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Urban Tourism Traffic Analysis Zone Division Based on Floating Car Data

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ABSTRACT

Tourism traffic has a considerable influence on the state of urban traffic in tourist cities. To consider tourism traffic demand in the division of conventional traffic analysis zones (TAZ), a spatial analysis method combining dynamic traffic state features with static land use and road network characteristics is proposed to define tourism traffic analysis zones (TTAZs). Taking Xiamen Island as an example, first, point of interest (POI) data for the tourism elements on Xiamen Island and kernel density estimation (KDE) are applied to determine the core zones impacted by tourism traffic. Second, within the impacted zones, this paper studies the dynamic distribution of the tourism traffic for peak hours during holidays and non-tourism period by employing spatial autocorrelation method based on floating car data (FCD) and determines the area of slow traffic agglomeration of tourism traffic. In view of the distribution of tourism infrastructure, land use, tourism traffic state distribution and road network, this study identified the characteristics of slow traffic agglomeration in the area near Siming Road and divided four TAZs into six TTAZs. By further dividing the urban TTAZs, this paper hopes to provide a reference for urban traffic planning and management, tourism planning and land use planning.

KEYWORDS

tourism analysis; traffic analysis zones division; spatial autocorrelation; FCD; POI data.

1. INTRODUCTION

In recent decades, tourism has become an important industry in the growth of urban economy, greatly driving the economic development. Urban tourism, which is defined as a complex tourism system, includes all the conditions and manifestations of tourism activities in an area and takes into account the attractiveness of urban space [1]. Urban tourism always has a certain impact on the traffic of the destination city, and traffic in turn plays a very important role in tourism and overall economic development, but the relationship between traffic and tourism has rarely been valued [2, 3]. For some tourism cities, the rapid development of urban tourism brings a large number of tourists into city and leads to traffic demand exceeding the carrying capacity of the urban transportation system in some periods, which has a substantial impact on the urban traffic conditions, making it difficult for urban tourists to fully enjoy the tourism services [4]. Most urban transport service providers focus on providing transport services to local residents and daily commuters, rather than seeing tourists as their main market. The traffic volume fluctuates with time and place, so the demand will change greatly. The number of trips during public holidays will increase significantly, which will easily lead to some serious traffic problems [5]. Cars have become a tool for most tourists to go to scenic spots, such as in Szczecin, Poland, and the increase in tourist traffic will conflict with the various functions of the city [1]. Due to its generation and attraction, tourism traffic differs from conventional urban traffic. The influx of tourists will put additional demand pressure on the urban transportation system, which may cause tourists and residents to compete for limited urban resources and bring serious negative externalities [6]. There have been many achievements in the research on the division of traffic analysis zones (TAZs), but the existing research mainly focuses on the division of urban traffic analysis zones, and pays less attention to the division of tourism traffic analysis zones (TTAZs). Tourism traffic is an important part of urban traffic in tourism cities. Therefore, in order to relieve the pressure of tourism traffic and manage and dispatch tourism traffic reasonably and effectively in a tourist city, it is necessary to carry out a study on the division of TTAZs.

Many cities confuse tourism traffic with conventional urban traffic, disregarding the development characteristics and basic rules of tourism traffic [7]. The generation and attraction of tourism traffic, which mainly concentrate on areas with tourist attractions and tourism infrastructures, are different from those of conventional urban traffic. At the same time, tourist flows are mainly generated during holidays. Therefore, the demand of tourism traffic which has regional and short-term traits proves to be different from that of conventional urban traffic. For some tourist cities in China, the number of visitors during the tourist season sometimes surpasses the number of residents in the city. Frequent travel of tourists leads to the paralysis of urban tourism traffic [8]. In order to accurately predict the demand for tourism traffic, it is necessary to re-divide the TTAZs on the basis of the original urban TAZs.

The division methods of traffic analysis zones can be divided into static and dynamic ones. Static methods usually consider the physical and socio-economic characteristics such as land use, area size, population density, road network and so on. Martinez et al. [9] proposed an algorithm for TAZ division, which considers the distribution of residents' travel OD, introduces air pollution emission, population density, work and study density and public transport accessibility indicators to measure the homogeneity in the region, and it determines the partition scheme of a traffic analysis area. Wang et al. [10] proposed a mixed integer programming model with the objective of minimising geographical errors within each zone to address the problem of traffic analysis zone delineation (TAZD). Chandra et al. [11] proposed an improved spatial aggregation method which a multi-objective optimisation concept using a genetic algorithm to develop the freight TAZs. Given socioeconomic development, the static partitioning method is incapable of adapting to the dynamic changes of traffic or satisfying the needs of urban traffic planning and management. Thus, scholars began to study dynamic division methods.

Dynamic division methods mainly consider the transport characteristics such as traffic status and traffic volume. Dong et al. [12] applied the K-means clustering method to divide the commuting TAZs, based on mobile phone data and traffic semantic attributes. Based on taxi GPS data, Tang et al. [13] used the Louvain method and the visualisation of similarities (VOS) method to identify TAZs from a network-based perspective and used the Rand index (RI) and the Fowkles–Mallows index (FMI) to evaluate recognition performance. Based on the traffic flow data of an urban road network and taking intersections as the research object, Yang et al. [14] established and validated the calculation model of correlation degree based on the connection index between intersections, studied the dynamic division of traffic control area under the oversaturated condition. In addition to proposing the method of dividing the TAZs, some scholars also focus on the methods of identifying areas with high incidence of traffic accidents [15–18].

Despite its capability to reflect the physical properties of a TAZ, static partitioning cannot show dynamic changes in traffic. TAZs are mainly divided based on population, administrative unit and road network structure within the zones [19]. Besides, trip generation and distribution of residents has also been included [9]. Dynamic partitioning, while able to demonstrate the dynamic traffic characteristics of a TAZ, is powerless in reflecting the spatial correlation of traffic. At the same time, since urban and tourism traffic often overlap, dynamic portioning alone cannot reveal whether tourism traffic is generated by tourism land use. The existing dynamic zone division takes into consideration traffic flow characteristics and road network topology. Some defects exist in the separate use of dynamic or static partitioning methods, and both cannot simultaneously reflect the spatial relationship between the traffic state and the physical properties of TAZs. Understanding the traffic conditions of tourist areas enables predicting the tourism traffic status, thus allowing for better implementation of flexible and coordinated control on slow traffic and emphasising the layout of tourism infrastructures. Thus, this paper proposes a method combining dynamic with static methods to divide TTAZs, which mainly considers the changes in the road network status and the spatial distribution of land use in a tourism core area. In addition, floating car data (FCD) was used based on the determination of the tourist area to analyse the dynamic distribution of tourism traffic in space and identify the agglomeration area of tourism traffic. Static factors, such as the distribution of tourism infrastructure, land use and road network in a traffic congestion area, are combined to divide the TTAZ in order to provide data support and a decision basis for urban traffic planning and management, tourism planning and land use planning.

