Research Paper

Digital Sentiment as Urban Indicator: Measuring POI Mix Effects Through Social Media Analytics in Nanjing

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Supported by the National Natural Science Foundation of China (ProjectNo.52178034)

Abstract

In the context of digital urban development, contemporary urban planning encounters a key dilemma: although functional mixed-use development is widely promoted to enhance urban vitality, its influence on residents' emotional well - being lacks effective quantification. Traditional planning evaluation indicators, mainly focusing on physical space and economic benefits, are unable to comprehensively reflect the psychological responses of urban residents to spatial environments, resulting in sub - optimal urban designs11[1]. This problem is evident in Nanjing's central urban area, where historical blocks face development stagnation due to insufficient functional mixing, while CBDs suffer from residents' psychological stress caused by excessive mixing.

This research innovatively integrates smart city facilities and social media data, applying the Bertopic-CRF big data model to establish a data - driven analysis framework. By extracting real - time emotional information from social media and correlating it with spatial elements, the framework analyzes the interaction between urban space and human psychology.

Keywords

Urban planing,Urban Sentiment Analysis,POI Functional Mix,Social Media Big Data,BERT Geo-Analytics

1. Introduction

The mixed development of historical functions and land use is an important strategy of contemporary urbanism. This strategy emphasizes the integration of multiple functions such as residential, commercial, cultural, institutional and production within a single land use function to maximize land use efficiency, enhance urban vitality and sustainability, and improve the quality of life for residents[2]. The purpose of implementing this strategy is to optimize urban space through the close integration of functions when facing the diversity and complexity of urban development[3], thereby providing people with a convenient lifestyle that integrates "life, work and entertainment".

From the perspective of historical evolution, human society has undergone a three-stage evolution from the mixture of natural functions to the artificial zoning of functions and then to the mixture of functions. In the primitive society, people's residences and workplaces were closely connected, and walking was the main mode of transportation. With the rise of the Industrial Revolution and functionalist thought, urban planning began to emphasize functional zoning and isolate urban activities by types such as residential,

commercial and industrial to avoid environmental problems and chaos brought about by industrialization. For instance, in the early 20th century, vertical urbanization models emerged in New York and Chicago in the United States, placing commercial areas at the bottom and residential areas at the top. This case is also regarded as the embryonic form of early mixed development practices. After World War II and from the 1950s to the 1960s, isolated land use reached its peak in the United States. One serious consequence of functional zoning is the separation of residential, working and entertainment areas, as well as the high reliance of urban residents on private cars, which has led to a decline in the vitality of traditional city centers.

Jane Jacobs pointed out in 1961 that single-function blocks lack vitality and diversity, and the mixed land use model is beneficial to urban vitality and resident interaction 345. Coupled with the increasingly serious deterioration of the urban center area, the concept of mixed use was redefined as a tool for urban renewal [3]. Since then, mixed Development has gradually incorporated modern planning concepts such as New Urbanism, Smart Growth and Transit-Oriented Development (TOD). The core lies in advocating the construction of compact, walkable and diverse communities to reduce urban sprawl and the ecological, economic and social negative impacts it brings[4]. Functional mixing, as an important strategy for urban development, is widely recognized. The "New Strategy for Sustainable Neighborhood Planning" of UN-Habitat also explicitly regards mixed land use as one of the five core principles to promote sustainable urban development[3].

Although the mixed development of function and land use is widely recognized for enhancing urban vitality and promoting social and economic development, existing research generally neglects residents' emotional perception, subjective satisfaction or psychological experience of quality of life. Many studies mainly focus on macro socio-economic indicators such as employment, housing supply, economic growth and the effectiveness of policy implementation, but fail to delve deeply into the specific impacts of mixed development on the psychological levels of individual residents and communities.

