Available online at www.sciencedirect.com

ScienceDirect

Journal of Urban Management 4 (2015) 135–146

www.elsevier.com/locate/jum

Research Article

Density and diversity of OpenStreetMap road networks in China

Yingjia Zhang[a], Xueming Li[a,*], Aiming Wang[b], Tongliga Bao[a], Shenzhen Tian[a]

[a]*School of Urban and Environmental Sciences, Liaoning Normal University, Dalian 116029, China*

[b]*Department of Educational Psychology, Miami University, Oxford, OH 45056, USA*

Received 18 July 2015; received in revised form 1 October 2015; accepted 21 October 2015

Available online 21 December 2015

Abstract

OpenStreetMap is a geographic information platform designed to provide real-time updates and user-generated content related to its freely available global map, and it is one of the most widely used examples of volunteered geographic information, a technique associated with so-called neogeography. This paper, based on the data from China's OpenStreetMap road network in May 2014, taking 340 prefecture-level cities in China as its study area, presents the geometric-related (road density) and attribute-related (type diversity) spatial patterns of the OpenStreetMap road network, and explores their relationship. The results are as follows. (1) The distribution of OpenStreetMap road density in Shenzhen, Shanghai, Hong Kong, and Macao predominantly obeys a "positive skewness distribution". OpenStreetMap data for eastern China shows a higher overall and circular structure. In central China, there are noticeable discrepancies in the road density, whereas in western China, the road density is low. (2) The OpenStreetMap road diversity shows a normal distribution. The spatial pattern for the so-called "Hu Huanyong line" was broken by the effect of diplomatic and strategic factors, showing a high diversity along the peripheral border, coastal cities, and core inland cites. (3) China's OpenStreetMap is partitioned into four parts according to road density and diversity: high density and high diversity; low density and low diversity; high density and low diversity; and low density high diversity. (4) The OpenStreetMap geographical information-collection process and mechanism were analyzed, demonstrating that the road density reflects the preponderance of traffic in the real world. OpenStreetMap road diversity reflects the road-related geographic information demand and value, and it also reflects the interests of users toward to OpenStreetMap geographical information.

Keywords: OpenStreetMap; Road density; Road diversity; VGI; Spatial pattern; China

1. Introduction

OpenStreetMap (OSM), founded in 2004, has grown from a local project into a worldwide map with widespread use and high-quality data. Since 2012, OSM has been embedded into Apple's iPhone, and it has provided services for Flickr, Foursquare, MapQuest, Wikipedia, Microsoft, etc. Currently, OSM is a strong competitor to Google Maps. OSM, through users' online cooperation, uses a handheld GPS terminal, high-resolution remote-sensing

*Corresponding author.

E-mail addresses: zyj575657@163.com (Y. Zhang), lixueming999@163.com (X. Li), wanga@miamioh.edu (A. Wang), tongliga113@126.com (T. Bao), shenzhen890038@163.com (S. Tian).

Peer review under responsibility of Zhejiang University and Chinese Association of Urban Management.

http://dx.doi.org/10.1016/j.jum.2015.10.001

images, and individual spatial cognitive knowledge as a basic geographic reference to create, edit, manage, and maintain geographical information. It is freely available to all users online around the world. Like Wikimapia and Flickr, OSM is the representative example of user-generated content (Haklay & Weber, 2008), and it is the Internet media platform authorized for ordinary user-generated global geographical information based on Web 2.0 network technology (Elwood, 2008). This platform works with user content known as volunteered geographic information (VGI), developed in 2007 by Goodchild (Goodchild, 2007). Compared with traditional geographic information, OSM exemplifies a new era of geographic data with the following characteristics: (1) The diversification of OSM data acquisition includes cartography by amateurs and volunteers, professionals of geographic information systems, and staff at national surveying and mapping agencies. Such users are not only information suppliers, but also disseminators and consumers (Goodchild, 2009). (2) Transparency and openness of data editing, copying, distributing, and transfering. As such, everyone can use the OSM geography information provided that they indicate the OSM copyright and acknowledge the contributor's work. However, traditional road data is protected with a security protocol or data encryption. (3) OSM is digitizing geographic information that is updated online in real-time. Nevertheless, traditional static road data has a fixed format, and it is updated at regular intervals. (4) OSM road data is collected in several ways, giving importance to user participation and creativity in order to enhance its multiple applications and increase its popularity as a public service.

After an evaluation of London's OSM information, Haklay concludes that OSM data is relatively accurate (Haklay, 2010). Girres and Touya (2010) evaluated a larger set of spatial data in France, showing that the advantage of OSM lies in its responsiveness and flexibility. Through the evaluation of OSM data, researchers have consistently held a positive attitude to OSM, considering it a representative of massive VGI data and marking a new age of geographic information (Goodchild, 2009; Haklay et al., 2008; Jacob et al., 2009; Li & Shao, 2009). OSM's road-related geographic information is often a central feature in research (Chen, Sun, & Vodacek, 2014; Estima & Painho, 2013; Fritz et al., 2009; Graham, 2015; Hagenauer & Helbich, 2012; Li, Fan, Luan, Yang, & Liu, 2014; Mooney & Corcoran, 2012; Neis, Goetz, & Zipf, 2012; Over, Schilling, Neubauer, & Zipf, 2010). Such research proceeds from a number of perspectives. First, research has been conducted to evaluate the quality of OSM road information. Haklay et al. (2010) applied a separate buffer analysis for each road category. The results indicated that the positional accuracy for OSM exceeded 80%, and that primary roads were better mapped. Zielstra and Hochmair (2012) compared pedestrian datasets for OSM, TIGER/Line, and other proprietary datasets in Miami, San Francisco, Berlin, and Munich, and found that OSM can provide relatively comprehensive data with increased user options. Second, researchers have explored the quality and quantity of contributors to OSM. Haklay et al. (2010) also verified that Linus' Law applies to OSM, and demonstrated that the relationship between the number of contributors and the quality of the data is not linear. An empirical study of western Kenya by De Leeuw et al. (2011) discovered that when volunteers, with local knowledge, classified roads, they were over 92% accurate on average. This is much more accurate than the results from professional surveyors without local knowledge. Third, research on OSM's road information has analyzed the status and evolution of the OSM road dataset. Neis, Zielstra, and Zipf (2011) sorted the evolution of Germany's OSM road network from 2007 to 2011. Other scholars in England, France, Iraq, and the USA have conducted research on OSM road status and evolution, generally showing a heterogeneous pattern, with stronger road-network concentrations in urban areas compared with rural areas (Neis & Zielstra, 2014). Finally, the application of OSM road data has been studied. OSM road data facilitate smart road search and navigation; for example, by using OSM geodata, the location of an ambulance can be evaluated and relocation models can be established to ensure optimum coverage of emergency medical services (Azizan et al., 2012). OSM outdoor pavement and indoor corridor information can be used to customize road navigation for international conferences and support multi-lingual guidance (Jacob, Zheng, & Ciepłuch, 2011). Amirian, Basiri, Gales, Winstanley, and McDonald (2015) pointed out that the use of OSM data can facilitate in establishing next generation navigational services by the integration of augmented reality and graph databases through standard textual and cartographic interfaces, and augmented images. The most famous model of the application of OSM data for urban management is the humanitarian aid provided in the 2010 Haiti earthquake; this was done to map roads and refugee camps in a short duration for government agencies, NGOs, and rescue teams to facilitate them to save lives (Coast, 2011). In addition, OSM is now being used for urban planning, urban modeling, sustainability, and environmental modeling (Mooney, 2015). Jia and Jiang (2010) used OSM street-node data to measure urban sprawl and define urban boundaries. By using OSM data related to road infrastructure and buildings, Over et al. (2010) investigated the prospects for generating data that can be used for establishing interactive 3D city models. Using OSM data, Gil (2015) built a multimodal urban network model, Estima and Painho (2015) investigated land use and land cover production, and Schlesinger (2015) quantified the complex urban fabric.

