Article

Identification of Urban Functional Areas Based on POI Data: A Case Study of the Guangzhou Economic and Technological Development Zone

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Abstract: Functional areas are the basic spatial units in which cities or development zones implement urban plans and provide functions. Internet map big data technology provides a new method for the identification and spatial analysis of functional areas. Based on the POI (point of interest) data from AMap (a map application of AutoNavi) from 2017, this paper proposes an urban functional areas recognition and analysis method based on the frequency density and the ratio of POI function types. It takes the Guangzhou Economic and Technological Development Zone as a case study to analyze the main function and spatial distribution characteristics of the detailed functional areas. The research shows the following: (1) The POI frequency density index and the function type ratio can effectively distinguish the functions of the grid units and analyze the spatial distribution characteristics of a complex functional area. (2) The single functional area is the most common area type in the Guangzhou Economic and Technological Development Zone. The largest proportion of all areas is allocated to traditional manufacturing industry functional areas, followed by high-tech enterprises, catering and entertainment, real estate, and education and health care, in descending order. The smallest proportion is allocated to finance and insurance functional areas. (3) The current layout of the functional areas in the Guangzhou Economic and Technological Development Zone conforms to the overall requirements and planning objectives of the central and local government. The layout and agglomeration of different blocks within the economic development zone are consistent with local industry's target orientation and development history.

Keywords: point of interest; data mining; function identification; spatial distribution; regional planning

1. Introduction

The urban functional areas are geographic units composed of various interrelated elements within a city [1–3]. These elements are rationally arranged in space and are interconnected through various material, capital, and information flows to provide space for people's living, production, recreation, and business activities, providing a good living environment and forming an exchange platform [4,5]. Scientific, rational, and consistent functional zone planning are crucial to the implementation of long-term urban development goals. The rational layout and formation of urban functional areas can reduce the cost of urban housing purchases and living expenses, of residents' travel and commuting, and of production logistics. These characteristics will effectively enhance the pleasure of urban living, reduce the cost of urban large-scale production, improve the quality and efficiency of urban material and cultural production, attract more farmers and other residents of small towns to live in the city,

and increase the city's competitiveness at the national and international levels [6,7]. The identification of urban functional areas is an important basis for judging whether urban and rural planning and construction goals are achieved during the process of construction, and it is also the starting point for future urban development planning work. With their important role of attracting foreign investment, increasing employment, and fostering export and economic growth, development zones have played a strong supporting role in promoting regional economic development [8–11]. The first batch of national economic and technological development zones was built in 1984, and as of September 2015, 219 national economic and technological development zones had been established throughout China, covering all provinces, municipalities, and autonomous regions [12]. By identifying and analyzing the urban functions of the development zones, we can compare their target orientation with the actual construction results, then evaluate the progress and effectiveness of their planning and construction, and, finally, appraise the performance of the relevant personnel in charge.

The early methods for identifying and dividing regions or urban functional areas were most often based on qualitative methods, such as breaking point theory and the field strength method [13]. After the 1960s, given the development and maturity of geographic metrology, the method of functional area identification and division has gradually become quantitative [14]. Wang Fa et al. selected 16 indicators that influenced the central intensity of the city, such as population size and natural obstacles, and then calculated the urban centrality intensity of Henan Province using a multivariate statistical method and delineated the urban circle in Henan Province [15]. William Mitchell introduced the hierarchical clustering algorithm into functional area identification to divide the Sydney commuter area. The resulting district divisions enhanced the understanding of the operating rules of Sydney's labor market [16]. Wang Bihui et al. proposed a city remote sensing image classification system to guide the manual interpretation of high-resolution images, and extracted high-precision urban elements in Beijing using this system [17]. Based on the object-oriented classification method, Wang Caiyan et al. completed the automatic extraction of urban land use in Beijing [18]. In general, although functional area identification based on economic statistics is a simple and effective method, it is difficult for economic geographers to obtain the statistical data that the method needs. In addition, it is difficult to determine whether the threshold is reasonable in the process of functional area identification and division. Although land use interpretation by remote sensing technology provides another method for identifying and classifying functional areas, land use classification is only an indirect indicator for characterizing urban functional areas. At the same time, there are still problems with remote sensing methods, such as time-consuming and laborious manual interpretation and the inaccurate identification by machine-aided automatic interpretation methods [19].