The rest of this paper is organised as follows. Section 2 introduces the research method. Section 3 introduces the dataset. The results of TTAZ division are discussed in Section 4. Discussion and conclusion are provided in Section 5.

2. MATERIALS AND METHODS

The distribution of tourism elements has a decisive influence on tourism traffic, given that they are concentrated and distinctly unevenly distributed. To increase the relevance of this research, this paper discusses the spatial agglomeration of tourism elements before the division and focuses on the core area impacted by tourism traffic as the research scope before the follow-up division of tourism traffic areas.

2.1 Spatial agglomeration analysis of tourism elements

Kernel density estimation (KDE) is used to analyse and visualise the clustering characteristics of tourism elements. KDE is applied to estimate the unknown density function in probability theory. In the kernel density mapping of GIS, the points that fall into the search area have different weights, and the points or lines near the centre of the grid search area are given greater weight. As the distance from the centre of the grid increases, the weight decreases.

The spatial density distribution of the Xiamen Island tourist element points (attractions, hotels, catering and commercial services) can be estimated based on KDE. According to the principle and method of KDE in ArcGIS, the bandwidth is calculated as *Equation 1*:

$$Bandwidth = 0.9 \cdot min\left(SD, \sqrt{\frac{1}{\ln 2}} \cdot D_m\right) \cdot n^{-0.2} \tag{1}$$

In *Equation 1*, SD represents the standard deviation, D_m is the median distance, n is the number of points and min is the method to obtain the minimum value of both [20]. This formula weighs the two parameters of standard deviation and median distance and takes the minimum value to participate in the final calculation. In this study, the bandwidth is 1374.66m.

The road sections in the same TAZ have similar traffic state characteristics [21]. For the TTAZs, because of the aggregation of tourism travel behaviour, the road sections in the same TTAZ have the same traffic status in the tourist rush season. Therefore, it is necessary to analyse the spatial distribution of urban tourism traffic status and the spatial relationship among traffic road sections before dividing urban TTAZs. Spatial autocorrelation analysis can be used to analyse the spatial distribution of tourism traffic conditions. The spatial adjacency matrix is used to define the spatial relationship of the road section, and the correlation and correlation degree of the traffic conditions between the road entities are measured as the basis for dividing the tourist traffic area.

2.2 Method of spatial autocorrelation

Spatial autocorrelation examines the spatial distribution and correlation of geographic objects using the statistical correlation in a certain attribute; it is employed to describe the potential correlation of neighbouring elements in a single variable within a region. The selection of conceptual parameters of spatial relations should reflect the inherent relationship between the elements to be analysed. The spatial correlation of spatial data can be expressed by Tobler's first law of geography, which was proposed in 1970, and neighbouring geographical elements will have more similarities than distant elements [22].

Spatial proximity is the distance relationship between two spatial objects, and the degree of proximity between two spatial objects is represented by a spatial weight matrix. Spatial weight is a number that reflects the distance, time or other cost between each element in the dataset and any other feature. According to the characteristics of a road network, this paper constructs a spatial weight matrix based on the topological relationship of the road network, i.e. spatial objects are abstracted as points, links between two objects are abstracted as lines. The spatial weight matrix can be expressed as *Equation 2*:

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \tag{2}$$

In the formula, w_{ij} describes the adjacency relationship between the spatial object *i* and the spatial object *j*, i.e. if the spatial object *i* is adjacent to the spatial object *j*, w_{ij}=1; otherwise, w_{ij}=0. The weight matrix that consists of 0 and 1 in the proximity matrix *W* between *n* area units is referred to as a binary adjacency matrix.

Local Moran's *I* was used to learn about the spatial distribution of slow and unblocked road sections of tourism traffic. Anselin local Moran's *I*, namely LISA (Local Indicators of Spatial Association), is a common index in local spatial autocorrelation. Compared to global spatial autocorrelation, which reflects the global distribution of phenomena, local spatial autocorrelation can indicate the agglomeration and similarity of regions and find the heterogeneity of regions [23]. For example, when global spatial autocorrelation analysis is positive, it is possible to analyse and determine whether there is spatial heterogeneity within a region.

2.3 TTAZ division steps

In this paper, the average travel speed of a road section is selected as an index to measure the traffic status of a road. The index was input as an attribute value for the spatial autocorrelation analysis. Combining the average travel speed of a road section and the relationship of the road section, the spatial distribution and cluster of traffic slow can be determined.

Step 1. Preprocess the obtained travel time data of the road sections and GIS map data. The processing of GIS map data mainly includes cleaning up the unusable sections of road network data and merging the broken lines. Floating car data processing mainly includes two steps. To begin with, the floating car data is connected with the road network, and the average speed of the floating car falling in each road section is calculated as the average speed of this road section. Then, the problem data of the road section are screened and replaced by the average speed of the road section.

