuntai Mountain Scenic Area Based on Multi-source Data

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Abstract

Selecting Yuntai Mountain Scenic Area as the case study, this research integrates multi-source heterogeneous data, including social media texts and tourist GNSS trajectories. By comprehensively applying the Analytic Hierarchy Process (AHP) and Direction-Constrained DBSCAN (DC-DBSCAN), it analyzes the characteristics of tourists' online attention and physical spatiotemporal behaviors, constructing a virtual-real coupling response mechanism for the scenic area. The results show: (1) The online attention of Yuntai Mountain Scenic Area exhibits an alternating "stable-pulse" fluctuation pattern, significantly influenced by statutory holidays, with tourists' focus concentrated on core attractions and considerable negative emotional feedback regarding physical exertion. (2) The physical flow of tourists demonstrates a temporal rhythm of "early entry, late exit, and single-peak aggregation." Spatially, a core skeleton road network primarily consisting of Fenghuang Ridge and Hongshi Gorge is formed. The duration of stay presents a bimodal clustering characteristic of short-term check-ins and in-depth experiences. (3) There is a significant spatiotemporal divergence between online attention and offline physical flow. Temporally, the rise in online heat precedes the peak of physical tourist flow by 1-2 weeks; spatially, Hongshi Gorge shows a virtual-real balance, Zhuyu Peak exhibits online overheating, while experiential attractions like Fenghuang Ridge and Xiaozhai Valley present significant offline overheating.

Keywords

Tourist spatiotemporal behavior; Multi-source data; Online attention; DC-DBSCAN clustering; Virtual-real coupling; Yuntai Mountain Scenic Area

1. Introduction

With the rapid development of the global economy and continuous improvements in living standards, the tourism industry has become a critical engine for driving economic growth in various countries. In recent years, the Chinese government has

attached great importance to tourism development, successively introducing a series of policies aimed at promoting high-quality growth in the sector. For instance, in November 2023, the Ministry of Culture and Tourism issued the "Domestic Tourism Improvement Plan (2023—2025)," emphasizing the innovation of tourism product systems and the promotion of smart and green tourism to meet the increasingly diverse needs of tourists.[1] The introduction of the high-quality development concept not only focuses on economic benefits but also prioritizes ecological environmental protection and social responsibility, fostering the practical application of smart and green tourism.[2] Furthermore, in August 2024, multiple departments jointly issued the "Guiding Opinions on Promoting the High-Quality Development of Tourism Public Services," further emphasizing the improvement of tourism public service systems to enhance tourist satisfaction.[3] Therefore, an in-depth study of tourist behavior is particularly crucial; scenic areas can scientifically adjust functional zones based on behavioral data to elevate the tourism experience and satisfaction.

Alongside the rapid advancement of computer and information technologies,[4] the number of internet users continues to climb, and the diversification of communication media has accelerated. The rise of new media platforms such as WeChat, Weibo, Tieba, and Xiaohongshu has significantly broadened communication channels, providing a free and equal environment for information sharing and interaction, thereby enriching information dissemination methods. Statistics show that the social platform "X" (formerly Twitter) has between 335 million and 666 million monthly active users, indicating an increasing inclination among people to share their emotions and views on daily life and global issues on social networks.[5] Consequently, by analyzing social text data posted by tourists on platforms like Weibo and Xiaohongshu, it is possible to reveal hotspot areas within scenic spots and tourists' emotional inclinations toward various attractions.

Simultaneously, with technological progress, tourists generate massive amounts of trajectory data during their travels. Systematic analysis of this data allows for the extraction of hot and cold spots within a scenic area and reveals the spatial distribution characteristics of tourist flows, thereby uncovering the spatiotemporal behavioral laws of tourists.[6] By combining social media data with tourist trajectory data, the spatiotemporal behavioral characteristics of different tourist types can be effectively captured. Subsequently, analyzing these behavioral patterns enables the precise identification of attraction properties, providing a more scientific and effective basis for the sustainable development of scenic areas.[7,8].