In the context of the information and digitalization era, media technology and urban space have been integrated (i.e., geographical media), enabling the boundaries of urban space to break through the physical dimension and create a brand-new media space dimension[5]. The expansion of the urban dimension has led to the expansion of the "objective material environmental basis of individual visual observation" that traditional cognition relies on - the temporal and spatial dimensions of the environmental basis have been extended in both directions[6][7]. A data-driven high-frequency, high-latitude and high-density virtual space layer is superimposed on the traditional physical space, forming a new perceptual environmental space that is dynamically changing in the dual dimensions of time and space. The perceptual environment of the traditional paradigm relies on static elements that can be directly grasped visually, and its characteristics are manifested as clear material forms[8], stable geographical boundaries and relatively static spatial relationships. The perception environment space of the new paradigm not only realizes the virtual mapping of physical space elements through digital twins, but also contains rich labels of group consensus cognition and individual perception information, etc. Its characteristics are manifested as subjective cognition, real-time changing spatial boundaries and dynamic spatial relationships. This transformation makes the media space present a composite structure interwoven with the virtual and the real. In terms of spatiotemporal attributes, the new perceptual environment space demonstrates significant dynamic characteristics and dual spatiotemporal dimensions. Its spatial boundary can change in real time with the status of digital services, and it also emphasizes immediacy and responsiveness in the temporal dimension.

Section 2 presents the methodological framework including data acquisition, BERT-CRF sentiment analysis, POI functional mixing measurement, and spatio-temporal coupling model. Section 3 reports empirical findings on sentiment distribution and the coupling relationship between POI mixing and public emotion. Section 4 concludes with recommendations for differentiated functional mixing strategies and dynamic urban emotion monitoring systems.

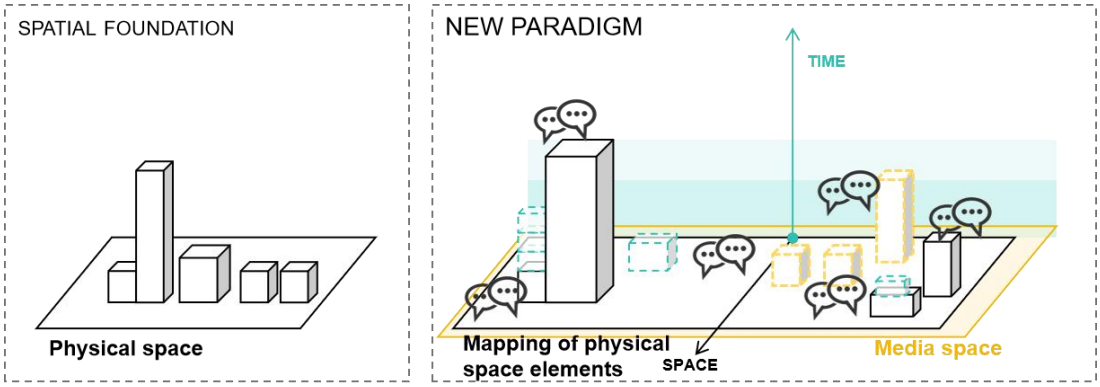

Fig.1Comparison of environmental space foundation between traditional paradigm and new paradigm

Professor Brian pointed out in his book "The Language of Space" : "Perception is actually the positive process by which we feel the world around us."[9] While urban space is expanding, the perception mode of the crowd is also undergoing profound changes. The perception mode has broken through the traditional paradigm of basic sensory combination and gradually shifted to a new paradigm of deep integration with media[10]. The perception process not only relies on people's visual interpretation and memory reconstruction of the physical environment, but also integrates the dynamic and multi-dimensional information environment mediated by media technology, forming a composite urban cognitive mechanism. Specifically, three new perception methods have emerged:

Users project fragmented experiences in real time onto the media space, forming a cognitive network driven by prior perception. Individuals, based on their own needs, preferences and digital literacy, actively filter, invoke and even customize digital information, thereby constructing a highly personalized and proactive perception picture. The perception process is no longer confined to the binary relationship between the individual and the environment, but is embedded in social and technological networks, achieving a dynamic group perception where multiple users participate together and influence each other.

