The evaluation of intra-urban developments through urban scaling indicators: empirical evidence from the Greater Bay Area, China

Jinzhou Cao[1,2], Wei Tu[1,2], Chen Zhong[3], Qili Gao[1,2], Qingquan Li[1, 2]
1 Guangdong Key Laboratory of Urban Informatics, Shenzhen Key Laboratory of Spatial Smart Sensing & Research Institute of Smart Cities, Shenzhen University, Shenzhen 518060, China
2 Department of Urban Informatics, School of Architecture and Urban Planning, Shenzhen University, Shenzhen 518060, China
3 The Bartlett Centre for Advanced Spatial Analysis (CASA), University College London (UCL) Gower Street, London WC1E 6BT, UK

Key Words: Scaling laws; Urban indicators; Urban mobility; Network analysis; The Greater Bay Area

Introduction

The rapid urbanization has led to a rapid population growth in cities. Cities are typical complex systems, within which various urban elements including the population, infrastructures and information intricately interact with each other(Li et al., 2017). The efforts to reach a better understanding of urban systems call for a new perspective to quantitatively describe interdependent relations of these elements rather than examine them individually.

Scaling laws is one of beneficial but simple rule to help understand complex urban systems. The existence of scaling laws has been widely proved in complex systems and has been theoretical and empirical explained by various mechanism models(Batty, 2008). Scaling laws indicate trends between two explainable indicators in systems of cities in a power-law-like regime $Y \sim P^{\beta}$, where β is the scaling exponent(Arcaute Elsa et al., 2015). The urban indicators describe the spatial configurations of urban elements, such as population distributions, infrastructural layouts, and levels of socio-economic activities. Urban scaling laws help quantify how urban indicators develop with the increase of urban population and assess the performance of a city.

Although considerable progress has been made in the study of urban scaling laws, however, as rapidly urbanizing cities, another crucial perspective in urban developments lacks understanding. Urban mobility describes residents movements and characterizes the networked interactions of travels between different intra-urban regions(Song et al., 2010). It is also essential for investigating the scaling laws in human mobility to characterize urban mobility patterns(Tang et al., 2016). Meanwhile, compared with the scaling laws in urban elements generally remaining stable for a period of time, human mobility patterns are quite dynamic and the temporal dynamics of scaling processes present key clues in the evolution of the urban systems.

Moreover, the spatial scale is another issue of determining the understanding for urban systems. Most of current studies of urban and mobility scaling laws treat the targeted cities as a whole and study the macroscopic scaling properties over a region or a country, thus lacks judgment on the difference of the micro-scale within the cities. It has been reported that the scaling laws also exists in the intra-urban system composed by districts or communities(Louail et al., 2015), however, an intra-urban scale around a few meters, which benefits more refined urban research and urban planning remains poorly understood.

In this study, we address the following two questions: whether the interaction among urban indicators at intra-urban scale around a few meters obey urban scaling laws; and what the scaling laws of the human mobility characterized by a series of statistical measures derived from the complex network perspective followed. These two questions highlight the necessity of a comprehensive study to quantify the intra-urban scaling laws in terms of both urban indicators and human mobility at meters level. Considering the typical mega-city region in China, the Guangdong-Hong Kong-Macau Greater Bay Area (GBA) as the study area, we firstly selected urban population, building areas and socioeconomic activities as the urban elements at 500m regular grid level and quantified the scaling relationship between them and compared it with the paradigm derived from urban size. The urban mobility networks were then constructed by aggregating the averaged travel flows of all population recorded every month from 2017 to 2019 within the city and considered the temporal variation in scaling relations between degree, strength and clustering coefficient to evaluate the development of the urban systems.

Study Area and data

The Guangdong-Hong Kong-Macau Greater Bay Area (GBA), which is our study area, is one of the major bay areas in the world. The GBA is located in the southern coastal area of China, comprising the two Special Administrative Regions of Hong Kong and Macao and nine mainland cities in Guangdong Province. It, covering < 1% of China's land area, creates 30% of the whole of mainland China GDP in 2020 with only 5% of total population and is the most active mega-city region in the country. The GBA as a whole is indeed a complex urbanized region with population dynamics, intensive economic activities and innovative clusters.

To derive the quantitative relationship between urban indicators, our analysis synthesizes information from a variety of sources. We use four extensive data, including a vector building data, a road network data, a point of interests (POIs) data, and a mobile phone data. Detailed data descriptions are as follows.

Building data. The building data were crawled from a digital map in China.