2. Methodology

2.1. Study Area

Yuntai Mountain, belonging to the Taihang Mountain range, was known in ancient times as Fufu Mountain or Nuwa Mountain. It is named for its towering peaks

frequently shrouded in white clouds. Located between 113°20'—113°26' E and 35°5'—35°29' N, Yuntai Mountain is situated in Xiuwu County, Jiaozuo City, Henan Province, at the eastern end of the northern Taihang Mountains and north of the Yellow River. Its main peak, Zhuyu Peak, has an elevation of 1297.6 meters.

The Yuntai Mountain Scenic Area covers a total area of 50 square kilometers and includes eight major attractions: Hongshi Gorge, Tanpu Gorge, Quanpu Gorge, Zhuyu Peak, Diecai Cave, Macaque Valley, Zifang Lake, and Wanshan Temple. It is a premium eco-tourism destination that features the abundant water landscapes of the Taihang Mountains, incorporates canyon geological landforms and a long historical culture, and integrates both scientific and aesthetic values.

2.2. Data Sources

Text data was obtained via a Python web crawler from Weibo location check-in pages, yielding a total of 1,013 check-in records for the general Yuntai Mountain area, 1,067 for Hongshi Gorge, 108 for Qinglong Gorge, and 1,033 for Zhuyu Peak. Additionally, 220 note entries were retrieved by searching "Yuntai Mountain" on Xiaohongshu. Trajectory data was sourced from the "Liuzhijiao" platform, which utilizes a "map travelogue" method to display travel routes alongside location-tagged photos, audio, and text on a map. After screening and processing the tourist trajectory data within the Jiaozuo Yuntai Mountain area, a total of 709 valid trajectory datasets were obtained.

2.3. Methods

2.3.1. Analytic Hierarchy Process

Online attention is a direct virtual projection of tourists' potential travel intentions and actual visitation experiences. This study constructs an online attention evaluation model based on the Analytic Hierarchy Process (AHP), integrating social media text data from Weibo and Xiaohongshu to reveal the temporal evolution characteristics of the scenic area's online heat.

To eliminate the interference of extreme values on the evaluation system, this study first applies a $\log(x + 1)$ smoothing transformation to the raw interaction data (x), followed by Min-Max normalization. The formula is as follows:

$$X_{norm} = \frac{\log(x + 1) - \min(\log(x + 1))}{\max(\log(x + 1)) - \min(\log(x + 1))} \quad (1)$$

After obtaining the standardized feature indicators, significant differences exist in the level of tourist involvement represented by different interaction behaviors. Generally, a "repost" represents the highest level of agreement and social endorsement, followed by a "comment," while a "like" carries the lowest sunk cost. Based on this behavioral logic, this study introduces AHP to construct a comprehensive heat evaluation model.

Combining expert scoring with the Delphi method, a pairwise comparison judgment

matrix A for the three-dimensional indicators of "repost-comment-like" was constructed. According to Saaty's 1-9 scale method, the importance of repost over comment is set to 3, repost over like to 5, and comment over like to 2. The judgment matrix A is as follows:

$$A = \begin{bmatrix} 1 & 3 & 5 \\ \frac{1}{3} & 1 & 2 \\ \frac{1}{5} & \frac{1}{2} & 1 \end{bmatrix} \quad (2)$$

The eigenvalue method is used to solve this matrix. By calculating the maximum eigenvalue λ_{max} of matrix A and its corresponding eigenvector, followed by normalization, the weight allocation vector for the three indicators is determined to be $W = [0.648, 0.230, 0.122]^T$. Concurrently, the matrix's consistency ratio $CR < 0.1$, successfully passing the consistency check. Considering that zero-interaction ordinary check-ins also represent authentic physical visits, this study introduces a base posting weight mechanism. An essential score of 1.0 is assigned to the tourist's posting behavior, and the AHP evaluation score serves as a premium weight to construct the comprehensive heat model for a single network text. Ultimately, the daily comprehensive online attention ($Heat_Score$) weighting model for Yuntai Mountain Scenic Area is established as:

$$Heat_Score = 1 + (0.648 \times X_{repost} + 0.230 \times X_{comment} + 0.122 \times X_{like}) \quad (3)$$