OSM geographic information is comprehensive and popular in many developed countries. Generally, there is an average of 20–30% more information than is available in commercial maps (Goodchild, 2009; Graham, 2015; Neis et al., 2011). Research has typically focused on developed countries (Girres & Touya, 2010; Haklay et al., 2010; Rehrl et al., 2013; Zielstra & Hochmair, 2011; Zielstra, Hochmair, & Neis, 2013; Zielstra & Zipf, 2010, pp. 14–17), with little attention paid to developing countries such as China. Developing countries often do not have the complete data available because of different languages, cultures, customs, and marketing. However, such data is being rapidly accumulated (Zhao, Jia, Qin, Shan & Jiao, 2015). Three types of road-data sources are used in road-network research in China: the vectorization of a published map (Fan et al., 2011; Wu, Cao, & Cao, 2006); authorized data accessed from relevant traffic and planning departments (Deng et al., 2012; Feng et al., 2009) or nationally provided basic geographical information; and remote sensing data that has been extracted and interpreted (Jin, Wang, & Li, 2008; Zhang, Hu, Liu, Ren, & Li, 2011). The so-called neogeographical information, such as the OSM road network data in China, has seldom been researched. Zhao et al. (2015) analyzed Beijing's road network, providing a geometric, topological, and centrality analysis. Long and Liu used road networks in OSM and points-of-interest to partition the geographical space, delineating urban parcels and inferring urban functions (Liu et al., 2015; Mao & Long, 2014, pp. 1–4). Zhou, Huang, and Jiang (2014) evaluated the quality of OSM data for three cities in China: Handan, Lanzhou, and Nantong. Among the limited published academic papers on OSM in China, most researchers focus on specific cities. Tthis paper aims to fill this gap through an empirical study on the overall density and diversity of the OSM roads for each city of China and discuss their spatial distribution, which enriches related studies in developing countries.

In this paper, 564,913 roads of China, which collectively are approximately 1,086,329 km long, were obtained from OSM's API using Python code in May 2014. We investigate the Chinese OSM road density and diversity in 340 areas: 284 prefecture-level cities, 4 municipalities under the direct administration of the central government, 2 special administrative regions, and 50 regions (Chen & Zhu, 2012; Feng et al., 2009) to further explore the relationship between road density and diversity.

2. OSM road density in China

As shown in Fig. 1, the overall status of the OSM road network shows that the southeast of China has a far more extensive road network than the west of China. Different types of OSM road networks in China have different spatial patterns. Highways (Fig. 1a) in significant political and economic locations crisscross throughout China, with Beijing as the center in the north, Guangzhou in the south, Shanghai in the east, and Chongqing in the west. Primary roads belong to the state. Regional channels are related to the national economy, culture, and political centers. Eastern China appears remarkably connected, given the relative disconnect in the west and the northeast. Secondary and tertiary roads belong to the sub-trunk, and these roads provide important internal connections between metropolitan areas, provinces, and autonomous regions. These roads are generally shorter than highways and primary roads. The majority of "others roads" are internal service roads inside cities, where the OSM users are in need of geographic data.

The road density is an important index for evaluating regional traffic (Hawbaker et al., 2005; Shen & Wu, 2006; Zhang, Wang, Peng, Gong, & Shi, 2002). OSM road density comprises geographical information that reflects real-world road networks, and it is an index for assessing the quality of OSM geographic data. We calculated the OSM road density in 340 city units as follows (Fan et al., 2011; Feng et al., 2009; Jin et al., 2008):

$$D_x = L_x / A_x \quad x \in (1, 2, 3, \ldots, 340) \tag{1}$$

where one city unit is X, the OSM road density in city X is D_x, the OSM road length for city X is L_x, and the area in city X is $_{Ax}$.