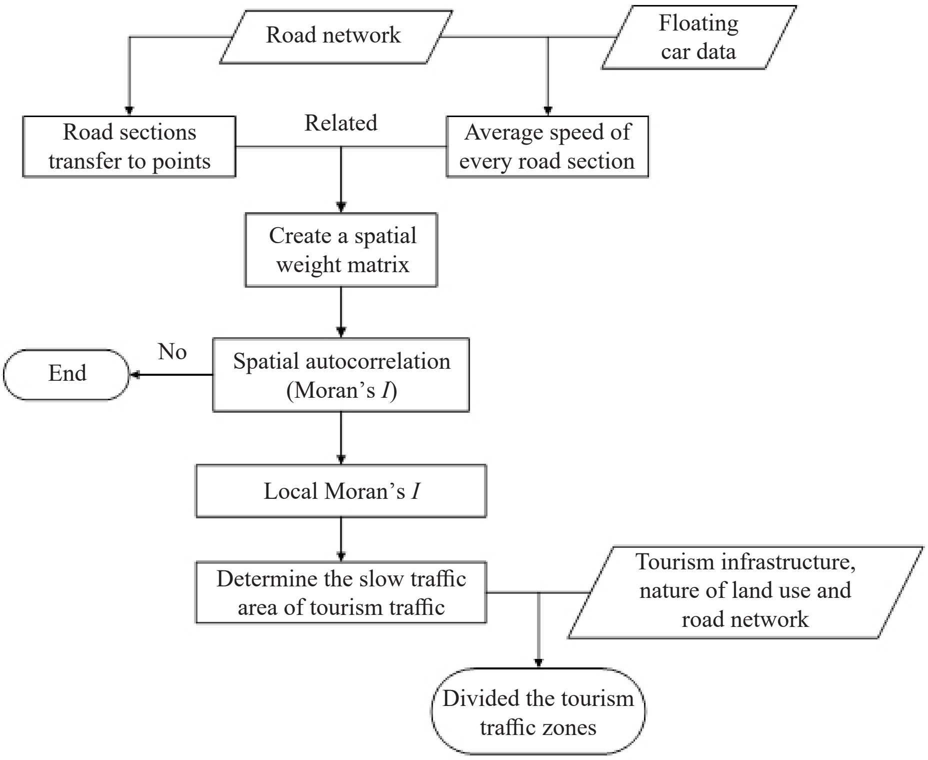


Figure 1 – Research technical route

*Step 2***.** Load the calculated average travel speed of the road section into the road section attribute table and create a spatial weight matrix that is based on the road section topology.

*Step 3***.** The average travel speed of road segments and the processed spatial weight matrix are considered as input values for statistics. Use the global Moran's *I* to evaluate the global distribution characteristics of the tourism traffic state. When the *I* value is greater than 0, the road section slow traffic agglomeration distribution proceeds to the next step. When the *I* value is less than or equal to 0, no clustering feature is available in this section of the road.

*Step 4***.** A local Moran's *I* analysis is performed to obtain the spatial distribution characteristics of the tourism traffic status and determine the tourism traffic concentration agglomeration area. Blue dots represent slow traffic, and when they are concentrated, it indicates that the road is in a slow state. Red dots represent unblocked traffic, and their concentration indicates that the road is unimpeded. Other dots do not indicate any unusual behaviour.

Step 5. Compare and analyse the slow traffic agglomeration area of tourism traffic in the present core zones above and consider the density distribution of tourism infrastructure, the nature of land use and the road network. The urban TTAZs are thus divided and the flowchart is shown in *Figure 1*.

3. RESEARCH OBJECT AND DATA

3.1 Research object

As one of the first highly valued tourist cities in the country, Xiamen is a beautiful city surrounded by the sea. Xiamen City comprises Xiamen Island, Gulangyu Island and many small islands, as well as Tong'an, Jimei, Haicang and Xiang'an districts. Xiamen received 2.1068 million domestic and foreign tourists in 2019, with a total tourism income of 2.437 billion yuan during the May Day holiday [24]. According to Ctrip's "Travel Trend Prediction Report on May Day, 2019", Xiamen was the second most popular destination for self-guided tours in China and the fourth most popular city for group tours [25].

3.2 Data presentation

The research data of this paper include two types. The first type is the POI data for Xiamen Island tourist elements (attractions, hotels, catering and commercial services) obtained from mafengwo.com. The POI data contain information such as name, latitude, longitude and category of information points. The second type is the GIS map data and FCD on Xiamen Island. The GIS map included road length, edge ID and the road name. The FCD included vehicle number, longitude, latitude, instantaneous vehicle speed, direction, GPS time and other information. As tourism traffic mainly occurs in areas with tourist attractions and tourism infrastructure, the first step is to determine the core area of tourism traffic. Secondly, on this basis, the dynamic and static methods are used to divide the TTAZs.

4. DIVISION RESULT OF URBAN TOURISM TRAFFIC ANALYSIS ZONE

4.1 Determination of core influence area

According to the KDE results, the distribution of the tourism elements on Xiamen is largely unbalanced and characterised by concentration in the southwest and sparsity in the northeast (*Figure 2*). The southwestern area of Xiamen Island is blocked by the landscape pattern. The distribution of the tourism elements is in a triangular area, which is surrounded by Xianyue Road, Chenggong Avenue and the coastline, whereas the periphery of Xiamen University, Nanputuo Road and Huandao South Road shows a trend in which the points are arranged in a line. However, the actual situation is that Xiamen University adopts closed-off management to reduce other traffic disturbances and the surrounding urban road network is sparse. Therefore, the triangular area formed

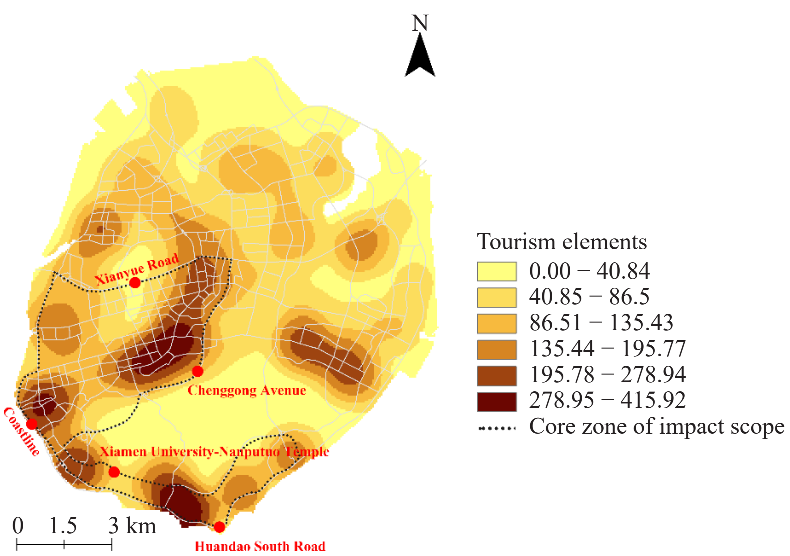


Figure 2 – Kernel density analysis of tourism elements and the core zone of impact scope

by Xianyue Road, Chenggong Avenue and the coastline is a primary consideration when defining the scope of the tourism core influence area (*Figure 2*).