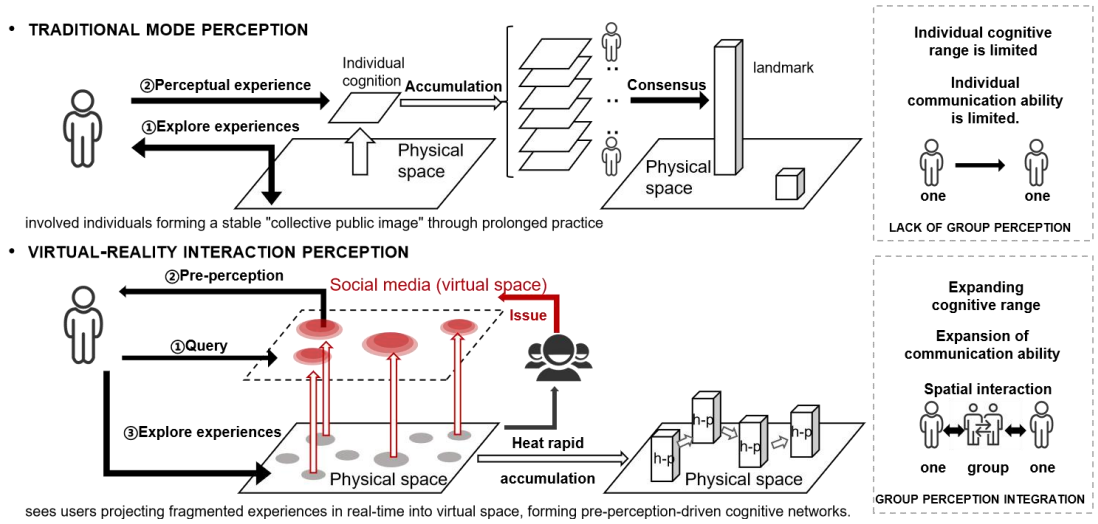

Fig.2New perceptual mode type

The emergence of new perception perspectives has expanded the exploration Angle of the impact of land use function mixing degree and made it more measurable.

This research innovatively integrates smart city facilities and social media data, applying the Bertopic-CRF big data model to establish a data - driven analysis framework. By extracting real - time emotional information from social media and correlating it with spatial elements, the framework analyzes the interaction between urban space and human psychology.

As one of the megacities with the highest social media activity in eastern China, Nanjing has a large user base and high activity level. The penetration rate of Weibo and the effect of content dissemination have long been among the top in domestic cities. Moreover, the historical urban area is home to cultural and tourism attractions such as Laomen Dong and Confucius Temple, and living Spaces like Yihe Road area and Kexiang Market continuously attract interactive evaluations from local residents and tourists. Form a unique digital landscape that combines the reproduction of historical memory with the critical nature of daily practice. The research scope is defined as the core area of the old city enclosed by the Ming City Wall of Nanjing (including Xuanwu Lake). This area has completely preserved the spatial pattern of "mountains, waters, cities and forests" of ancient Chinese capitals. There are currently 11 historical and cultural blocks and 127 cultural relics protection units. The stability of its physical space and the fluidity of digital perception form a strong tension. It provides an ideal experimental field for observing the new perception mode under the intervention of media.