Shanghai, Macao, Hong Kong, and Shenzhen are first-grade cities. These four cities have a high level of economic development and an extensive road network. Hong Kong and Macao are considerably influenced by the Western culture, Shanghai and Shenzhen are two of the most innovative cities in China, and they can easily and quickly adopt Western Internet applications such as OSM. The second-grade density cities are located in urban agglomeration of the Pearl River Delta, Yangtze River Delta urban agglomeration, Bohai urban agglomeration, Sichuan-Chongqing urban agglomeration and so on. The third-grade cites mainly distribute ordinary cities near urban agglomerations and most cities in the North China Plain, where such

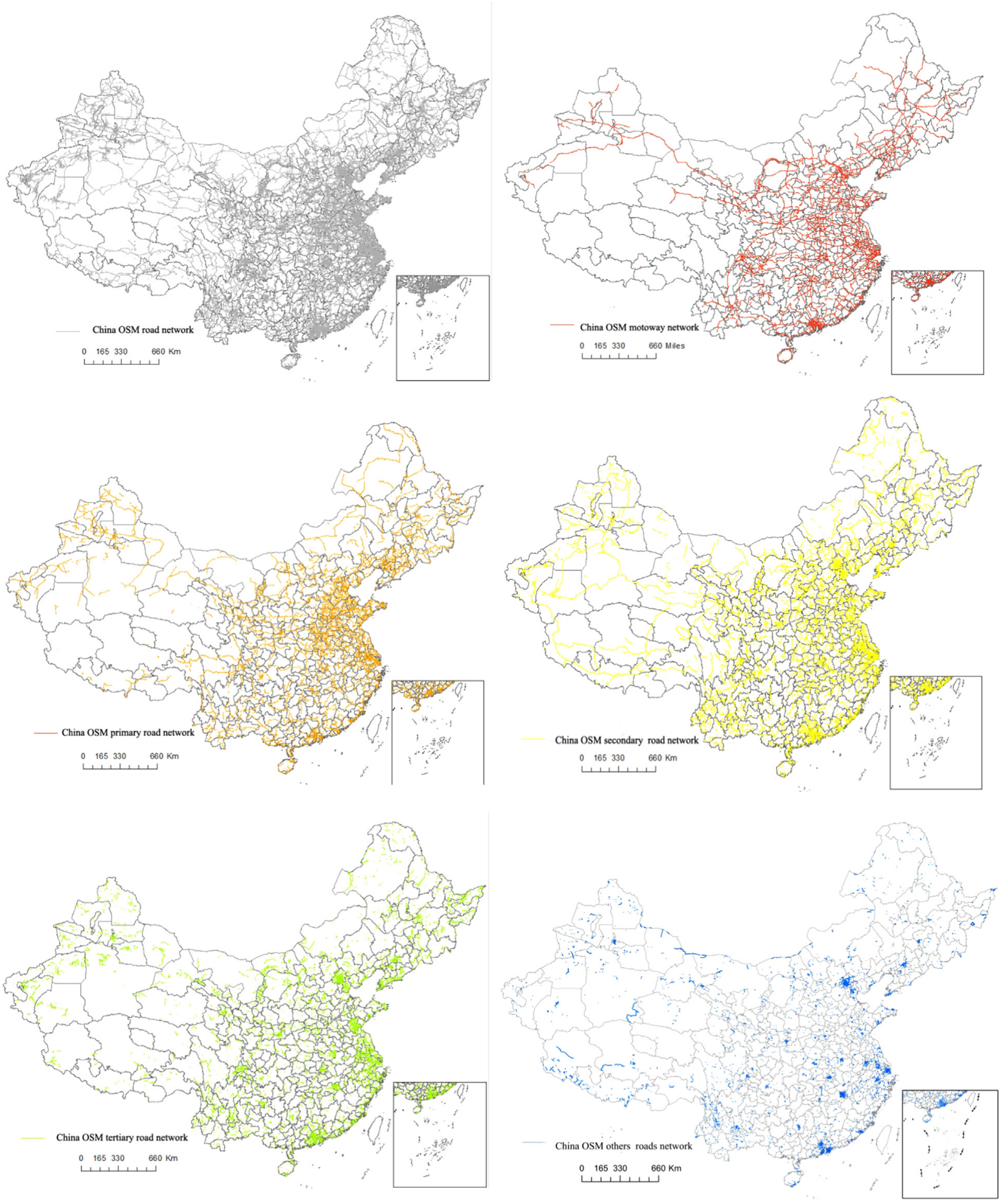

Fig. 1. Spatial distribution of China's OSM road network.

roads are the only connection to Beijing, and the south, east, and west of China. The fourth- and fifth-grade have relatively low road density, and such roads are commonly located in central China and in cities outside an urban agglomeration. The sixth grade has the lowest OSM road density, mainly located in the northern and

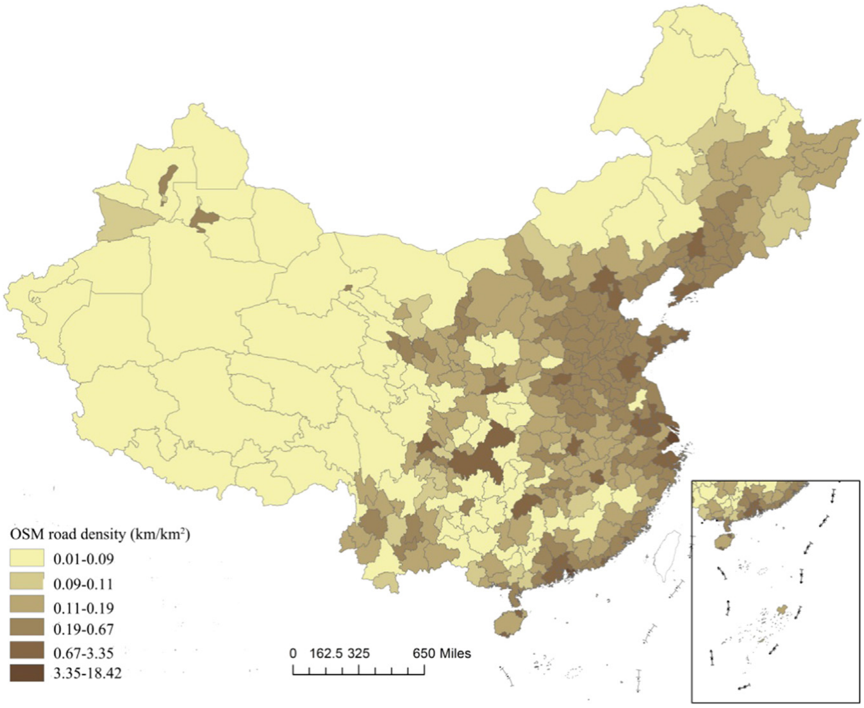

Fig. 2. Spatial distribution of OpenStreetMap road density in China.

Table 1
OSM road density grade and city examples.