2.3.2. DC-DBSCAN Clustering

DBSCAN is a density-based spatial clustering algorithm proposed by Ester et al. in 1996. Unlike distance-based algorithms such as K-means, DBSCAN does not require a pre-specified number of clusters, can discover clusters of arbitrary shapes, and automatically marks points in low-density regions as noise. The core concepts of DBSCAN include: the ε -neighborhood (a circular area centered at a point with radius ε), core points (points containing at least $MinPts$ within their ε -neighborhood), boundary points (points located within the ε -neighborhood of a core point but are not core points themselves), and noise points (points that are neither core nor boundary points). The algorithm merges core points and points within their neighborhoods into the same cluster through density-reachability, thereby achieving density-based spatial clustering.

This study utilizes the DC-DBSCAN (Direction-Constrained DBSCAN) algorithm, an improved version of standard DBSCAN, to cluster tourist trajectories. Standard DBSCAN exhibits certain limitations when processing tourism trajectory data: internal scenic roads (e.g., hiking trails, boardwalks) are usually narrow and carry bidirectional pedestrian flows. The traditional algorithm solely relies on Euclidean distance for similarity measurement, making it difficult to effectively distinguish trajectory sequences that are extremely close in spatial location but opposite in flow direction. It is highly prone to erroneously merging ascending and descending flows

into the same cluster. DC-DBSCAN introduces a direction constraint to standard DBSCAN; when determining whether two trajectory points belong to the same neighborhood, it requires both their spatial distance and heading angle difference to meet specified constraint conditions. Through the neighborhood determination criterion of a "spatial-direction dual hard constraint," the instantaneous heading angle of tourist trajectory points is incorporated into the similarity measurement framework, effectively resolving the issue of mismerging bidirectional flows. Furthermore, the algorithm incorporates a dynamic cluster direction update mechanism, enabling the clustering process to naturally extend along winding scenic paths, and utilizes a graph topology-based chain-stitching mechanism to reconnect fragmented clusters broken by continuous sharp turns into complete trajectories.

3. Results and Analysis

3.1. Text Analysis

Based on the aforementioned model, long-time series aggregation and visualization of the daily heat in 2025 were conducted. The results indicate that the online attention of Yuntai Mountain Scenic Area exhibits a rigorous and objectively consistent alternating "stable-pulse" fluctuation pattern. During regular non-holiday periods, the heat curve closely aligns with the X-axis, forming a stable baseline running at a low level; however, when entering statutory holiday windows, the heat curve experiences an instantaneous structural surge. The formation of this pulse peak is the superimposed outcome of massive independent tourist check-ins and social premium on that day, successfully replicating the spatial-temporal tidal baseline of physical tourist flows.

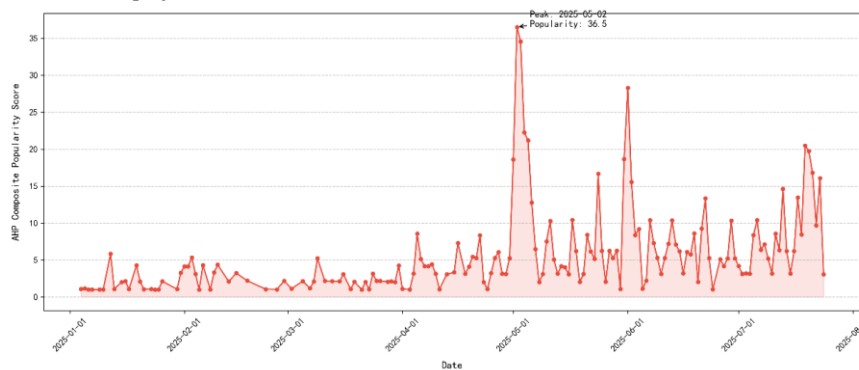


Figure 1. Time-series Evolution of Daily Network Attention in Yuntaishan

After aggregating single-day data into a weekly series, this study further explores the spatial behavioral heterogeneity driven by different types of holidays on scenic area online heat. Given the difference in the magnitude of valid network data samples between 2024 and 2025 (with an explosive growth observed in 2025), forcefully placing them in the same coordinate system would cause the severe

magnitude discrepancy to mask the data variance and fluctuation details within the lower-frequency year. Therefore, this study adopts a strategy of temporal splitting and independent coordinate systems, mapping the weekly online attention evolution and holiday coupling for 2024 and 2025 respectively.