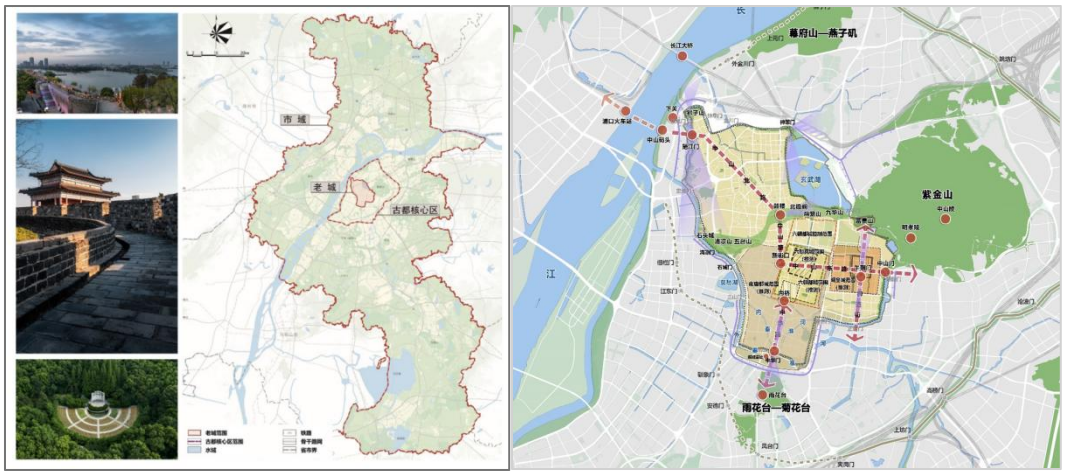

Fig.3 Research Scope

2. Methodology

This study constructed a coupled data analysis framework, aiming to systematically reveal the spatio-temporal coupling mechanism between the functional mixture of POI and public emotional responses. The research methods mainly include four parts: data acquisition and processing, sentiment analysis model construction, POI hybrid measure, and spatio-temporal coupling analysis model.

1. Data source and preprocessing

This study adopted two types of multi-source heterogeneous data, mainly including social media text data and POI data, and ultimately located the data in the fishing net grid of Arrcgis through the coordinate information of the data.

1.1Social media data:

Text data with geographical locations collected from mainstream Chinese social platforms (such as Weibo and Dianping) published within the Nanjing metropolitan area from 2015 to 2024. After deduplication, denoising and spatial matching, approximately 600,000 valid corpora were obtained.

KEYWORD	CONTENTS OF HIROFUMI	LIKE	FORWARD	UID	TIME	IP
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KEYWORD	CONTENTS OF HIROFUMI	LIKE	FORWARD	UID	TIME	IP
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1.2POI data: Sourced from the open platform of Autonavi Maps, it covers 10 types of urban functions including business, culture, green Spaces, and transportation. Taking a 50-meter by 50-meter grid as the basic spatial unit, the POI mixing degree panel data is aggregated quarterly.

All data undergo spatial projection unification (WGS1984 coordinate system), missing value interpolation and outlier elimination processing to ensure the consistency of spatio-temporal dimensions.

NAME	DALIE	ZHONGLEI	XIAOLEI	LOCATIONX	LOCATIONY
南京大吉会馆	科教文化服务	会展中心	会展中心	118.486748660760000	32.07729587
正源尚峰尚水别墅	商务住宅	住宅区	别墅	118.486138372387003	32.06683578
高淳区古柏幼儿园	科教文化服务	学校	幼儿园	118.934836590369002	31.36751244
桃园雅居 A 区	商务住宅	住宅区	住宅小区	118.934833980562999	31.36318083

2. Emotion Analysis Model

To accurately identify the sentiment polarity contained in the text, this study constructs a hybrid sentiment recognition model based on BERT:

Context semantic embedding is carried out using the pre-trained bert model (BERT-Base-Chinese);

Introduce the CRF layer to perform sequence labeling on the BERT output, optimizing the coherence and contextual consistency of the sentiment labels (positive/negative/neutral).

The model was fine-tuned on 30,000 manually labeled emotional corpora, achieving an accuracy rate of 82.7% and an F1 value of 0.891, demonstrating a strong adaptability to the Chinese context.