In recent years, geoscience big data based on Internet spatiotemporal mega data has brought new ideas and methods, helping us to understand and quantitatively analyze the spatial and temporal pattern characteristics of complex natural regions and socioeconomic systems [20–25]. For example, point of interest (POI) data provide a fast and effective alternative to the division of urban functional areas [24,26–29]. POI data include all geographic entities that can be abstracted as points, such as schools, banks, companies, restaurants, and supermarkets [30–34]. POI data record the spatial and attribute information of geographic entities, including name, address, coordinates, type, and evaluation of the entity. They have the advantage of detailed information coverage, huge data volume, and convenient access to quantitative analyses. In related works, many researchers have studied urban spatial patterns based on POI data. Based on POI data, Xu Zening et al. proposed the DensiGraph analysis method to identify the boundaries of urban built-up areas [35]. Chi Jiao and Kang Yuhao et al. used POI data to identify functional zones in Wuhan City with the quadrature density method [36,37]. Based on Beijing logistics POI data, Li Guoqi et al. used industrial concentration evaluation and nuclear density analysis methods to describe the spatial pattern of Beijing logistics [38]. Yuan Jing et al. used Beijing taxi trajectory data to characterize population flow with the assistance of POI data. They proposed a framework named DRoF that discovers regions with different functions to identify Beijing's functional areas [39]. Previous studies illustrate that we can identify and zone the urban and rural borders, logistics patterns, or urban functional areas by using POI data [40,41].

However, these methods also have some problems. For example, the calculation model was too complex, the scale of research was too large, and the analyses of the mechanism behind the development of functional areas was still insufficient and needs in-depth study [42].

In summary, the morphology of a city affects its ecological and socioeconomic functions, and thus, how a city is spatially structured has an important bearing on urban sustainability [43]. A reasonable distribution of urban functional areas can improve the efficiency of urban land use and promote sustainable urban development [44]. The availability of big data provides great potential for identifying and mapping urban functional zones [45]. The advantages of POI data, such as a large amount of data, easy access, and detailed information, offer a new perspective for urban functional zone identification methods. To solve the problems in the existing urban functional zone identification methods based on POI data, we applied a method for functional area identification based on POI data that is simple, effective, and can be used in complex areas in the Guangzhou Economic and Technological Development Zone. We also conduct a detailed analysis of the main functions and spatial distribution rules for various functional combinations in the Guangzhou Economic and Technological Development Zone. The main issues that we focused on are as follows:

1. How can the spatial distribution of urban functional areas based on POI data be quickly and effectively identified?
2. What is the spatial distribution of the functional zones in the Guangzhou Economic and Technological Development Zone?
3. Does the current functional zone distribution of the Guangzhou Economic and Technological Development Zone conform to the central and local government planning objectives?

2. Materials and Methods

2.1. Study Area

The Guangzhou Economic and Technological Development Zone was established in 1984 with the approval of the State Council. It was one of the first national economic and technological development zones in China. The total area of Guangzhou Economic and Technological Development Zone is about 33.35 km², with its GDP (Gross Domestic Product) reaching 320.953 billion yuan in 2017. The specific location and scope of the study area are shown in Figure 1. The districts are Yonghe District, Eastern District, and Western District, from top to bottom in the right of Figure 1, with an area of 11.45 km², 16.53 km², and 5.37 km², respectively.

Figure 1. The Location and Boundaries of Research Zones. The administrative division data are from the 1:250,000 basic geographic database provided the National Geomatics Center of China, the DEM data are SRTM30_1 km DEM data (http://files.ntsg.umd.edu/data/SRTM30_1km/), and the remote sensing image data are from Google Earth (<https://earth.google.com/web/>).

2.2. Data and Preprocessing

In this paper, more than 128,000 POIs for Guangzhou City were obtained from AMap in 2017 [46], of which 27,192 were within the Guangzhou Economic and Technological Development Zone. Attributes of POI data include 12 fields, such as POI name, type, type code, contact mode, longitude, latitude, address, city, county, street, postal code, and door number. POI data are divided into 20 categories based on their business services. Considering the specific needs of urban planning, this paper reclasses the above 20 categories of POI into 6 categories: high-tech enterprises, traditional manufacturing industry, real estate, catering and entertainment, education and health care, finance, and insurance. The correspondence in the reclassification process is shown in Table 1.