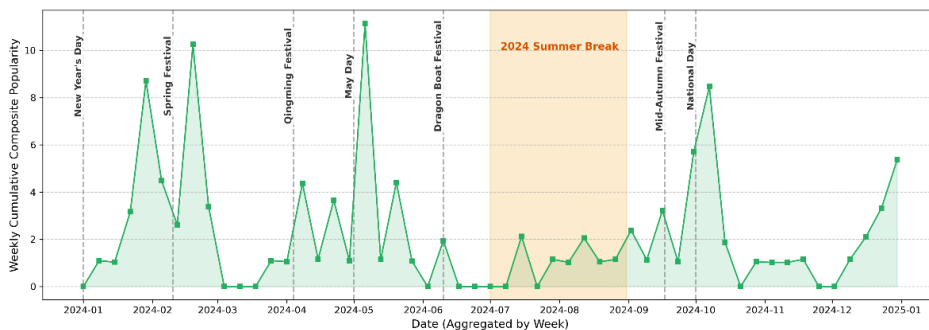


Figure 2. Weekly Network Attention Evolution and Holiday Coupling in 2024.

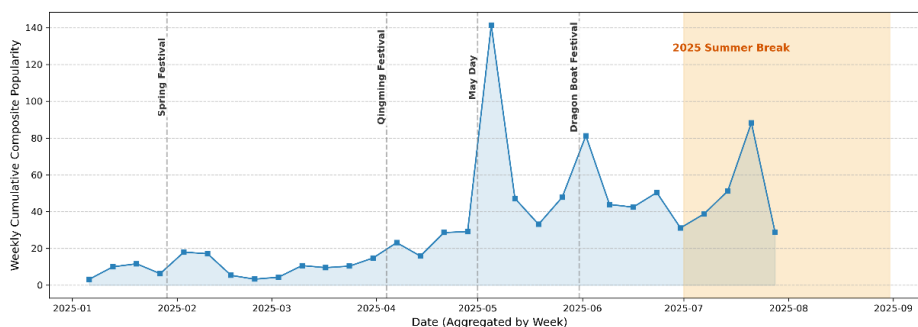


Figure 3. Weekly Network Attention Evolution and Holiday Coupling in 2025.

When exploring the spatial behavioral heterogeneity driven by different types of holidays, it was found that the week containing the May Day Labor Day constitutes the absolute extreme core of the first half of the year, while the National Day in October forms the core peak of the second half. During three-day short holidays like Tomb-Sweeping Day and Dragon Boat Festival, the overall growth in comprehensive heat is relatively gradual. This phenomenon occurs because Yuntai Mountain, as a typical large-scale mountainous scenic area, entails high physical exertion and long dwell times due to objective physical constraints. It is highly noteworthy that during the summer vacation period from July to August each year, a high-traffic plateau lasting for two months forms on the time series curve, reflecting the ample time elasticity of family tours and student groups, resulting in a more gradual and sustained release of tourist flow.

Table 1. Sample texts of negative emotions regarding Yuntai Mountain.

Time	Text Content	Sentiment Value
2025/8/15 11:32:00	#Yuntai Mountain# The scenery is beautiful, but the steamed buns and spicy soup (Hulatang) taste awful.	0

	Don't ruin the reputation of our Henan spicy soup. The hygiene is also very poor! Jiaozuo · Zhuyu Peak Scenic Area	
2025/5/3 19:48:00	It's completely packed with people. My legs are about to break from walking.	0
2025/5/22 13:52:00	Teacher, is this right? Isn't the rain too heavy??? Jam Hsiao* (Scenic Area Edition)	0
2025/6/7 20:00:00	It's scorching hot at Yuntai Mountain.	0

(Note for your manuscript: You may want to add a footnote explaining that "Jam Hsiao" is a famous Chinese singer jokingly known as the "God of Rain" because it frequently rains during his concerts, to help international reviewers understand the context).