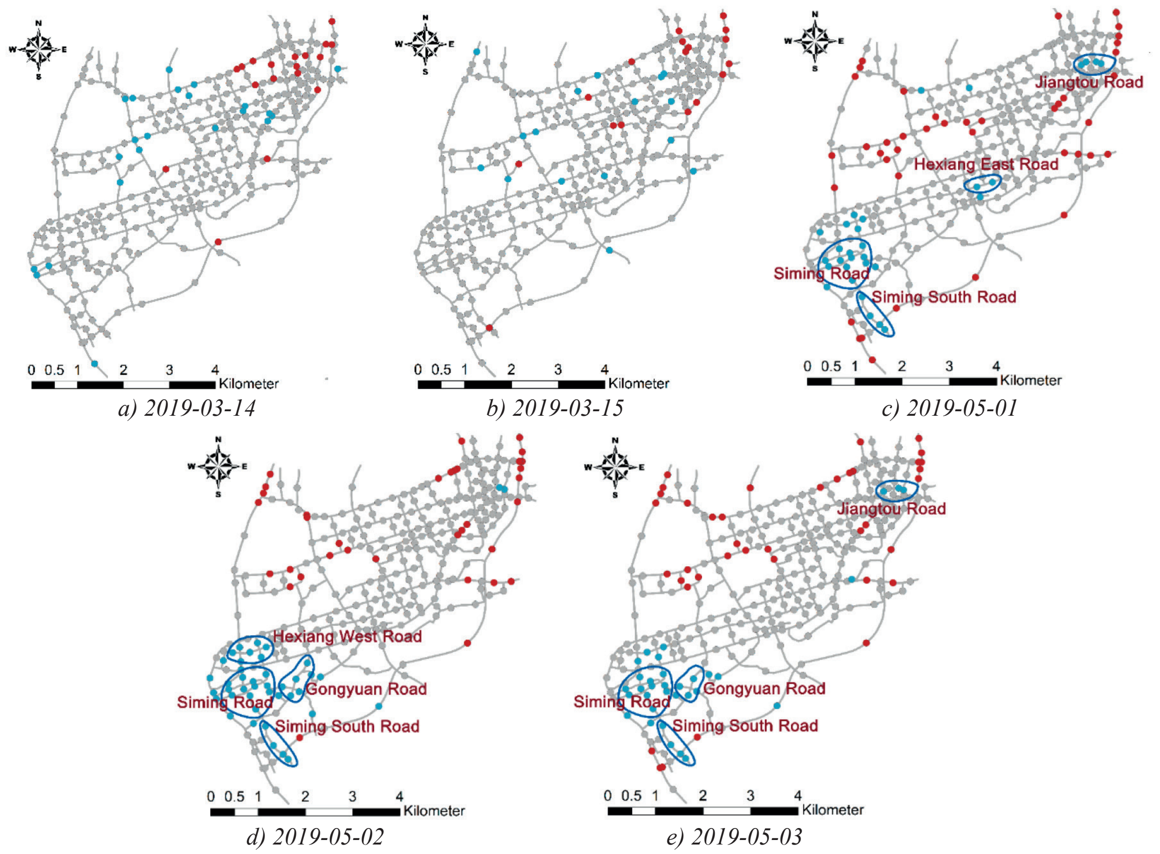
To obtain accurate results for the division of TTAZs, the May Day holiday (1–3 May) was selected as the sample date. According to an existing study concerning the temporal and spatial characteristics of vehicular traffic on a tourism day in Xiamen [26], the peak traffic hours occurred between 10:00 and 12:00 in Xiamen during the tourism period, with an emphasis on the period between 10:30 and 11:30. Therefore, 10:30–11:30 was selected as the sample time for the division of the TTAZs. In order to learn more about the traffic condition between tourism periods and non-tourism periods, 14 and 15 March of 2019 were selected as the sample of non-tourism days for comparison.

4.2 Results of Moran's *I* of tourism traffic status

The spatial autocorrelation of 1 hour during the peak hours is used to analyse the global Moran's I in ArcGIS based on the average travel velocity of the core section. When the I value is greater than 0, the Z-score (standard deviation) is greater than 2.58, and the p value (probability) is less than 0.01, it implies a 99% confidence level of spatial agglomeration. In this paper, the I value for tourism period (the May Day) and non-tourism period are both greater than 0, and the Z-scores are much greater than 2.58 (*Table 1*). The results of Global Spatial Autocorrelation showed that average traffic speed had a strong spatial autocorrelation, especially during tourism period.

Table 1 – Global Spatial Autocorrelation Index Table

Period	Tourism period			Non-tourism period	
Date	2019-05-01	2019-05-02	2019-05-03	2019-03-14	2019-03-15
I value	0.60	0.66	0.63	0.42	0.31
Z-score	17.12	18.84	17.94	11.96	8.87
P value	0.00	0.00	0.00	0.00	0.00