Table 1. Classification System of POI Data.

Classification System of AMap	Classification System of This Paper
Enterprises focus on science, new technology, information, medical, network and electronic	High-tech enterprises (High-tech)
Enterprises except high-tech enterprises	Traditional manufacturing industry (Industry)
Commercial real estate	Real estate (Estate)
Catering services, shopping services, sports and leisure services, accommodation services, scenic spots	Catering and entertainment (C&E)
Scientific and Educational Cultural Services, Medical and Health Care Services	Education and health care (E&H)
Finance and insurance services	Finance and insurance (F&I)
Automobile services, car sales, car maintenance, motorcycle services, life services, government agencies and social organizations, transportation facilities services	Others

The classification system in AMap is from the webservice site of AMap (<https://lbs.amap.com/api/webservice/download>).

2.3. Identification Framework

The process of urban functional area identification based on POI data is shown in Figure 2. Based on POI data reclassification, we eliminate the POIs outside the study area according to the scope of the study area. After repeat experiments, we chose a 250 m grid as a basic unit. Then, the POI data are superimposed on the 250 m fishnet data of the development zone, and the number of POIs of various types in each grid was counted.

To identify the main function of each 250 m grid unit, we construct two indicator indexes, the frequency density index (F_i) and the ratio index (C_i), to judge the type of functional area. The formula is as follows:

$$F_i = \frac{n_i}{N_i} \quad (i = 1, 2, \dots, 6) \quad (1)$$

$$C_i = \frac{F_i}{\sum_{i=1}^6 F_i} \times 100\% \quad (i = 1, 2, \dots, 6) \quad (2)$$

In the formula, i is the POI type, n_i is the number of type i POIs in a grid unit, N_i is the total number of type i POIs, F_i is the frequency density of type i POIs in a grid unit, and C_i is the proportion of the frequency density of type i POIs in a grid unit.

After calculating F_i and C_i of every grid unit, the function discriminant analysis can be performed. When C_i of one type in a grid unit is more than 50%, this unit can be seen as a single functional area, and the type of this unit is the same as i of maximum C_i . When all C_i are less than 50%, this unit can be seen as a mixed functional area, and the types of this unit are determined by the i of the top three C_i . When any POI is not included in a grid unit, that is, when C_i is null in this unit, the unit is seen as no data area.

Figure 2. The Process Flow of Functional Area Identification Based on POI Data. The figure shows the process of functional area identification based on POI data, including data preprocessing and functional area identification with 2 indicators.

3. Results

3.1. Functional Areas in Whole Development Zone

The Guangzhou Economic Development Zone takes the single functional areas as its main layout form as a whole (Figure 3). Specifically, on the 250 m scale, single functional areas account for 52.46% of the total area of the development zone, mixed functional areas account for 17.07%, and no data areas account for 30.46%. Spatially, the Yonghe District and the Eastern District are dominated by single functional areas, while the Western Region is characterized by single functional areas and mixed functional areas, with the mixed function areas being slightly larger than the single functional areas.

Figure 4 shows the proportions of all types. In terms of single functional areas, the traditional manufacturing industry type has the largest proportion, accounting for 26.34% of all single functional areas, followed by the high-tech enterprises type, which accounts for 9.53%. There are two reasons for the dominance of the traditional manufacturing industry and high-tech enterprise functional areas. One is that companies or enterprises are numerous, and the other is that every company or enterprise occupies a large area. Then, the next largest proportion is devoted to catering and entertainment, real estate, and education and health care functional areas, while the proportion of the finance and insurance functional area is smallest. From the perspective of spatial distribution,

traditional manufacturing industry and high-tech enterprise functional areas are concentrated in Yonghe District and Eastern District but are sparse in the Western District. Other types of areas are scattered throughout the development zone.

Figure 3. Spatial Distribution of Functional Areas in the Guangzhou Economic and Technical Development Zone: (a) Distribution of Single/Mixed Functional Areas. (b) Distribution of Single Functional Areas. (c) Distribution of Mixed Functional Areas. On a 250 m scale, single functional areas account for 52.46% of the total area of the development zone, while mixed functional areas account for 17.07%.