OSM road density grade	The range of road density (km/km^2)	Amount/percent (%)	City examples
The first	$3.35 \le D \le 18.42$	4/1.18	Shanghai, Macao, Hong Kong, Shenzhen
The second	$0.67 \le D < 3.35$	33/9.71	Guangzhou, Nanjing, Tianjin, Beijing, Zhengzhou
The third	$0.19 \le D < 0.67$	118/34.71	Luoyang, Guiyang, Kuiming, Changchun, Wenzhou
The fourth	$0.11 \le D < 0.19$	89/26.18	Zhuzhou, Fangchenggang, Xiaogan, Baotou, Anqing
The fifth	$0.09 \le D < 0.11$	20/5.88	Mudanjiang, Liupanshui, Heyuan, Sanming, Yulin
The sixth	$0.01 \le D < 0.09$	76/22.32	Bazhong, Kashi, Tongren, Dazhou, Qinyang

western regions where the population is relatively sparse and the ecological environment is vulnerable (see Fig. 2 and Table 1).

3. OSM road diversity in China

OSM issues community standards through user management and applies tags to describe the attributes of geographical features. Users are advised to use these tags. At the same time, users can create new tags to build and upgrade the style of the map to support spatial analysis (Shen & Wu, 2006; Zhang et al., 2002). Thus, OSM roads have more diverse types compared with traditional or official road-type systems. Until May 1, 2014, there were 23 road types that outnumbered 2000 items. These include highways, primary roads, secondary roads, and tertiary roads, highway lines, steps, bicycle lanes, special roads, footway, steps, and so on.

The OSM road categories have been created by users who pay attention to the actual needs of the users. For example, residential roads, footways, and service roads are closely related to urban public infrastructure and to road information that is vital to residents in their everyday life. However, compared with official geographic information, these categories are often trivial and multifarious. At the national level, the amount of residential data is 104,786, far higher than other types of road data. In Hong Kong, the longest is a footway, and the largest number is a service among 23 OSM road types. In Shanghai, the longest is a secondary road, and the largest number is residential.

A heterogeneous spatial pattern is obvious in China in terms of OSM road diversity. More meticulous users provide detailed types in certain areas, depending on the interest and pertinence to the users in those regions. In scenic spots such as the Imperial Palace in Beijing (see Fig. 3), there are as many as nine kinds of OSM road types for which the geographic information is especially detailed. In such areas, the data often includes access ramps, cycle ways, footways, pedestrian roads, and steps, and this information is rare in official maps. By contrast, in Zhangjiajie, a prefecture-level city in central China (as shown in Fig. 4), there are only 12 kinds of OSM types for the entire city.

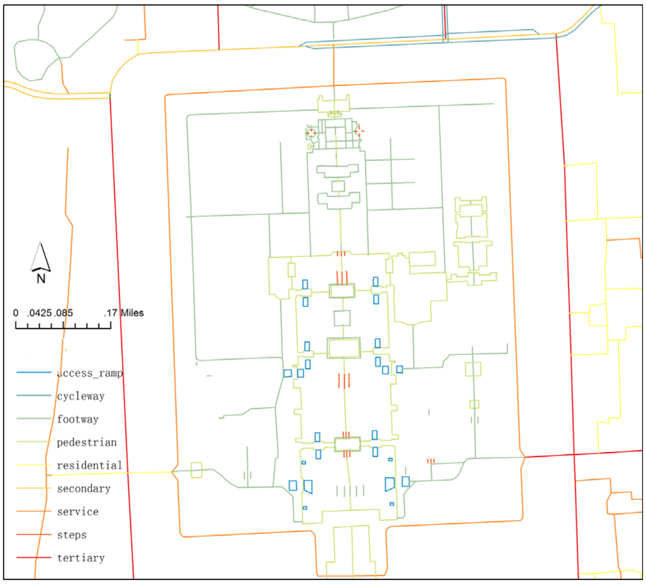

Fig. 3. Different OSM road types for the Forbidden City.

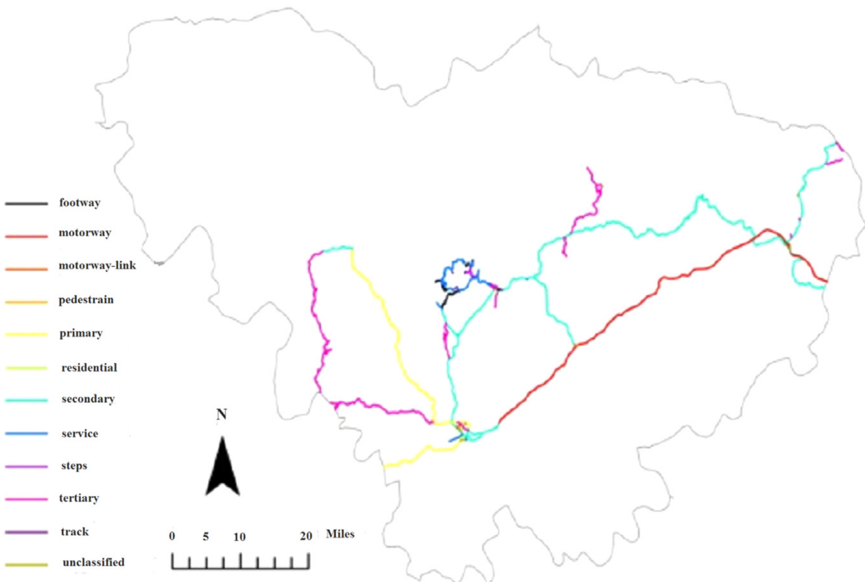

Fig. 4. Different OSM road types in Zhang Jiajie.

In this paper, the Shannon–Wiener index was used to evaluate the diversity of road types, for which a total of 340 city units were included.

$$H' = -\sum_{i=1}^{n} P_{\mathrm{i}} In P_{\mathrm{i}},$$
$$P_{\mathrm{i}} = ni/N \quad \mathrm{i} \in (1, 2, 3, \ldots n) \tag{2}$$

where H' is the road-diversity index, i represents the road type, n is the number of road types, ni refers to the road length for type i, N is the total length for all road types, and Pi is the relative importance of type i.