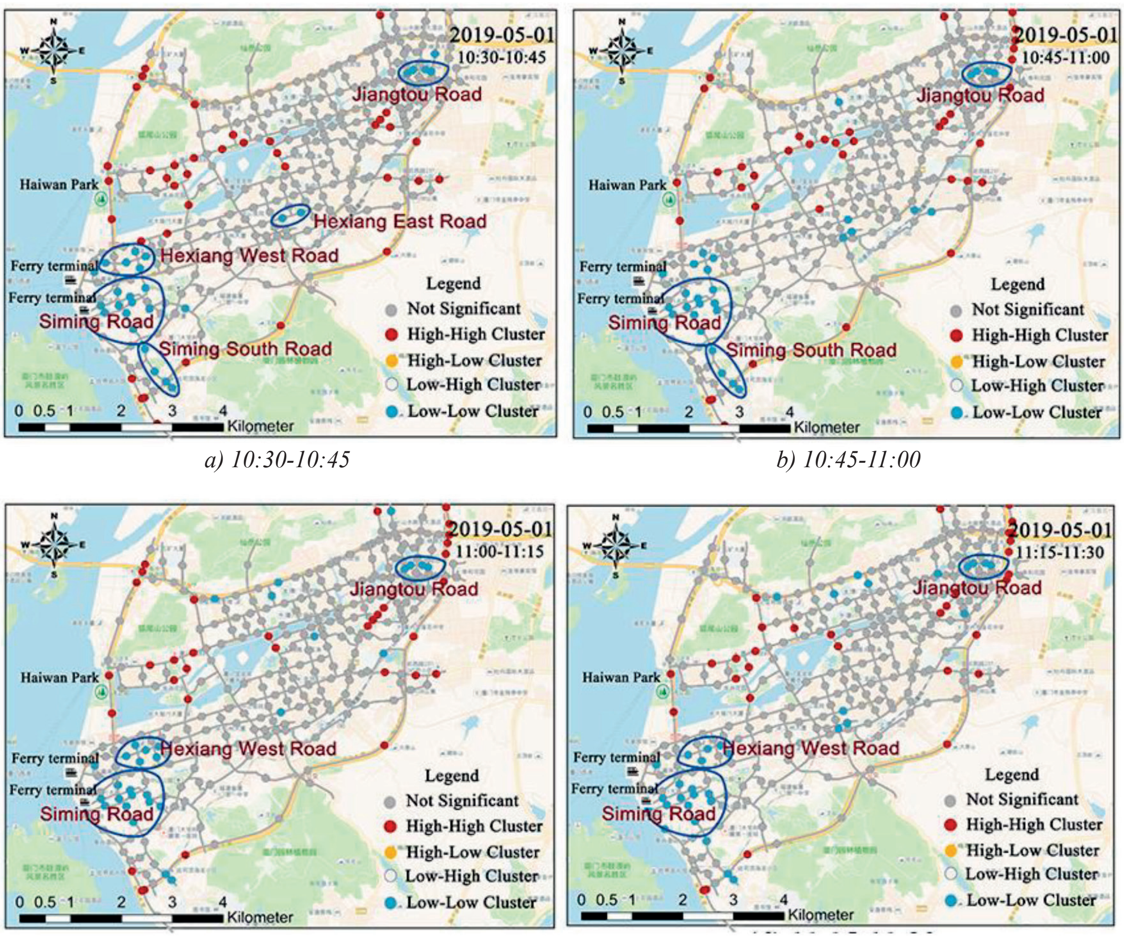
● Not significant ● High-high cluster ● High-low outlier ● Low-high outlier ● Low-low cluster —— Road network

Figure 3 – Average speed gathering characteristics of peak hour sections during non-tourism period (a, b) and tourism period (c-e)

A local spatial autocorrelation analysis of the peak hours in tourism and non-tourism periods was conducted, and the results (*Figure 3*) show that during those periods, the old city is a concentrated area of traffic conflicts. Tourism traffic has an obvious and significant impact on urban traffic during tourism period, and slow traffic concentration in the old city during non-tourism period is not conspicuous. Comparing the concentration characteristics of average speed of 1-hour peak road section 1 to 3 May, the slow traffic agglomeration area has only undergone minimal changes, which are characterised by the regional concentration of Siming Road.

4.3 Cluster results of traffic status on peak hour every 15 minutes

The early peak period of 1 May was extracted, and the average speed distribution in the peak period was studied at 15-minute intervals (as shown in *Figure 4*). First, according to the average speed distribution obtained from the local spatial autocorrelation analysis of the road sections in the core zone, the average speed of the majority of the road sections and adjacent road sections in the core zone of tourism are randomly distributed. The blue dots reflecting slow agglomeration areas of tourism traffic are concentrated on Siming Road in the old city area, with a small number scattered in the vicinity of Jiangtou Road. These congested areas and the distribution areas of tourism elements and infrastructure show similar results. For example, Siming Road is surrounded by Xiamen old city and is a gathering place for Xiamen's important tourist attractions; Zhongshan Road Historic and Cultural blocks, the ferry terminal and Haiwan Park are all located nearby (as shown in *Figure 4*).



a) 10:30-10:45 *b) 10:45-11:00*

c) 11:00-11:15 *d) 11:15-11:30*

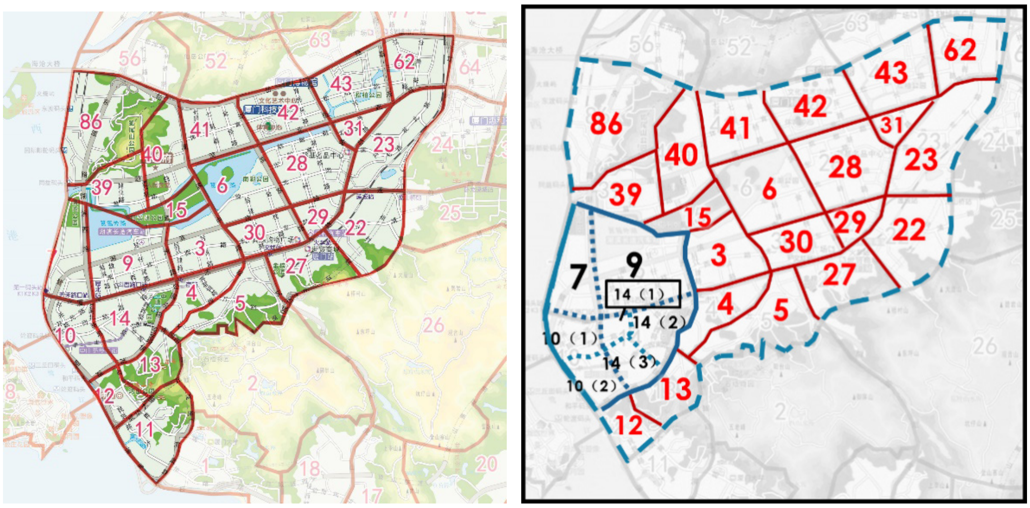
Figure 4 – Average speed of road sections every 15 minutes during peak hours on May 1

Second, the results of the spatial distribution of tourism traffic in the core impact zone (*Figure 4*) indicate that the form and quantity of the slow tourism traffic agglomeration area change with time. For example, in the first 15 minutes (*Figure 4a*), a slow traffic cluster appeared near Jiangtou Road, Siming Road, Hexiang West Road and Hexiang East Road, and Hexiang East Road became obscure in the second 15 minutes (*Figure 4b*). In the first two 15 minutes, the traffic on Siming South Road was obviously slow and the cluster of tourism traffic was not significant in the third (*Figure 4c*) and fourth (*Figure 4d*) fifteen minutes. From 10:30 to 11:30, the largest area of slow traffic agglomeration in the core zone impacted by tourism is mainly located near Siming Road and Hexiang West Road.