Figure 4. Proportion of All Types: (a) Proportion of Single Functional Areas. (b) Proportion of Mixed Functional Areas. For single functional areas, the traditional manufacturing industry type represents the largest proportion, accounting for 26.34%, while for mixed functional areas, the combination of real estate, traditional manufacturing, and high-tech enterprises represents the largest proportion, at 2.73%.

For the mixed functional areas, the combination of real estate, traditional manufacturing, and high-tech enterprises account for the largest proportion, at 2.73% of all mixed functional areas, followed by the combination of finance and insurance, education and health care, and catering and entertainment, which accounts for 2.36%. Considering the spatial distribution, the mixed functional areas are mainly distributed in the south of Yonghe District, the south of the Eastern District, and the majority of the Western District. The mixed functional areas of real estate, traditional manufacturing, and high-tech enterprises are mainly distributed in the south of the Western District, while the mixed functional areas of finance and insurance, education and health care, and catering and entertainment are mainly distributed in the southwest of the Eastern District.

3.2. Functional Areas in Every District

The spatial distribution of functional areas in Yonghe District is shown in Figure 5. In Yonghe District, single functional areas represent a larger proportion, accounting for 60.98%, while mixed functional areas account for 12.70%. The proportion of single functional areas in the Yonghe District

is higher than that in the whole development zone, which reflects the centralized and compact distribution of POIs of the same type in that district. From the perspective of the spatial distribution of the single functional area, Yonghe District is mainly dominated by traditional manufacturing industry areas, accounting for 27.78% of the total Yonghe District, mainly concentrated in the northeast and west of Yonghe. The second type is high-tech enterprises, accounting for 10.53%, mainly distributed in the west and south of Yonghe. Then, the proportion of catering and entertainment areas, real estate areas, and education and health care areas decrease in turn. Finance and insurance functional areas have the least grid units. In terms of the spatial distribution of mixed functional areas, the combination of education and health care, and catering and entertainment with traditional manufacturing industry or high-tech enterprises occupies the most grid units. These units are staggered with single function areas in the southern Yonghe District.

Figure 5. Spatial Distribution of Functional Areas in Yonghe District: (a) Distribution of Single Functional Areas. (b) Distribution of Mixed Functional Areas. In Yonghe District, the total area devoted to single functions is larger than that for mixed functions. For the single functional areas, Yonghe District is mainly dominated by traditional manufacturing industry areas, while for the mixed functional areas, the combination of education and health care and catering and entertainment with traditional manufacturing industry or high-tech enterprises occupies the most grid units.

The spatial distribution of functional areas in the Eastern District is shown in Figure 6. In the Eastern District, the single functional areas have a larger proportion, accounting for 51.14%, while the mixed functional areas account for only 12.39%. From the perspective of the spatial distribution of the single functional areas, the Eastern District is dominated by the traditional manufacturing industry areas, accounting for 26.44% of the total Eastern District, evenly distributed throughout the Eastern District. The second type is high-tech enterprises, accounting for 9.38%, which are mainly distributed in the eastern fringe of the Eastern District. Then, the proportion of catering and entertainment areas, education and health care areas, and real estate areas decreases in turn. Finance and insurance functional areas have the least grid units. In terms of the spatial distribution of mixed functional areas, the combination including finance and insurance occupies most grid units, containing various

investment companies and commercial bank outlets, and is mainly distributed along Pioneer Avenue in the north and in the Southeast corner of the Eastern District.

Figure 6. Spatial Distribution of Functional Areas in Eastern District: (a) Distribution of Single Functional Areas. (b) Distribution of Mixed Functional Areas. In the Eastern District, the total area devoted to single functions is larger than that for mixed functions. For the single functional areas, the Eastern District is mainly dominated by traditional manufacturing industry areas, while for the mixed functional areas, the combination including finance and insurance occupies most grid units.

The spatial distribution of functional areas in the Western District is shown in Figure 7. In the Western District, the total area of single functional areas accounted for 47.14%, which is smaller than the proportion of single functional areas in the Yonghe District and Eastern District, while the total area of mixed functional areas accounted for 32.87%, which is significantly larger than the other two districts. From the perspective of the spatial distribution of the single functional area, the Western District is mainly dominated by traditional manufacturing industry areas, accounting for 23.44% of the total Western District, which are evenly distributed throughout the Western District. The second type is real estate, accounting for 8.44%, which is mainly distributed at the edge of the Western District. Then, the proportion of high-tech enterprises areas, education and health care areas, and finance and insurance areas decrease in turn. The catering and entertainment functional areas have the least grid units. In terms of the spatial distribution of mixed functional areas, the combination of real estate, high-tech enterprises, and traditional manufacturing industry occupies most grid units, accounting for 9.10%, which are mainly concentrated in the center of Western District. The second is the combination of education and health care, traditional manufacturing industry, and high-tech enterprises, accounting for 4.78%, mainly distributed in the north of the Western District.