Through emotional analysis of Weibo text contents regarding Qinglong Gorge, Yuntai Mountain, Hongshi Gorge, Zhuyu Peak, and Zifang Lake, it is evident that these scenic spots generally received positive feedback. The majority of comments display positive sentiments, with tourists widely praising the natural landscapes, activities, and travel experiences. A minority of neutral comments typically comprise informational content, while negative comments are relatively scarce. Overall, these scenic spots enjoy high satisfaction among tourists, indicating a generally positive scenic image. Table 1 demonstrates that tourists' negative emotions toward the Yuntai Mountain Scenic Area primarily stem from weather conditions, crowd volumes, service levels, and the scenic environment.

3.2. Trajectory Data Analysis

By applying the improved DC-DBSCAN algorithm to the massive trajectory data of Yuntai Mountain Scenic Area, the Top 9 core skeleton road networks with clear physical significance were successfully extracted. Combining spatial feature comparisons with high-resolution satellite basemaps and official guide maps, this study achieved an in-depth semantic mapping of attractions for the popular trajectories.

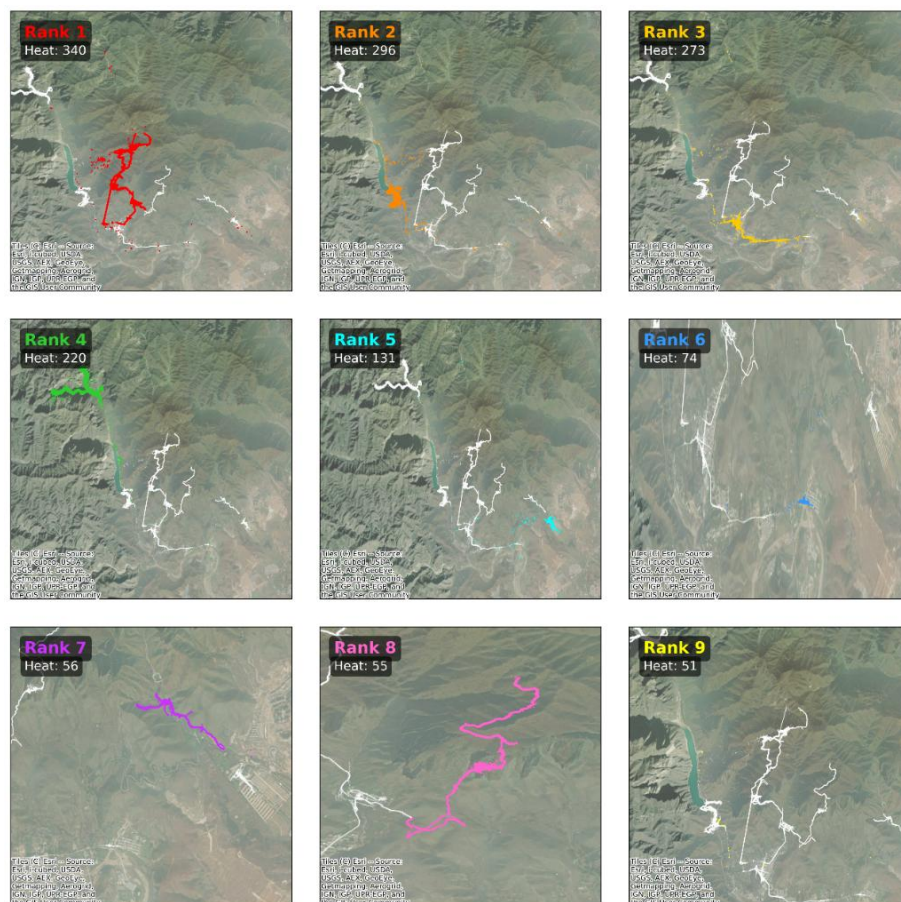


Figure 5. Extraction Results and Spatial Mapping of Popular Trajectory Routes in Yuntaishan Scenic Area.