The first grade diversity cities occupies core economic, political, cultural, and tourist areas (see Fig. 5). These cities include two special administrative regions (viz., Hong Kong and Macao), municipalities directly under the administration of the central government (viz., Beijing, Shanghai, and Tianjin), provincial capitals (viz., Shenyang, Guangzhou, and Chengdu), deputy provincial cities (viz., Xiamen, Dalian, and Hangzhou), tourist cities (viz., Sanya, Guilin, Qinhuangdao), and a rocket launch site (viz., Jiuquan). The second grade includes important coastal economic or military port cities such as Weihai and Zhenjiang, some provincial capitals (Xi'an, Changsha, Ji'nan, etc.), many border cities and minority communities, and some important inland cities. The third grade includes some ethnic minority areas and border cities, such as Baishan City, Hotan

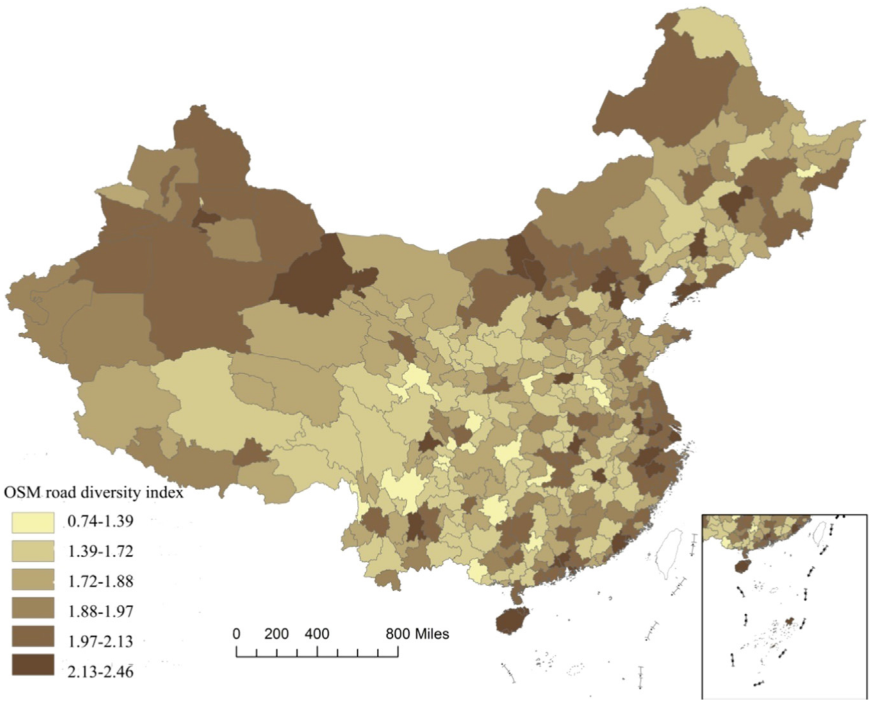

Fig. 5. Spatial distribution of OpenStreetMap road diversity in China.

Table 2
The OSM road diversity grade and city examples.

OSM road diversity grade	Range of road density (km/km^2)	Amount/percent (%)	City examples
First	$2.13 \leq H' \leq 2.46$	35/10.29	Shanghai, Macao, Hong Kong, Shenzhen, Beijing
Second	$1.97 \leq H' < 2.13$	62/18.24	Xi'an, Changsha, Ji'nan, Liuzhou, Zhangjiakou
Third	$1.88 \leq H' < 1.97$	38/11.18	Tangshan, Daqin, Xiangyang, Kashi, Datong
Fourth	$1.72 \leq H' < 1.88$	94/27.64	Hengyang, Maanshan, Huludao, Xuzhou, Mudanjiang
Fifth	$1.39 \leq H' < 1.72$	91/26.76	Huaihua, Yichun, Kaifeng, Zhangjiajie, Hezhe
Sixth	$0.74 \leq H' < 1.39$	20/5.89	Maozhou, Qitaihe, Xinyu, Xinyu, Bazhong

Prefecture, and the Turpan region, and some outbalanced cities. The fourth grade tends to apply to regions with ordinary diversity, including ordinary cities in metropolitan areas. The fifth and sixth grades tend to apply to regions with lower diversity that are mainly distributed in central and coastal regions (see Fig. 5 and Table 2).

4. Relationship between OSM road density and diversity in China

Kurtosis (see Eq. (3)) and skewness (see Eq. (4)) were calculated, the skewness of the Chinese OSM diversity index is −0.50. The kurtosis is 0.89. The skewness of the road density is 10.32, and the kurtosis is 116.93. Road density is strongly skewed, indicating that the OSM road density in most cities of China is less than the average.

The variable of road density has been transformed using a log(base10) transformation considering road density is very strongly skewed. Such transformation can make data easier to model. Then take the standard road diversity density index (see Eq. (5)) as the abscissa and the transformed standard road density index (see Eq. (5))as the ordinate. Using these calculations, we generated an OSM scatter diagram for road networks in China (see Fig. 6), with a histogram and a normal curve.

$$K = \frac{1}{n-1}\sum_{ij=1}^{n}\left(x_{ij}-\overline{S}_{ij}\right)^4/\mathrm{SD}^4-3 \tag{3}$$

$$S = \frac{1}{n-1}\sum_{ij=1}^{n}\left(X_{ij}-\overline{S}_{ij}\right)^3/SD^3 \tag{4}$$

$$Z_{ij} = \frac{X_{ij}-\overline{S}_{ij}}{\sqrt{\frac{\sum_{ij=0}^{n}\left(x_{ij}-\overline{s}_{ij}\right)^2}{\mathrm{n}}}} \tag{5}$$

where i and j represent the road density and diversity index respectively, K is the kurtosis, S is skewness, x is the original data, S is the average value, n is the number of units (340), and SD is the standard deviation, Z refers to the standard value, when calculate $Z_{i,}$ transformed density data has been used.