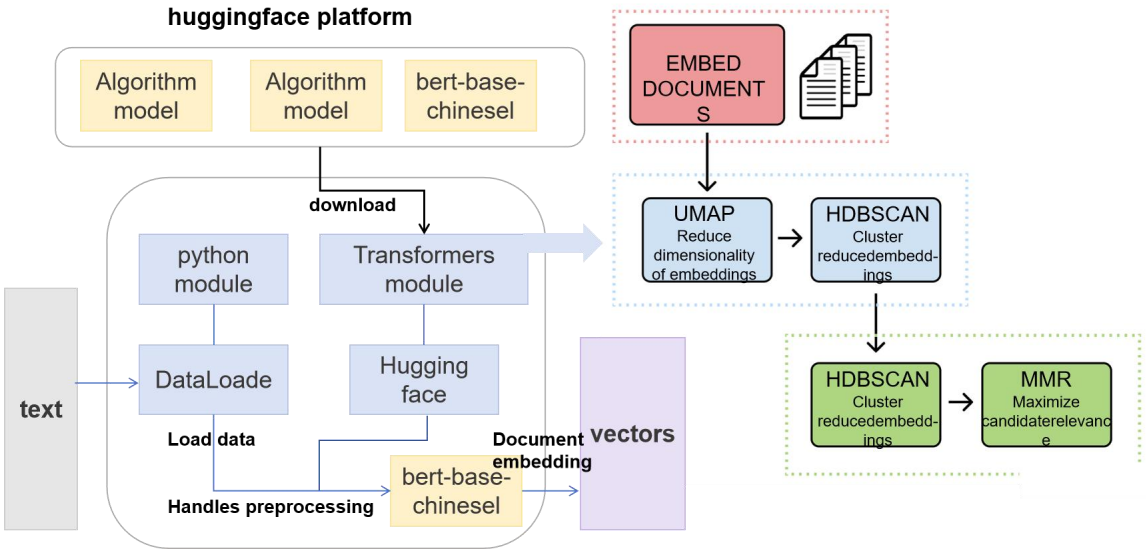

Fig.4 BERT-CRF Model

3. POI function Hybrid measure

Drawing on the theory of information entropy and using the Shannon index, the functional diversity of 10 types of POIs within each grid cell is characterized:

$$H' = -\sum_{i=1}^{S} (p_i \times \ln p_i)$$

Among them, H': Shannon Diversity Index value. The higher the H 'value, the greater the diversity of the system. S: The total number of species (or types, categories) in the system; p_i: The proportion of the number of individuals (or area, proportion) of the i-th species (or type) to the total number (or total area), calculated by the formula: $p_i = \frac{N_i}{N}$ Here, N_i represents the number of individuals (or area) of the i-th category, and $N_i$is the total number of individuals (or total area). ln is the natural logarithm (with base e).

4. Spatio-temporal coupling diagnostic model

To explore the dynamic relationship between POI mixture and emotion, a spatio-temporal coupling diagnostic model was constructed. By using the analysis method of bivariate local Moran index, spatial clustering regions with significant emotion-mixture associations were identified to reveal the "emotional hotspots" and "mixed cold zones". A hybrid-emotion coupling coordination model was constructed to quantify the synergy level between the two, and a vector autoregressive model was built based on panel data to reveal the causal relationship and time lag effect between POI mixture and emotion.

3. Finding

1. The distribution characteristics of positive and negative emotions

Over the past decade or so, the positive sentiment in the old urban area of Nanjing has shown a clear trend of developing towards the center and gradually strengthening in intensity. From the perspective of time changes, from 2013 to 2018, the positive emotion area gradually expanded from a small range to a large area. From 2019 to 2024, these red areas not only did not shrink but also continued to expand outward, and their color became even redder. This indicates that both citizens and tourists are deepening their affection for the old town and expanding the scope of their exploration of it. It is worth noting that, as seen from the map, the heat in the central area decreased compared to the surrounding areas in the later period. For instance, areas like Xinjiekou and Fuzimiao, which once generated high positive emotions, have gradually been replaced by positive emotions in areas such as Huowa Lane and Ke Lane.