Rank 1 (Red): Fenghuang Ridge alpine sightseeing area and vertical transportation core. The linear segment highly correlates with the "Fenghuang Ridge Cableway," disregarding terrain undulations; the network segment corresponds to open summit sightseeing areas like the glass skywalk and Chongyang Pavilion, reflecting tourists' high-frequency, multi-modal transport transition behavior of "direct cableway access—summit roaming".

Rank 2 (Orange): Hongshi Gorge deep valley one-way tourist route. Constrained by extreme deep valley topography and strict one-way boardwalk management, the physical activity space of tourists is severely compressed, presenting a typical high-density, strip-shaped congestion characteristic.

Rank 4 (Green): Xiaozhai Valley dead-end branching canyon. The trajectory exhibits a classic Y-shaped topological structure, corresponding to the Xiaozhai Valley square and its three independent deep valley extensions (Tanpu Gorge, Quanpu Gorge), indicating the spatial exploration behavior of tourists penetrating deep into the dead-end attraction and returning via the original route.

Rank 8 (Pink): Upward route from Wanshan Temple to Zhuyu Peak. Continuous

sharp switchbacks were completely extracted, verifying the effectiveness of the topological chain-stitching algorithm in overcoming fragmentations caused by continuous sharp turns.

3.2.1. Analysis of Tourist Spatiotemporal Behavior Characteristics

Statistically evaluating the number of active tourists using an hourly granularity, Yuntai Mountain Scenic Area exhibits a highly representative temporal characteristic of early entry, late exit, and single-peak aggregation. The tourist flow rises sharply between 08:00 and 10:00, reaching its peak around 10:00. Between 10:00 and 14:00, due to the large scale of the mountainous terrain, most tourists lunch within the park and continue sightseeing without a noticeable "midday resting trough," forming a stable high-level plateau phase. After 15:00, the tourist flow drops precipitously.

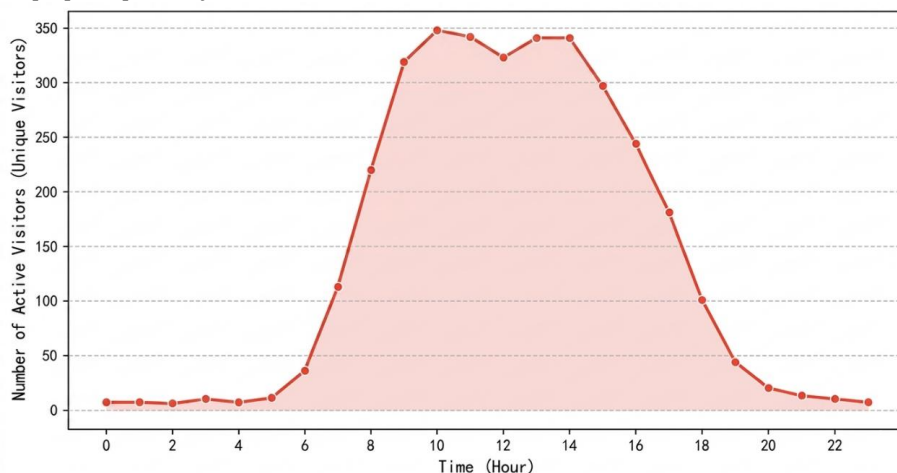


Figure 6. Unimodal Tidal Pattern of Tourists' All-day Time Distribution Rhythm.

Plotting the histogram of tourists' duration of stay, the overall average playing time reaches 4.8 hours. Its kernel density estimation curve presents an asymmetrical bimodal clustering characteristic: the first peak (1-3 hours) represents the short-term check-in crowd solely visiting core attractions; the second peak (6-9 hours) represents the full-day depth-experience crowd penetrating into high-altitude branch routes.