Figure 7. Spatial Distribution of Functional Areas in the Western District: (a) Distribution of Single Functional Areas. (b) Distribution of Mixed Functional Areas. In the Western District, the total area devoted to single functions is larger than that for mixed functions. For single functional areas, the Western District is mainly dominated by traditional manufacturing industry areas, while for the mixed functional areas, the combination of real estate, high-tech enterprises, and traditional manufacturing industry occupies most grid units.

4. Discussion

4.1. Comparative Analysis

To verify the feasibility of the functional area identification method used in this article, we selected one grid unit in each type of functional area as the sample according to the results from the single functional area identification in the Eastern District of the Guangzhou Economic and Technological Development Zone. Then, we visually interpreted the Google Earth satellite images of all of the sample units and compared the functional area identification results based on POI data with the visual interpretation results. The comparison is shown in Figure 8. The sample units containing traditional manufacturing industry and high-tech enterprise functional areas are shown as large factories, the sample unit containing education and health care functional area is shown as playgrounds, and the sample unit containing real estate functional area is shown as a residential area. The entities within the catering and entertainment or finance and insurance function types occupy a small area and are mostly mixed with other entities. The land use characteristics of these entities are not significant, so it is hard to distinguish them in the image. However, in the electronic map, we can see that restaurants and shops are the main entities in the catering and entertainment sample unit, while banks, ATM machines, and insurance companies are the main entities in the finance and insurance sample unit.

By comparing functional area identification results with satellite images or electronic maps, it can be seen that the spatial distribution of different functional areas in the Guangzhou Economic and Technological Development Zone can be effectively identified by POI-based methods if we do not consider errors in the original POI data.

Figure 8. A comparison of the functional area identification results based on POI data with the visual interpretation results for the sample units. The spatial distribution of different functional areas in the Guangzhou Economic and Technological Development Zone can be effectively obtained by the POI-based identification method.

4.2. Development Process and Industry Layout in Guangzhou Economic and Technological Development Zone

The State Council established the following aims for economic and technological development zones: “to develop industries, to utilize foreign capital, to earn foreign exchange through exports, and to devote themselves to the development of high-tech industries” [47]. Since its establishment in 1984, the Guangzhou Economic and Technological Development Zone has actively introduced foreign capital, advanced technology and management experience, and vigorously developed the processing manufacturing industry and high-tech industries [48–50]. Since 2014, given the profound changes in the global economic and industrial structure, China’s economic development has transitioned into “The New Normal”. Faced with this new context, the State Council has proposed “optimizing the shape and layout of development zones, and speeding up the transformation and upgrading of development zones” [51]. The Guangzhou Economic and Technological Development Zone actively responded to the aims of the State Council by adjusting its industrial structure, changing its development mode, and optimizing its industrial space layout.

Examining the results for the urban functional areas identified using POI data from the Internet map, an analysis of the various functional areas and the characteristics of their overall area proportion at the 250 m scale show that the Guangzhou Economic Development Zone has indeed formed a general pattern of functional construction with the traditional manufacturing industry and high-tech enterprises as the main functional areas supported by real estate, catering and entertainment, education and health care, and finance and insurance. This pattern is consistent with the general requirements and specific planning objectives of the central and Guangdong provincial governments for economic development zones. The instructions from the central government to the Guangzhou Economic and Technological Development Zone for the construction of economic development zones

have been followed, and the actual construction results conform to the planning documents and development goals.

Furthermore, the monitoring results based on POI data from Internet maps are consistent with the data from statistical channels. The statistical yearbook of development zones shows that in 2017, the GDP of the Guangzhou Development Zone reached 320.953 billion yuan. The benefits of traditional pillar industries were stable, and the gross output value of industries above the scale reached 745.911 billion yuan. The high-tech industry has seen significant improvement as a driving force in economic development. The total number of high-tech enterprises identified has reached 1632, and the output value of high-tech industrial enterprises above the region's scale has reached 170.422 billion yuan. The development zone now forms a modern service agglomeration area including a business district, economic zone headquarters, and financial innovation service zone.