The negative emotions within the study area also have certain regularity in their spatio-temporal evolution. Firstly, in terms of the time dimension, the hotspots of negative emotions have gradually shifted from a scattered and low-intensity state in the early period (2013-2018) to a local aggregation and increased density. During the second stage, that is, from 2019 to 2024, the density of negative emotion hotspots was generally higher than the early level, reflecting that the scenarios that trigger negative emotions are constantly increasing. Secondly, in terms of spatial distribution, negative emotions are concentrated on major traffic arteries such as Zhonghua Road and Zhongshan South Road, as well as around old residential areas. This indicates that traffic experience and the convenience of life are important factors that can easily trigger negative emotions. On the other hand, negative and positive emotional hotspots overlap in the central area space. In the central region of the city, negative and positive emotions coexist. In terms of the intensity changes of negative emotions, the color of hotspots in some areas has transitioned from light blue to dark blue, and the scope has also expanded, reflecting that the intensity of anxiety and dissatisfaction among the people in some areas is on the rise. This result clearly indicates that in the future, urban governance should focus on traffic guidance and the precise optimization of public welfare facilities in old residential areas.

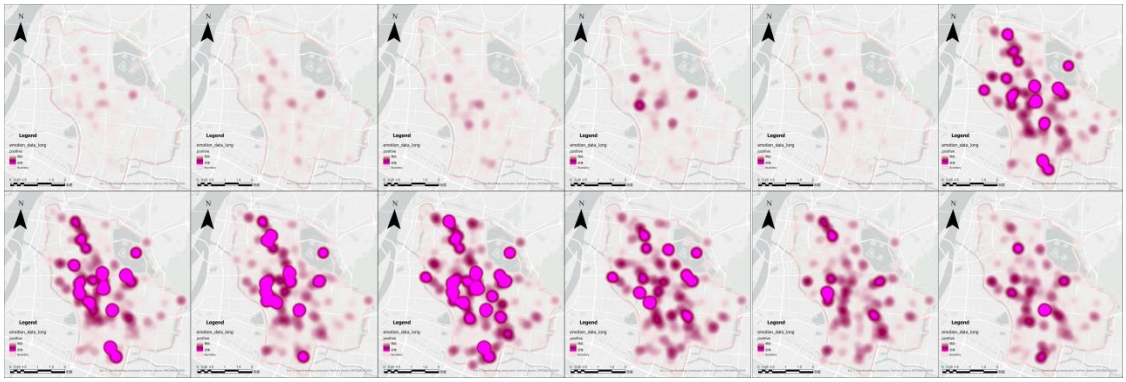

Fig.5 POI Mixing vs. Positive Sentiment

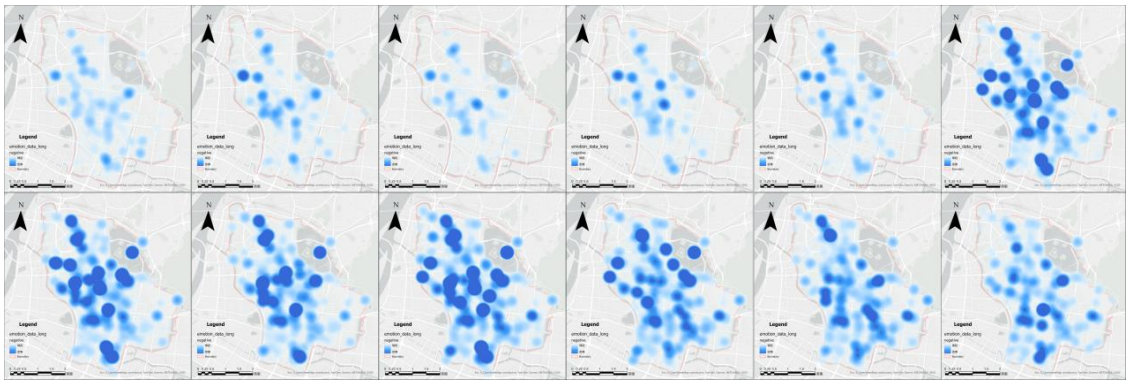

Fig.6 POI Mixing vs. Negative Sentiment

2. Analysis of Spatial Coupling and Time-delay Effects

Through the establishment of the space-time cube technology, we have discovered an interesting phenomenon: the influence patterns of different types of emotions on the POI mixture degree are different. Specifically, the POI mixture degree has a time lag effect on negative emotions, among which the two-year lag effect is the most obvious. In contrast, positive emotions and the degree of POI mixture show a stable positive correlation. These findings provide important empirical evidence for understanding the complex interaction between urban space and public psychology.