According to this analysis, the form of the slow tourism traffic agglomeration area on Xiamen Island has different characteristics compared to the non-tourism period. Tourism traffic has little impact on the traffic situation in most parts of the city. Besides the tourist core area, other slow traffic sections are scattered, and the traffic conditions of unblocked and slow areas are more apparent. In addition, according to the four periods of tourism traffic in the study area, the tourism traffic in Xiamen Island is dynamic but also relatively stable, which further shows the agglomeration of tourism traffic.

4.4 Division of tourism traffic analysis zones

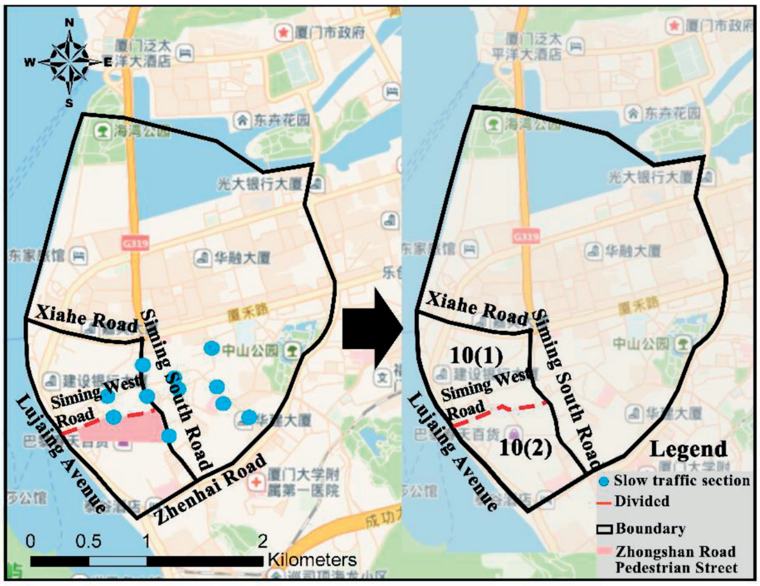
The current TAZs of Xiamen Island (*Figure 5*) show the overall characteristics of a small construction land and a large non-construction land area, whereby the TAZs of the construction land are relatively uniform. This approximate division does not reflect the complex traffic conflicts caused by tourism traffic agglomeration. For a tourist city, the spatial distribution of tourism traffic shows unbalanced and regional characteristics, which increases the impact of tourism traffic on the flow direction of urban traffic sources. Based on the above analysis, the tourism traffic slow area in the core zone impacted by the peak hour is concentrated in the Siming Road and Hexiang West Road. However, according to field investigations, the slow traffic of Hexiang Road may be caused by the damage of traffic lights and the vehicles and pedestrians are not separated. According to *Figure 3*, compared with the traffic conditions during tourism and non-tourism, there are more sections with slow traffic speed during the tourism period, which are concentrated around Siming Road. Thus, the focus of this paper is the zone division of the Siming Road slow traffic agglomeration area.



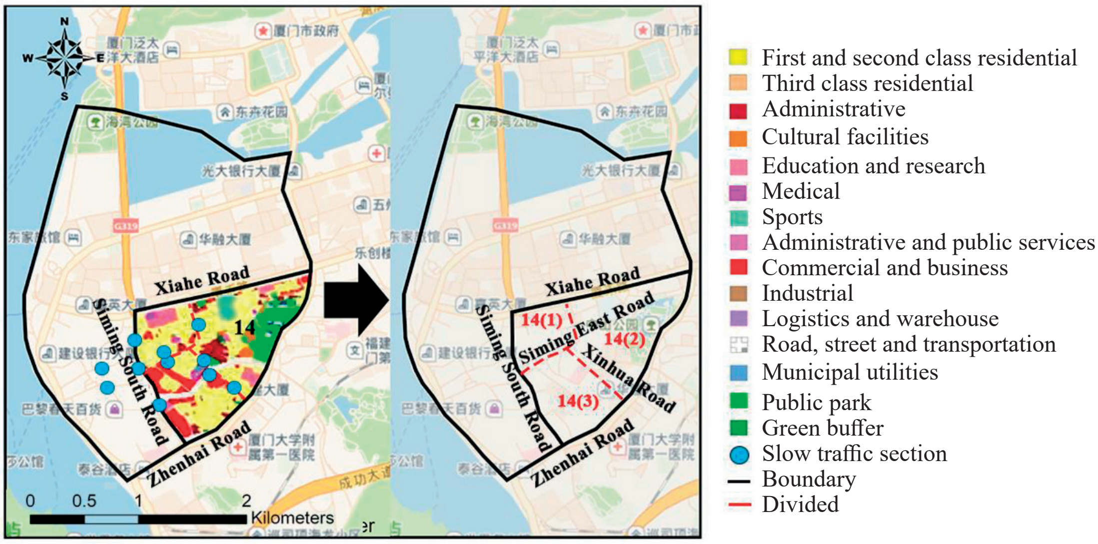
a) *b)*

Figure 5 – Current TAZs (a) and TTAZs in the tourism core area (b)

Taking the slow traffic agglomeration area during peak hours as an example, this paper compares and analyses the slow traffic agglomeration area on Siming Road under the current urban TAZs and selects the area formed by closing the boundary of the corresponding current TAZs as the partition object. The density distribution of tourism infrastructure, land use, the road network and the distribution of tourism traffic status are comprehensively considered within the study area to re-divide the TTAZs. The comparison shows that the slow traffic nodes are concentrated on the west side of the study area, and the area formed by the No. 7, No. 9, No. 10 and No. 14 TAZ is chosen as the boundary area of the TTAZ division. Based on the traffic conditions, the study further takes into consideration the distribution of tourism infrastructure within TAZ No. 10, therefore dividing the TAZ. The analysis of the spatial distribution of tourism infrastructure shows that south of the TAZ is dominated by high-grade commerce and forms the Zhongshan Road Pedestrian Street with a centralised distribution. North of the TAZ, lower grade food and beverage outlets are primarily scattered. Thus, the TAZ is divided into two TTAZs (*Figure 6a*) to ensure their homogeneity and integrity. Due to the complexity of the land use and the road network in TAZ No. 14, the division results will not be accurate if only the traffic states are used to divide the zone. By analysing the difference in the land use within the zone (*Figure 6b*), it was found that the commercial facilities and educational research land use within the zone are more concentrated on the left side of the zone, where commercial land use is distributed in area No. 14 (3), and education and research land use is distributed in the area No. 14 (1). However, the land use in area No. 14 (2) is relatively complex. Different types of facilities, such as schools, catering facilities and business buildings, are distributed in this area. Dividing the area according to tourism service facilities is difficult because it has a higher mixed of land use. Therefore, by analysing the tourism infrastructures, land use nature and the road network of the study area, the No. 14 TAZ was divided into 3 TTAZs. However, the No. 14(1) is not a TTAZ.