The high diversity, high density type cities mainly distributed in coastal metropolitan areas (e.g., the Pearl River Delta metropolitan area, the Bohai metropolitan area, the Yangtze River Delta metropolitan area, etc.) and inland core cities (Xi'an, Zhengzhou, Wuhan, etc.). Cities of the low diversity, high density type play an important role in

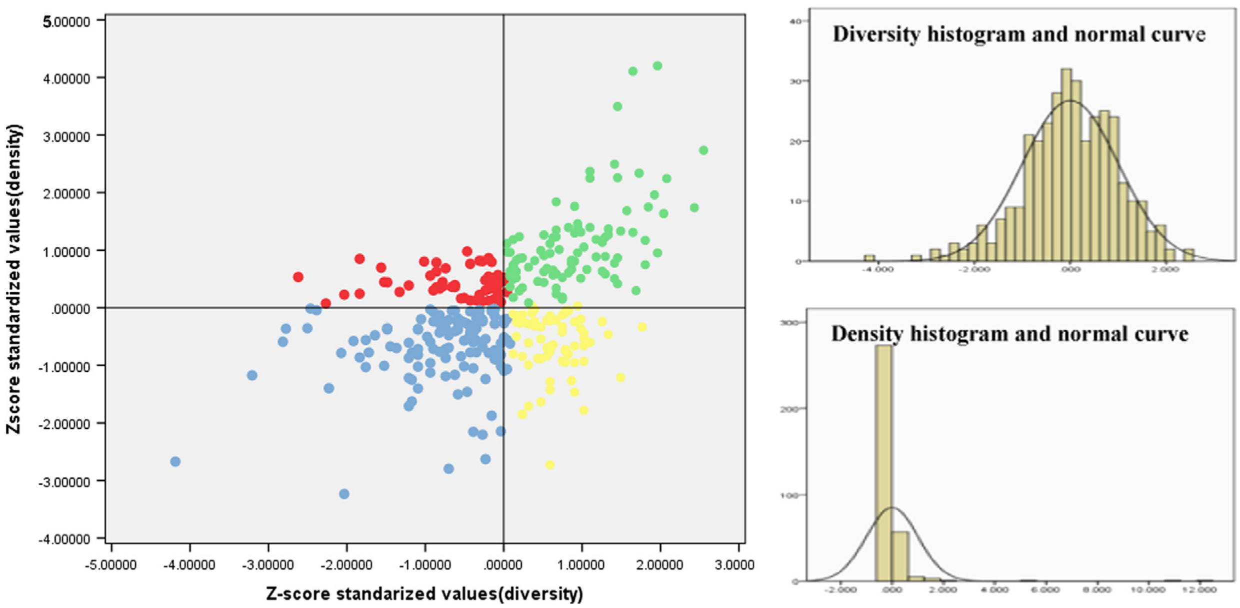

Fig. 6. Scatter diagram and histogram of OpenStreetMap road diversity.

Table 3
The OSM four road types.

OSM road type	Quadrant	Amount/percent	City examples
High diversity, high density	First	103/30.29	Shanghai, Macao, Hong Kong, Shenzhen, Beijing
Low diversity, high density	Second	52/15.29	Handan, Hengshui, Benxi, Xiangtan, Zhumadian
Low diversity, low diversity	Third	113/33.24	Changde, Zhangjiajie, Xiaogan, Heyuan, Bazhong
High diversity, low density	Fourth	72/21.18	Guilin, Hengyang, Yichang, Daqin, Hetan district

connecting to hub cities. Anshan is central city between Dalian and Shenyang, for instance, where Panjin provides access to the sea for Shenyang, and Huibei connects Shandong province with Henan province. high diversity, low density cities are mainly distributed in the ordinary metropolitan areas that are close to H–H cities and Chinese inland border provinces (such as part of the city, southwestern Yunan, northwestern Tibet in Xinjiang City, northwestern Gansu, most of Qinghai City, north of Inner Mongolia City, northeast of Jilin, and most of the border of Heilongjiang city). The low diversity, low diversity regions mainly distribute in the southwest and northeast regions of central China (Table 3).

5. Diversity and density in OSM road formation

The difference between OSM path diversity and density spatial patterns is the result of geometrical and attribute-related characteristics. The OSM road editor collects geometric features from roads, such as nodes, pathways, and relationships, through smartphones with GPS, HD satellite, etc. It then uses an OSM editor (such as JOSM) to complete the attributes for this data. These two kinds of data can be compiled either by the same editor or by different editors. The geometric data is mainly based on real-world road data. The comparison results show that the spatial distribution pattern of OSM road density is very similar to the traditional spatial road density (Jin et al., 2008), the source of which is basic geographical information and remote sensing data; there are other studies also that can validate this result (Chen & Zhu, 2012; Zhang et al., 2011; Feng et al., 2009). The degree of completion and accuracy is based on actual roads, and this is a key factor in quality assessment. The attribute data is privy to social and personal information. The users or editors, through actual surveys or their knowledge of the local roads, comment on

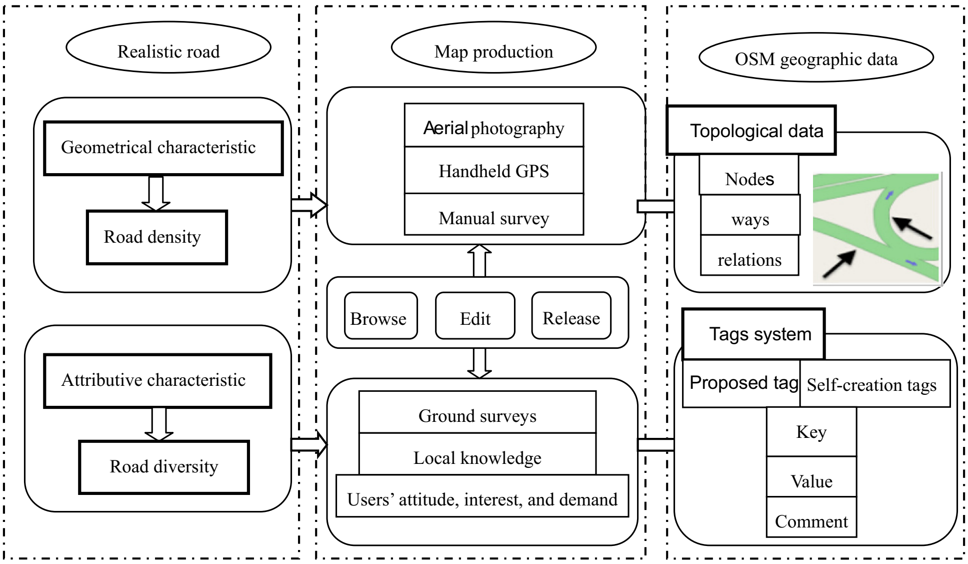

Fig. 7. Influential factors and the mechanism for OpenStreetMap road density and diversity.

these attributes and classify attribute values. According to fractal theory, the smallest city has different road types and characteristics. If the editor and users think that some city or regional road information is relatively more important, such information will be collected meticulously. Thus, road density better reflects the importance of particular roads in the real world, and OSM road diversity better reflects what the interests, needs, and values of users are with regard to road-related information (see Fig. 7).