Specifically, the mixture degree of positive emotions and POI shows a relatively strong correlation in both spatial and temporal dimensions. The results of spatial autocorrelation analysis show that the regions with high positive emotions also have a higher degree of POI mixture in the same period, and this positive correlation reaches a statistically significant level in most years. Further time-delay analysis indicates that the positive emotions in the early stage have a continuous positive impact on the POI distribution in the later stage, suggesting that the influence of positive emotions on urban functional configuration has a considerable degree of persistence.

In contrast, the relationship between negative emotions and POI presents different spatiotemporal characteristics. Although in the concurrent analysis, the mixture degree of negative emotions and POI did not form a relatively stable association, the time-delay regression results showed that in the high negative emotion region, there was a significant delayed effect on the impact of negative emotions on POI. Time delay analysis reveals that there is a certain correlation from a time delay of one year to five years, and the years with a time delay of two years are the most significant. This indicates that it takes about two years for a series of negative emotional issues to have observable impacts on POI configuration. The analysis results reveal the delayed characteristics of the urban system's response to negative emotions.

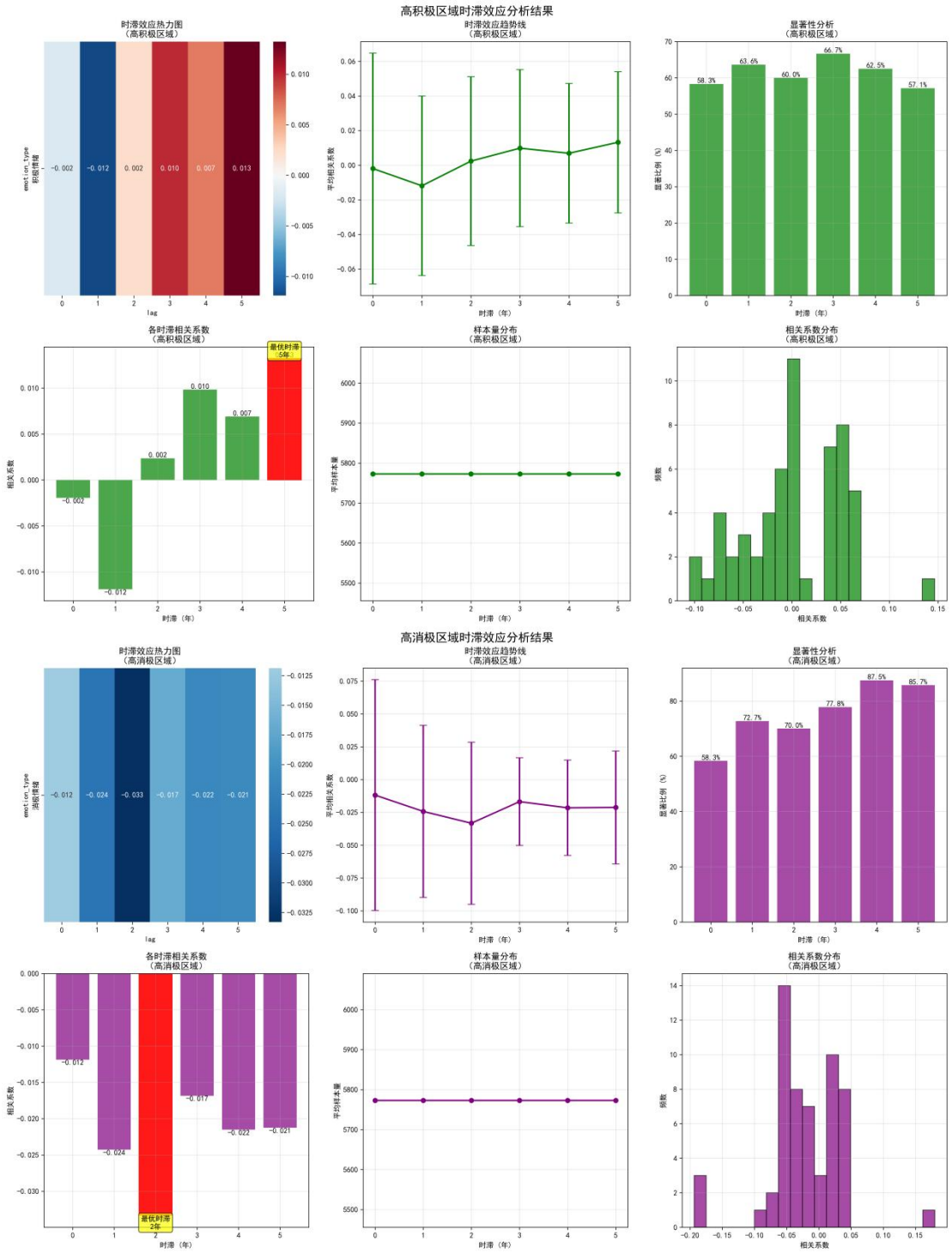

Fig.7 Time-Lag Effects Analysis

4.Conclusion

1. Implement coupled optimization partitioning and establish differentiated functional mixing thresholds

Research has shown that there is a nonlinear coupling relationship between the degree of POI mixing and public sentiment. Both excessive and insufficient mixing may lead to the generation of undesirable emotions. Therefore, the planning practice should abandon the extensive concept that the more mixed functions, the better. What is worth learning from is to adopt a refined zoning control strategy. In the core high-mix area of the city, through planning guidelines, appropriate "subtraction" should be carried out to relieve some functions that are not important to the central area but may trigger strong negative emotions. At the same time, small-scale green Spaces and cultural facilities should be implanted to alleviate sensory