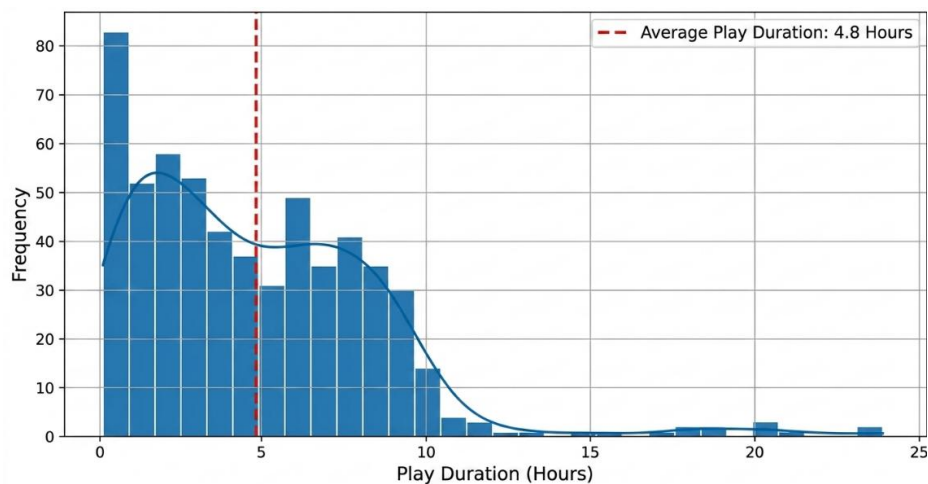


Figure 7. Bimodal Characteristic Map of Tourists' Duration of Stay Distribution

3.3. Virtual-Real Coupling Response Mechanism of the Scenic Area

By cross-comparing the virtual attention based on online text mining with the physical tourist flow distribution derived from GNSS trajectory clustering, the coupling and divergence laws of the scenic tourism flow across both temporal and spatial dimensions can be revealed.

3.3.1. Advanced Dislocation Characteristics in the Temporal Dimension

Superimposing the online attention sequence with the holiday timeline reveals that the upward inflection point of network heat does not occur on the first day of the holiday but advances by 1-2 weeks prior. This temporal mismatch reflects the informational behavior characteristics of tourists' travel decision-making: pre-trip strategy searching, itinerary inquiries, and anticipation expressions constitute an information accumulation phase preceding the arrival of physical crowds. The premature escalation of online heat can serve as a leading indicator for physical tourist flow peaks, providing an approximately 7-14 day response window for holiday capacity allocation and flow early warning.

3.3.2. Virtual-Real Divergence Characteristics in the Spatial Dimension

To quantitatively compare the online and offline coupling relationship of various attractions, the Spatial Mismatch Index (SMI) is introduced:

$$SMI = X_{\text{norm}} - Y_{\text{norm}} \quad (4 - 6)$$

The SMI is defined as the difference between the normalized value of online mention frequency and the normalized value of offline visited trajectories. A positive value indicates that online attention exceeds offline visit volume (online overheating), while a negative value signifies the reverse (offline overheating).

Table 2. Comparison of online attention and offline visit volume among attractions

Attraction	Online Mentions	Online AHP Heat	Offline Visited Trajectories	Average Stay Duration (h)	Spatial Mismatch Index (SMI)	Mismatch Type
Hongshi Gorge	34	40.69	329	0.3	0.0000	Virtual-Real Balanced
Fenghuang Ridge	16	16.89	314	1.0	-0.5245	Offline Overheated
Xiaozhai Valley	15	17.77	326	1.3	-0.6017	Offline Overheated
Tanpu Gorge	9	10.72	91	0.4	-0.0903	Virtual-Real Balanced
Quanpu Gorge	8	8.71	257	0.5	-0.5690	Offline Overheated
Zhuyu Peak	27	29.32	239	2.6	0.1113	Online Overheated
Wanshan Temple	3	3.58	62	1.2	-0.1046	Offline Overheated

Combining the analysis of seven core attractions, the virtual-real dislocation presents a distinct differentiation pattern.