Road network data. The data for road networks were downloaded from the OpenStreetMap (OSM) (http://www.openstreetmap. org/) in June 2020.

POIs data. We collected POIs data from GaoDe, the largest online map service in China. Here we extracted points of restaurants and shops for our analysis.

Mobile phone data. A granular mobile phone tracking data was acquired from a dominant communication operator in China. The dataset recorded long-period phone users' stay activities and their movements between signaling towers from 2017 to 2019. The positions of phone users had been recorded at the signaling tower level. The data reveal information in two aspects. One is the grid-cell data, such as the aggregated numbers of the user visits for every cell and certain period or the total home locations of users for each cell. The operator also provided another type of data, namely the travel flows between two certain areas per day. A travel-flow record includes origin-grid id, destination-grid id, and population count belongs. Based on these datasets, we construct various population measures and urban mobility networks over time to capture the population and flow dynamics.

Methodology and ongoing results

This study develops a quantitative approach to understanding the scaling laws in both urban elements and human mobility. Our approach involves the following major parts. The first part involves in the urban indicators. We will firstly produce various urban indicators from various data, such as total building area, total road length, to represent urban infrastructural development, and POIs of commercial facilities, to represent urban socio-economic activities.

In this study, we consider the diverse measures of gridded population as alternative simple registered population usually reported in the cities' official statistics to uncover a better measure of the urban population distribution. To do so, we employ three measures, i.e., the number of home locations of phone users(NH), the number of work locations of phone users(NW), the number of stays of phone users(NS), which is more appropriate proxy for estimating socioeconomic activity. These three measures reflect a multi-dimensional portrait of dynamic urban population within a given region.

We then constructed urban mobility networks with different timings which will be used as the measures of scaling laws in human mobility. Specifically, a set of weighted directed networks was created by aggregating and summing the travel flows of all individuals at time t. We selected one week data from every month from June 2017 to June 2019 as the monthly network. Finally, a total of 36 networks represents monthly properties of urban mobility. We then employed a series of complex network-driven measures, including the node degree, node strength, and clustering coefficient, to characterize the urban mobility networks and define two types of scaling relationship among these measures: the scaling relation between degree and strength and the scaling relation between degree and clustering coefficient.

In the third part, given the detailed spatial distributions of urban indicators and network measures, the urban boundaries will be divided into a set of 500m × 500m grid regular grids, then aggregate them into corresponding grid. A fitting procedure will be performed to derive the scaling exponents at last.

Based on these datasets, we will present various empirical observations. First, the results of fitted scaling laws in urban indicators and urban mobility and spatiotemporal evolution will be analyzed. By further exploring city differentiation of scaling laws and spatiotemporal variations of scaling coefficients, the interaction between urban indicators and urban mobility behaviour in different cities can be profoundly revealed. The results of the scaling relations demonstrated a multi-facet portrait of urban mobility networks, which provides crucial implications and policies for data-informed urban planning.

References

Arcaute Elsa, Hatna Erez, Ferguson Peter, Youn Hyejin, Johansson Anders, & Batty Michael. (2015). Constructing cities, deconstructing scaling laws. *Journal of The Royal Society Interface*, *12*(102), 20140745. https://doi.org/10.1098/rsif.2014.0745

Batty, M. (2008). The Size, Scale, and Shape of Cities. *Science*, *319*(5864), 769–771. https://doi.org/10.1126/science.1151419

Li, R., Dong, L., Zhang, J., Wang, X., Wang, W.-X., Di, Z., & Stanley, H. E. (2017). Simple spatial scaling rules behind complex cities. *Nature Communications*, *8*(1), 1841. https://doi.org/10.1038/s41467-017-01882-w

Louail, T., Lenormand, M., Picornell, M., García Cantú, O., Herranz, R., Frias-Martinez, E., Ramasco, J. J., & Barthelemy, M. (2015). Uncovering the spatial structure of mobility networks. *Nature Communications*, *6*, 6007. 83. https://doi.org/10.1038/ncomms7007

Song, C., Koren, T., Wang, P., & Barabási, A.-L. (2010). Modelling the scaling properties of human mobility. *Nature Physics*, *6*(10), 818–823. 80. https://doi.org/10.1038/nphys1760

Tang, J., Zhang, S., Zhang, W., Liu, F., Zhang, W., & Wang, Y. (2016). Statistical properties of urban mobility from location-based travel networks. *Physica A: Statistical Mechanics and Its Applications*, *461*, 694–707. https://doi.org/10.1016/j.physa.2016.06.031