overload and psychological pressure. On the other hand, in low-mix areas such as historical districts, the land use functions should be strategically increased. Under the premise of respecting the style and features, emotionally positive business forms such as boutique retail and cultural and creative experiences should be introduced to achieve the goal of stimulating the vitality of the district.

2. Establish an emotional response process and build a dynamic monitoring and intervention system for urban emotions

To meet the real-time monitoring requirements of the dynamic changes in the emotional state of cities, a closed-loop management process based on big data should be planned and established. Specifically, multi-source data such as social media and mobile device signaling can be integrated through the smart city platform, and real-time sentiment computing can be carried out using the STCDM model developed in this research. When the system detects that the emotional synergy in a specific area continues to decline and triggers a preset threshold, it will automatically issue a warning to the management department. Based on this, planning managers can activate a rapid response mechanism and take appropriate spatial optimization measures, such as adding rest facilities in high-mix areas and organizing public art activities to alleviate negative emotions, thereby achieving precise regulation of the urban psychological environment.

This research bridges spatial analysis and psychological perception, revealing non-linear effects of functional mixing on sentiment. Positive emotions show immediate correlation with POI diversity, while negative emotions exhibit a two-year lag effect. This validates the framework of composite urban cognitive mechanisms.The findings support differentiated strategies: high-mix areas require strategic reduction to alleviate psychological stress, while low-mix historical districts benefit from selective addition of positive-emotion functions. Real-time emotional monitoring systems enable precision-based urban governance.This research demonstrates how AI and big data optimize 24-hour city environments by understanding residents' emotional needs in real-time. The BERT-based sentiment analysis and dynamic intervention system represent concrete applications of AI-driven urban governance for more livable, emotionally balanced cities.

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