1. Virtual-Real Balanced Type: The SMI of Hongshi Gorge approaches zero, acting as a typical virtual-real balanced attraction that possesses both network traffic attributes and physical carrying capacity.
2. Online Overheated Type: Zhuyu Peak is the sole attraction exhibiting online overheating characteristics (SMI = +0.11). This originates from its cultural symbolic effect (e.g., the Double Ninth Festival climbing tradition), which grants it high online discussion volume. However, because it is located deepest within the scenic area and at the highest altitude, actual visitation is constrained by physical exertion and time costs.
3. Offline Overheated Type: Fenghuang Ridge (SMI = -0.52), Xiaozhai Valley (SMI = -0.60), and Quanpu Gorge all present offline overheating characteristics. Taking Xiaozhai Valley as an example, its online mentions are relatively low, but offline visited trajectories are extremely high with an average stay duration of 1.3 hours. This indicates that the attraction hosts profound tourist experiences in physical space but lacks network dissemination momentum, revealing a structural divergence between online influencer labels and actual offline stays.

4. Conclusion and Discussion

4.1. Conclusion

Taking the Yuntai Mountain eco-tourism destination as a case study, this research integrates multi-source data such as network texts and GNSS trajectories to conduct an in-depth analysis of tourists' spatiotemporal behavioral characteristics and virtual-real coupling patterns. The primary conclusions are as follows:

1. The physical tourist flow exhibits a single-peak tidal rhythm, with pronounced spatial clustering on core routes. Traffic peaks around 10:00 AM. The Direction-Constrained clustering algorithm (DC-DBSCAN) effectively extracted a core skeleton road network dominated by Fenghuang Ridge, Hongshi Gorge, and

Xiaozhai Valley. Tourists' dwell times show distinct polarization between check-in types and in-depth experience types.

2. Online attention possesses a significant "stable-pulse" characteristic, where statutory holidays exert an overwhelming driving effect on traffic. Furthermore, semantic focal points objectively reflect the dual experience of mountainous scenic areas: aesthetic beauty coupled with physical fatigue.

3. Tourist behaviors demonstrate clear virtual-real divergence across spatiotemporal dimensions: Temporally, the accumulation period of online heat precedes physical flow by 1-2 weeks. Spatially, Hongshi Gorge achieves virtual-real balance; the physically demanding Zhuyu Peak shows online overheating; while experiential areas like Xiaozhai Valley and Fenghuang Ridge exhibit offline overheating.

4.2. Discussion

1. Based on the tourist spatiotemporal behavioral laws and virtual-real divergence mechanisms revealed in this study, the following targeted strategies are proposed for spatial management and service enhancement in Yuntai Mountain Scenic Area. First, construct a dynamic tourist flow early-warning mechanism based on preemptive heat. The upward inflection point of online heat often precedes physical flow by 1-2 weeks; the scenic administration can utilize this information accumulation phase as a warning window to initiate capacity reserves in advance and issue staggered-travel advisories, thereby alleviating carrying pressures on core routes (e.g., Hongshi Gorge) during peak hours (10:00-14:00). Second, implement spatial differentiated management tailored to the virtual-real divergence characteristics of different attractions. For online overheated attractions (like Zhuyu Peak), efforts must focus on mitigating spatial resistance caused by high physical exertion, appropriately adding resting and shuttle facilities. For offline overheated experiential zones (like Xiaozhai Valley and Fenghuang Ridge), where physical dwell time is long but online buzz is insufficient, efforts should concentrate on implanting scenario-based interactive installations to transform the deep experiences of physical tourists into online word-of-mouth, realizing an effective mapping from offline traffic to online marketing.

2. At the methodological level, addressing the spatial physical characteristic of bidirectional intertwined pedestrian flows in mountainous scenic areas, this study introduces the DC-DBSCAN clustering algorithm equipped with direction constraints. This effectively overcomes the mismerging issue inherent in traditional density clustering when processing switchback routes, providing a reliable tool for trajectory pattern extraction in complex terrains. Concurrently, the introduction of the Spatial Mismatch Index (SMI) quantifies the structural contradiction between influencer tags and physical stays. However, this study also possesses certain limitations: constrained by the user personas of social media data, the sample

demographic may carry a certain age bias. Future research could further incorporate multi-source data, such as mobile phone signaling, for cross-validation to improve the accuracy of full-sample passenger flow information mapping and spatiotemporal behavioral profiling.

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