a) Division of TTAZs according to commercial facilities



b) Dividing TTAZ according to the land use

Figure 6 – Dividing TTAZ according to commercial facilities (a) and land use (b)

5. DISCUSSION

In this paper, a dynamic and static combination is proposed to divide TTAZs. Division of these zones is indispensable given the inconsistency between the traffic demand on tourism holidays and the daily traffic demand of residents. At present, the division of TAZs is mostly treated as a static division. A dynamic division method, if existed, is mostly based on traffic flow characteristics and network topology. Because the occurrence of tourism traffic is a regional and spatiotemporal difference, firstly, this paper determines the core area of tourism traffic occurrence via the kernel density estimation of tourism infrastructures. Secondly, through spatial autocorrelation analysis, the agglomeration area of tourism traffic is determined, and the land use situation of the agglomeration area is analysed, so as to divide the TTAZs on the basis of the original TAZs. Taking Xiamen as an example, applying FCD to analyse the spatial distribution of traffic conditions in peak hours during holidays, and through the comparison with the non-tourism period of the same period, this study accurately captures the agglomeration areas of Xiamen's tourism traffic. Based on the current TAZs, TTAZs are divided in combination with dynamic and static factors. On the strength of the density distribution of tourism infrastructure in the research scope, the traffic distribution state and the nature of land use are analysed, and finally, the TTAZs are divided according to road network, thereby improving the accuracy and credibility of the division results. Besides increasing the consideration of tourism traffic demand, this division method also avoids the immense workload caused by the sudden increase in the number of urban TAZs. This represents a partial change brought out by the targeted division of TAZs rather than a global change, and thus it does not drive an increase in a large number of TAZs. During the prime time of holidays, traffic control management is carried out in areas with a surge in tourist numbers in the big cities of China, such as Hangzhou [27] and Guangzhou [28]. Due to the extensive traffic regulation, residents in the vicinity of scenic spots are also affected. The application of this partition method to tourism traffic demand prediction in tourist cities will help facilitate the management of traffic congestion, and at the same time limit the growth of tourist traffic through the control of tourism land use.

This paper focuses on the urban tourism traffic issue, mainly because a spurt of progress in tourism has brought tremendous pressure to urban traffic. In the study of Xiamen, the areas with prominent traffic are still in the centre of the Xiamen Island. The results show that the tourism elements on Xiamen Island are unevenly distributed, the zone with the greatest impact of tourism traffic during the holidays is on the area around Siming Road, where the tourism elements are concentrated and located in the old city. The narrow street dimensions mean that the carrying capacity of traffic is limited in this road section. According to this finding, within the boundary of the four current TAZs affected by slow traffic and agglomeration around Siming Road, the area is re-divided into six TTAZs. A combination of dynamic and static methods is used to divide the core zones in this paper, and the results reflect not only the distribution of tourism elements but also the spatial relation of traffic status. In order to ensure the smooth operation of traffic around the tourism core area and improve road safety, the driving speed of vehicles around No. 10 (1), 10 (2), 14 (2) and 14 (3) TTAZs shall be limited to 30 km/h. In addition, during the peak hours of tourism period, private vehicles can be restricted from entering the No. 10 and No. 14 TTAZs, and only buses and taxis can be allowed, so as to promote passengers to choose public transport, reduce the number of vehicles and alleviate traffic congestion. Moreover, further investment in tourism related industries should be reduced, or investment layout should be improved, so as to improve the issue of excessive concentration of tourism traffic.

6. CONCLUSION

This paper proposes a method to divide TTAZs in a tourism core area, and it can provide a basis for traffic management in tourism periods and be of great significance to the prediction of tourism traffic volume. It will enable urban managers to effectively control sections with slow traffic which will be of guiding significance to the formulation of scientific and feasible urban traffic planning, tourism planning and land use planning. This study of the division of TTAZs compensates for the lack of research on TTAZs at the city level and can serve as a reference for the division of urban TAZs by traffic planning management departments in some tourist cities. This paper is not immune to limitations, and future studies should be conducted to improve TTAZ identification. For example, the current research method which requires the tourist city to have a sustained and stable tourist attraction, is not suitable for cities where the tourist industry has not reached scale. In the follow-up research, multiple types of data, such as mobile phone signalling data and social network data, can be employed to compensate for possible errors caused by single data research. Through exploratory spatial data analysis, the spatial correlation between various types of tourism infrastructure and the traffic status of tourism vehicles can be investigated.

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REFERENCES

[1] Łapko A. Urban tourism in Szczecin and its impact on the functioning of the urban transport system. *Procedia - Social and Behavioral Sciences.* 2014;151:207-214. DOI: 10.1016/j.sbspro.2014.10.020.

[2] Le-Klähn D, Gerike R, Hall CM. Visitor users vs. non-users of public transport: The case of Munich, Germany. *Journal of Destination Marketing & Management.* 2014;3:152-161. DOI: 10.1016/j.jdmm.2013.12.005.

[3] Truong NV, Shimizu T. The effect of transportation on tourism promotion: Literature review on application of the Computable General Equilibrium (CGE) model. *Transportation Research Procedia.* 2017;25:3096-3115. DOI: 10.1016/j.trpro.2017.05.336.

[4] Zheng W, Liao Z, Lin Z. Navigating through the complex transport system: A heuristic approach for city tourism recommendation. *Tourism Management.* 2020;81:104162. DOI: 10.1016/j.tourman.2020.104162.

[5] Lohmann G, Duval DT. Destination morphology: A new framework to understand tourism–transport issues? *Journal of Destination Marketing & Management.* 2014;3(3):133-136. DOI: 10.1016/j.jdmm.2014.07.002.