Considering the spatial distribution details for the functional areas of the three major districts—Yonghe District, Eastern District, and Western District—in the development zone, the three districts have formed their own unique layout characteristics given their different development histories and locations. The West District was the earliest construction in the Guangzhou Economic and Technological Development Zone. In 2015, the Guangzhou Economic and Technological Development Zone proposed promoting the transformation of the Western District from an old industrial zone to a modern science and technology city integrating industry, residential space, and modern service industries. Since that time, the West District has carried out large-scale industrial upgrading and public infrastructure construction, and it is expected that the proportion of mixed function areas in the West District will further increase in the future. The Eastern District has been striving to build an industrial upgrading base in Guangzhou since 1992. Therefore, the industrial structure of the Eastern District is mainly composed of light industries, such as the chemical industry, food and beverage manufacturing, and electronic communication equipment manufacturing, and heavy industries, such as transportation equipment manufacturing. In April 2000, the Guangzhou Export Processing Zone was established in the Eastern District, with automobile manufacturing as the main industry. The above industrial development goals and the characteristics of the enterprise scale contribute to the formation of single functional areas. The Yonghe District is the most recent, founded in 1993 mainly as a gathering area for Taiwanese investment. It is the main gathering area of the advanced processing industry in the Guangzhou Economic and Technological Development Zone. The overall positioning of this industrial park and its goal of attracting investment contribute to the formation of single functional areas, and it is easier to form high-tech industrial chain enterprises. The results of the POI-based functional area identification shows that Yonghe District is indeed dominated by manufacturing and high-tech enterprises.

5. Conclusions

To identify functional areas within the development zone based on POI data, this paper conducts spatial identification of the functional areas of the Guangzhou Economic and Technological Development Zone and analyzes and discusses the spatial distribution and spatial aggregation characteristics of the detailed functional areas within the three districts of the Guangzhou Economic and Technological Development Zone. The main conclusions are as follows:

1. POI data provided by Internet maps are free, easily obtained, and have the advantage of large volumes and more detail. These advantages mean that POI data offer a new perspective for urban functional area identification methods. Constructing the POI frequency density and function type proportion index model allows for the rapid and effective identification of urban functional areas.
2. In the Guangzhou Economic and Technological Development Zone, on a 250 m scale, the area devoted to single functions is greater than that given to mixed functions. The traditional manufacturing industry functional areas hold the largest proportion, followed by high-tech enterprises areas, catering and entertainment areas, real estate areas, and education and health care areas. The finance and insurance areas account for the smallest proportion. Among the

mixed functional areas, the mixed areas with real estate, traditional manufacturing industry, and high-tech enterprises account for the largest proportion.

3. The Guangzhou Economic Development Zone has indeed constructed development goals following the general pattern of traditional manufacturing and high-tech enterprises as the main functional areas, and real estate, catering and entertainment, education and medical treatment, and finance and insurance as supporting facilities. Based on a historical analysis of the development of the economic development zone, it can be seen that the current development and functional layout of the Guangzhou Economic Development Zone conforms to the general requirements and planning objectives of the Central Committee and Guangdong Province. Within the economic development zone, the layout and clustering characteristics of functional areas in different plots agree well with the industrial development goals, construction planning, and development history of the region.

This research provides a method for urban functional area identification based on POI data from the Internet map and carries out a case application for the Guangzhou Economic Development Zone. The results indicate that this method using POI data has high potential for application to the analysis of spatial distribution characteristics of urban functional areas and urban functional allocation planning. It should be noted that although the POI method has the above advantages, in its future applications, we still need to consider the uncertainty and incompleteness of POI data from the Internet map. In particular, when POI data are mainly collected through crowdsourcing, the above problems will become more prominent. In addition, in the process of urban functional area analysis, the scale should be considered in the grid division of urban functional areas. The size of the cell grids may have a slight impact on the conclusions of the study. An important future research direction is to recognize and divide functional areas with adaptive scales by combining traffic road data and the multiscale segmentation method from remote sensing images.

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