6. Conclusion and discussion

OSM data is the product of Web 2.0 networking combined with geographic information systems, and such data is up-to-date and widely applicable. In this paper, we used data obtained in May 2014 from 340 cities based on the Chinese OSM road network. We used this data to explore OSM road geometry (road density) and road attributes (road type) and their relationship.

(1) The OSM road density follows a positively skewed distribution across all cities. There is a higher OSM road density in the east,; however, the density gradually reduces along the periphery, indicating a layered structure. Among the central cities in China, significant differences are observed; the OSM road density of the core cities and ordinary cites are radically different. The OSM road density in the far western regions is low.
(2) OSM road diversity among 340 cities in China shows a normal distribution. Coastal and border cities form a circular pattern. Core inland cities resemble an island distribution with high diversity.
(3) Four classifications of OSM road networks in China were obtained through a double index of OSM road density and diversity. We then analyzed the underlying reason for the uncorrelated characteristics between the geometry and attributes of OSM geographic information through a data collection process and a VGI/Web 2.0 mechanism. The road density better reflected the importance of roads in the real world, and the OSM road diversity better reflected the pertinence of road information to users.
(4) The findings presented may provide urban managers with an overview of the density and diversity of OSM roads in China and also enhance the understanding of OSM data development standard in China. This helps urban managers pay attention to the unbalanced and heterogeneity of the OSM data quality in urban and rural areas, eastern and west areas, and developed and developing cities, which is useful for improving the quality and completeness of OSM data. The findings also help in enriching their knowledge on road networks from the perspective of volunteers' mapping activities. OSM provides information on various road types, such as abandoned, proposed, bridleways, crossings, access ramps, and so on, to enhance its multiple applications and increase its popularity as a public service.
(5) Traditionally, map data was collected and distributed by private enterprises and governments that tend to charge high prices and restrict the usage rights of the data. OSM data is freely available and can be used for many data infrastructure applications and value-added services. This data has numerous applications for urban network modeling, routing, land management, and urban form. In addition, increasing number of people are considering it as a potential alternative to commercial or authoritative data. OSM is of high quality in Western countries, especially in Germany. However, in developing countries, including China, there is not much development in this field (despite its rapid expansion). In this paper, research was conducted on the current situation of OSM road networks in China. In future, urban managers will determine whether VGI OSM map applications in China will encounter setbacks similar to those encountered by Google and Facebook, or whether OSM is feasible for users in China. They will also determine whether these applications will appeal to the Chinese Internet enterprises. Moreover, urban managers should consider VGI as an upcoming trend. If OSM in China is developed at the same pace as that in developed countries in the coming years, the government can foster and encourage Chinese brand VGI geo-data companies, which is a promising and prosperous direction.

Acknowledgments

This work was funded by foundation items: National Natural Science Foundation of China (No. 41171137).

References

Amirian, P., Basiri, A., Gales, G., Winstanley, A., & McDonald, J. (2015). The next generation of navigational services using OpenStreetMap data: The integration of augmented reality and graph databases. In *OpenStreetMap in GIScience* (pp. 211–228). Springer International Publishing.

Azizan, M. H., Lim, C. S., Hatta, W. Application of openstreetmap data in ambulance location problem. *Proceedings of the fourth IEEE international conference on Computational Intelligence, Communication Systems and Networks (CICSyN)*, 321–325.

Chen, P., & Zhu, X. (2012). Regional inequalities in China at different scales. *Acta Geographica Sinica*, *67*, 1085–1097.

Chen, B., Sun, W., Vodacek, A. (2014). Improving image-based characterization of road junctions, widths, and connectivity by leveraging OpenStreetMap vector map. *Proceedings of the IEEE Geoscience and Remote Sensing Symposium (IGARSS).*

Coast, S. (2011). *How OpenStreetMap is changing the world. Web and Wireless Geographical Information Systems*. Berlin Heidelberg: Springer.

De Leeuw, J., Said, M., Ortegah, L., Nagda, S., Georgiadou, Y., & DeBlois, M. (2011). An assessment of the accuracy of volunteered road map production in Western Kenya. *Remote Sensing*, *3*, 247–256.

Deng, Y., Cai, J., Yang, Z., & Wang, H. (2012). Measuring time accessibility with its spatial characteristics in urban areas of Beijing. *Acta Geographica Sinica*, *67*, 169–178.

Elwood, S. (2008). Volunteered geographic information: future research directions motivated by critical, participatory, and feminist GIS. *GeoJournal*, *72*, 173–183.

Estima, J., & Painho, M. (2013). Exploratory analysis of OpenStreetMap for land use classification. *Proceedings of the Second ACM SIGSPATIAL international workshop on crowdsourced and volunteered geographic information: ACM*, 39–46.

Estima, J., & Painho, M. (2015). *Investigating the potential of OpenStreetMap for land use/land cover production: A case study for Continental Portugal. OpenStreetMap in GIScience* (pp. 273–293)Springer International Publishing273–293.

Fan, K.-H., Li, Y.-B., & Feng, Y.-L. (2011). *Spatial distribution of roading density in Chongqing based on GIS*, 365–371.

Feng, Z., Liu, D., & Yang, Y. (2009). Evaluation of transportation ability of China: From county to province level. *Geographical Research*, *28*, 419–429.

Fritz, S., McCallum, I., Schill, C., Perger, C., Grillmayer, R., Achard, F., … Obersteiner, M. (2009). Geo-Wiki.Org: The use of crowdsourcing to improve global land cover. *Remote Sensing*, *1*, 345–354.

Gil, J. (2015). *Building a multimodal urban network model using OpenStreetMap data for the analysis of sustainable accessibility. OpenStreetMap in GIScience* (pp. 229–251)Springer International Publishing229–251.

Girres, J. F., & Touya, G. (2010). Quality assessment of the French OpenStreetMap dataset. *Transactions in GIS*, *14*, 435–459.

Goodchild, M. (2009). NeoGeography and the nature of geographic expertise. *Journal of Location Based Services*, *3*, 82–96.