[6] Albalate D, Bel G. Tourism and urban public transport: Holding demand pressure under supply constraints. *Tourism Management*. 2010;31(3):425-433. DOI: 10.1016/j.tourman.2009.04.011.

[7] Dai J, Du H, Zhang G. Study on the technical methods of comprehensive transportation planning in tourist cities – A case study of Sanya City. *Urban Traffic.* 2013;11(01):25-32.

[8] Xiang Y. *Research of tourist traffic flow characteristics based on phone signaling data*. Master thesis. Southeast University; 2017.

[9] Martinez LM, Dupont-Kieffer A, Viegas J. An integrated application of zoning for mobility analysis and planning: The case of Paris Region. *World Conference on Transport Research Society. 12th World Conference on Transport Research, Jul 2010*, *Lisbonne, Portugal.* 2010.

[10] Wang L, et al. A mixed integer programming formulation and solution for traffic analysis zone delineation considering zone amount decision. *Information Sciences.* 2014;280:322-337. DOI: 10.1016/j.ins.2014.04.040.

[11] Chandra A, Sharath MN, Pani A. A multi-objective genetic algorithm approach to design optimal zoning systems for freight transportation planning. *Journal of Transport Geography.* 2021;92:103037. DOI: 10.1016/j.jtrangeo.2021.103037.

[12] Dong H, et al. Traffic zone division based on big data from mobile phone base stations. *Transportation Research Part C: Emerging Technologies.* 2015;58:278-291. DOI: 10.1016/j.trc.2015.06.007.

[13] Tang J, et al. Statistical properties of urban mobility from location-based travel networks. *Physica A: Statistical Mechanics and its Applications.* 2016;461:694-707. DOI: 10.1016/j.physa.2016.06.031.

[14] Yang X, Huang W, Ma W. Method of delimiting urban traffic signal coordinate control subarea under oversaturated condition. *Journal of Tongji University (Natural Science).* 2010;10:1450-1457. DOI: 10.3969/j.issn.0253-374x.2010.10.009.

[15] Dong N, Huang H, Zheng L. Support vector machine in crash prediction at the level of traffic analysis zones: Assessing the spatial proximity effects. *Accident Analysis and Prevention.* 2015;82:192-198. DOI: 10.1016/j.aap.2015.05.018.

[16] Lee J, et al. Analysis of crash proportion by vehicle type at traffic analysis zone level: A mixed fractional split multinomial logit modeling approach with spatial effects. *Accident Analysis and Prevention.* 2018;111:12-22.

[17] Pulugurtha SS, Duddu VR, Kotagiri Y. Traffic analysis zone level crash estimation models based on land use characteristics. *Accident Analysis and Prevention.* 2013;50:678-687. DOI: 10.1016/j.aap.2012.06.016.

[18] Siddiqui C, Abdel-Aty M, Huang H. Aggregate nonparametric safety analysis of traffic zones. *Accident Analysis and Prevention.* 2012;45:317-325. DOI: 10.1016/j.aap.2011.07.019.

[19] Binetti M, Ciani E. *Effects of traffic analysis zones design on transportation models*, *Proceedings of the 9th Meeting of the Euro Working Group on Transportation, 2002, Bari, Italy.* 2002.

[20] *How Kernel Density works?* https://pro.arcgis.com/zh-cn/pro-app/latest/tool-reference/spatial-analyst/how-kernel-density-works.htm [Accessed 19th Dec. 2022].

[21] Li X, Yang X, Chen H. Study on traffic zone division based on spatial clustering analysis. *Computer Engineering and Applications.* 2009;45(05):19-22.

[22] Tobler WR. A computer model simulation of urban growth in the Detroit region. *Economic Geography.* 1970;46:234-240.

[23] Meng B, et al. Evalutation of regional disparity in China based on spatial analysis. *Scientia Geographica Sinica.* 2005;25(4):393-400.

[24] Xiamen Municipal Bureau of Culture and Tourism. *2.1068 million visitors came to Xiamen during the May Day holiday in 2019.* http://wlj.xm.gov.cn/gzdt/rdyw/201905/t20190505_2248208.htm [Accessed 11th Oct. 2020].

[25] Trip's tourism trend forecast report: 160 million people are expected to reach more than 900 destinations. *Zhejiang Daily*. May 1 2019. https://baijiahao.baidu.com/s?id=1631223915915525890&wfr=spider&for=pc [Accessed 12th Oct. 2020]

[26] Zheng C, Gao Y, Wu G. Study on the temporal and spatial characteristics of motor vehicle traffic in tourism day based on FCD data. *Annual Meeting of China's Urban Planning, Guiyang, Guizhou, China.* 2015.

[27] Zhejiang Police Department. *Announcement on the adjustment of some road traffic organization measures during the Spring Festival in 2019.* http://police.hangzhou.gov.cn/art/2019/1/25/art_1229436776_3804920.html [Accessed 18th Oct 2020].

[28] Guangzhou Police Department. *Guangzhou traffic police said temporary traffic control measures will be taken on some roads on New Year's Eve.* https://baijiahao.baidu.com/s?id=1654359889983163408&wfr=spider&for=pc [Accessed 18th Oct. 2020].

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基于浮动车数据的城市旅游交通小区划分研究

摘要
旅游交通对旅游城市的城市交通状况有相当大的影响。为了在传统交通小区（TAZ）划分中考虑旅游交通需求，提出了一种将动态交通状态特征与静态土地利用以及道路网络特征相结合的空间分析方法来定义旅游交通小区（TTAZ）。以厦门岛为例，首先，应用厦门岛旅游要素的兴趣点（POI）数据和核密度估计（KDE）方法来确定受旅游交通影响的核心区域。其次，在受影响区域内，采用基于浮动汽车数据（FCD）的空间自相关方法研究了旅游日和非旅游日高峰时段旅游交通的动态分布，并确定了旅游交通的聚集区域。最后，根据旅游基础服务设施、土地利用、旅游交通状态分布和道路网络的分布，研究确定了旅游交通主要集聚在思明路区域，并将四个TAZ划分为六个TTAZ。通过对城市TTAZ的进一步划分，希望为城市交通规划与管理、旅游规划和土地利用规划提供参考。

关键词

旅游分析；交通小区划分；空间自相关；FCD；POI数据