Goodchild, M. F. (2007). Citizens as sensors: the world of volunteered geography. *GeoJournal*, *69*, 211–221.

Graham, M. (2015). Uneven geographies of OSM.

Hagenauer, J., & Helbich, M. (2012). Mining urban land-use patterns from volunteered geographic information by means of genetic algorithms and artificial neural networks. *International Journal of Geographical Information Science*, *26*, 963–982.

Haklay, M. (2010). How good is volunteered geographical information? A comparative study of OpenStreetMap and Ordnance Survey datasets. *Environment and Planning B: Planning and Design*, 682–703.

Haklay, M., & Weber, P. (2008). Openstreetmap: User-generated street maps. *IEEE Pervasive Computing*, *7*, 12–18.

Haklay, M., Singleton, A., & Parker, C. (2008). Web mapping 2.0: The neogeography of the GeoWeb. *Geography Compass*, *2*, 2011–2039.

Haklay, M., Basiouka, S., Antoniou, V., & Ather, A. (2010). How many volunteers does it take to map an area well? The validity of Linus' law to volunteered geographic information. *The Cartographic Journal*, *47*, 315–322.

Hawbaker, T. J., Radeloff, V. C., Hammer, R. B., & Clayton, M. K. (2005). Road density and landscape pattern in relation to housing density, and ownership, land cover, and soils. *Landscape Ecology*, *20*, 609–625.

Jacob, R., Zheng, J., Ciepłuch, B. (2011). *Campus guidance system for international conferences based on OpenStreetMap. Web and Wireless Geographical Information Systems* (pp. 187–198)Berlin Heidelberg: Springer187–198.

Jia, T., Jiang, B. (2010). *Measuring urban sprawl based on massive street nodes and the novel concept of natural cities*. arXiv:1010.0541.

Jin FengJun, Wang Chengjin, & Li Xiuwei, (2008). Discrimination method and its application analysis of regional transport superiority. *Acta Geographica Sinica, 63*(8), 787–798.

Li, D. R., & Shao, Z. F. (2009). Discussion on the new geographic era (in Chinese). *Science in China (F)*, *39*, 579–587.

Li, Q., Fan, H., Luan, X., Yang, B., & Liu, L. (2014). Polygon-based approach for extracting multilane roads from OpenStreetMap urban road networks. *International Journal of Geographical Information Science*, *28*, 2200–2219.

Liu, X., Song, Y., Wu, K., Wang, J., Li, D., & Long, Y. (2015). Understanding urban China with open data. *Cities*

Mao, M., Long, Y. (2014). Open data, crowdsourcing, and city planning. *Proceedings of the IEEE 22nd international conference on geoinformatics (GeoInformatics).*

Mooney, P., & Corcoran, P. (2012). *Using OSM for LBS – An analysis of changes to attributes of spatial objects*. Springer.

Mooney, Peter (2015). *An Outlook for OpenStreetMap. OpenStreetMap in GIScience* (pp. 319–324)Springer International Publishing319–324.

Neis, P., & Zielstra, D. (2014). Recent developments and future trends in volunteered geographic information research: The case of OpenStreetMap. *Future Internet*, *6*, 76–106.

Neis, P., Zielstra, D., & Zipf, A. (2011). The street network evolution of crowdsourced maps: OpenStreetMap in Germany 2007–2011. *Future Internet*, *4*, 1–21.

Neis, P., Goetz, M., & Zipf, A. (2012). Towards automatic vandalism detection in OpenStreetMap. *ISPRS International Journal of Geo-Information*, *1*, 315–332.

Over, M., Schilling, A., Neubauer, S., & Zipf, A. (2010). Generating web-based 3D city models from OpenStreetMap: The current situation in Germany. *Computers, Environment and Urban Systems*, *34*, 496–507.

Rehrl, K., Gröechenig, S., Hochmair, H., Leitinger, S., Steinmann, R., & Wagner, A. (2013). *A conceptual model for analyzing contribution patterns in the context of VGI. Progress in Location-Based Services* (pp. 373–388)Springer373–388.

Schlesinger, J. (2015). *Using Crowd-Sourced Data to Quantify the Complex Urban Fabric – OpenStreetMap and the Urban–Rural Index. OpenStreetMap in GIScience* (pp. 295–315)Springer International Publishing295–315.

Shen, J., & Wu, R. (2006). *urban road and transportation (in Chinese).* Wuhan: Wuhan University Press.

Wu, W., Cao, Y., & Cao, W. (2006). Spatial structure and evolution of highway accessibility in the Yangtze River Delta. *Acta Geographica Sinica – Chinese Edition*, *61*, 1074.

Zhang, Q., Wang, J., Peng, X., Gong, P., & Shi, P. (2002). Urban built-up land change detection with road density and spectral information from multi-temporal Landsat TM data. *International Journal of Remote Sensing*, *23*, 3057–3078.

Zhang, Q., Hu, Y., Liu, J., Liu, Y., Ren, W., & Li, J. (2011). Identification of urban clusters in China based on assessment of transportation accessibility and socio-economic indicators. *Acta Geographica Sinica*, *6*, 006.

Zhao, P., Jia, T., Qin, K., Shan, J., & Jiao, C. (2015). Statistical analysis on the evolution of OpenStreetMap road networks in Beijing. *Physica A: Statistical Mechanics and its Applications*, *420*, 59–72.

Zhou, P., Huang, W., & Jiang, J. (2014). Validation analysis of OpenStreetMap data in some areas of China. *ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *1*, 383–391.

Zielstra, D., & Hochmair, H. H. (2011). Comparative study of pedestrian accessibility to transit stations using free and proprietary network data. *Transportation Research Record: Journal of the Transportation Research Board*, *2217*, 145–152.

Zielstra, D., & Hochmair, H. (2012). Comparing shortest paths lengths of free and proprietary data for effective pedestrian routing in street networks. *Transportation Research Record*, *2299*, 41–47.

Zielstra, D., Hochmair, H. H., & Neis, P. (2013). Assessing the effect of data imports on the completeness of OpenStreetMap – A United States case study. *Transactions in GIS*, *17*, 315–334.

Zielstra, D., Zipf, A. (2010). OpenStreetMap data quality research in Germany. *Proceedings of the 6th international conference on geographic information science (GIScience)*. Zurich, Switzerland.